A view of colonial life in South Australia: An osteological investigation of the health status among 19th-century migrant settlers

Angela Gurr

A thesis submitted in fulfilment of the requirements of

DOCTOR OF PHILOSOPHY

In the

School of Biomedicine,

Discipline of Anatomy and Pathology

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Thesis Abstract

Studies of human skeletal remains contribute to understanding the extent to which conditions prevailing in various past communities were detrimental to health. Few of these studies have evaluated the situation in which the first European colonists of South Australia lived. Colonial Australian skeletal collections are scarce, especially for research purposes. This makes the 19th-century skeletal remains of individuals, excavated from St Mary's Cemetery, South Australia, a rare and valuable collection.

The overarching aim of this thesis was to investigate the general and oral health of this specific group of 19th-century settlers, through the examination of their skeletons and dentitions. Four research papers in this thesis address this overarching aim. The first two papers determine the general skeletal health of the settlers, with a focus on pathological manifestations on bones associated with metabolic deficiencies and the demands of establishing an industrial society. Paper 3 investigated whether Large Volume Micro-Computed Tomography (LV Micro-CT) could be used as a single technique for the analysis of the in situ dentoalveolar complex of individuals from St Mary's. This led to a detailed investigation of the dentitions of the St Mary's sample, in paper 4, with the aims of determining the oral health status of these individuals, and understanding how oral conditions may have influenced their general health.

The skeletal remains of 65 individuals (20 adults and 45 subadults) from St Mary's sample were available for the four component investigations using non-destructive techniques - macroscopic, radiographic and micro-CT methods.

Signs of nutritional deficiencies (vitamin C and iron) were identified in Paper 1. The findings of paper 2 showed joint diseases and traumatic fractures were seen and that gastrointestinal

and pulmonary conditions were the leading causes of death in subadults and adults respectively. Paper 3 found that the LV Micro-CT technique was the *only* method able to generate images that allowed the full range of detailed measurements across all the oral health categories studied. A combination of macroscopic and radiographic techniques covered a number of these categories, but was more time-consuming, and did not provide the same level of accuracy or include all measurements. Results for paper 4 confirmed that extensive carious lesions, antemortem tooth loss and evidence of periodontal disease were present in the St Mary's sample. Developmental defects of enamel (EH) and areas of interglobular dentine (IGD) were identified. Many individuals with dental defects also had skeletal signs of co-morbidities. St Mary's individuals had a similar percentage of carious lesions as the British sample, which was more than other historic Australian samples, but less than a contemporary New Zealand sample.

The 19th-century migrants to the colony of South Australia were faced with multiple challenges such as adapting to local environmental conditions as well as participating in the development of settlements, infrastructure and new industries. Evidence of joint diseases, traumatic injuries and health insults, seen as pathological changes and/ or abnormalities on the bone and/or teeth, confirmed that the settlers' health had been affected. The number of burials in the 'free ground' area between the 1840s -1870s was greater than the number in the leased plots, reflecting the economic problems of the colony during these early years.

Validation of the reliability and accuracy of the LV Micro-CT system for the analysis of the dentoalveolar complex, in situ within archaeological human skull samples, provided a microanalytical approach for the in-depth investigations of the St Mary's dentition. Extensive carious lesions, antemortem tooth loss and periodontal disease seen in this group would have affected their general health status. The presence of developmental defects (EH and IGD) indicated that many of the settlers had suffered health insults in childhood to young adulthood. Contemporaneous Australian, New Zealand and British samples had comparable findings suggesting that little improvement had occurred in their oral health since arriving in South Australia.

In conclusion, the findings of this investigation largely fulfilled the initial aims. Our understanding of the extent to which conditions prevailing in the new colony were detrimental to human health has increased, as has our knowledge of why pathological manifestations and/or abnormalities were seen on the bones and teeth of individuals from the St Mary's sample. A multiple-method approach, to derive enhanced information has been shown to be effective, whilst establishing a new methodology (LV Micro-CT) for the analysis of dentition in situ in human archaeological skulls. Further, this investigation has digitally preserved data relating to this historical group of individuals for future comparisons.

Declaration

I certify that this work contains no material which has been accepted for the award of any other degree or diploma in my name, in any university or other tertiary institution and, to the best of my knowledge and belief, contains no material previously published or written by another person, except where due reference has been made in the text. In addition, I certify that no part of this work will, in the future, be used in a submission in my name, for any other degree or diploma in any university or other tertiary institution without the prior approval of the University of Adelaide and where applicable, any partner institution responsible for the joint-award of this degree.

The author acknowledges that the copyright of published works contained within the thesis resides with the copyright holder(s) of those works.

I give permission for the digital version of my thesis to be made available on the web, via the University's digital research repository, the Library Search and also through web search engines, unless permission has been granted by the University to restrict access for a period of time.

I acknowledge the support I have received for my research through the provision of an Australian Government Research Training Program Scholarship.

Angela Gurr

Signature: Date: 10.03.2023

Acknowledgements

The long road from a nervous undergraduate student of Archaeology, through Honours and then on to PhD has only been possible due to the support of my supervisors, family, friends, and fellow students. I could not have achieved all that I have without you. Thank you for believing in me!

To my supervisors, Prof. Alan Brook, Prof. Maciej Henneberg, and Dr Jaliya Kumaratilake, I wish to express my sincere thanks for your immense patience, academic expertise and continuing guidance. Thank you to Ruth Williams and Dr Agatha Labrinidis of Adelaide Microscopy, University of Adelaide, and Assoc/ Prof. Egon Perilli and Dr Sophie Rapagna of Flinders University, for their expert guidance regarding all things micro-CT, and for answering a million questions from an over-eager student. To Assoc/ Prof. Denice Higgins and her Forensic Odontology group thank you for accepting me into your meetings and sharing your expertise. I have learnt so much from you all. Thank you to everyone who has generously given their time for my project: Ella Kelty, Claudia Barrientos, Dr John Wetherell, Prof Lindsay Richards, and Dr Derek Lerche.

To my fellow PhD students/ office mates/ inmates, I could not have survived this journey without you! Meghan Mckinnon and Florence Lees, my IT helpers, thank you so much for tolerating, with good humour, every ‘silly’ question I asked. Thank you, Saeed Nourmohammadi and Sidra Nawaz Khan for your good humour, and Zein Amro, thank you for your emotional support, we have travelled so far.

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Achievements

Conference Presentations

2023 ‘*A fresh start on the other side of the world! A multidisciplinary view of the establishment and early history of a new British colony, through the health logs of the voyage and the health of early migrant settlers*’

Matthew Brook O’Donnell, Alan H. Brook, and Angela Gurr

Abstract accepted and presentation to be given at the Third International Conference on Historical Medical Discourse (CHIMED-3) will be held at Mary Ward House, London (UK) on 11th-12th May 2023.

2020 ‘*Large volume micro-CT: a new methodology enhances the microscopic study of archaeological skull samples’*

Angela Gurr, Alan Brook, Denice Higgins, Jaliya Kumaratilake, Maciej Henneberg.

Abstract accepted and presentation given at the Australasian Society for Human Biology (ASHB), 34th Annual Conference. 7th & 8th December. Virtual Conference in response to COVID-19, University of Western Australia - hosted by Zoom.

2020 ‘*Investigation of oral and skeletal health parameters in a sample of 19th-century migrant settlers to South Australia*’.

Angela Gurr

Presentation for The Tri-University Anatomy Dept. of South Australia (the Universities of Adelaide, South Australia & Flinders) December - In person at the University of South Australia, Adelaide.

2019 ‘*Nutritional deficiency indicators in 19th century human skeletal remains from St Mary’s Cemetery, South Australia*’.

Angela Gurr, Alan Brook, Jaliya Kumaratilake, Stella Ioannou, Donald Pate, Maciej Henneberg.

Abstract accepted and poster presented at the British Association for Biological Anthropology and Osteoarchaeology (BABAO), 21st Annual Meeting, 13th-15th September 2019, Natural History Museum, London, England.

2019 ‘*A healthy new life for all? Nutritional deficiency indicators in human skeletal remains buried at government expense from 1847 to 1927 at St Mary’s Anglican Church Cemetery, South Australia’*.

Angela Gurr, Alan Brook, Jaliya Kumaratilake, Stella Ioannou, Donald Pate, Maciej

Henneberg.

Abstract accepted and poster presented at the National Archaeology Student Conference (NASC), 1st- 4th October 2019, Flinders University, Adelaide, South Australia.

Conference attendance

2023 The third International Conference on Historical Medical Discourse (CHIMED-3) will be held at Mary Ward House, London (UK) on 11th-12th May.

2023 Paleopathology Association – 50th Annual Conference (hybrid/online)- April.

2022 Paleopathology Association – 49th Annual Conference (hybrid/online).

2021 The Society for the study of Childhood in the Past (SSCIP) - Annual Conference.

2020 Australasian Society for Human Biology (ASHB) - Annual Conference, (hybrid/online).

2019 British Association for Biological Anthropology and Osteoarchaeology (BABAO).

2019 National Archaeology Student Conference (NASC).

Grants and funding

2019-2022 The Australian Government and Research Training Program Scholarship (Stipend) – Awarded for academic achievements in Honours (Upper First class) in Anatomical Sciences, at the University of Adelaide. $31, 000 per annum

2020 Research Funding Grant - Adelaide Dental School, University of Adelaide. $5,000. I was involved in the drafting and submission of this application with my PhD supervisor Prof. Brook and Co-author of Paper 3, Assoc/ Prof. Denice Higgins. This funding supported papers 3 and 4 of this thesis.

Additional training

2022 Adelaide Microscopy, Adelaide Health and Medical School

- Small Volume Micro-CT scanning - Bruker SkyScan 1276 – annual refresher training
- Avizo 9 specialised 2D & 3D volumetric – micro-CT post-processing software refresher training.

2021 Adelaide Microscopy, Adelaide Health and Medical School

- Reviewed, evaluated, and tested three types of data visualisation post-processing software – Avizo, CTan, CTVol
- Small Volume Micro-CT- post-processing software training – 2D & 3D image analysis and measurements of the dentition and skulls scan data sets – annual refresher training

2020 Dental Anthropology Association Workshop - online

- Sex determination using peptides in tooth enamel.
- Types of post-processing software for image analysis - instruction.

2020 Adelaide Microscopy, Adelaide Medical School

- Small Volume Micro-CT scanning - Bruker SkyScan 1276 – refresher training
- Post-processing software training – Nrecon, CTan and Avizo 9.
- Histological techniques training
    - Embedding tooth samples in resin - Equipment training.
    - Polishing a sample embedding in resin - Equipment training
    - Stereo microscope - Equipment training

2020 Medical Device Research Institute, Flinders University, South Australia

- Large Volume Micro-CT scanning – Nikon XH 225 ST – Induction training

2019 Griffith University via Future Learn © platform - online course

- Introduction to Forensic and Bioarchaeology: Reading Human Remains

Collaborations/ Professional Acknowledgements

- Adelaide Microscopy- Dr Agatha Labrinidis and Ruth Williams – kindly provided technical support and training for Small Volume Micro-CT scanning - Bruker SkyScan 1276 and post-processing software usage.
- Adelaide Microscopy- Dr Animesh Basak – kindly provided technical support and training for histological techniques.
- Medical Device Research Institute, Flinders University, South Australia - Associate Professor Egon Perilli and Dr Sophie Rapagna- kindly provided technical support and training for Large Volume Micro-CT and post-processing software usage.
- Dr Derek Lerche – Radiology Coordinator, Adelaide Dental School - kindly provided technical support and education regarding dental radiographic techniques.
- Associate Professor Denice Higgins – Forensic Odontology unit, Adelaide Dental Sch., University of Adelaide – who kindly allowed me to attend meetings with her research group and provided advice and support for my PhD research relating to oral health.

Other Publications and Achievements

2022 Adelaide Advertiser – South Australian newspaper article highlighting our research publications – Chapter 2 and 3 (papers 1 & 2.

2022 Archaeology Magazine – (08.04.2022) International magazine for the general public. News article regarding our research publication (Chapter 2 - paper 1) in the International Institute of America. https://www.archaeology.org/news/10450-220408-south-australia-colony

2022 Current World Archaeology Magazine - International magazine for the general public.

News article regarding our research publication (Chapter 2 - paper 1). (Issue 114 -9).

2022 ‘*Pandemic realism as the indispensable political precondition for global disease eradication*’. Galassi, F.M., Pate, F.D., You, W., **Gurr, A**., Lucas, T., Antunes- Ferreira, N., Habicht, M.E. Public Health (London), Vol. 212, pp. 55–57.

2021 *‘A stable inexpensive and widely available burial environment or keeping place for archaeological or historical human skeletal remains*.

F. Donald Pate, Maciej Henneberg, Anson, T. J., Owen, T.J., Newchurch, J., Draper, N., Wight, C., Lucas, T., Moffat, I., Weyrich, L.S., Skelly, E., Naumann, J., Gurr, A., Logan, C. and Walsh, J. Australasian Historical Archaeology.

2020 National Archaeology Student Conference: National Committee Member

2020 Australasian Forensic Anthropology and Archaeology (AFAA) Newsletter – News Article regarding the presentation of PhD research at the British Association for Biological Anthropology and Osteoarchaeology (BABAO) conference in London, UK.

2020 **‘***Spaceship Ice-Lollies’* Space Archaeology. **Gurr. A.** In Gorman, A. et al. 2020 *SPACE: an Exploration of Objects, pp.22-23. Indooroopilly, QLD, Australia: Wallis Heritage Consulting. Space Archaeology.*

Research and Knowledge Dissemination – Public engagement

Online presence

2018 to present - Founder/ Owner: @bioarch.ive - Instagram: social media/ public engagement concerning Archaeology, Bioarchaeology, Biological Anthropology and Forensic and my research interests.

Presentations - public

2023 – Planned - ‘Oral and skeletal health of migrant settlers to the early colony of South Australia, buried at the expense of the government’, co-presentation of PhD research outcomes (A. Gurr and Prof. A. H. Brook).

- Parish of St Mary’s Anglican Church (St Marys, SA), St Mary’s Suburb, South Australia
- Southern District Neighbourhood Watch members, St Marys Suburb, South Australia

Bound for South Australia

South Australia is my land,
Heave away, haul away,
Mountains rich in quartz and sand,
Heave away, haul away,
We're bound for South Australia.

A Sea Shanty

Chapter 1. Introduction to Thesis

1.1. Overview

The study of skeletal remains contributes to understanding the extent to which conditions prevailing in various communities were detrimental to human health. Some human diseases, dietary deficiencies, accidents and industrial demands affect bones and teeth causing characteristic lesions and/or manifestations. These lesions or changes in the bones and/or teeth are evidence of past health insults and experiences, that can be observed long after the death of an individual. Bioanthropological studies, in various countries, have been devoted to such assessments (Buckley et al., 2020; Klaus and Tam, 2009; Molleson and Cox, 1993; Van Der Merwe et al., 2011). However, there is limited evidence of the situation in which the first European colonists of South Australia lived, and how these conditions influenced their health.

1.2. Historical background to the new British colony of South Australia

The foundations for new British colonies were laid in the first decades of the 19th century (Fig. 1), during the Industrial Revolution. People from rural areas hoping to escape unemployment, poor harvests, and the effects of the 'new' Poor Law (Archer, 2000; Crowther, 1981; Shave, 2018), moved to urban industrial cities in search of work. These cities did not have the infrastructure to accommodate and support the rapidly increasing population density. The outcome was overcrowded accommodation, contamination of water supplies, and unsanitary living conditions, all of which threatened public health (Fig.1) (Allen, 2009; Betsinger and DeWitte, 2020; Crane-Kramer and Buckberry, 2023; Engels, 1971; Lindert and Williamson, 1983; Szreter, 1997, 1999, 2004, 2005). In this context, Edmund Gibbon Wakefield published his ideological approach to the systematic colonization of new lands. His ideas underpinned the establishment of South Australia as a planned, non-custodial colony (Curtis, 2019) (Fig. 2).

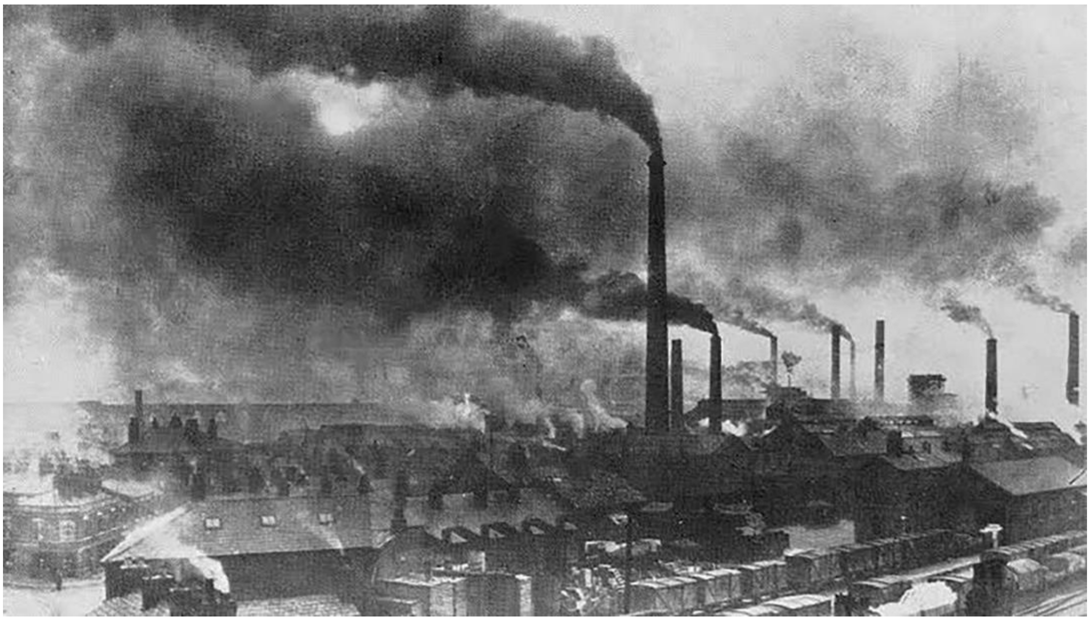

Figure 1. An image of an industrial city in the north of England shows the proximity of the housing to the factories and the air pollution caused by coal-fired industries. (Bergen, 2017).

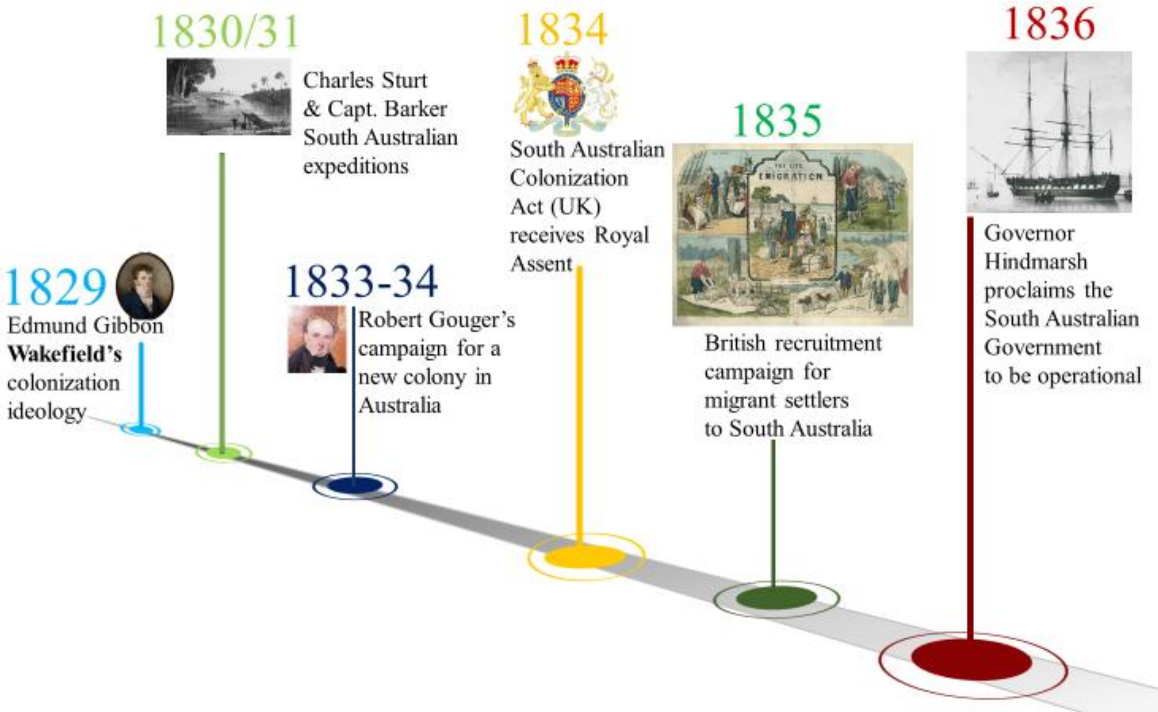

Figure 2. A timeline showing the key historical events leading to the establishment of the new colony of South Australia in late 1836. © Angela Gurr (National Portrait Gallery, 2023; State Library of South Australia, 2012).

Individuals from different socio-economic backgrounds were encouraged to migrate to South Australia to create the stratified class system of Wakefield's Britain (Fig. 2) (Capper, 1975; Curtis, 2019; Haines, 1997; Wilkinson, 1848, 1849). The 'assisted passage' scheme was introduced to help 'working' class labourers and skilled individuals who could not afford the fare (Haines 1995; Haines & Shlomowitz 1990, 1991).

The long voyage to Australia had health challenges, especially for families with young children due to the spread of infectious diseases, gastrointestinal conditions and dehydration, as well as from sea sickness (Haines, 2005; Haines and Shlomowitz, 2003). Even the safe arrival of migrants to the colony did not assure a prosperous future. The initial instability of the South Australian government delayed the surveying and allocation of arable land to migrants, which hindered the planned production of food, and the establishment of industries (Price, 1973). This, in conjunction with the influx of migrants markedly increased unemployment leading to the first financial downturn of the colony (Dare, 1992; Dickey, 1986; Gibbs, 2013; Pike, 1967). The result was poverty for some segments of the settler population (Dickey, 1986; Government of South Australia, 2021).

1.3. St Marys-on-the-Sturt, South Australia

The village of St Marys-on-the-Sturt was located approximately 8km south of the developing City of Adelaide, close to the Sturt River (Fig. 3).

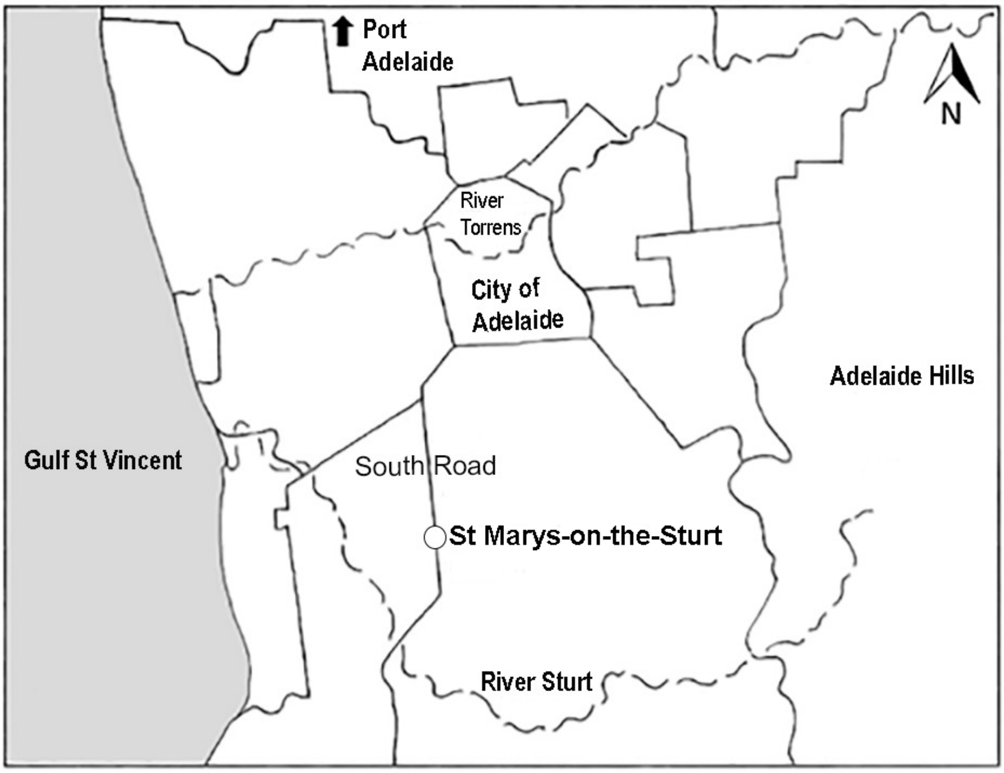

Figure 3. Location map: The village of St Marys-on-the-Sturt in relation to the City of Adelaide and the surrounding regions. Reprinted and under a CC BY license, with permission from the City of Marion Council, original copyright 2020. (City of Marion Council, 2020).

Migrants who had purchased large blocks of land in this area established farms and small enterprises. Settlers with less money, but who aspired to own land, had to find employment in local industries such as the quarry from which stones for the church were gathered (Davies, 1991; Somerset and Ragless, 2009).

The images presented in Figures 4a-4c show the types of working conditions that individuals from this St Marys-on-the-Sturt could have encountered.

Figure 4a. 1895. Workers of the Cement Works at Brighton, South Australia, which was approximately 6 km from St Marys-on-the-Sturt. Image B30816, (State Library of South Australia, 2023)

Figure 4b. 1878. An example of hard physical labour in the construction industry. Labourers (men and boys) working on a bridge over the Murray River in South Australia. Image B7258/1 (State Library of South Australia, 2023)

Figure 4c. 1890. Agriculture. A farmer transports a wagon full of hay. Riverton, South Australia. Image B16943 (State Library of South Australia, 2023).

While many settlers from all socio-economic groups thrived and became wealthy, others did not. People living in the rural areas of South Australia were affected by the economic depression as much as the city dwellers.

1.4. St Mary's Anglican Church Cemetery, South Australia

St Mary's Anglican Church was built in 1841 by the first settlers of the colony. The church was constructed of native stringy-bark timber for the small rural community of St Marys-on-the-Sturt and was the third Church of England building to be erected (Davis, 1991; Somerset and Ragless, 2009). After six years, the church was relocated and replaced with a stone building (Fig. 5) (Somerset and Ragless, 2009).

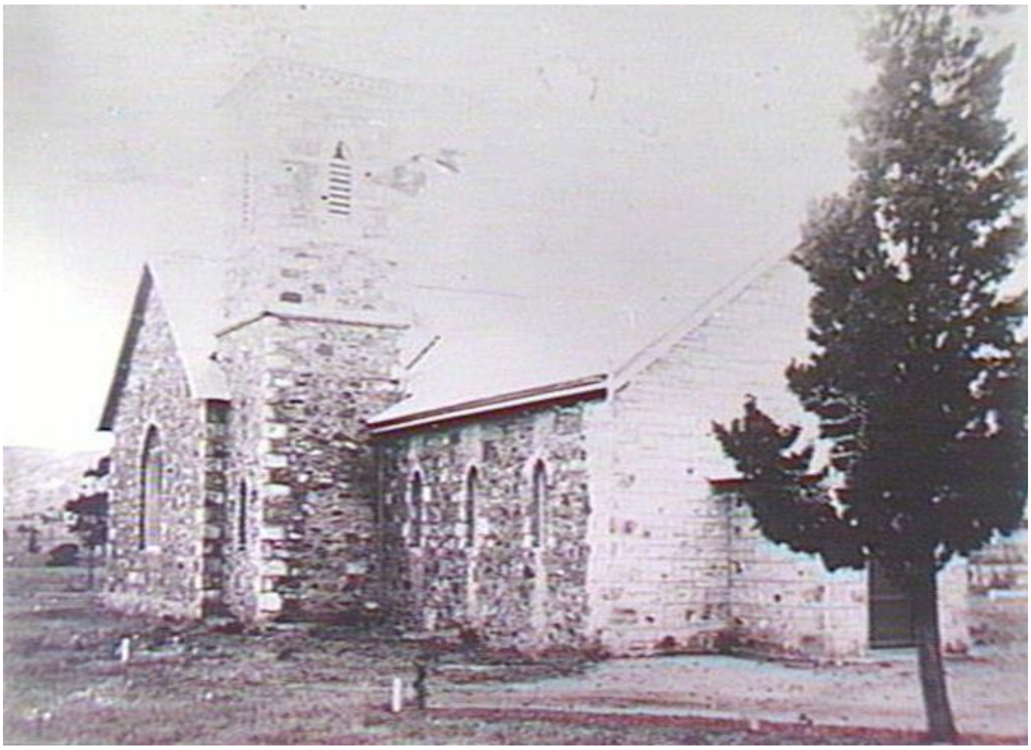

Figure 5. A photograph of St Mary's Anglican Church, South Road, South Australia, circa 1880. (State Library of South Australia, 2012).

Individuals or their families from St Mary's Church Parish, who could not pay for a burial were interred, at the government's expense, in a section of the cemetery often referred to as the 'free ground'. This burial area was unmarked and located at the rear of the church building.

1.5. Scarcity of skeletal samples of colonial migrants in Australia and New Zealand

Human skeletal remains and dentitions dating from the colonial period of Australia and New Zealand are limited, especially for research purposes. The majority of these skeletal samples are from cemeteries in New South Wales (NSW), Australia, close to and/or used by the penal colonies there.

Previous investigations of other 19th-century Australian cemeteries include Paramatta Convict Hospital, NSW, (1790- 1818) (Donlon et al., 2008), the Old Sydney Burial Ground, NSW, (1792-1820) (Donlon et al., 2017), Randwick Destitute Children's Asylum Cemetery, NSW, (1863-1915) (Donlon and Wright, 1997), Cadia Cemetery, NSW, (1864-1927) (Higginbotham and Associates Pty Ltd., 2002), and the North Brisbane Burial Grounds in Queensland (1843-1875) (Haslam, 2003).

In the Otago region of New Zealand's South Island, some individuals have been excavated and investigated from St John's Anglican Burial Ground, Milton, (1860s-1890s) (Buckley et al., 2020), Ardrossan Street Cemetery, Lawrence, (1861-1866) (Petchey et al., 2018), Gabriel Street Cemetery, Lawrence, (1866-present) (King et al., 2021), and Cromwell Cemetery, Lawrence, (1888-present) (Petchey et al., 2018).

The date range for burials and the backgrounds of the individuals excavated from these cemeteries vary compared with the migrants who settled in the region of St Marys-on-the-Sturt, South Australia. This makes the skeletal remains of individuals excavated from the 'free ground' area of St Mary's Church Cemetery, at the request of the parish authorities, a rare and valuable collection.

1.6. Thesis scope and originality

Consideration was given to previous studies of the St Mary's Anglican Church Cemetery sample, that commenced almost 20 years ago (Anson, 2004; Anson et al., 2002; Ioannou 2017; Ioannou and Henneberg, 2017; Ioannou et al., 2015; 2016; Pate and Anson, 2012; Skelly, 2019), which led to the formulation of new ideas for investigations. The availability of new technology and methodologies provided opportunities to overcome the limitations of previous studies and to implement innovative approaches. In addition, the accessibility of online resources and published information for other 19th-century skeletal samples permitted the St Mary's sample to be compared to other historic cemetery samples in Australia, and New Zealand and with their contemporaries back in Britain. All of these factors prompted new research questions. Therefore, the overarching aims of this study were to investigate the general and oral health status of the migrant settlers buried in the 'free ground' area of St Mary's Cemetery and to consider how the conditions in the colony affected their general health.

The four studies reported in this thesis (Chapters 2 to 5) covered the investigation of the general and oral health of these migrant settlers by examining their skeletons and dentitions. The research cycle, presented in Figure 6, supported a thorough investigation by addressing the research questions, and evaluations of the findings. The information generated was composed into four publications. In each paper (papers 1 to 4 in Chapters 2 to 5), the information was analysed and compared to other contemporaneous samples from historic Australian, New Zealand and British Cemeteries.

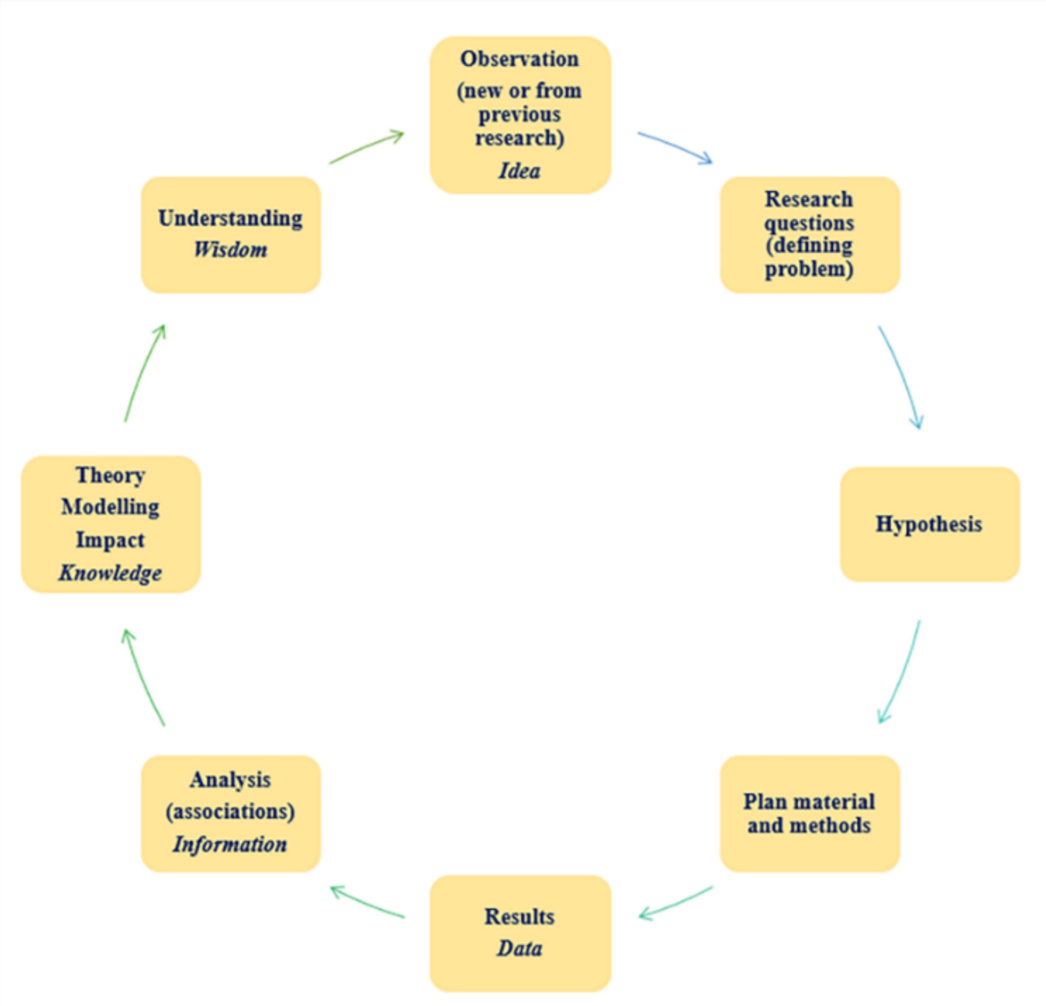

Figure 6. The research cycle incorporating the wisdom hierarchy (in *italics)* (Brook and Brook O'Donnell, 2023)

The first two studies (papers 1 and 2 in Chapters 2 and 3) focused on the evidence of pathological changes and abnormalities seen on the skeletons of the individuals from St Mary's Cemetery. Historical documents were also used to answer the research questions. Paper one (Chapter 2) investigated pathological manifestations on bones resulting from health conditions associated with a disturbance of metabolism. The changing economic status of these settlers was also examined using data from gravestones in the main section of St Mary's Cemetery and Church records. An introduction to this manuscript precedes Chapter 2.

The second study (paper 2- Chapter 3) explored the effects of the industrialisation of South Australia on the health of the St Mary's settlers. This study examined the manifestations that indicated the effects of long-term hard physical labour. Such evidence was seen in joints, vertebrae and other bones. Some skeletal abnormalities, caused by accidents associated with employment and/or lifestyle were also seen. To determine the extent to which the individuals buried in the 'free ground' area of St Mary's Cemetery had been negatively impacted by industrialisation, health findings were compared with contemporaneous cemeteries in NSW, Australia and in London, England. Analysis of information from historical documents provided an understanding of the common causes of death, during this period, for many of the St Mary's individuals.

The oral health status of the St Mary's migrant settlers has been documented in two further manuscripts (papers 3 and 4 in Chapters 4 and 5). Paper 3 evaluated the advantages and limitations of the Large Volume (LV) Micro-CT scanning method for the investigation of the human dentoalveolar complex in situ in fragile skull samples. The fourth manuscript (Chapter 5) investigated the oral health status of the St Mary's sample and explored how poor oral health could have influenced their general health. The presence of dental developmental defects, such as enamel hypoplasia and areas of interglobular dentine were explored to understand health insults in childhood to young adulthood. These findings were compared with those from other historic cemeteries in Australia, New Zealand, and Britain.

Chapter 2. Introduction to Paper 1

2.1. Paper 1 - Overview

The first manuscript (paper 1) explored the hardships that the settlers buried in St Mary's Cemetery 'free ground' could have experienced during the establishment of the new 'self-sustaining' colony, due to the lack of political and economic stability, unemployment and the potential of poverty in a country far from Britain. An investigation of the skeletal health of the St Mary's sample focused on signs of disturbances of metabolism. These skeletal findings were compared with data from two contemporary 19th-century British cemeteries to explore similarities and differences in health status. This comparison was also used to determine whether migration and the conditions in the new colony had affected the health of the St Mary's individuals. The abnormal manifestations seen in the bones of some of St Mary's settlers indicated that they had indeed suffered from nutritional deficiencies (i.e., vitamin C and iron). Information from gravestones in St Mary's Cemetery and historical documents were analysed to understand the changing economic status of the migrant settlers, throughout the 19th century, by the location of their burial within this cemetery. Changes that could have occurred in the economic status of the individuals buried in the 'free ground' were also discussed.

Statement of Authorship

Title of Paper	Health effects of European colonization: An investigation of skeletal remains from 19th to early 20th century migrant settlers in South Australia
Publication Status	[x] Published [ ] Accepted for Publication [ ] Submitted for Publication [ ] Unpublished and Unsubmitted work written in manuscript style
Publication Details	Published on April 6, 2022 in PLOS ONE Journal Gurr, A., J. Kumaratilake, A. H. Brook, S. Ioannou, F. D. Pate and M. Henneberg (2022). "Health effects of European colonization: An investigation of skeletal remains from 19th to early 20th century migrant settlers in South Australia." PloS one 17(4): e0265878-e0265878.

Principal Author

Name of Principal Author (Candidate)	Angela Gurr		
Contribution to the Paper	Conceptualization, data curation, formal analysis, investigation, methodology, project administration, visualization, writing - original draft, and writing - review and editing. Submission of manuscript and acted as corresponding author.		
Overall percentage (%)	85%		
Certification:	This paper reports on original research I conducted during the period of my Higher Degree by Research candidature and is not subject to any obligations or contractual agreements with a third party that would constrain its inclusion in this thesis. I am the primary author of this paper.		
Signature		Date	17.06.2022

Co-Author Contributions

By signing the Statement of Authorship, each author certifies that:

i. the candidate's stated contribution to the publication is accurate (as detailed above);
ii. permission is granted for the candidate in include the publication in the thesis; and
iii. the sum of all co-author contributions is equal to 100% less the candidate's stated contribution.

Name of Co-Author	Maciej Henneberg		
Contribution to the Paper	Conceptualization, data curation, formal analysis, investigation, methodology, supervision, writing - review and editing.		
Signature		Date	9.03.23

Name of Co-Author	Jaliya Kumaratilake		
Contribution to the Paper	Conceptualization, formal analysis, investigation, supervision, writing - review and editing.		
Signature		Date	17/06/2022

Name of Co-Author	Alan Brook
Contribution to the Paper	Formal analysis, investigation, methodology, supervision, writing - review and editing.
Signature	Date 13/03/2023

Name of Co-Author	Stella Ioannou
Contribution to the Paper	Data curation, writing - review and editing.
Signature	Date 8/08/2022

Name of Co-Author	F.Donald Pate
Contribution to the Paper	Resources, writing - review and editing.
Signature	Date 17/06/2022

2

2.3. Health effects of European colonization: An investigation of skeletal remains from 19th to early 20th-century migrant settlers in South Australia

Paper 1 Published: Gurr, A., Kumaratilake, J., Brook, A.H., Ioannou, S., Pate, F.D., and M. Henneberg. 2022. Health effects of European colonization: An investigation of skeletal remains from 19th to early 20th-century migrant settlers in South Australia. *PLoS ONE*, 17(4): e0265878.

doi: https://doi.org/10.1371/journal.pone.0265878

PLOS ONE

RESEARCH ARTICLE

Health effects of European colonization: An investigation of skeletal remains from 19th to early 20th century migrant settlers in South Australia

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Abstract

The British colony of South Australia, established in 1836, offered a fresh start to migrants hoping for a better life. A cohort of settlers buried in a section of St Mary's Anglican Church Cemetery (1847–1927) allocated for government funded burials was investigated to determine their health, with a focus on skeletal manifestations associated with metabolic deficiencies. Findings of St Mary's sample were compared with those published for contemporary skeletal samples from two British cemeteries, St Martin's, Birmingham, and St Peter's, Wolverhampton, to explore similarities and differences. To investigate the changing economic background of the St Mary's cohort, which may have influenced the location of their burial within the cemetery, the number and demographic profile of government funded burials and those in privately funded leased plots were compared. The study sample consisted of the skeletal remains of 65 individuals (20 adults, 45 subadults) from St Mary's Cemetery 'free ground' section. The bones and teeth of individuals in this cohort showed evidence of pathological manifestations, including areas of abnormal porosity in bone cortices in 9 adults and 12 subadults and flaring of metaphyses (one subadult) and costochondral junctions of the ribs (one subadult). Porous lesions of orbital roof bones (Types 3 to 4) were seen on three subadults. Macroscopic examination of teeth identified enamel hypoplastic defects and micro-CT scans showed areas of interglobular dentine. Comparison of St Mary's findings with the British samples revealed that prevalences of manifestations associated with vitamin C deficiency were higher at St Mary's and manifestations associated with vitamin D deficiency were lower respectively. The location of burial pattern at St Mary's Cemetery, from the mid-1840s to1860s, showed differences in the economic status of migrants. This pattern changed from the 1870s, which reflected improvements in the local economy and the economic recovery of the colony.

Introduction

Early 19th century migrant settlers in the new British colony of South Australia would have hoped for a better life than they had experienced in Britain. The palaeopathological investigation of this rare skeletal sample from the 'free ground' area of St Mary's Anglican Church Cemetery, near the city of Adelaide, South Australia, allows an insight into some of the health and economic challenges that these migrant settlers faced. The free ground section of this cemetery was allocated for individuals whose burials were paid for by the Government of South Australia, when they or their families did not have the funds to cover the costs. This study investigates the health status of this small cohort of settlers who lived in the region of the village of St Marys-on-the-Sturt from the 1840s to the1920s, with a focus on the pathological manifestations that may indicate a disturbance of the metabolism. To determine if the health of these individuals was different from their British contemporaries, findings are compared to published data for skeletal samples from St Martin's Cemetery in Birmingham, and St Peter's in Wolverhampton. Data from St Mary's Church records and headstones associated with privately funded burials in leased plots in this cemetery, provide information to compare the number of burials in each section of the cemetery, as well as assemble demographic profiles including seasonality of death. These data are valuable in gaining an understanding of the lives and deaths of these settlers and any changes that occurred in burial location patterns within the cemetery (1847–1927), to provide the economic background for the cohort, for example, was the free ground area of the cemetery used continuously during the study period or was there a 'peak' in the burial numbers? How many infants under one year of age were buried in the free ground?

The aims of this study are to:

1. Investigate skeletal remains of a group of migrant settlers to South Australia who were buried in the free ground area of St Mary's Anglican Church Cemetery from 1847 to 1927, with a focus on the pathological manifestations that may indicate a disturbance of the metabolism.
2. Compare the findings of the St Mary's samples with those published for individuals buried at two 19th century British cemeteries to explore similarities and differences in health, particularly skeletal manifestations associated with metabolic deficiencies.
3. Compare the number, percentage and demographic profiles of the cohorts buried in the government funded free ground area of St Mary's Cemetery and those in privately funded leased burial plots during the study period (1847 to 1927), to investigate if there were any changes in the pattern of burial locations within St Mary's Cemetery.

A new non-custodial colony

Industrialisation of Britain during the 19th century altered the landscape of many parts of the country, both urban and rural, the economy and the lives of many people. The rapid expansion of British industries led to the marked increase in employment opportunities and this in turn led to the mass migration of workers to industrialised centres. Most of these centres lacked the infrastructure to cope with the increase in the population size. Many people had to live in overcrowded buildings, where the sanitary conditions were poor and water supplies could be easily contaminated [1–3]. These conditions, together with long hours of working inside factories powered by coal fired engines and diets lacking in essential nutrients, contributed to the poor health of the working classes [2–7].

The indutrialisation of many urban centres also affected the traditional smaller industries in rural regions of Britain. The inability to compete with the low production costs of commercial items in large factories led to the closure of many small rural trades [8–10]. Furthermore, importation of large quantities of raw materials, such as iron, copper and tin ores at cheaper prices to feed large industries caused the downturn of regional mining industries [9, 10]. Poor harvests and the spread of disease in potato crops (blight), further affected farmers [8–11]. The net outcome was unemployment and economic hardships in regional and rural areas of Britain.

The British government encouraged the migration of people to new colonies in order to reduce overcrowding in industrialised centres and unemployment in regional and rural parts of the country. South Australia was one such colony and established partly to help solve some of these problems [12, 13]. The South Australian Act (1834) allowed the sale of land in the proposed new settlement to individuals who would establish primary industries such as farming, mining and manufacturing [13–15]. Thus, emigration to South Australia was extensively advertised in Britain [16]. The vast size, climate and the natural environment of South Australia for farming opportunities may have attracted many people to migrate [16]. Development of this new Australian colony required builders, mechanics, agricultural labourers and miners who wished to create their own opportunities [17]. A high number of migrants to South Australia came from the counties of Cornwall, Devon, Dorset and Somerset, followed by Lancashire, Middlesex, Staffordshire and Warwickshire [16, 18, 19].

The policy for migration to South Australia was designed to maintain a regular supply of skilled workers to landowners, new industries and for the continued development of the infrastructure and new settlements [16, 17, 20]. Migration was regulated by the Colonial Land and Emigration Commission (CLEC), whose agents selected healthy young males and females of good character in equal numbers [16, 17, 20]. Skilled migrants who could not afford the cost of the voyage to South Australia were encouraged to apply for an assisted passage. The assisted passage program was funded by the British Government and the South Australian Company. Individuals selected for an assisted passage had the opportunity to obtain additional financial support from local charitable organisations. This money covered the cost of transport to the port of departure and/or the compulsory deposit required for bedding, utensils and a set of clothing for all weathers during the long voyage [16, 20].

In total, 186,054 indivduals migrated to South Australia between 1836–1900 from Britain. The government assisted passage was received by 123,039 migrants (66% of total) [17]. The CLEC selection criteria were not applied to individuals who paid the full costs of their passage and had adequate funds to support themselves in the colony. The health of migrants, who travelled to South Australia was considered a high priority by the British Government. Therefore, the CLEC monitored conditions on board by appointing a qualified surgeon superintendent on each ship, who was accountable for the health and wellbeing of all passengers [16, 20, 21].

Political disagreements within the new South Australian Government delayed the surveying of land for migrant settlements and the development of supporting infrastructure [12]. This affected the initial establishment of farms, food production, industrial enterprises and permanent housing for migrants. These issues also delayed the development of the economy, caused unemployment and led to the removal of the first Governor, Captain John Hindmarsh. The second Governor, Lieutenant Colonel George Gawler, was appointed by the British Government in 1838 [19, 22]. This Governor had a proactive approach and commissioned multiple infrastructure projects to rapidly develop the colony [22, 23]. However, the cost of these projects was very high, and the British government refused to pay the expenditure and recalled Governor Gawler back to London in 1841 [19, 24].

South Australia's third Governor in five years, Captain George Grey, was appointed in 1841. During this decade the colony faced its first economic depression [19, 25]. A lack of funds to continue with public infrastructure developments and other works meant Governor Grey faced retrenchment from1841 to 1845. His decision to redirect the majority of the unemployed workforce into agricultural industries [12, 19], resulted in an increase of agricultural goods, particularly wheat and animal products. This in turn led to the establishment of export industries to other Australian colonies and Britain [12, 15].

Destitute in South Australia

The climatic conditions of South Australia, such as high summer temperatures and limited rainfall, often resulted in periods of drought and poor harvests. These conditions may have also contributed to the poor economic growth and the unemployment experienced during the development of the colony. Throughout this period, life for many settlers was harsh, particularly those who were unemployed and had to depend on charitable organisations and/or the government for their survival [23]. State Records of the Government of South Australia [26], state that 446 sick and destitute people received help in the form of food rations from the Emigration Department in 1839–1840. This number increased to 904 persons during the period of 1840–1841 [23]. The Maintainace Act of 1843 [27], was passed to address the care of "deserted wives and children and other destitute persons" [27:1]. The establishment of the Destitute Board followed six years later in 1849. This board offered support to the elderly, chronically infirm and some widows. The Board also initiated the construction of the Destitute Asylum in the city of Adelaide during the 1850s [23, 28, 29].

The Destitute Asylum was modelled on the British workhouse system [28–30], with strict regulations, such as complusory wearing of uniforms for inmates and severe penalties if regulations were not followed [23, 30]. Admittance to the Destitute Asylum to receive indoor "relief" was a last resort and individuals had to prove that they had no other relatives or means of support [27, 30]. Deserted women with children could apply for admission to the asylum [30] and expectant mothers considered to be destitute could also stay for up to six months [23, 30]. Individuals, who still had their own accommodation but no other support were given weekly food rations and firewood from the Asylum as outdoor "relief" [30]. People who lived in rural areas either had to travel long distances into the city of Adelaide to receive support from the asylum or cope as well as they could within their own community.

Health in the early colony

Potential health burdens that early settlers may have faced include the spread of infectious diseases such as diphtheria, typhoid, typhus fever and tuberculosis, and/or metabolic deficiencies resulting from hardships faced in their new environment [31–37]. Individuals who could not afford the cost of local medical services may have been badly affected, as the only public hospital was located in the city. This meant people living in rural areas may have had limited access to health services or had to travel long distances to receive treatment [36, 37]. Some of the above mentioned diseases, as well as the interactions between them, may in some chronic cases have caused changes in the bone or tooth morphology [38–42]. An example of morphological changes in bone can be seen with a chronic deficiency of vitamin D, which can cause pathological manifestations in bones of the skeleton such as bending distortion in long bones [38]. A number of skeletal manifestations, such as abnormal porosity of cortical bones, enlargement and flaring of costochondral junctions of ribs and/or porous lesions on the bones of the orbital roof, have been previously interpreted as signs of chronic metabolic disturbance or deficiencies [43–47].

Bones of the skeleton are a dynamic tissue and undergo remodelling during life, in response to varying forces acting upon them [48]. Therefore, disease manifestations seen in skeletal remains, particularly in bone cortices, had occurred during the last remodelling that took place before death. Careful investigation of the characteristics of the manifestation/s and the pattern of distribution overall among the bones of the body may help to identify metabolic deficiencies that a person had experienced [43, 44, 49].

Abnormal porous lesions on bone cortices result from defective calcification of the bone matrix [50, 51]. Vitamin C and vitamin D deficiencies affect collagen synthesis [52–54] and affect mineralisation [44, 55, 56], respectively. Both processes could produce abnormal porosity of the bone cortices seen in archaeological skeletal samples. Determining the aetiologies of porous lesions on the bones of the orbital roof (often referred to as cribra orbitalia) has been controversial [49, 57, 58]. The morphology of these porous lesions can vary according to the processes that occurred to produce them. These may include subperiosteal inflammation in relation to a deficiency of vitamin C, vitamin D, vitamin B12, and/ or related to infection [43, 44, 47, 59, 60]. Some porous lesions in this anatomical location have been associated with anaemia. When haemoglobin becomes inadequate, due to the lack of iron in the body, the red marrow compensates by the overproduction of red blood cells and proliferates causing the expansion of the trabecular bone and of the diploe [61–63]. In some chronic cases of anaemia, the surface cortical bone of the orbital roof may 'thin out' and expose the underlying trabecular bone, which could appear as porous lesions. Iron deficiency anaemia could result from chronic bleeding, malabsorption of iron in the gut and/or parasitic infections and/or a dietary deficiency of iron [59, 62–66]. Furthermore, hemoglobinopathies such as hereditary anaemia, a combination of the above conditions, or other aetiologies should also be considered [63, 67].

Enamel is a highly specialised dental tissue, in which the only responses to various insults during tooth development are to form hypoplastic or hypomineralised enamel or both [41, 42, 68]. Unlike bone, it does not remodel after the development of the tooth is complete [40, 41, 68]. Therefore, any lesion/s produced by pathological processes that disrupt the enamel producing ameloblast cells remains in the tooth for the rest of an individual's life. Tooth development commences at six weeks in utero and continues until approximately 21 to 23 years of age [69, 70]. After eruption, the tooth can be affected by erosion, abrasion, attrition and caries, which may over time affect the appearance of enamel defects [68].

Dentine is also a highly sensitive tissue which can be affected by health insults during the development of the dentition. Such insults could disrupt the mineralisation process of the dentine and produce areas of under-mineralised matrix referred to as interglobular dentine (IGD) [41, 42, 68]. Unlike enamel, dentine is a vital tissue due to the dentine-pulp complex that allows dentine to respond to caries (decay), erosion, and trauma after the development of the tooth is complete [41, 42, 68]. However, the remodelling process in dentine is much less than that in bone [42]. Therefore, teeth are a valuable source of information for the investigation of the effects of the environment on an individual's health.

St Marys-on-the-Sturt—A rural settlement in the colony

St Marys-on-the-Sturt was established in the late 1830s [71]. This was a small village located eight kilometres south of the city of Adelaide (Fig 1A). The majority of migrants were of British origin and an Anglican Church (St Mary's) was established in the village. The land surrounding the church was allocated for a cemetery (Fig 1B) and the first burial was in 1847 [72]. A small section of the cemetery at the rear of the church was allocated for individuals whose burials were funded by the Government of South Australia [73, 74]. This section was referred to as the 'free ground' area and the burials here were unmarked (Fig 1B) [71].

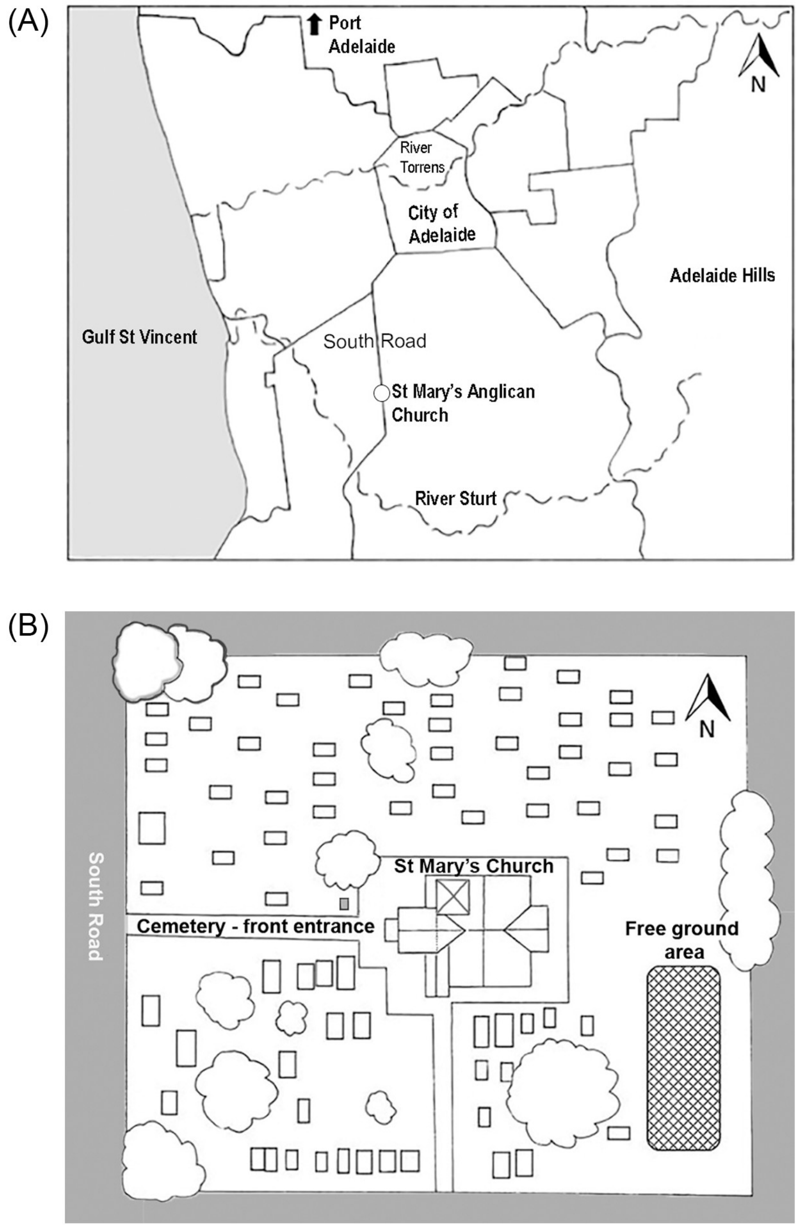

Fig 1. **A**. Location map: Position of St Mary's Church and Cemetery in relation to the City of Adelaide and surrounding region. Reprinted [75] and under a CC BY license, with permission from the City of Marion Council, original copyright 2020. **B**. A schematic diagram of St Mary's Anglican Church Cemetery. The hatched rectangle at the rear of the church building shows the free ground area. Illustrative purposes only and not to scale or representative of the number of burials/gravestone memorials in this cemetery.

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Material and methods

Sample

The Flinders University Social and Behavioural Research Ethics Committee (SBREC project number 8169) approved the research. The excavation and the study of skeletal remains were conducted at the request of the St Mary's Anglican Parish. The burials at the free ground area were unmarked, thus preventing the identification of the buried individuals. No permits were required for the described study, which complied with all relevant regulations [73].

Skeletal remains of 70 individuals (20 adults and 50 subadults) were excavated in 2000 [73], from the free ground section of St Mary's Anglican Church Cemetery, South Road, South Australia. The individuals had been buried in this area of the cemetery between 1847 and 1927. Skeletons were not excavated from any other areas of the cemetery. A site code (SMB—St Mary's Burial) and identification number were allocated to each excavated skeleton [73]. Skeletal remains of St Mary's sample are part of an archaeological collection; thus, no destructive analysis was permitted.

Previous investigations: Immediately after the excavation (in 2000), an examination of the skeletal samples was conducted by Timothy Anson [73]. This included an assessment of i) the state of preservation of the remains, ii) an estimation of age range at death and iii) determination of sex. A summary of the methods used are given below but full details of the methods, systems, and categories used for these estimations can be found in Anson [73].

i). The state of preservation of each skeleton was estimated as very poor, fair, good to very good [73].

ii). Age range at death:

Subadults: Dental development and eruption rate charts were used in conjunction with assessment of changes in ossifiction centres of the skeleton during development. [76–78].

Adults: Multiple skeletal changes were investigated such as morphological changes in the pubic symphysis and auricular surface, and stature [76, 79–81]. Degenerative changes in the dentition were also used as an indicator of age-related changes [82]. The accuracy of this method is subjective, and results may differ in each individual [83].

iii). Estimation of sex

Subadults: Determination of sex was not possible for the subadults from St Mary's sample due to a lack of changes associated with sexual maturity.

Adults: Observations of morphological changes described by Buikstra and Ubelaker [76], Scheurer et al. [78] and Bass [84] were used to attribute sex.

The St Mary's skeletal collection is temporarily held in an osteological laboratory at the University of Adelaide, South Australia. The unidentified specimens are the property of St Mary's Anglican Church, with Flinders University, South Australia, having a professional oversight of the collection.

Scoring of skeletal material

Current study: Examination of the St Mary's samples found that the skeletons of five subadults were in a very poor state of preservation (i.e., extremely fragmented with little cortical bone available). Therefore, these subadults were excluded from this investigation, thus the remaining total sample size was of 20 adults and 45 subadults. Skulls from eight subadults had disintegrated post-mortem and therefore were not examined.

Macroscopic examination

Each skeleton was arranged in the anatomical position and an inventory of the bones was prepared as described by Buikstra and Ubelaker. [76] and Mitchell and Brickley [85].

The anatomical sites and criteria used for the identification of skeletal manifestations associated with metabolic deficiencies are extensive and are presented in S1 Table. Criteria used for this assessment were as described by Ortner et al. [43], Brickley et al. [44], Brickley and Ives [45], Ortner and Mays [46], Ortner & Ericksen [47], and Heron and Grauer [86] and the characterisation of abnormal porosity was taken from Ortner et al. [43], Brickley et al. [44] and Ortner & Ericksen [47].

Porous lesions seen on the bones of the orbital roof were scored according to the method described by Stuart Macadam [59:109], for example, Type 1- "capillary-like impression on bone", Type 2- "scattered fine foramina", Type 3 to 5 -ranged from "large and small isolated foramina to outgrowths from trabecular bone that extended to the surface of the outer table.

Enamel hypoplastic defects were recorded using an adaptation of the Enamel Defect Index (EDI), as described by Brook [87], Brook et al. [88], and Elcock et al [89]. The above investigation was carried out using a magnification lamp.

Micro-CT examination

Investigation of the internal structure of tooth samples for interglobular dentine (IGD) was part of the study. Traditionally, histological techniques were used for this type of investigation, which required sectioning of the tooth sample. Consequently, a non-destructive method, X-Ray Computed Tomography (micro-CT) was used. The cost of this method allowed the investigation of only a selected sample of teeth from the St Mary's skeletal collection. One tooth from each of the 19 individuals was selected. The individuals were from a broad age range (~2 years to 60+ years of age). The collected tooth samples included two permanent incisors, three permanent canines, three permanent premolars, nine permanent first molars, and two primary molars, as the same tooth type was not available from each individual. Each tooth was scanned using the Bruker SkyScan 1276 Micro-CT scanner at Adelaide Microscopy, The University of Adelaide [90]. The scanner was set at source voltage: 100 kV, source current 200 μA, camera binning: 4032 x 2688, filter: aluminium and copper, and pixel size: 9.0 μm. The tooth sample from SMB 63 was scanned for a second time using the pixel size of 5.21 μm. Micro-CT scan datasets were reconstructed into a visual image using NRecon, a volumetric reconstruction software. These reconstructed scan data sets were viewed as either two-dimensional (2D) or three-dimensional (3D) images using Dataviewer, a volume rendering software and Avizo 9 software [91]. The 2D and 3D images were analysed to identify mineralisation defects in the teeth. Dentine defects seen on the micro-CT scans were scored, as described by Colombo et al. [92] and Veselka et al. [93].

St Mary's Cemetery burial records

Data from St Mary's Church records, in relation to burials in the 'free ground' area of the cemetery (1847 to 1927) were used [73:356–381]. Parish burial records recorded the location of an individual's burial site within St Mary's Cemetery. Burials were either in 'lease' plots, which were privately funded in the main section of the cemetery (Fig 1B), with a memorial marker (i.e., headstone), or in the unmarked government funded 'free ground' area at the rear of the church building (Fig 1B). If an individual was buried in a 'leased' plot the church register recorded the assigned burial plot number and the personal details of the interred individual, plus any notes regarding the funeral arrangements (73:38). For individuals buried in the free ground section of this cemetery, minimal information was recorded. Some individuals whose names are listed in this burial register did not have their burial location site recorded. This was especially true for many infants. Some infants just had the words "unbaptised-no service" recorded (73:362). It is difficult to know if the individuals without the location of their burial recorded were interred in the free ground area of St Mary's Cemetery. However, as the leased plots were paid for by the individual or their family, the details of the interred would have been recorded in full with the identifying number of the assigned burial plot and it is unlikely that such minimal details would have been acceptable. Therefore, for the purpose of this study individuals who did not have a location for their burial recorded in the church records were included in a list of individuals that *could* have been buried in the free ground area of St Mary's Cemetery.

Comparison of St Mary's findings with those published for two British skeletal samples

Findings from the St Mary's samples on pathological manifestations that could indicate a disturbance of the metabolism were compared with those published for the two-19th century to early 20th century British skeletal samples. This was to assess the effect of the establishment of a new colony on early migrants. One sample was from St Martin's-in-the-Bullring Church, Birmingham, England (N = 406) [45, 94, 95], where the majority of burials were between 1810 and 1864, with declining numbers of individuals interred until 1915 [94]. St Martin's Cemetery was located in an industrial city where many individuals buried may have been from the working classes. Thus, this sample was considered appropriate for the comparison with the St Mary's sample, as many of the buried individuals were British migrants and were from a similar socioeconomic working-class background.

The published results for the second comparison sample were individuals from St Peter's Collegiate Church overflow burial ground, Wolverhampton, England, (1819 to approximately 1900) [96, 97]. Wolverhampton was originally a market town with a similar mix of agriculture and small industries to St Mary's-on-the-Sturt. The industrial development of local mining activities during the 19th century eventually contributed to the increase in population size in this British town [96]. Published findings from St Peter's skeletal samples were also considered as an appropriate comparison sample to the St Mary's sample. The majority of the individuals in St Peter's sample were from agricultural, industrial and mining backgrounds, and thought an appropriate sample for comparison with the results of St Mary's collection [16, 17, 96, 97].

Results

Demography

Estimated age range at death and the sex for the skeletal samples from St Mary's free ground are presented in Table 1. Among the 45 subadults in this sample, 36 were under two years of age.

St Mary's Cemetery burial records

Data from burial records for St Mary's Church Cemetery for 1847–1927 (73:356–381), listed individuals with the location of their burial as the free ground (Fig 1B). Some individuals did not have the location of their burial site recorded. As previously discussed, for the purpose of this study, both these types of listings (i.e., burials in free ground and no burial location recorded) in the burial records were considered to be individuals who *could* have been buried at the free ground area of St Mary's Cemetery. The number of individuals included in this list amounted to N = 195. This number was made up of 71 individuals listed as buried in the free ground and 124 individuals with no location of burial site recorded.

A survey of the gravestone memorials associated with privately funded leased burial plots in the main section of St Mary's Cemetery (Fig 1B), indicated that at least 227 people were buried

Table 1. Demography. Estimated age range and sex of St Mary's sample [72].

Age range at death (years)	Sex			Total
	Female	Male	Undetermined	
0–1	0	0	17	17
1–4	0	0	22	22
5–9	0	0	3	3
10–14	0	0	3	3
15–19	1	0	0	1
20–29	1	0	0	1
30–39	2	1	0	3
40–49	3	2	0	5
50–59	1	7	0	8
60+	0	2	0	2
Subtotal	8	12	45	65
Total sample				**65**
Adult	8	12	0	**20**
Subadults	0	0	45	**45**

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in these plots during the study period (1847–1927). A comparison of the 195 individuals that could have been buried in the free ground area with those buried in leased grave plots (n = 227) by the decade of burial is presented in Fig 2.

Analysis of individuals who could have been buried at the free ground, as listed in the church records, whose age and month of death had *also* been recorded (n = 191), over the period of 80 years (1847–1927) is presented in Table 2 and Fig 3. These findings indicated that 63% of these deaths were of infants age range 0–11 months and 64% were of subadults age range from 0–4 years (Table 2). Four individuals from the original list of N = 195 were not included in the analysis (Table 2 and Fig 3), as they either did not have their month of death recorded or their age range listed.

The burial records list 80 infants under the age of one year that *could* have been buried in the free ground area of St Mary's Cemetery. As previously mentioned, there were four individuals (i.e., from the original total of N = 195) that could not be included in Table 2. Three of these four individuals were infants less than one year old, who had their *age* at death listed in the burial register but *not* the month of death. This meant that they could not be included in Table 2 or Fig 3 but they could be included in Fig 4, along with the other 77 infants already listed in Table 2 (n = 80). The fourth individual did not have either an age at death or a month of death recorded and therefore could not be included in Table 2, Figs 3 or 4.

Fig 4 represent an analysis of the 'age range at death' of infants less than one year of age from the burial list of N = 195 individuals that *could* have been buried in the free ground. This analysis shows that the majority of infants buried in the free ground died between 4 months and 11 months of age.

Summary of observed skeletal manifestations

Pathological manifestations that were observed on the excavated skeletal remains of individuals buried at St Mary's free ground area (N = 65) are presented below.

Bones. i) Abnormal porosities in the bone cortices:

Nine adults and 12 subadults had at least one area of abnormal porosity in the cortical parts of the following bones: maxilla—infra-temporal surface, alveolar process, and palatine processes

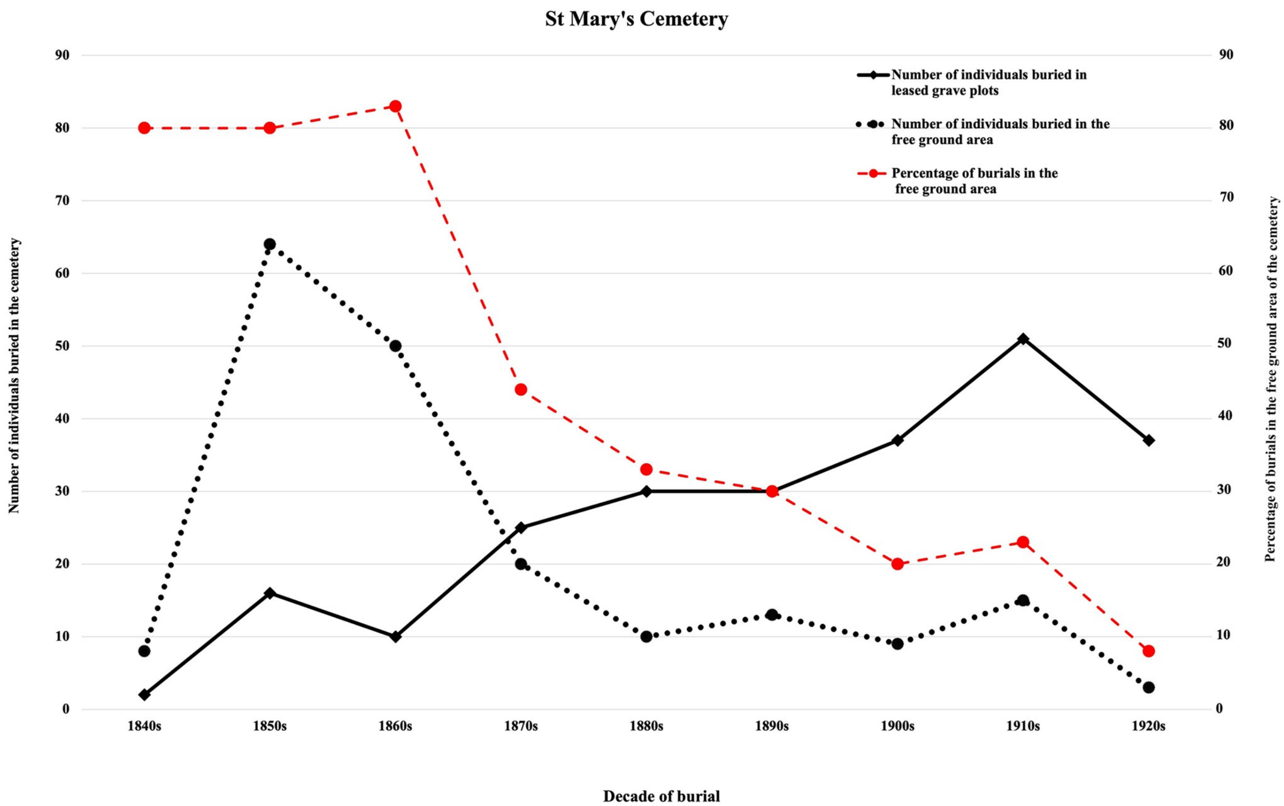

Fig 2. St Mary's burial records. A comparison of the number of people listed a either buried in the free ground area or with no location of burial listed (n = 195), with those buried in leased plots with gravestone memorial markers (n = 227) in St Mary's Cemetery, by decade of burial [73]. Red *dashed* line indicates the percentage of burials in the free ground area of this cemetery.

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Table 2. St Mary's Cemetery—The individuals that could have been buried at the free ground area, whose age range *and* month of death had been recorded (1847–1927) (n = 191) [73].

Month of burial:	Age range (years)									
	0–11 (months)	1–4	5–9	10–14	15–19	20–29	30–39	40–49	50–59	60+	Total
January	7	4	0	0	0	0	1	1	0	3	16
February	5	2	0	1	0	0	1	0	1	1	11
March	11	6	0	0	0	1	0	0	2	3	23
April	7	2	0	1	0	0	0	1	0	1	12
May	8	5	0	2	1	0	3	0	0	3	22
June	3	2	0	0	0	2	1	0	0	0	8
July	9	4	2	1	1	0	1	1	0	2	21
August	4	4	0	2	0	0	0	1	0	1	12
September	2	6	1	0	1	1	2	4	1	3	21
October	2	0	1	0	0	0	0	2	1	2	8
November	5	4	0	0	1	0	0	0	0	2	12
December	14	6	0	0	0	0	1	2	1	1	25
Total per age group	77	45	4	7	4	4	10	12	6	22	N = 191

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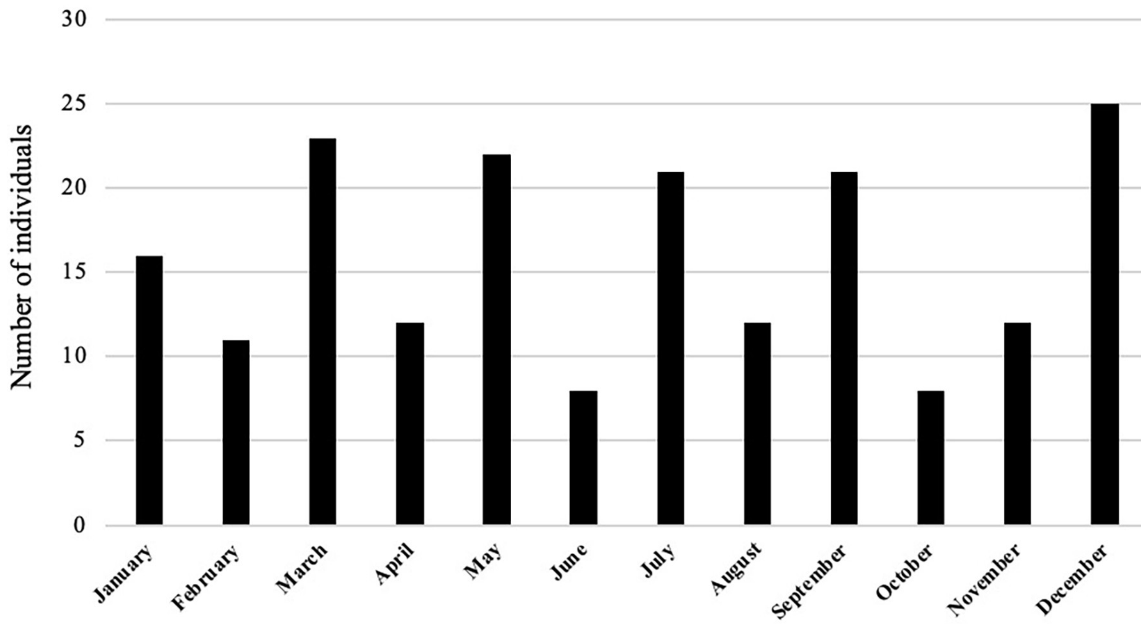

Fig 3. St Mary's Cemetery—A visual representation of the number of individuals who could have been buried at the free ground with their month of burial as listed in church records (1847 to 1927) (n = 191) [73].

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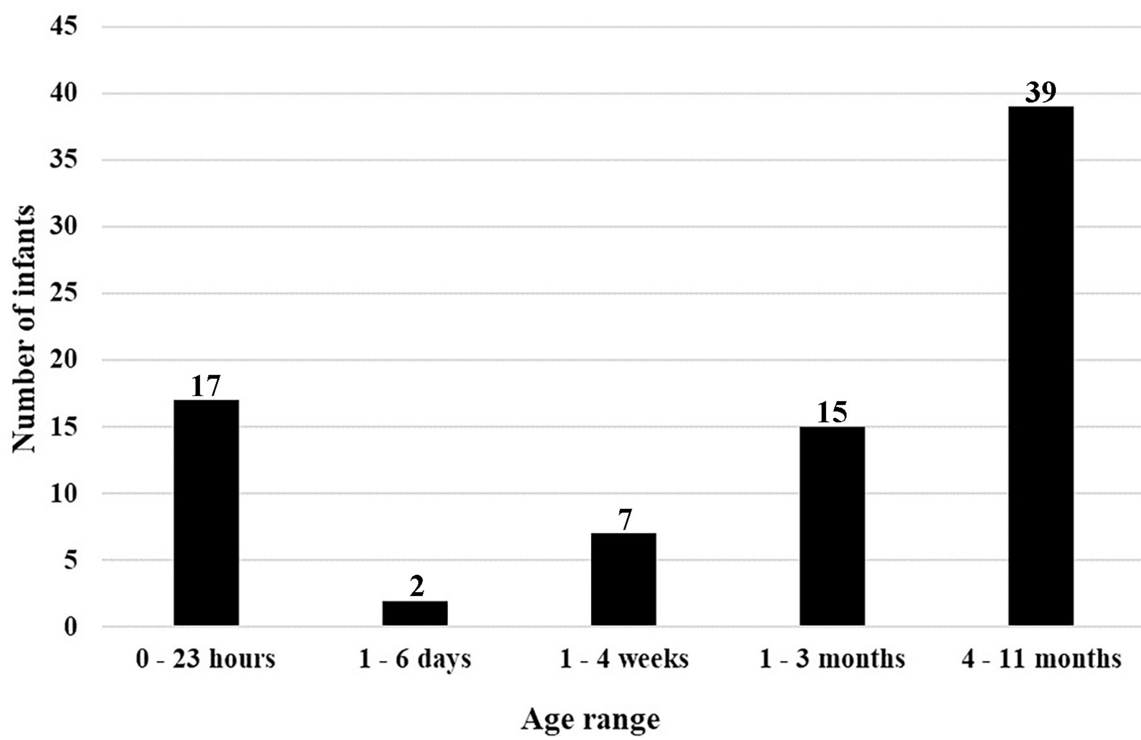

Fig 4. St Mary's Cemetery—Age range at death—The number of infants under one year of age listed in St Mary's burial records that could have been buried in the free ground area of the cemetery.

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Fig 5. Infant, SMB 56. Palate, inferior view, showing areas of abnormal porosity that extended throughout the alveolar process of the maxillae.

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(Fig 5); mandible—medial surfaces of the coronoid process, alveolar process; sphenoid—greater wing. One infant, SMB 56 (approximately 6–9 months of age), in addition to the above bones showed areas of abnormal porosity in the cortices of the lateral and basilar portion of the occipital bone, scapulae, ribs, vertebral arches, ilia, and the extremities of long bones. The prevalences of abnormal porosities and other bony changes are presented in Table 3. The

Table 3. St Mary's. prevalences of pathological manifestations associated with metabolic deficiencies in different bones of the skeletons of individuals excavated from the free ground area of the cemetery.

Age (years)	0–11 mths	1–4	5–9	10–14	15–19	20–29	30–39	40–49	50–59	60+	Total	Total Prev.%
Abnormal porosity in the cortex of bones listed below:												
Maxillae: infra -temporal surface [46:215]	1/5	2/11	0/2	0/2	0/1	0/1	0/2	0/3	0/2	0/1	3/30	10
Palatine proceses	1/4	0/13	0/2	0/3	0/1	0/1	0/3	1/5	1/6	0/1	3/39	8
Alveolar process	2/3	4/13	1/2	1/2	0/1	0/1	1/3	0/5	0/6	0/1	9/37	24
Mandible: Coronoid process medial surface	1/9	0/13	0/2	0/3	0/1	0/1	0/3	1/5	0/6	0/1	2/44	5
Alveolar process	1/9	0/15	0/2	1/3	0/1	0/1	0/3	0/5	0/7	0/2	3/48	6
Greater wing of the sphenoid bones	0/3	1/6	1/3	1/2	0/1	0/1	0/3	0/5	0/6	0/2	3/32	9
Other skeletal changes to bones listed below:												
Ribs: Enlargement of the costochondral junctions	1/4	0/5	0/1	0/2	0/1	0/1	0/3	0/3	0/2	0/0	1/22	5
Long bones: Flaring of the distal metaphysis	0/13	1/14	0/3	0/1	0/1	0/1	0/3	0/5	0/7	0/1	1/49	2
Orbital roofs porous lesions (any Type)	0/7	2/14	1/3	3/3	1/1	0/1	0/3	0/5	2/8	0/2	9/46	20
Orbital roofs porous lesions (Types 3 or 4) [58]	0/7	1/14	1/3	1/3	0/1	0/1	0/3	0/5	0/6	0/2	3/46	7

Note. Results presented as the number of individuals with the observed sign (-n-) over the total number (-N-) of individuals with the bone available for observation (n/N), with age groups of the individuals.

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prevalences presented in the table are in relation to the number of individuals who had the particular bone.

ii) Enlargement and flaring of the costochondral junctions of ribs:

One infant, SMB 56, had bilateral enlargement and flaring of the costochondral junctions of ribs (Table 3).

iii) Enlargement and flaring of the metaphyses:

One subadult, SMB 8 (approximately 18 months of age), showed flaring and enlargement of the distal metaphyses of the femora (Table 3).

iv) Porous lesions on the bones of the orbital roof:

Three subadults, SMB 4A (approximately 4 years of age), SMB 19 (approximately 8 years of age), and SMB 28 (approximately 13 years of age), showed porous lesions on the bones of the orbital roof of Types 3 and 4 [59]. The lesions observed on SMB 28 were composed of small and large pores on the right and left orbital roof respectively (Fig 6). The pores on the right orbital roof penetrated the cortical bone, while those on the left exposed trabecular bone (Fig 6). This subadult also displayed areas of abnormal porosity in the cortex of the greater wing of the sphenoid bones bilaterally.

v) Subadults, SMB 27B (approximately 2 years of age), SMB 28, SMB 51 (approximately 11 years of age), SMB 56 and SMB 58 (approximately 2 years of age) who had two or more macroscopic pathological manifestations are summarised and presented in Table 4.

Teeth. i) Enamel—hypoplastic defects

A group of 42 individuals from the St Mary's excavated sample (n = 65) had teeth available for examination. Eighteen of these individuals showed evidence of enamel hypoplastic defects and findings are presented in Table 5. The prevalence of this defect was higher among the adults

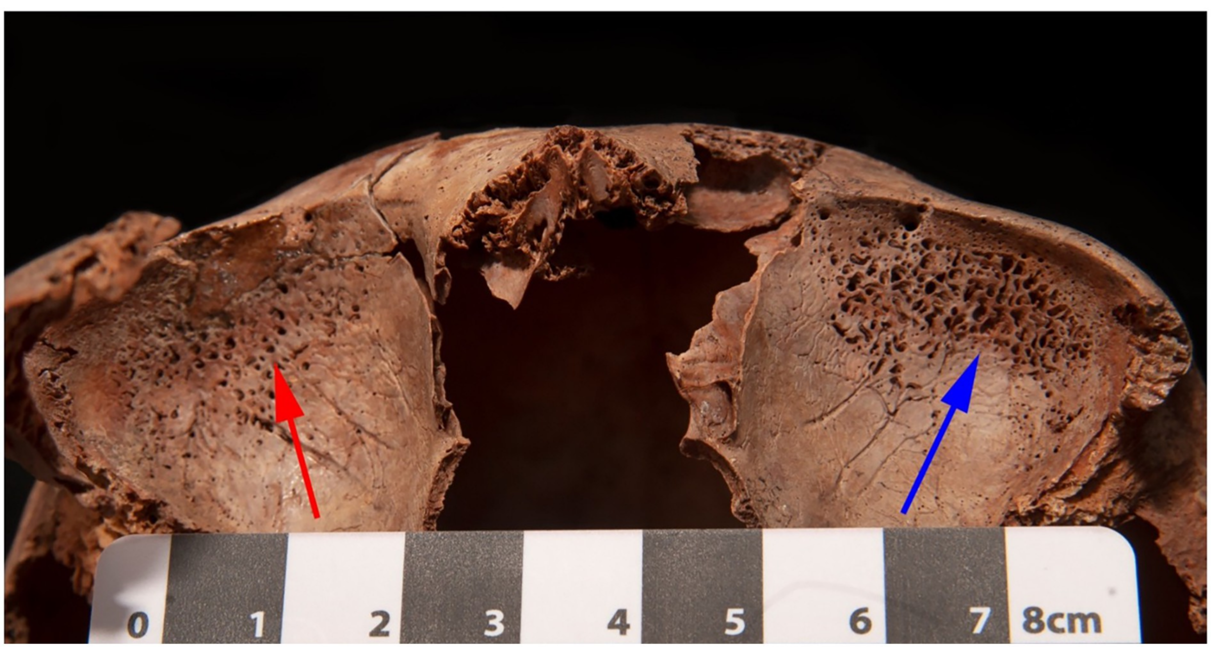

Fig 6. Subadult, SMB 28. Porous lesions on the bones of the orbital roof. Red arrow indicates small pores in the right bone cortex. Blue arrow indicates exposed trabecular bone on the left.

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Table 4. St Mary's. subadult samples with their age at death, who showed two or more macroscopic pathological manifestations associated with metabolic deficiencies.

	Approximate age at death (years)					
	SMB 27B	SMB 28	SMB 51	SMB 56	SMB 58	SMB 70
	~2	~13	~11	~6 to 9 months	~2	~ 9
Abnormal porosity in the cortex of bones listed below:						
Greater wing of the sphenoid bones	--	P	--	--	A	P
Zygomatic bones: internal surface	--	--	--	--	P	--
Maxillae: infra-temporal surface [46:215]	A	A	--	P	P	A
Maxillae: palatine process	A	A	A	P	A	A
Maxillae: alveolar process	P	P	--	P	P	P
Mandible: coronoid process medial surface	A	A	A	P	A	--
Mandible: alveolar process	A	A	P	P	P	--
Orbital roofs: Type of lesion [58:109]	P Type 1	P Type 4	P Type 1	--	A	A
Scapulae: area of the supraspinous *or* infraspinous fossa	--	A	A	P	A	P
Pelvic bones	A	A	A	P	A	P
Other skeletal changes to bones listed below:						
Ribs: enlargement of costochondral junctions	--	A	A	P	A	--

Key: P = condition present, **A** = condition absent, - - = condition unobservable due to skeletal part missing

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(14 individuals—78% of this group) compared to subadults (4 individuals—22%) (Table 5). One subadult, SMB 70 (approximately 9 years of age), was previously diagnosed by Ioannou et al. [98] as having suffered from congenital syphilis and was treated with mercury. The infectious disease and toxic treatment given to this subadult would have affected the development of the teeth and enamel [98]. The full account of this individual's diagnosis, skeletal lesions and analysis is published [98].

The incisors and canines (anterior teeth) (Table 5) were the most affected tooth type by enamel hypoplastic defects (linear and/or enamel hypoplastic pits [41]) in the St Mary's samples.

ii) Interglobular dentine (IGD)

Lesions in the internal structure of the tooth seen on micro-CT scans were areas of deficient mineralisation in the dentine. Such lesions have been described as IGD [42, 68]. Areas of IGD were seen in two adults, SMB 6 (45 to 55 years of age) and SMB 63 (55 to 60 + years of age) (Fig 7), and one subadult, SMB 70. The latter subadult was previously mentioned as the individual who had suffered from congenital syphilis and treated with mercury [98]. The tooth sample from the adult SMB 63 (a permanent lower lateral incisor) was selected or further investigation using a higher resolution of the micro-CT scanner (pixel size: 5.21 μm). This revealed areas of IGD in three separate incremental linear arrangements. One of the areas of IGD was observed opposite an external enamel hypoplastic defect (Fig 7). The crown of this tooth type commences mineralisation at approximately 30 weeks of intrauterine life (±1 month) and completes at approximately 3.5 years (±1 year) [69, 70].

Comparison of St Mary's findings with two British skeletal samples

Findings of the skeletal manifestations in the St Mary's sample and the demographic profile were compared with those published for skeletal samples of two 19th century British

Table 5. St Mary's sample. Individuals who showed enamel hypoplastic defects in permanent dentition.

St Mary's burial code	Age range at death (years)	Sex	Total number of permanent teeth present	Total number of permanent teeth affected	Percentage of permanent teeth affected	Permanent tooth type & the number of teeth affected
SMB 19	5–9	U	21	7	33%	I x4, C x2, P x1
SMB 70	5–9	U	16	7	44%	I x3, C x2
SMB 51	5–9	U	25	2	8%	C x2
SMB 28	10–14	U	32	7	22%	I x4, C x 1, M1 x2
SMB 79	15–19	F	28	2	7%	C x2
SMB 5	20–29	F	5	2	40%	I x 2
SMB 53C	30–39	F	11	4	36%	I x4
SMB 9	40–49	M	23	8	35%	I x6, C x4
SMB 66B	40–49	M	17	8	47%	I x1, C x1, P x4, M2 x4
SMB 73	40–49	M	19	14	74%	I x7, C x4, P x2, M1 x1
SMB 6	40–49	M	14	1	7%	I x1
SMB 57	50–59	M	26	6	23%	I x3, C x3
SMB 72	50–59	M	29	6	21%	I x1, Cx2, Px1, M3 x2
SMB 83	50–59	M	15	6	40%	C x4, M2 x1, M x1
SMB 59	50–59	M	17	6	35%	I x5, C x1
SMB 68	50–59	M	18	6	33%	C x2, P x4
SMB 23	50–59	M	23	3	13%	I x2, C x1
SMB 63	60+	M	3	2	67%	I x2

Note: U = undetermined sex.

Key: For permanent tooth types: I = Incisor, C = Canine, P = either first or second premolar, M1 = first molar, M2 = second molar, M3 = third molar.

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cemeteries. One sample is from St Martin's-in-the-Bullring Church Cemetery, Birmingham, [94], and the other from St Peter's Collegiate Church burial ground, Wolverhampton [96, 97]. A comparison of the number and percentage of adults and subadults from each sample is presented in Table 6.

Skeletal manifestations

A comparison of the macroscopically observed skeletal manifestations among the subadult samples from the three cemeteries is presented in Fig 8.

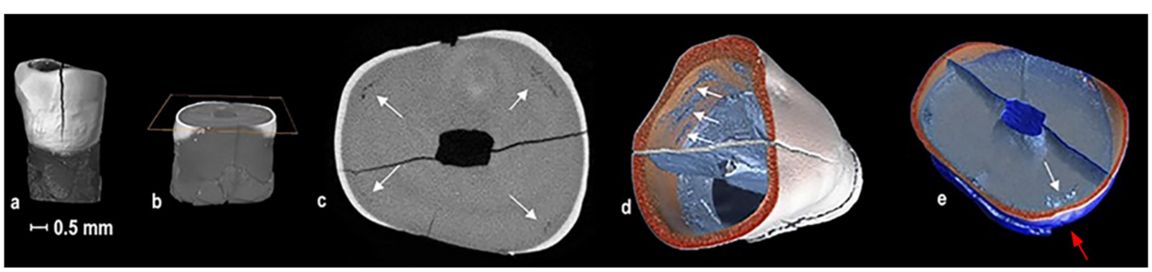

Fig 7. St Mary's Cemetery. Micro-CT images. Adult, male, SMB 63. (a) Lower lateral permanent incisor with a post-mortem fracture in the crown. (b) Transverse slice: At the level of the IGD in the crown. (c) Transverse slice: Arrows show four areas of IGD. (d) Transverse slice: Arrows show three areas of IGD, image was angled to show location of IGD in three concentric layers. (e) White arrow shows IGD (internal) opposite an enamel hypoplastic defect red arrow (external).

https://doi.org/10.1371/journal.pone.0265878.g007

Table 6. Demographic profiles of St Mary's, St Martins and St Peter's cemeteries.

Cemetery	Total Sample Size N =	Adults		Subadults	
		number	%	number	%
St Mary's (SA)	65	20	31	45	69
St Martin's (UK)	406	242	60	164	40
St Peter's (UK)	150	92	61	58	39

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i) Abnormal porosity in the bone cortices:

Subadults from St Martin's and St Peter's Cemeteries had areas of abnormal porosity in the cortices of bones in the following anatomical sites: maxillary bone—area surrounding the infra-orbital foramen, alveolar process and the antero-medial portion of the palatine process; mandible—medial surface of the coronoid process; frontal bone—orbital plate (roof of orbit); parietal and occipital bones—external surfaces; and scapulae—supraspinous fossae [45, 94, 97]. This manifestation (abnormal porosity in the bone cortex) was higher among St Mary's subadults compared to St Martin's and St Peter's subadult samples (Fig 8). Nine adults from the St Mary's sample also had one area of abnormal porosity in the cortices of cranial bones, however, this skeletal manifestation was not observed in adults of St Martin's or St Peter's samples [45, 94, 97].

ii) Bending /bowing distortion of long bones:

This skeletal abnormality was seen only among the subadults of St Martins and St Peter's samples (Fig 8) [94, 95, 97]. Furthermore, no adults from the three cemeteries were seen with this skeletal abnormality.

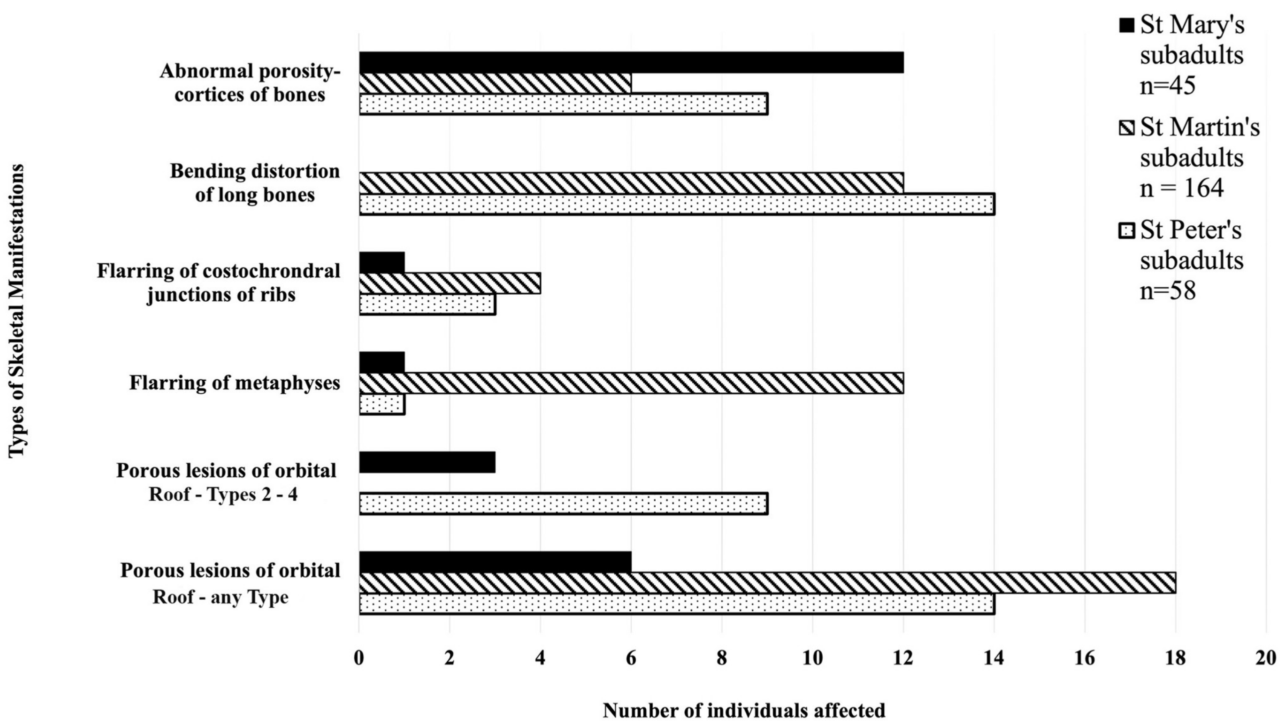

Fig 8. Comparison of the skeletal manifestations observed in the subadult samples from St Mary's Cemetery, South Australia and St Martin's and St Peter's Cemeteries, England and the number of individuals affected.

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iii) Enlargement and flaring of metaphyses:

St Martin's had a greater number of subadults with flaring of metaphyses than St Mary's and St Peter's subadult samples (Fig 8) [94, 95, 97]. No adults from the three cemeteries were seen with this skeletal manifestation.

iv) Porous lesions on the bones of the orbital roof:

The scores for this specific skeletal manifestation were not available for St Martin's samples, thus could not be compared between St Mary's and St Peter's samples. However, the published results for St Martin's Cemetery state that 17 adults and 18 subadults were observed with "varying degrees" of porous lesions on the bones of the orbital roof [94:135]. These results have been included in Fig 7 as porous lesions of any Type (i.e., according to the description supplied by Stuart Macadam [59:109]). Therefore, St Martin's had the highest number of subadults with porous lesions on the bones of the orbital roof of any Type compared to St Peter's (14 subadults) and St Mary's (6 subadults) samples [94, 97]. A comparison of porous lesions of Types 2 to 4 [59:109] showed that St Peter's had nine subadults with Types 2 and 3, while St Mary's had three subadults with Types 3 and 4 (Fig 8).

Discussion

St Mary's Cemetery free ground burial records

St Mary's burial records and data collected from headstone of leased burial plots for the decades of 1840s, 1850s and the 1860s, show that the majority of people interred in St Mary's Cemetery, during the early years of this colonial settlement, were buried in the free ground section (Fig 2). This indicates that for approximately 30 years or more, many individuals who were buried at this cemetery or members of their family could not pay for a burial. This was a period of establishment for the new colony, during which time the new settlement experienced an economic recession and had a high unemployment rate [13, 20]. Therefore, it is likely that a percentage of the early settlers in the region of St Marys-on-the-Sturt may not have had regular employment. If individuals or families had economic difficulties, they may have had to depend on charitable organisations or the government for their survival. This early economic hardship in the colony is reflected in the need for relief from the Destitute Asylum for many people living in or near the city of Adelaide.

A high mortality rate for infants is also reflected in the burial records from St Mary's (Table 2 and Fig 4). This could be the result of many factors, including poor living conditions, lack of social/family support systems and/or inadequate availability of health services. An analysis of the month of burial, for individuals listed in the St Mary's Church records [73], that could have been interred in the free ground area of the cemetery from 1847 to 1927, (n = 191) (Table 2 and Fig 3), showed that a higher number of infant burials took place in the summer month of December (Table 2). However, the total number of burials per month for this group (any age group) (Fig 3) showed no seasonal pattern. The weather during a South Australian summer could be extreme, with temperatures above 100ºF (38ºC). In December 1897, a local newspaper in Adelaide reported a record heat wave since the foundation of the colony, with temperatures of "over 90˚F in the shade for 17 days followed by temperatures of over 100˚F in the shade for a further eight days" [99:5]. They described that multiple deaths occurred in and around the city of Adelaide due to the heat, including eight deaths at the Destitute Asylum in two days [99:1]. In addition, a number of children were affected by the high summer temperatures and the public were advised that they could "be brought around by applying ice to the head" [99:1]. The findings from St Mary's burial records and the information from this 19th

century newspaper suggests that the summer temperatures in South Australia could have magnified any health conditions that an individual may have been suffering. This finding contrasts with the published results for colonial settlers buried at Milton, Otago, New Zealand by Buckley et al. [100]. They were able to identify a pattern in the monthly burials at Milton, with a higher number of deaths occurring in the winter months of June, July and August and fewer deaths in the summer months [100]. The difference in seasonal trends may well be related to the different climatic conditions in South Australia and the South Island of New Zealand [100].

At St Mary's Cemetery, the location of burial for some infants was not documented in the burial records [73:364]. This may be the result of an infant having been stillborn or dying a short time after their birth (Fig 4). The burial records listed 41 infants that were under the age of three months (Fig 4), which is 21% of the total number of individuals whose age at death was *also* listed, that could have been buried in the free ground area (n = 194—one individual did not have their age recorded). In the new colony no official regulations were in place in relation to the location of a burial for a stillborn infant, or the requirement to register the birth of a stillborn child until 1936 [74, 101]. Burial practices of perinates excavated at the 19th century Parramatta Convict Hospital in New South Wales, Australia, showed they were afforded very little respect or care [102].

Economic recovery of the new colony

The improved economic condition of the colony following the first depression during the 1840's could have influenced the economic changes seen at St Marys-on-the-Sturt. A local financial recovery is reflected in the lower number of burials in the free ground section of St Mary's Cemetery (Fig 2) [13, 20]. The percentage of these burials began to decrease during the 1860s and reduced to only 8% of the total burials in the cemetery in the 1920s (Fig 2). This suggests that there was a gradual improvement in the economic status of the individuals who lived in the region of St Marys-on-the-Sturt and that the majority of the excavated skeletons studied could be those of individuals who lived during the establishment of the colony. The South Australian economy improved sufficiently for the introduction of an old age pension after the turn of the 20th century which reduced the need for the Destitute Asylum [30].

Skeletal manifestations indicating metabolic disturbance

Abnormal porous lesions seen in the cortical bone of 9 adults and 12 subadults were the common manifestations present in the St Mary's skeletal collection (Tables 3 and 4). This abnormality could be caused by a deficiency of vitamin C, which affects the synthesis of collagen in body tissues including blood vessels and bone, resulting in weak vessel walls and defective production of osteoid [45, 51, 103]. Ortner and Ericksen [47:215] have suggested that areas of abnormal porosity seen on the infra-temporal surface could be the result of an inflammatory response to "leakage from scorbutic deep temporal arteries". They propose that abnormal porous lesions with "fine holes that are less that 1mm in diameter" are a result of localised increased vascularity seen in response to extravasated blood from weak vessels [47:212]. Different processes, including defective mineralisation in cortical bone, could appear as porous lesions in dry bone samples resulting from the decomposition of the unmineralised bone matrix [44]. The porous lesions resulting from both vitamin C and vitamin D deficiencies are similar. Therefore, it is important to differentially diagnose the lesions from normal anatomical variation, non-specific localised infections that cause an osteoblastic response, trauma, neoplastic disorders and/or genetic causes [51, 104, 105]. Furthermore, the location, distribution and quantity of lesions on the skeleton should be considered [44].

The subadult, SMB 56 (approximately 6 to 9 months of age), had abnormal cortical porous lesions in multiple locations of the skeleton (Table 4), as well as flaring of the costochondral junctions of the ribs. These skeletal manifestations could be attributed to either vitamin C or vitamin D deficiencies or a combination of both [43, 45, 95]. The rapid growth of an infant bone produces areas of new formation in the skeleton, which could appear as porosity on the cortical surface of bone. However, this change in surface texture would not penetrate the cortex of the bone in the same way as an increase of vascularity would as an inflammatory response from the body [43, 47]. The extensive and symmetrical nature of the porosity seen in the bone cortices of multiple bones of this infant is suggestive of a chronic systemic disorder that could have disturbed the metabolism near the time of death [106]. The infant's fragmented and missing cranial bones was a limitation to a full diagnosis and could have biased the findings. It is possible that other manifestations could have been located on areas of the skeleton, for example such as porous lesions bilaterally on the greater wing of the sphenoid bones or bones of the orbital roof that were no longer present.

Five subadults, SMB 27B (approximately 2 years of age), SMB 28 (approximately 13 years of age), SMB52 (approximately 11 years of age), SMB 58 (approximately 2 years of age) and SMB 70 (approximately 9 years of age), showed two to four skeletal manifestations associated with metabolic deficiencies (Table 4). Three of these subadults had porous lesions on the bones of the orbital roof of Types 3 and 4 [59:109] (Tables 3 and 4). These types of porous lesions have been considered as an indicator of anaemia, which as previously mentioned, may have resulted from a dietary deficiency of iron and/or vitamin B12, malabsorption of iron from the gut due to chronic diseases and/or chronic blood loss resulting from gastrointestinal parasites conditions [59, 63–66]. Subadult, SMB 28 had areas of abnormal porosity on orbital roof (Type 4) and the greater wings of the sphenoid bones (bilaterally) (Table 4). This individual could have had a co-occurence of vitamin C deficiency and anaemia, as vitamin C enchances the absorption of iron from the gut [51], therefore, a deficiency of this vitamin may have aggravated any anaemia that was present in SMB 28.

The remaining adults and subadults in St Mary's sample only showed one manifestation on one location of the skeleton, for example subadult, SMB 8 (approximately 18 months of age) had flaring of the distal metaphyses of the femora, but without any other pathological manifestations observed in their skeleton this subadult was considered as not suffering from a chronic metabolic deficiency (Table 3). It is possible that these individuals died before changes to the bone structure could occur and the state of preservation of some of the skeletal remains may also have biased the findings.

Dental defects

i) Enamel hypoplastic defects

The enamel hyperplastic defects seen in the 18 individuals from the St Mary's sample were all on permanent teeth (Table 5). This may be due to developmental timing, as the primary (deciduous) dentition is less affected by developmental enamel defects than the permanent dentition [68, 69]. The health insult/s that caused the enamel hypoplastic defect/s occurred during the development of the specific permanent tooth types (Table 5) [42, 68, 69]. The location and distribution of these enamel defects seen in the St Mary's sample suggest they were caused by insults between birth and 4 years of age.

The 14 adults and 4 subadults who showed evidence of these enamel hypoplastic defects represented 43% of the individuals with remaining dentition (n = 42). There are 20 adults in the St Mary's collection, two of these adults were edentulous. Fourteen of the remaining 18 adults had hypoplastic defects of the enamel (78%). This percentage is comparable to a cohort of adults (86%) with enamel hypoplastic defects who were migrants to Milton, New Zealand, during the 19^{th} century [100]. Isotopic analysis of this New Zealand cohort indicated that none of them were born locally [107], thus the health insult that caused the enamel hypoplastic defects would have occurred in their home country [100]. This is also highly likely for the adults in the St Mary's sample. The high percentage of adults with enamel hypoplastic defects in St Mary's sample and the sample from Milton, New Zealand, suggests that the this dental defect was common amongst the migrant settlers.

Enamel hypoplastic defects are a general, non specific indicator of disturbance and/or disease during dental development [108]. The four St Mary's subadults with enamel hypoplastic defects (Table 5) also had other skeletal manifestations (Table 4), which have been previously discussed. The pathological conditions suffered by these individuals may have contributed to the formation of the enamel hypoplastic defects during dental development.

ii) Interglobular dentine

Two adults and one subadult from St Mary's sample had areas of IGD on micro-CT scan images. Adult, SMB 63 (55 to 60 + years of age), had three separate areas of IGD (Fig 4), which indicates that he could have suffered from three separate episodes of health insults during the development of this tooth. Again, these health insults could have occurred before migration. One of the areas of IGD in the internal structure of this tooth was opposite an external enamel hypoplastic defect. It is possible that the enamel hypoplastic defect could have resulted from the same health insult that caused the IGD (Fig 4) [109–111].

Comparison of St Mary's free ground skeletal samples with those of St Martin's and St Peter's samples in Britain

The working-class background of some of the people buried at the free ground area of St Mary's Cemetery could be similar to those published for St Martin's and St Peter's cemeteries in Britain [45, 94–97]. However, the demographic profile of the St Mary's sample is somewhat different from those of the British samples. The majority of St Mary's sample was composed of subadults (Tables 1 and 6), with 60% of subadults under the age of four years. The cause of deaths of many subadults was from gastrointestinal conditions such as dysentery and/or vomiting from contaminated water supplies, or pulmonary conditions from bacterial infection such as whooping cough [73:372–381]. Some of these deaths may have resulted from limited access to emergency medical help in the region of St Marys-on-the-Sturt. A study of mortality records from the neighbouring state of Victoria, Australia, indicated that there had been epidemics of scarlet fever and measles between 1853–1916 [112]. These infectious diseases could have spread across the border to South Australia.

The skeletal manifestation, abnormal porosity in the cortices of bones, was seen in subadults from St Mary's, St Martin's and St Peter's skeletal samples [45, 94, 96]. The prevalence of such lesions was higher among the subadults from the St Mary's sample (13%) compared to that from St Martin's (4%) and St Peter's samples (2%). The lower prevalence of this manifestation (probable vitamin C deficiency) among the subadults of the British samples could be due to the availability of fresh fruits and vegetables in Birmingham and Wolverhampton. The initial difficulties and delays in establishing farms and the production of food could have caused scarcity of provisions rich in vitamin C during the first decades of the development of South Australia. Subadults affected by this deficiency from the three cemeteries may have been breastfed infants [45, 94, 96, 97]. Therefore, their insufficient intake of vitamin C may have resulted from a dietary deficiency of the mother [44, 65, 113]. Elevated nitrogen isotope values (+ 1.7‰) observed in skeletal remains of some infants from the St Mary's sample [114], relative to those of adult females in the same sample, suggested that breastmilk was a principal source of diet for infants. However, these findings do not indicate whether the child received adequate amounts of milk during breast feeding. Infants may also have been affected by the feeding and weaning practices of that period [114–117].

The number of individuals with the manifestation of enlargement and flaring of the costochondral junctions of ribs and metaphyses of long bones was higher among St Martin's and St Peter's subadult samples compared to those of St Mary's samples (Fig 8) [95, 97]. The manifestation of bending distortions of long bones was only seen among subadults of St Martin's and St Peter's samples and not observed in any of the subadult samples from St Mary's (Fig 8). Skeletal remains of adults from the three cemeteries were free of the above-mentioned manifestations. These skeletal abnormalities have been linked to a chronic deficiency of vitamin D [95, 97]. Among the St Mary's subadults the lower incidence of the manifestations linked to vitamin D deficiency (Fig 7), may well be due to the abundance of sunlight (UV rays) in South Australia.

St Martin's had the highest number of subadults with porous lesions in the bones of the orbital roof (Fig 8) [94]. The scores for these porous lesions, as described by Stuart-Macadam [59], were not available for this sample (Brickley, personal communication, 2018), which made it difficult to compare the findings from St Martin's with those of St Mary's and St Peter's samples (Fig 7). A comparison of this manifestation for Types 2 to 4 [59:109], between the St Mary's and St Peter's subadults showed that St Peter's had more subadults with this pathological manifestation (9 subadults) than St Mary's (3 subadults) (Fig 8). However, St Mary's had one subadult with a Type 4 porous lesion compared to St Peter's subadult samples who had Type 2 or Type 3 porous lesions on the bones of their orbital roof [59:109]. This may indicate that the St Mary's subadult, SMB 28 with the Type 4 porous lesion may have suffered a different, or more severe systemic metabolic disturbances, or may have had a co-occurance of multiple conditions that produced this manifestation.

Conclusion

The rare skeletal sample from the free ground of St Mary's Anglican Church Cemetery in South Australia, generated an opportunity to understand the effects of the establishment of the new colony on the health of these migrant settlers. The abnormal manifestations seen in the bones and teeth of the individuals excavated from St Mary's reflect the health issues they experienced. Many of these issues could have been due to the marked hardships brought about by the unprepared state of the colony for the settlement of the new arrivals and the local environmental conditions. This is supported by the higher percentage of observed skeletal manifestations indicating a deficiency of vitamin C in St Mary's sample compared with the two British skeletal samples. The people who decided to migrate to South Australia during the 19th century may have arrived with hopes of prosperity through the use of natural resources. However, economic differences were seen between migrants, who had lived in the region of St Marys-on-the-Sturt, in the number of burials at the government funded free ground compared to privately funded leased burials from the mid-1840s to 1860s, in St Mary's Cemetery. A decrease in this number of burials in the free ground area from the 1870s to 1920s, suggests a gradual improvement in the economic status of these migrants. This local improvement reflected the economic recovery seen in the rest of the colony.

Supporting information

S1 Table. Combined table of anatomical sites and descriptive features: 'X' indicates which metabolic deficiency the skeletal lesion may be associated with.
(DOCX)

S1 Data. Observed skeletal manifestation listed with location on the skeleton. St Mary's Cemetery: Supporting Data 1.
(XLSX)

S2 Data. Summary—Enamel hypoplastic defects_macroscopic examination. St Mary's Cemetery: Supporting Data 2.
(XLSX)

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2.4. Appendix to Paper 1 (Chapter 2) –Supporting Information

2.4.1. Table S1. Combined table of anatomical sites and descriptive features

Table S1. Combined table of anatomical sites and descriptive features: *'X' indicates which metabolic deficiency the skeletal lesion may be associated with.*

Bones affected	Pathological manifestation	Vitamin C deficiency	Vitamin D deficiency - rickets	Vitamin D deficiency - osteomalacia	Anaemia
SKULL:					
Cranium- exterior surface of bones	Abnormal porosity of cortex	**X**	**X**		
Cranial vault	Fine pitting, diffuse porosity spread over a large area			**X**	
Cranial vault	Late closure of fontanelles		**X**		
Basio-cranium	Invagination if severe			**X**	
Cranial vault- internal surface of bones	Abnormal porosity of cortex (cribra cranii)				**X**
Frontal bone	Slight bossing		**X**		**X**
Parietal bone	Slight bossing		**X**		**X**
Parietal bone	Porous lesion (porotic hyperostosis)				**X**
Parietal bone	Craniotabes		**X**		
Occipital bone	Craniotabes		**X**		
Occipital bone	Porous lesion (porotic hyperostosis)				**X**
Orbital roof	New bone growth	**X**			
Orbital roof	Porous or hypertrophic lesion (i.e,. cribra orbitalia)	**X**	**X**		**X**

	any type				
Orbital roof	New bone growth	**X**			
Greater wing of the sphenoid	Abnormal porosity of cortex	**X**			
Zygomatic (lateral-orbital surface)	Abnormal porosity of cortex	**X**			
Zygomatic bone, internal surface	Abnormal porosity of cortex	**X**			
Maxilla – infra-temporal surface (posterior)	Abnormal porosity of cortex	**X**			
Maxilla - alveolar process	Abnormal porosity of cortex	**X**			
Maxilla- area surrounding infraorbital foramen	Abnormal porosity of cortex	**X**			
Palatine processes	Abnormal porosity of cortex	**X**			
Mandible - coronoid process, medial surface	Abnormal porosity of cortex	**X**			
Mandibular ramus	Deformed		**X**		
Mandible - alveolar process	Abnormal porosity of cortex	**X**			
VERTEBRAE					
	Kyphosis (severe)		**X**	**X**	
	Scoliosis (severe)		**X**	**X**	
Superior & inferior surface of vertebral bodies	Biconcave depression / compression	**X**	**X**	**X**	

Vertebral bodies	Buckling			**X**	
SCAPULAE:					
Lateral border	Fractures			**X**	
Scapulae: body	Exaggerated posterior curve of (when viewed from medial side)			**X**	
Scapulae: Superior border	Buckling/ collapse of the			**X**	
Supra-spinous fossa area - cortical bone	Abnormal porosity of cortex	**X**			
Infra-spinous fossa area- cortical bone	Abnormal porosity of cortex	**X**			
STERNUM:					
	Bending			**X**	
	Protrusion		**X**		
RIBS:					
	Pseudo fractures seen as linear ridges of irregular, spiculated bone			**X**	
	Complete fractures			**X**	
	Lateral straightening			**X**	
	Rib angulation, pigeon chest/ Harrison's grove		**X**		
Costochondral junctions	Enlargement/ flaring/	**X**	**X**		

	swelling/ beading- ‘scorbutic rosary’ or ‘rachitic rosary’				
	Fracture adjacent to the costochondral junction.	**X**			
Osteo-cartilaginous junction	Transverse fractures	**X**			
PELVIS:					
All pelvic bones	Abnormal porosity of cortex	**X**			
All pelvic bones	New bone growth	**X**			
All pelvic bones	Subperiosteal haemorrhage (rare)	**X**			
Superior/ inferior pubic ramus	Pseudo fractures			**X**	
Pubis:	Anterior protrusion			**X**	
Pubic rami	Adjacent not opposing			**X**	
Ilia - medial aspect adjacent to greater sciatic notch:	Pseudo fracture			**X**	
Ilia	Protrusion into pelvic inlet			**X**	
Iliac blade	Curvature/ folding		**X**	**X**	
Iliac crest	Fracture			**X**	
Acetabulae	Anterior facing			**X**	

Acetabulae	Protrusion into pelvic inlet		**X**	**X**	
Sacrum: S3	Extreme ventral angulation/ pelvic obstruction			**X**	
LONG BONES					
Femoral neck	Pseudo fracture			**X**	
Femoral neck	Coxa vara (angulation)		**X**	**X**	
Femoral shaft:	Antero-lateral bending			**X**	
Epiphysis Adult / subadult	Small calcified spurs protrude from lateral border	**X**			
Distal metaphyses	Flaring & swelling		**X**		
Metaphyses	Cupping deformities		**X**		
Growth plates	Abnormal porosity of cortex		**X**		
Growth plates	Cupping deformities		**X**		
Diaphysis - Adult:	Fracture in diaphysis (caused by general de-ossification <u>without</u> new bone growth)	**X**			
Long bones	Bending laterally (bow legged) Genu varum		**X**		

Long bones	Bending medially (knock knees) Genu valgus		**X**		
Cortical bone Adult:	Thin cortices, (due to bone resorption & deficient periosteal new bone formation)	**X**			

Chapter 3. Introduction to Paper 2

3.1. Paper 2 - Overview

Evidence of pathological manifestations on skeletal remains from the St Mary's individuals (paper 1), showed that they had experienced health insults caused by a disturbance of the metabolism. The living conditions in the new colony such as the delay in food production could have influenced these health issues. This new information and confirmation that the majority of individuals buried in the 'free ground' area of St Mary's Cemetery were interred in the first three decades stimulated further research questions. These were related to the effect of the establishment of an industrial society on the skeletal health of St Mary's 'free ground' settlers.

Paper 2 identified that many of St Mary's adults had undertaken long periods of hard physical labour, which pathologically impacted their skeletons. Evidence of joint diseases and/or traumatic injuries was identified. Data from historical documents were explored to understand the common cause of death for the adults and children buried at St Mary's. To determine if the health of St Mary's migrant settlers was different to settlers in NSW, Australia or their contemporaries back in Britain, and therefore the establishment of the new colony had affected them, findings were compared.

Statement of Authorship

Title of Paper	Was it worth migrating to the new British industrial colony of South Australia? Evidence from skeletal pathologies and historic records of a sample of 19th-century settlers
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Principal Author

Name of Principal Author (Candidate)	Angela Gurr		
Contribution to the Paper	Conceptualization, data curation, formal analysis, investigation, methodology, project administration, visualization, writing - original draft, and writing - review and editing. Submission of manuscript and acted as corresponding author.		
Overall percentage (%)	85%		
Certification:	This paper reports on original research I conducted during the period of my Higher Degree by Research candidature and is not subject to any obligations or contractual agreements with a third party that would constrain its inclusion in this thesis. I am the primary author of this paper.		
Signature		Date	17.06.2022

Co-Author Contributions

By signing the Statement of Authorship, each author certifies that:

i. the candidate's stated contribution to the publication is accurate (as detailed above);
ii. permission is granted for the candidate in include the publication in the thesis; and
iii. the sum of all co-author contributions is equal to 100% less the candidate's stated contribution.

Name of Co-Author	Maciej Henneberg		
Contribution to the Paper	Conceptualization, formal analysis, supervision, writing - review and editing.		
Signature		Date	9.03.23

Name of Co-Author	Jaliya Kumaratilake		
Contribution to the Paper	Conceptualization, formal analysis, supervision, writing - review and editing.		
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Contribution to the Paper	Conceptualization, formal analysis, investigation, supervision, writing - review and editing.		
Signature		Date	13/03/2023

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Contribution to the Paper	Resources, writing - review and editing.		
Signature		Date	8/08/2022

Name of Co-Author	F.Donald Pate		
Contribution to the Paper	Resources, writing - review and editing.		
Signature		Date	17/06/2022

3.3. Was it worth migrating to the New British industrial colony of South Australia? Evidence from skeletal pathologies and historic records of a sample of 19th-century settlers

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Research article

Was it worth migrating to the new British industrial colony of South Australia? Evidence from skeletal pathologies and historic records of a sample of 19th-century settlers

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ABSTRACT

Objectives: To examine pathological evidence present in a sample of 19th -century settlers to South Australia in the context of an early industrial society.
Materials: Skeletal remains of 20 adults and 45 nonadults from the government funded burial site (free ground) of St Mary's Anglican Church Cemetery, gravestones of privately funded burials and local parish records.
Methods: Investigation of pathological manifestations of skeletal remains, church records and historic literature. Comparison with similar samples from Britain and from New South Wales.
Results: Joint disease seen in 35% of adults. Porosity in bone cortices indicative of vitamin C deficiency seen in 32% of the total sample and porous lesions in the orbit (cribra orbitalia) in 7% of nonadults. Traumatic fractures identified in two adult males. Gastrointestinal conditions were the leading cause of death for nonadults, most adults died of pulmonary conditions. Life expectancy of people buried at the expense of the government was 23.8–42.6 years, those in private burials 57.1 years.
Conclusion: Health of migrant settlers from the St Mary's free ground did not differ much from that of a similar population in Britain nor of settlers in New South Wales. Thus, it is characteristic for lower socioeconomic groups in early industrialised societies.
Significance: St Mary's sample is a rarity due scarcity of similar Australian skeletal samples.
Limitations: Small sample size and lack of similar samples for comparison.
Suggestions for further research: Comprehensive investigation of dentitions in St Mary's sample and studies of more skeletal samples of early settlers in other Australian locations.

1. Introduction

Human skeletal collections available for research from 19th-century colonial Australia are scarce. Therefore, the mid-19th to early 20th-century skeletons from St Mary's Anglican Church Cemetery, South Australia, (Fig. 1D) provided a rare opportunity for research. The skeletal sample is from a section of the cemetery referred to as 'free ground' (Somerset and Ragless, 2009) that was allocated to individuals or their family who did not have funds to pay for a burial. These costs were paid by the Government of South Australia (Nicol, 1994). The burials in the free ground section of the cemetery (Fig. 1D) were not marked by memorials (i.e., headstones) to identify the individuals who

Abbreviations: OSBG, Old Sydney Burial Ground; SMB, St Mary's Burial; BABAO, British Association for Biological Anthropology and Osteoarchaeology; DISH, Diffuse Idiopathic Skeletal Hyprostosis.

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had settled around the city of Adelaide (Fig. 1C). However, these skeletal remains provide valuable evidence of joint disease, trauma, metabolic deficiencies and infectious diseases. Together with historical documentation, the findings allow the reconstruction of mortality profiles and provide information on general living and changes in economic conditions during the development of the colony. This study is important since data from a skeletal sample of this time period and type in Australia are rare.

1.1. Historical background and context

The British colony of South Australia (Fig. 1A) commenced in 1836 as a non-custodial settlement. It was planned for the establishment of industries. The authors acknowledge that the First Peoples of the region, now referred to as Adelaide, are the Kaurna who hold the native title to the land. The new colony was a direct result of the British Government's policy of emigration to reduce the growing population pressure in Britain's industrial cities in the early nineteenth century (Price, 1929; Roberts and Cox, 2003). Migration was voluntary and aided by the government's free passage scheme (Capper, 1975; Haines and Shlomowitz, 1991; Royal South Australian almanack for, 1839 (1969); Wilkinson, 1848, 1849). Suitable people in 'good health and with a good character' were chosen with the two sexes being selected in equal numbers. Ambitious people from all social classes with different skills migrated to this new colony (Pike, 1967; Price, 1929, 1973).

While the new colony was expected to be financially independent, initial political and logistical difficulties, along with the lack of financial support from Britain for infrastructure development, led to the colony's first economic depression in the 1840's. The colonial government reacted by reducing infrastructure projects and focusing on agriculture (Price, 1929). This strategy led to an expansion of many related industries, particularly wheat production (Dickey, 1986; Pike, 1967; Price, 1929). Products such as cereals, meat, leather, and wool were exported to Britain (Dickey, 1986; Harcus, 1876; Pike, 1967), which helped the economic recovery of the colony.

The use of locally sourced stone, bricks and timber for the construction of new government offices, hospitals, schools, banks, shops, private residences and roads led to the expansion of building industries (Ragless, 2006; Ragless and Schuman, 2003; Wilkinson, 1848). In addition, copper, iron and silver-lead ores were discovered and mined in large quantities in the 1840's expanding the South Australian metallurgical industries, supplying both local and export markets (Both and Drew, 2008; Grguric and Toma, 2017).

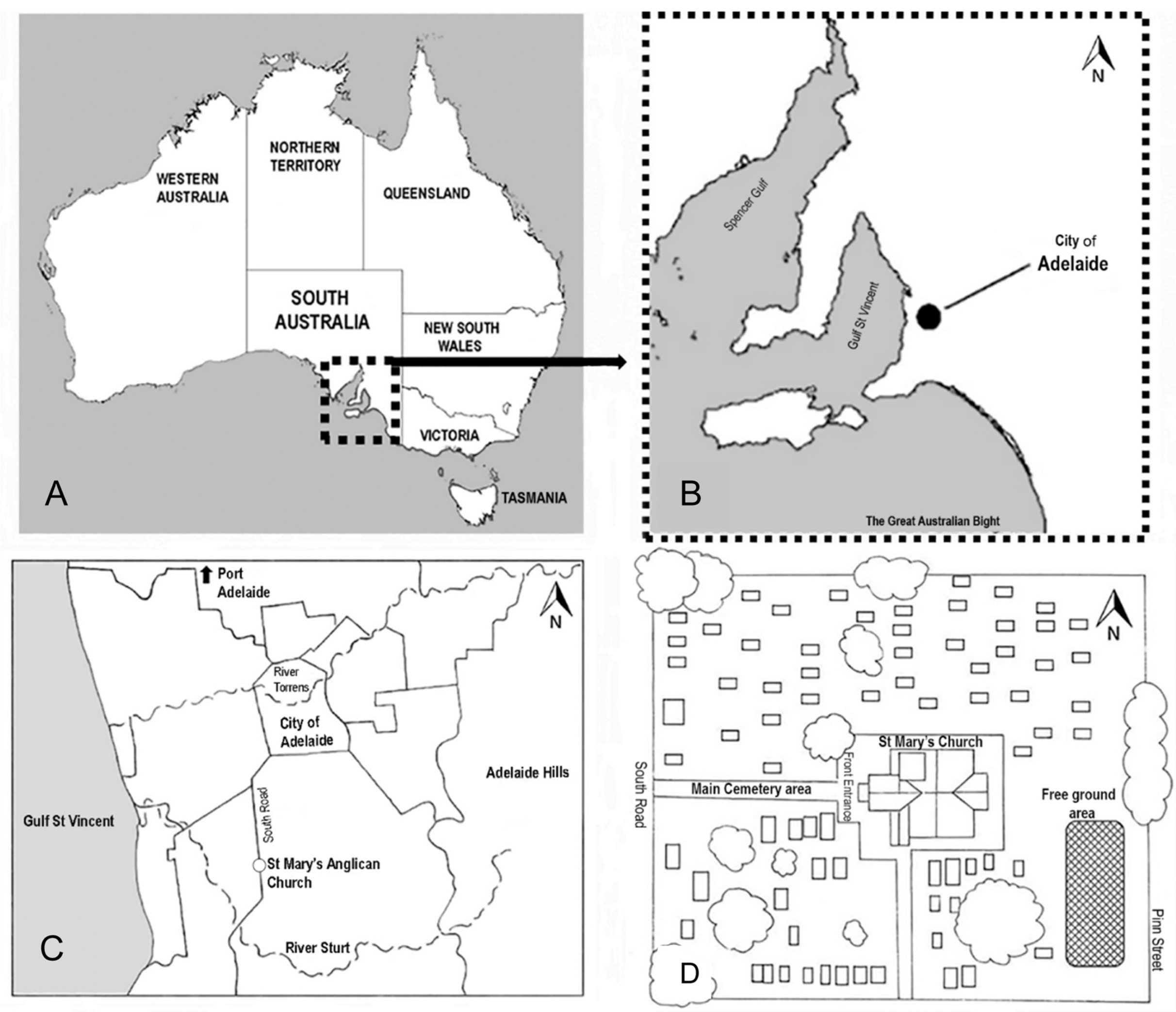

Fig. 1. Image **A** Location of South Australia in relation to other Australian states. **B**: Location of the capital city of South Australia, Adelaide. **C**: Location of St Mary's Anglican Church Cemetery in relation to Adelaide city. **D**: St Mary's Anglican Church and Cemetery. At the rear of the church building is the excavated free ground area of this cemetery and is represented by the hatched rectangle. Leased burial plots with memorial gravestones are located in the main section of the cemetery. (Reprinted from City of Marion Council (2020), under a CC BY license with permission from the City of Marion Council, original copyright 2020).

1.2. The industries surrounding St Marys-on-the-Sturt

The village of St Marys-on-the-Sturt is located on the Adelaide Plains, a region between the Gulf of St Vincent to the west and the Mount Lofty Ranges to the east (Fig. 1C). Migrants settled in this region soon after the formation of the colony (Somerset and Ragless, 2009). The development of new agricultural industries was labour intensive. Specific agricultural machinery such as the 'stump, jump plough' and Ridley's reaping machine (The Pioneers Association of South Australia, 2001), were developed to assist in the cultivation of land previously considered by colonists as unusable. Large-scale pastoralism in South Australia increased productivity well beyond subsistence levels. The work available to settlers in this area often required hard physical labour and included the cultivation of crops and/or the raising of cattle or sheep. Employment in nearby quarries, brickworks, mines and infrastructure projects was available (Norman, 1953; Piddock et al., 2009; Ragless, 2006; Ragless and Schuman, 2003; Smith et al., 2005). Local communities offered work for schoolteachers, blacksmiths, publicans and retail shopkeepers (Somerset and Ragless, 2009). The first burial at the local St Mary's Anglican Church Cemetery took place in 1847 (Somerset and Ragless, 2009). The free ground area of this cemetery is located at the rear of the church building (Fig. 1D).

1.3. Reality of life in the new colony

The primary conduit for sewage disposal, as well as drinking water, was the River Torrens (Fig. 1C) (Smith, 2007; Smith et al., 2020; The South Australia Register, 1873), during the first decades of the city of Adelaide. The Waterworks and Drainage Commission was established in 1856 (Burgess, 1978) to initiate plans for the development of a fresh water supply system. A sewage drainage system was not established until the 1880's and assisted in the expansion of some residential developments (Burgess, 1978; Price, 1929). Regions without this drainage system had 'long drop' or "night soil collection" style toilets (Burgess, 1978).

Infectious diseases associated with unsanitary living conditions, such as typhoid fever and cholera, occurred in South Australia during the 19th century (The Adelaide Observer, 1845; The South Australia Register, 1873, 1898; The South Australian Register, 1847). The health of migrants was affected by multiple interacting factors, such as socioeconomic status, sociocultural practices, lifestyle choices and the physical condition of individuals, such as their age and status of the immune-system (Forbes, 1996; Manning, 2001). The annual report of The Central Board of Health in 1883, states "1627 infant deaths had occurred in Adelaide, a rate of 145 deaths in the first year of life for every 1000 live births" (Woodruff, 1984:43), showing the vulnerability of infants to health insults during the first year of life.

Acute infectious diseases may not produce manifestations on the skeleton due to the short duration of the condition. However, chronic infections such as tuberculosis and syphilis can affect bone tissue leaving observable pathologies in the skeletal remains (Baker et al., 2020; Holloway et al., 2013; Snoddy et al., 2020). In addition, metabolic deficiencies can cause manifestations in bones (Brickley, 2008; Brickley and Ives, 2006; Brickley and Mays, 2019; Snoddy et al., 2018; Stark, 2009; Steinbock, 1976; Stone and Meister, 1962; Walker et al., 2009).

Previous Australian investigations on 19th century skeletal remains from individuals of European descent included those from The Old Sydney Burial Ground (1792 –1820) (Donlon et al., 2017; Lowe and Mackay, 1992; Owen and Casey, 2017; Owen et al., 2017; Pitt et al., 2017), Paramatta Convict Hospital (1790–1818) (Donlon et al., 2008), Randwick Destitute Children's Asylum Cemetery (1863–1915) (Donlon and Wright, 1997) and Cadia Cemetery (1864–1927) (Higginbotham and Associates Pty Ltd, 2002), which are all located in New South Wales and the North Brisbane Burial Grounds in Queensland (1843–1875) (Haslam et al., 2003).

The Old Sydney Burial Ground (OSBG) is one of the earliest colonial cemeteries investigated in Australia. Isotopic analyses of teeth and bones from this cemetery established the origin and ancestry of the interred individuals (Donlon et al., 2017; Owen and Casey, 2017; Owen et al., 2017), dietary patterns (Donlon et al., 2017; Owen et al., 2017), and details of dental and oral health (Donlon et al., 2017). The people buried at the OSBG lived in an earlier period and under different environmental conditions than those buried at the free ground area of the St Mary's Cemetery. Furthermore, some of the individuals from the OSBG were not free settlers; that is, they were convicts or sailors and some may have come from different socioeconomic backgrounds. Thus, the OSBG sample was not selected for comparison. The skeletal remains excavated from Cadia Cemetery were considered to be the most suitable Australian sample to compare with those of the St Mary's sample., The people buried at these two cemeteries were contemporaries, lived in rural settings and may have worked in mines or agricultural farms (Higginbotham and Associates Pty Ltd (2002)).

The free ground section of St Mary's Cemetery was sometimes referred to as a "pauper's" area. Therefore, individuals interred at Cross Bones Burial Grounds, Southwark, London, England (1800–1853) (WORD database, 2020), which was used by the poorest of the society (Nally, 2018:247), were considered an appropriate comparison sample from Britain.

The aims of this study were to investigate the pathological evidence present in the skeletal remains excavated from the free ground area of St Mary's Anglican Church Cemetery in the context of the early industrial society and to explore the changing socioeconomic conditions experienced by the migrant settlers during the development of the South Australian colony. Then, to compare findings with a sample of their counterparts in Britain and another similar site in Australia.

2. Materials and Methods

2.1. Skeletal sample

Excavation of a section of the free ground area at the St Mary's Anglican Church Cemetery in 2000 revealed 70 burials (20 adults and 50 nonadults) (Fig. 1D) (Anson, 2004). The skeletal remains were identified by the site code SMB (St Mary's Burial) and an identifying number (e.g., SMB 25).

Five nonadults from the original 70 excavated individuals were poorly preserved, having no cortical bone: and were not included in the current study. The remaining 65 individuals (20 adults and 45 nonadults) were investigated. The skulls of eight infants had disintegrated and were not available for the examination.

2.1.1. Assessment of the St Mary's skeletal remains

The following assessments were conducted immediately after the excavation of the skeletal remains by Anson (2004:86 -108): a) level of preservation, b) estimation of age range and c) sex of the skeletal remains.

a) Level of preservation was estimated subjectively by scoring the degree of completeness from 1 to 5.

1 = preservation very poor; 2 = preservation poor; 3 = preservation fair; 4 = preservation good and 5 = preservation very good (Anson, 2004:143).

b) Age range was estimated using the following methods:

i) Method described by Henneberg and Steyn (1994) – divided the skeletal remains into following age range categories:0–1 year, 1–4 years, 5–9 years (i.e., at five-year age intervals) until the age of 20 years and then in 10-year categories until 60 + years of age.

ii) Tooth eruption rate.

Nonadults: The tooth eruption chart of Schour and Massler (1941:1154) and Buikstra et al., (1994:54) were used to estimate the age range by evaluating the sequence of emergence of different tooth types into the oral cavity.

Adults: Age related changes to the dentition as described by

Gustafson (1950). This method uses degenerative changes to the dentition, which could vary between individuals (Buckberry, 2015).

iii) Age related changes in bony tissues:

Nonadults: Assessment of osseous developmental changes (i.e., epiphyseal ossification) followed descriptions by Buikstra et al., (1994:40–43), Scheuer and Black (2000) and Scheuer et al. (2008).

Adults: Age related changes in the pubic symphysis (Brooks and Suchey, 1990) and sacroiliac joint i.e., on auricular surface (Lovejoy et al., 1985).

c) Estimation of sex.

Sex of adults was estimated using dimorphic variations of cranial bones and the os coxae as described by Bass (1995: 25–35), Buikstra et al., (1994: 15–38) and Phenice (1969).

2.1.2. Scoring of macroscopic manifestations of skeletal pathologies

i) Vertebral body osteophytes and Schmorl's nodes were scored using the system proposed by Buikstra et al., (1994:154).

ii) Pathological manifestations associated with a deficiency of vitamin C, and/or vitamin D were identified using criteria recommended by Mitchell and Brickley (2017) in the BABAO Guidelines and publications by Brickley (2008:41–150), Brickley and Ives (2006), Heron (2013), Mays et al. (2006), Ortner (2002), Ortner et al. (1999; 2001), and Ortner and Ericksen (1997).

iii) Porous lesions on the bones of the orbital roof (cribra orbitalia) have been associated with iron deficiency by Oxenham & Cavill (2010), but have also been linked with other disease processes (Brickley, 2008; O'Donnell et al., 2020; Rivera and Mirazon Lahr, 2017; Wapler et al., 2004). Cribra orbitalia was scored using the system described by Stuart-Macadam (1991). This system quantified porous lesions as follows: "capillary-like impression on bone" – Type 1, "scattered fine foramina" – Type 2 and "large and small isolated foramina to out-growths from trabecular bone to the surface of the outer table" – Types 3–5 (Stuart-Macadam, 1991:109). Porous lesions of Types 1 and 2 have been related to a multitude of conditions, including deficiencies of vitamin B12, vitamin C and vitamin D (Brickley, 2018; O'Donnell et al., 2020; Rivera and Mirazon Lahr, 2017; Wapler et al., 2004).

iv) Pathological lesions on bone and teeth associated with infectious diseases (tuberculosis and treponemal disease) were identified macroscopically by Anson (2004) and Ioannou et al. (2015; 2016) according to criteria described by Buikstra et al., (1994) and Steinbock (1976). The original works by Hutchinson (1863, 1874, 1878, 1888, 1909, 1914), Moon (1877, 1884) and Fournier (1884, 1886) were consulted by Ioannou et al. (2016) for visual comparison.

2.1.3. Trauma

Injuries to the skeleton were identified macroscopically. Antemortem and perimortem fractures were distinguished by presence/absence of new bone formation. Bone fractures were described following protocols of Buikstra et al. (1994:95–106), Redfern and Roberts (2019) and Roberts (2000).

2.1.4. Variability of scoring of bone lesions

The 'Types' of porous lesions observed on orbital roof bones (cribra orbitalia) were scored by the authors independently. The scores showed a good level of agreement.

Non-parametric (Spearman's) correlation coefficients were calculated.

Intra-observer rho= 0.90, inter-observer AG/MH rho= 0.89 (n = 11), AG/JK rho= 0.68 (n = 22). All significant.

2.2. St Mary's Parish records

St Mary's Church burial records include the date of death and burial, age of deceased, location of burial and occupation of the deceased, or spouse of the deceased, or parent of the deceased. The cause of death was often recorded, if known. The location of burial was listed as either in a 'leased' plot (i.e., privately funded) in the main section of St Mary's Cemetery or in the free ground area (also recorded as, 'common ground', 'unleased ground', or as a 'paupers grave') (Fig. 1D). Occasionally, the location of a burial was not recorded.

Investigation of parish burial records in relation to the free ground area of the cemetery from 1847 to 1927 was undertaken. People with no burial location in church records were included in a list of people that *could* have been buried in the free ground, thus the number of people on this list was greater than the number of skeletons excavated in 2000 (Anson, 2004). The excavated individuals investigated in this study could be on this list, but cannot be identified as the free ground graves were unmarked.

2.3. Mortality

The distribution of skeletal age at death provides an indication of mortality in a population. This, however, is a biased indication because numbers of people dying in a population are a combined result of age-specific mortality and fertility (Pressat, 1961). In a living population with fertility greater than mortality, the positive natural increase will result in greater numbers of children than adults, which, at a given set of age-specific mortality rates, will produce an overabundance of deceased children. Thus, the age-at-death distribution of skeletons will be biased towards seemingly greater premature mortality (Buikstra and Konigsberg, 1985; Sattenspiel and Harpending, 1983). This effect must be corrected. In historical populations, published fertility/natural increase information needs to be applied (e.g., Piontek and Henneberg, 1981).

Life tables characterising actual mortality for St Mary's were constructed using census information for the period 1851–1900 (Caldwell, 1987) and the method published by Henneberg and Steyn (1994). These Tables used: (1) ages at death and sexes as estimated from the skeletal sample, and (2) information from parish records: 192 entries of deceased as "destitute at death" persons and 272 entries for *other* deceased buried at St Mary's Cemetery in 1848 − 1900. These "others" were assumed to have had paid private burials. Age-at-death distributions were used to produce life tables with an estimated rate of natural increase of 0.025 per year assuming stable population state (Henneberg and Steyn, 1994).

2.4. Comparison of St Mary's with an Australian and British samples

Findings from the St Mary's Cemetery sample were compared with those of two 19th-century skeletal samples. First, Cadia Cemetery, New South Wales, Australia, (N = 110) (1864–1927) (Higginbotham and Associates Pty Ltd, 2002). Findings from Cadia Cemetery have not been published; therefore, permission was obtained from the copyright holder Newcrest Mining Ltd and the archaeological consultant Dr Edward Higginbotham and Associates Pty Ltd. Second, Data from Cross Bones Burial Ground in Southwark, London, have been published (Brickley et al., 1999). These data were accessed using the Wellcome Osteological Research Database (WORD database, 2020).

3. Results

3.1. Free ground only

3.1.1. Level of preservation of skeletal remains

The mean preservation values for the excavated skeletal remains ranged from 2.6 to 4.4 (Table 1). Infants under one year of age, are the least well preserved in this sample (Anson, 2004).

3.1.2. Estimation of age range and sex

Estimated age range and sex for the excavated free ground individuals are shown in Fig. 2.

3.1.3. Summary of pathologies

The following pathologies were identified in the skeletons excavated

Table 1
Mean preservation values assigned to St Mary's excavated individuals.

Age range(Years)	Number of individuals	MeanPreservation value
0–0.9	28	2.6
1–2.9	13	3.5
3–12.5	9	4.4
13–60	20	4.1

Note: Preservation assessment was for the original 70 individuals excavated in 2000. Values: 1 = very poor, 2 =poor, 3 =fair, 4 =good, 5 =very good (Anson, 2004).

from of St Mary's Cemetery free ground. Prevalence rates are shown as % of total sample (n = 65) and/or % of adult sample (n = 20).

3.1.3.1. Evidence of joint disease. Seven of the eight adults with evidence of joint disease (11% of total sample, 35% of adult sample) (age range 25–60 + years), showed osteophytes (bony outgrowths) on vertebral bodies (Table 2.). One adult (SMB 85) from this group (approximately 40 + years), had osteophytes on the anterior bodies of two thoracic vertebrae (Table 2 and Fig. 3). This may be an early stage of development of Diffuse Idiopathic Skeletal Hyperostosis (DISH) (Castells Navarro and Buckberry, 2020; Forestier and Rotes-Querol, 1950). Schmorl's nodes (vertical herniation of the nucleus pulposus into the vertebral body) were seen in three of the eight adults (5% of total, 15% of adult sample) (Table 2). These adults also had other signs of joint disease. Evidence of eburnation was seen in various joints (Table 2) of two individuals in this group (3% of total sample, 10% of adult sample). One adult (SMB 14) showed extensive eburnation on the facet joints of the vertebrae and areas of other joints of the upper and lower limbs (Table 2).

3.1.3.2. Metabolic Deficiencies. Vitamin C Deficiency

Twelve nonadults (19% of total sample) (age range 6 months to 13 years) and nine adults (14% of total sample) showed areas of abnormal porosity of the bone cortex in at least one location of the skeleton. These locations were: posterior surfaces of the maxilla, alveolar processes of maxilla and mandible, medial surface of the coronoid process of the mandible, greater wing of the sphenoid, scapula, ilium, and the palate. In addition, one nonadult (SMB 56) (2% of total sample) (age range 6–9 months), showed abnormal porosity in bone cortices on areas of the occipital bone, vertebral arches, ribs and ends of long bones as well as the above bones. Abnormal porosity was differentiated from areas of new bone growth (Clarke, 2008; Standring and Adams, 2016) and has been suggested as a sign of a deficiency of vitamin C (Brickley, 2008;

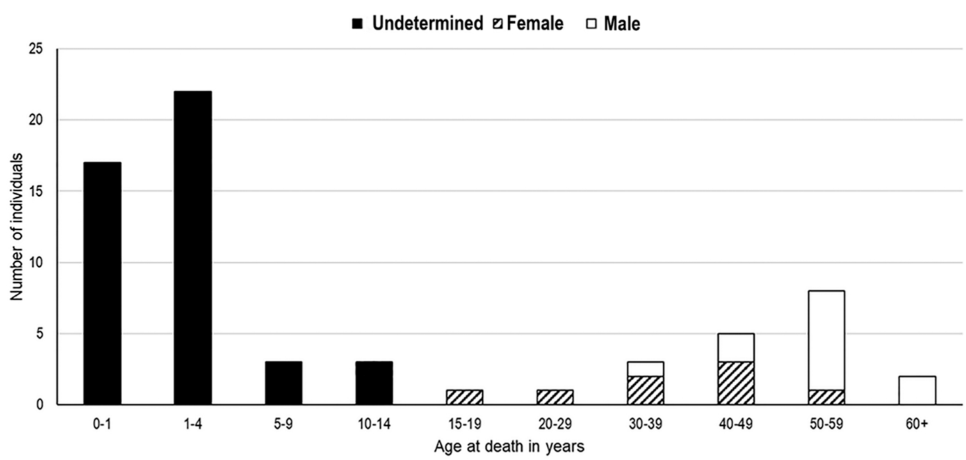

Fig. 2. Distribution of St Mary's excavated skeletal samples by estimated age range at death and sex.

Table 2
Evidence of joint disease in skeletons from St Mary's Cemetery free ground.

Evidence of joint disease	SMB 6	SMB 10	SMB 14	SMB 53C	SMB 68	SMB 78	SMB 83	SMB 85
Vertebral osteophytes (bodies)	L3 – L5	C1	C4,5,6; T3 – T10; L3 & L4	C1; T10; L1 – L5	Fragmented region not specified	C2; T5 – T12; L1 – L5	T8 & T9	C1; T8 – T11 (Fig. 3); L1 – L4
Vertebral facet joints with eburnation			C2 inferior, C3 superior & inferior (left), C3 inferior (right), C4 & C5 superior & inferior (bilateral), C6 superior (right)					
Schmorl's nodes	L3 – L5			T10				T6 – T11; L1 – L4
Other synovial joints with eburnation			Radial notch of ulna, trochlear & olecranon (bilateral); femoral head (right); acetabulum – lunate surface; talus head & navicular bone (left)		Femoral head (left); acetabulum – lunate surface (bilateral); talus & calcaneus (left)			

Fig. 3. St Mary's Cemetery free ground sample. Adult male (SMB 85) ~40 + years of age, showing osteophytes on the right anterolateral margins of the inferior and superior epiphyseal rims of the ninth and tenth thoracic vertebrae.

Snoddy et al., 2018).

Vitamin D Deficiency

Minimal signs of vitamin D deficiency were seen in St Mary's individuals. Two nonadults (SMB 8 and SMB 56) (3% of total sample) both under two years of age had enlargement and flaring of the ribs at the costochondral junction. Flaring of the distal metaphyses of the femora was also seen in one of these nonadults (2% of total sample) (Mays et al., 2006). These skeletal manifestations could also co-occur with vitamin C deficiency (Snoddy et al., 2018).

Cribra Orbitalia

Three nonadults (SMB 4 A, SMB 19 and SMB 28) (5% of total sample) (age range 4–13 years), showed porous lesions on orbital roof bones. According to Stuart-Macadam's (1991) system of scoring, the lesions seen on these nonadults were of Types 3 and 4. Porous lesions of Types 3–5 (Stuart-Macadam, 1991), have been suggested as being associated with an acquired nutritional deficiency of iron (Camaschella, 2015; Camaschella and Nai, 2016; Godde and Hens, 2021). This could result from gastrointestinal parasitic infections, chronic blood loss and/or malabsorption of iron from the gut and/or a dietary deficiency. In addition, the pathological process that caused the porous lesions may have genetic origins or could be caused by a combination of the above conditions (Blackwell and Hendrix, 2001; Brickley, 2018; Ferguson et al., 1996; Jelliffe and Blackman, 1962; O'Donnell et al., 2020; Weiss and Goodnough, 2005).

3.1.3.3. Infectious diseases. One nonadult (SMB 70) (2% of total sample) (age range 8–10 years) was previously diagnosed as suffering from tuberculosis and congenital syphilis. Detailed description of the lesions and diagnostic reasoning has been published by Ioannou et al. (2015; 2016) and is not repeated here.

3.1.4. Trauma

Five adult males (8% of total sample, 40% of adult sample) showed signs of either antemortem or perimortem trauma.

Antemortem trauma

Three adults (SMB 73, SMB 78 and SMB 83) (5% of total sample, 15% of adult sample) (approximately 30 + years of age) showed evidence of healed antemortem fractures. 1) SMB 78 showed a rectangular-shaped bony growth, approximately 20 mm in length and 10 mm in width, below the mid-shaft on the medial surface of the left fibula**,** projecting towards and linking with the medial surface of the left tibia. This bony growth could be an ossified haemorrhage, which had involved the interosseous membrane. 2) SMB 83 had a bony thickening approximately 30 mm in length, 20 mm in width and 3 mm thickness on the lateral surface of the mid-shaft of the right femur, suggesting a trauma to this bone. 3) SMB 73 showed a healed fracture of the nasal bones resulting in a slight deformity.

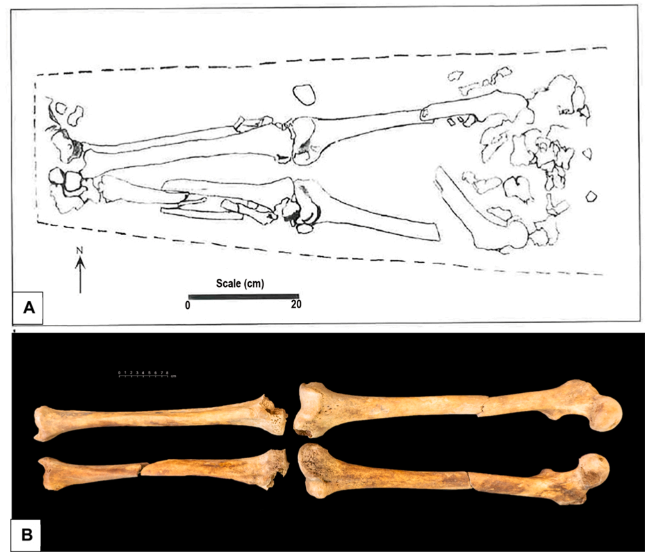

Fig. 4. SMB 59, Adult male, 50 + years of age. Image **A:** Sketch of this individual in situ at St Mary's Cemetery free ground before removal in 2000, showing positioning of fractured femora and left tibia. Image **B:** Probable perimortem traumatic injuries: complete oblique fractures in femora at the junction of the upper and middle thirds of shafts with irregular edges of the broken bones. A complete oblique fracture of the left tibia also with irregular edges below mid-shaft area. Poor preservation of fragmented fibulae prevented inclusion.
(Drawing by Danielle Griffith from Anson, 2004).

Perimortem trauma

Two adult males (SMB 59 and SMB 83) (3% of total sample, 10% of adult sample) showed evidence of perimortem trauma. 1) SMB 59 (approximately 50 + years of age), had fractures to his lower limbs (Fig. 4 A and B). Complete oblique fractures were seen in femora at the junction of the upper and middle thirds of shafts. The fractured ends were irregular. A complete oblique fracture of the right tibia also with irregular edges was seen below mid-shaft area. The fragmented right fibula had a fracture in the lower shaft at same level as the fracture in the tibia. The colour of the fractured ends was the same as the surrounding bone surfaces. Evidence of healing, infections or any other pathologies was not observed. Therefore, these fractures most likely occurred perimortem.

2) SMB 83 (approximately 55 + years of age), had multiple fractures of the cranial bones (Fig. 5.). One major fracture extended from the right temporo-mandibular region to the left temporal bone. This fracture extended posteriorly and then anteriorly in a zig-zag pattern through the parietal bones, initially following the coronal suture on the right side to the temporal bone on the left. A complete fracture of the left mandibular ramus was also seen. No evidence of healing, infections or any other pathologies was seen.

3.1.5. St Mary's Parish records and cemetery data

Data from gravestones of leased burials showed that 227 individuals were interred between 1847 and 1927 (Fig. 1D). During the same period, parish records listed 195 individuals as buried either in the free ground or the burial location was not recorded. Therefore, a total of 422 people were buried in St Mary's Cemetery from 1847 to 1927. Comparison of the percentage of individuals buried in leased graves and those listed as buried in the free ground area (or with no burial location) is presented by time period and age cohort in Table 3 (1847–1899) and Table 4 (1900–1927), showing that more individuals were buried between 1847 and 1899, than between 1900 and 1927.

A comparison, by the decade of burial, for all individuals interred

Fig. 5. SMB 83, Adult male, ~55 + years of age. Excavated from St Mary's Cemetery free ground in 2000 (Anson, 2004). Image **A.** (right side view) showing multiple fractures of the cranial bones with a major fracture extended from the right temporo-mandibular region to the left temporal bone (Image **B** - left side view). This fracture extended posteriorly and then anteriorly in a zig-zag pattern through the parietal bones, initially following the coronal suture on the right side to the temporal bone on the left. Image C: – a superior view of the fractured cranial bones. A complete fracture of the left mandibular ramus was also seen (Image B). No evidence of healing, infection or other pathologies was seen.

Table 3
1847–1899 - Percentage of individuals with known age ranges *listed as buried at St Mary's Cemetery.

Age range (years)	Leased plot burials (n = 114)	Free ground burials (*n = 163)
	%	%
0 – 11 months	4	44
1 – 4	8	25
5 – 9	3	2
10 – 14	3	4
15 – 19	4	1
20 – 29	9	2
30 – 39	4	6
40 – 49	4	4
50 – 59	14	3
60 – 69	14	3
70 – 79	14	5
80 – 89	5	1
90 +	2	0
Unknown age	12	0
Total	100	100

Note: *The total number of individuals listed with either the free ground or no burial location recorded in St Mary's parish records.

Table 4
1900–1927 - Percentage of individuals with known age ranges *listed as buried at St Mary's Cemetery.

Age range (years)	Leased plot burials (n = 113)	Free ground burials (*n = 32)
	%	%
0–11 months	4	28
1 – 4	4	13
5 – 9	2	3
10 – 14	2	3
15 – 19	2	3
20 – 29	12	0
30 – 39	7	3
40 – 49	5	16
50 – 59	8	3
60 – 69	13	3
70 – 79	13	13
80 – 89	10	9
90 +	3	0
Unknown age	15	0
Total	100	100

Note: *The total number of individuals with either the free ground or no burial location recorded in the St mary's Parish Records.

from 1847 to 1927 in leased burial plots (n = 227) (Fig. 1D), and the total number of individuals listed as buried in the free ground area or with no burial location (n = 195) is shown in Fig. 6. This suggests that the majority of burials in the free ground area of St Mary's took place in the first three decades after the establishment of this cemetery.

St Mary's Parish documents also recorded a cause of death for 143 of the 195 individuals listed as interred in the free ground (or with no burial location) (Fig. 7). Calculations for Fig. 7 were based on these 143 individuals. Interestingly, 48% of individuals with no cause of death recorded were under the age of one year.

3.1.6. *Mortality*

Using the tests of statistical significance of differences between life

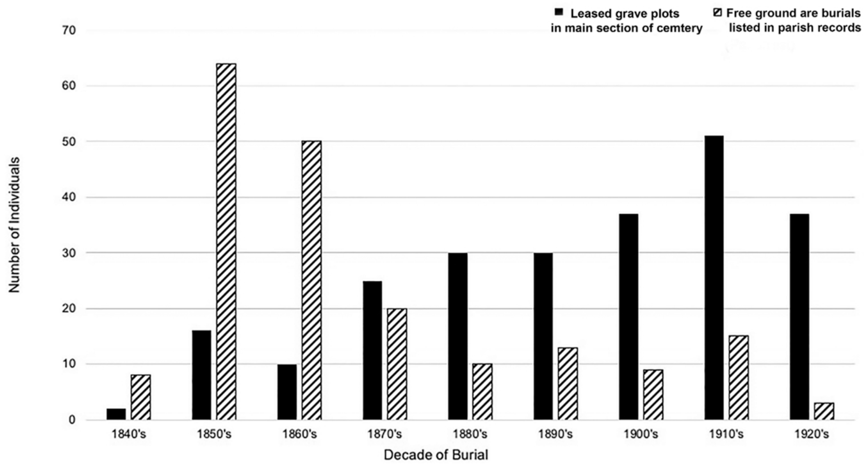

Fig. 6. St Mary's Cemetery. A comparison of the number of individuals listed in St Mary's Church records as buried in the free ground area or with no burial location listed, to the number of individuals buried in leased burial plots in the main section of the cemetery, with the decade of burial.

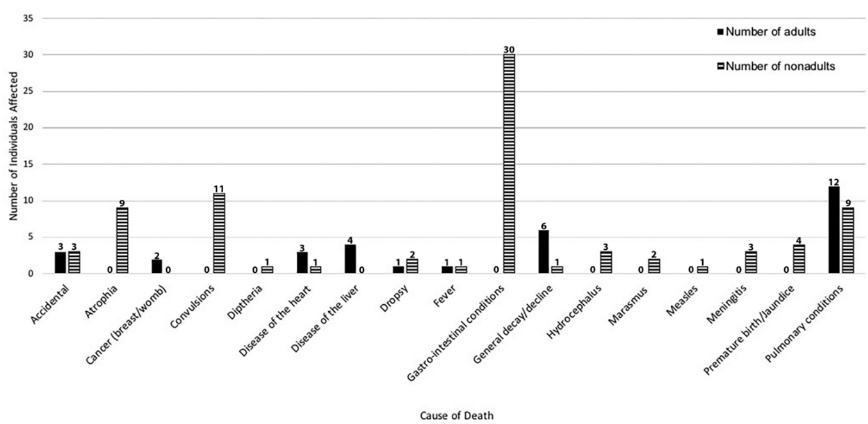

Fig. 7. St Mary's Cemetery. The number of individuals listed in parish records as either buried at the free ground area of the cemetery or with no burial location recorded, with the listed cause of death.

Table 5
Selected biometric functions' values of life tables for St Mary's Cemetery.

Data source:			
Biometric function	Free ground skeletons	Registers	Other burials registers
Early childhood mortality (d_{04-5}, %)	40.9	29.4	11.3
Survivorship to reproductive age (l_{15}, %)	51.1	66.2	86.1
Life expectancy at birth (e_0, years)	23.8	42.6	57.1
Age at death of adults ($e_{20} +20$, years)	43.1	63.4	66.6

expectancy values (Henneberg and Strzalko, 1975), life expectancies of people buried in the free ground were significantly lower than those of other people buried at St Mary's Cemetery (Table 5). There were also significant differences between values for the skeletal sample and the parish registers, indicating greater mortality ascertained from skeletons (Table 5). Mortality of young children (percentage of deceased infants and children below age of 5 years, d_{0-45}) in the skeletal sample was greater than that recorded in parish registers.

3.2. Comparison of St Mary's findings to an Australian and a British sample

3.2.1. Demographic profiles of Cadia Cemetery

New South Wales, (Higginbotham and Associates Pty Ltd (2002))

Table 6
Comparison of sex and age distribution between the South Australian, New South Wales and UK cemeteries.

Cemetery	Total sample size	Adults Males	%	Adults Females	%	Adults unknown sex	%	Nonadults undetermined sex	%
St Mary's (SA)	65	12	19	8	12	0	0	45	69
Cadia (NSW)	110	23	21	14	13	0	0	73	66
Cross Bones (UK)	148	12	8	27	19	5	3	104	70

Table 7
Comparison of observed pathologies on skeletal samples from St Mary's, Cadia and Cross Bones Cemeteries, with the percentage of individuals affected.

	St Mary's (n = 65) %	Cadia (n = 110) %	Cross Bones (n = 148) %
Pathology:			
Osteophytes (vertebral)	12	n/a	29
Schmorl's nodes	6	n/a	23
Skeletal abnormality (congenital)	0	2	8
Treponemal disease (congenital or acquired)	2	0	6
Vitamin C deficiency	32	n/a	15
Vitamin D deficiency	3	n/a	8
Trauma:			
Antemortem	5	9	12
Perimortem	3	1	0

Note: n/a= no data available

and Cross Bones Burial Ground, London (WORD database, 2020) samples were similar to St Mary's Cemetery free ground sample. A comparison of the number and percentage of adults and nonadults from each sample are presented in Table 6.

3.2.2. Skeletal pathologies

A higher percentage of St Mary's samples (32%) showed skeletal signs of probable vitamin C deficiency compared to Cross Bones (15%), data for Cadia were not available (Table 7). A higher percentage of Cross Bones samples were affected by osteophytic growths of the vertebral column (29%), compared to the St Mary's sample (12%). Cadia sample recorded evidence of eburnation in joints, particularly in the knee and elbow joints. This was seen in one adult male (approximately 50 + years of age -3% of adult sample) from Cadia, whereas two males from St Mary's sample (10% of adult sample) had evidence of eburnation on multiple areas of the skeleton (Table 2). No data relating to eburnation were available for Cross Bones sample.

3.2.3. Cribra orbitalia

The prevalence of porous lesions on the orbital roof recorded as Types 3–5 (Stuart-Macadam, 1991) was lower for St Mary's (3 nonadults - 5% of total sample) than for Cross Bones (28 nonadults - 19%). No data were available for this specific skeletal manifestation for Cadia Cemetery.

3.2.4. Comparison of Australian parish and court records

Causes of death recorded in St Mary's parish records (listed as free ground burials or no burial location), and in court records for Cadia Cemetery are presented in Table 8. Gastrointestinal conditions were the leading cause of death for the nonadults from St Mary's, whereas more nonadults from Cadia Cemetery died from pulmonary conditions.

4. Discussion

4.1. St Mary's Cemetery free ground

Findings from this study provide insight into some conditions the early migrant settlers faced during the establishment of the new colony of South Australia. Several individuals listed in St Mary's records, who where likely to have been buried in the free ground area, had skilled occupations such as blacksmith, mason, brick layer, teacher, publican, shopkeeper and accountant. This suggests that they may have come from different socioeconomic classes and represented a cross section of the community of St Marys-on-the-Sturt, though these individuals, or their families had no funds to pay for a burial.

One of the unsolved problems of palaeopathology is that skeletal remains of many younger individuals may not show pathological manifestations of disease (Wood et al., 1992). Their deaths may have resulted from conditions that do not leave signs on bony tissues. Besides rare congenital conditions or toxins and soft tissue trauma, likely causes could be infections. Thus, study of mortality schedules was a necessary part of the palaeopathological aspect of the investigation, as this identified the deaths potentially caused by infectious diseases, though could not specifically identify the etiology.

Mortality of children below 5 years of age was greater in the skeletal sample of St Mary's Cemetery (Table 5) than those recorded in parish registers and leased burial gravestones (Tables 3 and 4, Fig. 1D). It is possible that the excavated portion of the free ground area contained a 'child quarter', a common subdivision of burial grounds. The stillborn children and neonates who were not yet baptised and thus not formally registered, may have been buried in this part of the cemetery.

The majority of the free ground burials took place during the first 30 years of colonial settlement (Fig. 6). This coincided with the period of economic hardship settlers experienced during the first financial depression of the colony from the 1840's (Price, 1929). The founding of the Destitute Asylum in Adelaide city during the 1850's (Dickey, 1986; Piddock, 2001) further suggests that there was a growing need for support to the migrant community. The number of burials in the free ground gradually reduced from the 1870 s, while those in leased plots increased (Figs. 1D and 6). This suggests that the socioeconomic status of the community gradually improved (Fig. 6).

Challenging living conditions in the colony may have contributed to the 'accidental' deaths listed in parish records, which were also reported in the local newspapers. Six individuals (3 adults and 3 nonadults), all males, aged between 10 years and 60 + years were listed with this type of death. Five of these six deaths occurred before 1869 and could have been related to activities of the individual's occupation. The deaths of a 10-year-old 'errand boy', who "fell from a horse" (The South Australia Register, 1866:2) and a 16-year-old male, who "slipped from a dray as he was working" (The South Australian Advertiser, 1869:2), are examples. The death of a 12-year-old boy "accidently shot by a revolver" (The Advertiser, 1920:8) may have been a domestic accident. Owning a firearm for hunting was likely to be common in colonial Australia (Douglas,1997).

Table 8
Comparison of causes of death listed in historic records from St Mary's and Cadia Cemeteries.

	St Mary's (n = 143*)			Cadia (n = 110)		
	adults	nonadults	total	adults	nonadults	total
Cause of death:						
Pulmonary conditions	11	9	20 (14%)	3	11	14 (13%)
Gastro-intestinal conditions	0	21	21 (15%)	5	10	15 (14%)
Atrophy	0	11	11 (8%)	0	1	1 (1%)
Accidental death	3	3	6 (4%)	4	3	7 (6%)

Note: *St Mary's sample (n = 143) were individuals either listed as buried in the free ground area or no burial location had been recorded ***and*** had a cause of death recorded (Anson, 2004). Cadia sample data was taken from historical reports (n = 110) (Higginbotham and Associates Pty Ltd (2002)). Access to records stating the cause of death for individuals from Cross Bones Burial Grounds was not available.

The pattern of traumatic fractures (Fig. 4), similar to those seen on one of St Mary's excavated adult males (SMB 59 - multiple fractures of the lower limbs), have been recorded in the parish records and reported in the local newspaper. This newspaper (The South Australia Register, 1854) described the death of a 53-year-old male who was crushed by a large falling branch from a gum tree that fractured his legs and ribs. This description was confirmed in the Coroner's Inquest report published on September 7, 1854 (The South Australia Register, 1854).

Skeletal manifestations of vitamin C deficiency seen among adults and nonadults could have resulted from poor dietary habits or non-availability of foods rich in vitamin C. Cribra orbitalia seen in 3 non-adults (age range 4–13 years) were of Types 3 and 4 (Stuart-Macadam, 1991), and thus could have resulted from vitamin B12 or iron deficiency, or both (Green, 2017; Somogyi, 2017; Walker et al., 2009). Vitamin B12 deficiency could have resulted from dietary deficiency or mal-absorption (Green, 2017). Iron deficiency could have resulted from dietary deficiency or chronic blood loss. The most likely cause of the latter is a heavy infestation of blood sucking intestinal parasites (Abuzeid et al., 2020; Kucik et al., 2004). It is less likely that these nonadults had a hereditary hemoglobinopathy (Jelliffe and Blackman, 1962; Lewis, 2018). The above skeletal manifestations may suggest chronic conditions but these may not be the main causes of death as listed in the parish records.

4.2. St Mary's Cemetery – comparison with an Australian and a British cemetery

The individuals interred at Cadia (Higginbotham and Associates Pty Ltd, 2002) were from leased burial plots and not from a free ground area. Therefore, they were likely from a different socioeconomic group at the time of death compared to the St Mary's sample. The skeletal remains excavated from the unconsecrated grounds of Cross Bones Cemetery in London (WORD database, 2020) may not have been able to pay for their burial, and thus, in some ways, socioeconomically similar to individuals buried at St Mary's free ground.

Causes of deaths listed for individuals buried at St Mary's free ground were comparable to those in court records from Cadia (Table 8). Similar data were not available for Cross Bones. Phthisis was listed as the cause of death for one adult from Cadia, while six adults from St Mary's Cemetery were recorded with this condition. Different medical terminology used during this period could account for the variances seen in causes of deaths between the cemeteries. More infants from St Mary's had 'atrophy' recorded as the cause of death compared to Cadia (Table 8). This term could represent undiagnosed conditions, as it is comparable to the phrase 'failure to thrive'. Gastrointestinal conditions, such as dysentery, affected nonadults in both cemeteries (Table 8). This may be related to the immature immune system in nonadults, poor hygiene, poor quality of the water supply and poor living conditions. In addition, infants could have been affected by feeding and weaning practices. Lewis (1980) and Thearle (1985), reported that tins of condensed milk boiled and diluted with water were a popular supplement for infant feeding. Starchy foods such as sago, maize, and boiled graded flour were also used to feed infants in Australia during the 19th century (Lewis, 1980; Thearle, 1985) Isotopic analysis by Pate and Anson (2012) of bone from infants of the St Mary's sample provided evidence of breastfeeding. The elevated nitrogen isotope values (+1.7%) relative to those of adult females in the same sample show that breast milk was part of the infant diet. Dehydration resulting from diarrhoea and/or vomiting could have also contributed to some infant deaths (Lewis, 1980).

Occupations during the 19th century were labour intensive and could have contributed to osteophytes, Schmorl's nodes, and eburnation on joints of the skeleton (Axmacher and Lindberg, 1993; Cardoso and Henderson, 2010; Klaassen et al., 2011; Pye et al., 2007; Thelin et al., 2004). Adult samples from both St Mary's and Cross Bones showed osteophytes in different regions of the vertebral column, 43 adults (29% of total sample) from Cross Bones (WORD database, 2020) and 8 adults (12% of total sample) from St Mary's sample (Table 2 and Table 7). Cross Bones also had more adults (34 individuals, 23%) with Schmorl's nodes compared to St Mary's (4 individuals, 6%) (Klaassen et al., 2011; Pye et al., 2007).

Individuals from the Cross Bones sample (WORD database, 2020), who had suffered from treponemal disease were more numerous compared to those from St Mary's Cemetery. This could be attributed to the burial of sex workers or associated individuals at the Cross Bones Cemetery during the 19th century (Brickley et al., 1999; Crane-Kramer and Buckberry, 2020).

Evidence of vitamin C and D deficiencies were seen in individuals buried at both St Mary's and Cross Bones cemeteries (Table 6) (WORD database, 2020). The St Mary's sample had a higher percentage of individuals with signs of vitamin C deficiency, which could be related to a delay in food production in the early colony, a lack of access to suitable soil, and the effects of the climate for vitamin C rich plants in the St Mary-on -the-Sturt area. The lower levels of sunshine (UVB rays) in London compared to South Australia would account for the higher percentage of individuals with signs of vitamin D deficiency at Cross Bones.

5. Conclusion

The investigation of St Mary's Anglican Church Cemetery sample broadened the understanding of how the establishment of the colony of South Australia affected the health and socioeconomic status of these migrant settlers. The poorly developed infrastructure, failing economy of the new colony combined with extreme environmental conditions and an unfamiliar landscape, negatively impacted the lives of settlers. However, the health effects experienced by these individuals, during the 19th century, were not much different than for contemporary colonists, who lived in other parts of Australia or to people of a similar economic background in England (who did not emigrate). Therefore, the single factor that most likely affected these migrant settlers was economic hardships. Whether the the individuals buried at the 'free ground' area of St Mary's Cemetery considered their migration as a worthwhile venture is not certain. However, as the economy of the colony improved, the health and economic status of their descendants and other subsequent migrants also improved.

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Chapter 4. Introduction to Paper 3

4.1. Paper 3 - Overview

The small Volume Micro-CT system used in paper 1 had limitations and was unable to examine the dentoalveolar complex in-situ within a human skull. Therefore, the relationship between the dentitions themselves and their surrounding structures could not be analysed. An innovative approach was required. The Large Volume Micro-CT (LV micro-CT) scanning system, however, can accommodate 'large' samples. The increased volumetric capacity of the LV Micro-CT permitted the fragile St Mary's skulls to be scanned and for structures such as dentine on the teeth, that have not been examined before, to be microscopically analysed. A search of the literature established that LV Micro-CT scanning had not been used for an investigation of the dentition or supporting structures that remain in situ in an archaeological human skull before.

Specific funding was sort and obtained, which allowed six individuals from the St Mary's sample to be investigated (paper 3). Two adults, two subadults, and two infants were carefully selected for their state of preservation, and to represent different age ranges, both sexes and a selection of tooth types i.e., primary teeth only, mixed dentitions, and permanent teeth only.

Paper 3, evaluated the reliability and accuracy of the LV Micro-CT method for the examination of the in-situ dentitions by scoring nine oral health categories. Detailed data were collected and compared with the scores and measurements collected using the standard non-invasive methods (macroscopic examinations and radiographic methods). This comparison established that the LV micro-CT technique was the only method able to provide information for all the oral health categories studied. The advantages and limitations of this non-destructive micro-CT method are discussed in paper 3.

Statement of Authorship

Title of Paper	Investigating the dentoalveolar complex in archaeological human skull specimens: additional findings with Large Volume Micro-CT compared to standard methods
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Principal Author

Name of Principal Author (Candidate)	Angela Gurr		
Contribution to the Paper	Conceptualization, methodology, investigation, data curation, software, formal analysis, visualization, writing - original draft, and writing - review and editing. project administration. Submission of manuscript and acted as corresponding author.		
Overall percentage (%)	85%		
Certification:	This paper reports on original research I conducted during the period of my Higher Degree by Research candidature and is not subject to any obligations or contractual agreements with a third party that would constrain its inclusion in this thesis. I am the primary author of this paper.		
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Co-Author Contributions

By signing the Statement of Authorship, each author certifies that:

i. the candidate's stated contribution to the publication is accurate (as detailed above);
ii. permission is granted for the candidate in include the publication in the thesis; and
iii. the sum of all co-author contributions is equal to 100% less the candidate's stated contribution.

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4.3. Investigating the dentoalveolar complex in archaeological human skull specimens: Additional findings with Large Volume Micro-CT compared to standard methods

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RESEARCH ARTICLE

Investigating the dentoalveolar complex in archaeological human skull specimens: Additional findings with large volume micro-CT compared to standard methods

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Abstract

Archaeological investigation of the dentoalveolar complex in situ within a human skull requires detailed measurements using non-invasive techniques. Standard macroscopic and radiographic methods have limitations but large volume micro-computed tomography (LV micro-CT) scanning has the potential to acquire data at high resolution in microns. In this study, archaeological specimens are analyzed using three-dimensional data visualization software from LV micro-CT scans with the aims of (1) determining whether LV micro-CT can act as a single technique to provide detailed analysis of the dentoalveolar complex and (2) how findings from the LV micro-CT technique compare with standard methods. These aims are explored by measuring a range of human skull specimens from a rare archaeological sample requiring non-invasive methods, for multiple dental and alveolar bone health categories. The LV micro-CT technique was the *only* method to provide a full range of detailed measurements across all categories studied. A combination of macroscopic and radiographic techniques covered a number of categories, but the use of multiple methods was more time consuming, did not provide the same level of accuracy, and did not include all measurements. There were high levels of reproducibility for intra-operator scoring and good inter-operator agreement from four operators with one operator whose results were outliers. As a further investigation of the potential of the LV micro-CT technique, an additional individual, a fragile, fragmented skull of an infant was studied. This investigation confirms the value of LV micro-CT scanning as a non-invasive, accurate, single technique for the extensive analysis of the dentoalveolar complex within archaeological skulls, which also allows the relationship of different tissues to be studied in situ.

KEYWORDS
Bioarchaeology, Dentoalveolar Complex, Micro-computed Tomography, Paleo-imaging, Paleopathology

1 | INTRODUCTION

Archaeological investigation of the dentoalveolar complex in human skull samples requires detailed measurements and analysis using non-invasive techniques. Standard methods commonly used for the analysis of dentitions, which remain in situ in the alveolar bone of human archaeological skulls, include visual macroscopic and radiographic examinations. These methods have limitations. Macroscopic examinations can only provide data for the external surfaces of the teeth and jaws, whereas dental radiographs can provide data for both the external and internal structures, but the images provided are only a two-dimensional (2D) slice of the specimen and the resolution is limited. Histological analysis can provide detailed information on the internal structures of a tooth and the bone, but this method is destructive and cannot examine the structures of the dentoalveolar complex as a whole. For many archaeological samples destructive analysis is not an option.

The "large volume" micro-computed tomography (LV micro-CT) scanner has the potential to provide high-resolution datasets of all structures scanned and can accommodate larger specimens such as a human skull. Other types of CT scanners such as the cone-beam CT (CBCT) scanner (Anderson et al., 2014; Lozano et al., 2022) and/or medical CT scanner (Anderson et al., 2014; Smilg, 2017) could also accommodate such samples and have been used in many investigations. However, an important distinction between the LV micro-CT scanner and these CT systems is the thickness of the scan slices. The CBCT and the medical CT scanners produce scan slices measured in millimeters (mm) (Minnema et al., 2018; Pour et al., 2016), whereas the LV micro-CT scanners have a slice thickness in microns (μm) (Orhan, 2020; Orhan & Büyüksungur, 2019). The difference in scan slice thickness is important when investigating small changes in structures, for example, details of a dental defect could be overlooked when analysing images of scan slices which are in millimeters rather than in microns.

The LV micro-CT scanning system also produces an isotropic volumetric data set (Litzlbauer et al., 2006; Orhan, 2020; Orhan & Büyüksungur, 2019). This means that the voxels in the data set have the same resolution on all three planes, like a cube (i.e., X = width, Y = height, Z = depth/slice thickness). The three-dimensional (3D) images produced from a reconstructed LV micro-CT scan data set could be viewed in any orientation, and the quality of the image remains the same. Medical CT scanners use a different resolution (voxel size) on the Z plane (slice thickness) than for the X and Y planes (Minnema et al., 2018, p 133 – Table 1). The difference in the voxel size for the Z plane decreases the quality of the image when viewed in the X–Z or Y–Z planes and affects the accuracy of data collection and analysis.

The LV micro-CT scanning system has been used in research for oral surgery (Beetge et al., 2018; Stan et al., 2019; Theye et al., 2018), biomedical (Grace et al., 2022; Kusins et al., 2019; Wearne et al., 2022) and medical research (Hutchinson et al., 2016; Kramer et al., 2019; Main et al., 2021; Smit et al., 2020; Tan et al., 2022; Welsh et al., 2020), paleontology (Clement et al., 2021), and forensic investigations (Alsop et al., 2022, Braun et al., 2022, Nikolova et al., 2019, Rutty et al., 2012). The non-invasive nature of this type of micro-CT scanner, as well as its technical capabilities, suggests that it could be of great value for the investigation of rare, delicate, and valuable archaeological human remains.

Computer software used with LV micro-CT scan data sets is capable of producing high-resolution 3D images of a specimen. The information gained from detailed measurements and analysis of such images could increase the understanding of the impact of dental and oral health on the general health of an individual as well as provide data on the prevalence of craniofacial conditions in past populations. For example, there is evidence that in cases of hypodontia not only are the formed teeth and the dental arches affected but also the craniofacial complex (Kerekes-Mathe et al., 2015; Patel et al., 2018).

TABLE 1 The five individuals selected from St Mary's cemetery archaeological sample to be large volume (LV) micro-CT scanned, with age range, sex, and the number of teeth and tooth type in situ within the dentoalveolar complexes.

St Mary's ID	Dental age range (years) [a]London Atlas (AlQahtani et al., 2010)	Skeletal assessment age range (years) (Anson, 2004)	Sex	Total number of teeth in-situ in the skull	Type of dentition: permanent or primary	Maxilla/right tooth types *with* FDI number	Maxilla/left tooth types *with* FDI number	Mandible/left tooth types *with* FDI number	Mandible/right tooth types *with* FDI number
SMB 82	1–1.5 (±3 months)	0–2	U	8	Primary	51, 52	61, 62	71, 74	81, 84
SMB 04A	3.5–4.5 (±3 months)	2–4	U	19	Primary	51, 52, 53, 54, 55	61, 62, 63, 64	71, 72, 73, 74, 75	81, 82, 83, 84, 85
SMB 52B	11–12 (±1 year)	8–12	U	26	Permanent and primary	11, 12, 13, 14, 15, 16, 17	21, 23, 24, 25, 26, 27	31, 32, 33, 34, 75, 36, 37	41, 42, 43, 44, 85, 46, 47
SMB 66B	Over 23.5	30–39	F	17	Permanent	12, 14, 15, 17	21, 22, 23, 27	31, 32, 33, 34	41, 42, 43, 44, 45
SMB 73	Over 23.5	30–39	M	19	Permanent	11, 12, 13, 16	21, 22, 23, 24, 28	31, 32, 33, 34, 35	41, 42, 43, 44, 45
Total number of teeth LV micro-CT scanned				**89**					

Sex: U = undetermined sex, F = female, M = male. Cent. = central; Lat. = lateral.

[a]The London Atlas of Human Tooth Development and Eruption.

The teeth and dental arches are complex adaptive systems (Brook, 2009; Brook et al., 2014; Brook et al., 2016), and for both fundamental studies and clinical applications, systemic interactions during development and mature functioning are important (Brook and Brook & O'Donnell, 2022). Therefore, the dentoalveolar complex needs to be studied as a whole. In previous studies, only specific individual components have been investigated for clinical purposes (Appleby et al., 2015; Beetge et al., 2017; Stan et al., 2019). The structures of the dentoalveolar complex arise from complex interactions between the tissues during development. Therefore, it is important and beneficial to study 3D digital images compared with 2D images so that all the structures and tissues of the dentoalveolar complex, in their relationship to one another, can be analysed in detail for normal and pathological changes because of development and disease.

Macroscopic and/or plain radiographic methods have been the standard techniques used in many investigations for the analysis of dentitions and their associated alveolar bone tissues, and/or the analysis of human skulls from an archaeological context (Brook & Smith, 2006; D'Ortenzio, Kahlon, et al., 2018; Heuck Henriksson et al., 2019; Manzi et al., 1999; Willmann et al., 2018). Archaeological investigations that have used an LV micro-CT scanner (Fraberger et al., 2021; Lacy et al., 2012; Trinkaus et al., 2021) did not focus on the in situ dentitions or the dentoalveolar complex.

This study aims to investigate (1) whether LV micro-CT can act as a single technique to provide a detailed analysis of these structures and (2) how findings from the LV micro-CT technique compare with standard methods. These aims will be explored by measuring a range of delicate human skull specimens from a rare archaeological sample, for multiple dental and alveolar bone health categories, and comparing these findings to standard methods. As a further test of the LV micro-CT technique, a sixth individual was scanned; the fragile, fragmented skull of an infant was chosen to investigate the potential of this method to provide data that cannot be obtained using standard methods.

2 | MATERIALS AND METHODS

2.1 | Materials – The archaeological sample

There is a scarcity of skeletal collections available for research in Australia. The recentness of colonial-era burials and a lack of necessity to move or re-use burial sites means very few 19th-century European settler cemeteries have been excavated. This makes the St Mary's Anglican Church Cemetery sample a rarity. The individuals in this sample were interred between 1847 and 1927, in an area of the cemetery that had been set aside for burials paid for by the South Australian Government. These burials were not marked with gravestone memorials and were located at the rear of the church building. Further background information, historical context, and findings from the macroscopic skeletal analysis of the St Mary's sample have been published (Anson, 2004; Gurr, Brook, et al., 2022; Gurr, Kumaratilake, et al., 2022), including the methods used for the estimation of age range and determination of sex. The excavated individuals are identified with a site code and context number (e.g., St Mary's Burial/number 73 = SMB 73) (Anson, 2004).

This study is fundamental to the next stage of investigations of this rare historic South Australian sample, which is the detailed examination of the dentoalveolar complex of all 70 individuals. Therefore, to determine the optimum methods of investigation, the well-preserved skulls of five individuals (infant SMB 82, subadults SMB 4A and SMB 52B, and adults SMB 66B and SMB 73), (Table 1), with dentitions in situ in the dentoalveolar complex, were selected to (i) cover a probable range of ages and sexes in archaeological samples, (ii) cover the change in relationships with the dentoalveolar/craniofacial complex at different ages during development and their interactions and (iii) cover a range of specimen sizes (Supplementary Table S1). The range of ages, sex, and sizes of the five selected skulls is important to investigate the resolution that could be achieved using the LV micro-CT method and the differences in the density of the teeth and/or alveolar bone tissues at different stages of development.

The fragile, fragmented skull of the infant, SMB 58, estimated dental age range = 1–1.5 years (±3 months) applying the London Atlas (AlQahtani et al., 2010), was selected to test the value of the non-invasive, high-resolution capabilities of the LV micro-CT scanning system.

2.1.1 | The archaeological sample – dentitions

Information for the five individuals, selected for the methodology comparison, including age range, sex, tooth type, and the number of teeth (total $N = 89$) which remained in situ, is presented in Table 1. The Fédération Dentaire Internationale (FDI) – World Dental Federation notation system was used in this study to accurately record and distinguish between permanent and primary teeth.

2.1.2 | The archaeological sample – ethics

St Mary's Anglican Church Parish requested the excavation of the free ground section of the cemetery as they wished to re-use the area and approved the study of the skeletal remains. Flinders University Social and Behavioural Research Ethics Committee approved the research (SBREC project number 8169). Destructive analysis was not permitted for the investigation of the sample as they are of a rare historical nature.

2.2 | Methods

2.2.1 | Comparative methods used

The LV micro-CT scanning system, macroscopic, and standard radiographs were used for the analysis of the dentoalveolar complex in situ in the selected archaeological human skulls.

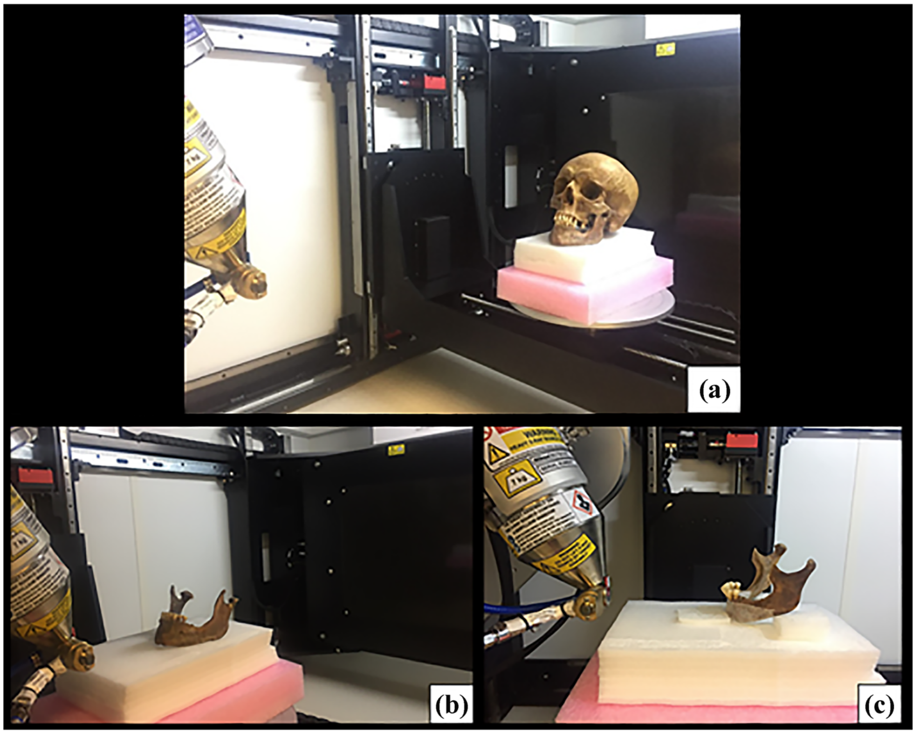

FIGURE 1 Large Volume Micro-CT. Skull SMB73 – adult male (skeletal age range 30–39 years). (a) (from left to right) X-ray source, rotation stage with the skull on polystyrene foam, (center), flat panel X-ray detector behind the skull. The skull in position before scanning using the Nikon XH T 225 ST cabinet system (Nikon Metrology, 2021). (b) Mandible only of adult SMB 73. (c) Mandible of SMB 66B – adult female (skeletal age range 30–39 years). Figure 1b, c is showing the position of the mandible with in situ dentition before scanning. © Angela Gurr. [Colour figure can be viewed at wileyonlinelibrary.com]

2.2.2 | Large volume micro-CT

The dentoalveolar complex was scanned using the Nikon XT H 225 ST cabinet Micro-CT scanning system (Nikon Metrology, 2021) at Flinders University (Clement et al., 2021; Wearne et al., 2022). The skull, the cranium without the mandible, and the mandible alone were scanned to investigate the achievable resolution of each specimen (Supplementary Table S2), as the spatial resolution (pixel/voxel size) selected for each scan was relative to the size of the specimen. In addition, it was important to investigate whether the positioning of the opposing maxillary and mandibular teeth within the skull, during the scanning process, could affect the analysis of the occlusal surfaces of these teeth. In choosing the scanning settings, the transmitted signal intensity and source power settings were considered according to guidelines (du Plessis et al., 2017; Wearne et al., 2022).

The skulls, of adult SMB 73 (Figure 1a) and subadult SMB 52B, were scanned at projection images 4056 × 4056 pixels in size, corresponding to a field of view of 243 × 243 mm, width × height, at 60 μm isotropic pixel size. Full details of the parameters used (X-ray source voltage [kV], source current [μA], source power [W], filter type and thickness [mm], X-ray projections, rotation step, and exposure time in seconds) for all of the LV micro-CT scans can be found in Supplementary Table S2.

The cranium with the maxilla of adult SMB 66B, subadult SMB 4A, and infants SMB 82 and SMB 58 were scanned *without* the mandible present. These scans were performed with the same X-ray source settings and rotation step as the skulls, as shown in Supplementary Table S2, but at 50 μm/pixel (for adult SMB 66B), 55 μm/pixel (subadult SMB 4A), 40 μm/pixel (infant SMB 82), and 35 μm/pixel (infant SMB 58), corresponding to a field of view of 202 × 202, 223 × 223, 162 × 162, and 142 × 142 mm, respectively, adapting (minimizing) the pixel size according to the specimen size. The total acquisition time was 1 hour and 10 minutes per scan.

The mandible (Figure 1b, c), of the six individuals, was scanned separately from the associated cranium. For further details of the scan parameters, see Supplementary Table S2. Projection images were 4056 × 4056 pixels in size, corresponding to a field of view of 81 × 81 mm at 20 μm/pixel (for SMB 4A), 89 × 89 mm at 22 μm/pixel (SMB 52B), 53 × 53 mm at 13 μm/pixel (SMB 73 and SMB 66B), 73 × 73 mm at 18 μm/pixel (for SMB 82), or 85 × 85 mm at 21 μm/pixel (for SMB 58; source current 95 μA, [18 W]). The total acquisition time was 1 hour and 40 minutes per scan. The mandible, being smaller than the entire skull or the cranium, allows higher-resolution scanning.

2.2.3 | LV micro-CT – post processing computer software

Axial cross-section images were reconstructed using CTPro3D software (Nikon Metrology, 2021) and saved as 8-bit bitmap images (256 gray levels, 0 = air, 255 = enamel). Avizo 9 (ThermoFisher Scientific, 2019) data visualization software was used for image analysis of the reconstructed scan data sets. The size of a high-resolution micro-CT scan requires a computer that has the capacity to process and navigate the reconstructed 3D volumetric data sets. Hardware constraints can sometimes require the micro-CT scan data sets to be reduced in size by one half (reading every second slice of the scan) or by one quarter (reading every fourth slice of the scan). For example, the original LV micro-CT scan data set size for the adult human skull of SMB 73 was 33 GB at 60 μm/pixel, and this could be reduced to 533 MB at 240 μm/pixel. The scan data set for the mandible of SMB 73 was originally 42.7 GB at 13 μm/pixel but could be reduced to 658 MB at 52 μm/pixel. The ability to change the size of the micro-CT scan data sets offers many benefits including the option to conduct an initial analysis, similar to triaging to identify the presence of pathology using the quarter or half sized scan data sets and then use the full-sized scan data sets for a more in-depth examination. To increase loading and analysis speed for this investigation, the scan data sets were reduced in size (Perilli et al., 2012).

2.2.4 | Standard methods

Macroscopic examination

Visual examination of the in situ dentoalveolar complex was conducted in a dry laboratory with the aid of a table magnification glass and enhanced lighting.

Standard radiographic methods

Intraoral periapical and bitewing radiographs were taken using Planmeca X-ray equipment (Planmeca, 2022), with Phosphor Storage Plates (PSP) as the detectors. Exposure settings were as follows: Tube voltage:70 kV; Tube current: 6 mA, with an exposure time of 0.32 s. Extraoral radiographs of the dentoalveolar complex of each individual's skull were taken, using orthopantomogram (OPG) X-ray equipment to rotate around the maxilla and mandibular area. The X-ray source used was a Kavo Pan eXam Plus (KaVo Dental GmbH, nd). The tube type for this equipment was stationary anode; 65 kV; Tube current: 15 mA, with an exposure time of up to 16.4 s.

2.2.5 | Scoring systems and identification criteria

The dentoalveolar complexes were analysed for the following dental and alveolar bone health categories: (i) dental inventory, (ii) category of tooth wear, (iii) evidence of dental trauma, (iv) class of occlusion, (v) presence of caries, including the category of radiolucency, (vi) grade of alveolar bone status, (vii) evidence of periodontal disease (i.e., measurement of horizontal bone loss), (viii) presence of enamel hypoplastic (EH) defects, (ix) presence of areas of interglobular dentine (IGD), and (x) an estimation of dental age range (Table 2).

Enamel opacities were not recorded as enamel hypomineralization defects are difficult to distinguish from areas of staining on the tooth caused by the post-mortem environment and/or taphonomic alterations which could cause variations in the mineralization density of the dental enamel (Efremov, 1940; Garot et al., 2017; Garot et al., 2019). The criteria used for the identification and scoring of the above dental and alveolar tissue health categories are presented in Table 2.

Crania and mandibles were radiographed separately. For that reason, information about occlusion is not available from radiographs and only severe cases of EH defects (EH) and/or IGD can be identified on radiographs; therefore, these categories were not assessed using this modality.

The bone density level of the teeth, the skull/cranium, and of the mandible of each individual was determined by applying a threshold level to the reconstructed scan data sets using the Avizo 9 software (ThermoFisher Scientific, 2019). This digital information was stored as an Avizo "project" (Figure 2a1, a2). These projects were used for the scoring of the oral health categories, using the post-processing software, as they provide a consistent and reliable platform for repeated measurements. Digitally reconstructed radiographs (DRR) (Figure 2b1, b2), together with the "clipping" tool, were used to remove a quadrant of the jaw (Figure 2c1, c2), in order to examine all the surfaces of the dentition during 3D image analysis.

2.2.6 | Validity of the scoring system of dental and alveolar bone tissue health categories

Five operators, either academic staff or postgraduate students in Biological Anthropology and/or Archaeology, were trained and calibrated before they scored the dental and alveolar bone tissue health categories independently 2 weeks after the training session (Table 2). The principal operator (AG) scored the categories for the in situ dentitions, alveolar bone tissues, and individual loose teeth not in the jaw, macroscopically, on dental radiographs, and on the 2D and 3D images produced by the Avizo software from the reconstructed scan data sets. Data scoring sessions were repeated for intra-operator reliability 2 weeks apart. Inter-operator scoring of the same categories using the same methods (Table 2) was undertaken by MM, on different dates and times from intra-operator (AG). Other operators conducted data scoring sessions for the categories (Table 2), on images produced by the LV micro-CT scan data sets only.

2.3 | Statistical analysis

Intra-operator and inter-operator reliability were assessed using Gwet's Agreement Coefficient (AC1), weighted Gwet's Agreement Coefficient (AC2), and Intraclass Correlation Coefficient (ICC) using a two-way random-effects model for absolute agreement, for binary and nominal scale data, ordinal scale data, and continuous data, respectively. All analyses were performed using Stata v17 (StataCorp, 2022).

3 | RESULTS

3.1 | Reproducibility – standard statistical analysis

Supplementary Table S3 presents a summary of the results from tests of intra- and inter-operator reliability for each of the methods assessed, followed by a brief written summary. Additional information relating to this statistical analysis can be found in the supporting information as Supplementary Table S4 and the raw data as Data_S1.

TABLE 2 Dental and alveolar bone categories, measured for the investigation of dentition and alveolar tissues in situ in the dentoalveolar complex of archaeological human skull specimens, with the identification criteria, the methods used, and the scoring systems followed for collection of data, including sources.

Categories measured	Identification criteria	Method/s to be used	System/s to be followed	Sources/references
Inventory – total number of teeth in situ	Inventory of teeth present	Macroscopic, Radiographic, LV Micro-CT	FDI (ISO 3950) notation system used, data was recorded on a visual chart representing the upper and lower permanent/ primary dentition.	FDI World Dental Federation, 2022, International Organisation for Standardization, American National Standard, American Dental Association, 2010
Inventory - ante-mortem tooth loss	Evidence of healing of alveolar processes	Macroscopic, Radiographic, LV Micro-CT	Location of healed alveoli where tooth was previously located-recorded on (FDI) visual chart as above	Araújo et al., 2015, Kinaston et al., 2019
Inventory – Post-mortem tooth loss	No evidence of healing of the alveolar bone – open socket observed	Macroscopic, Radiographic, LV Micro-CT	Location of open socket in alveolar process/missing tooth type-(FDI) visual chart used as above.	Hillson, 1996
Occlusion	Position of jaws and dental arches – in relation to each other mesio-distally.	Macroscopic, LV Micro-CT	Scored using Angel's (1966) classes of malocclusion.	Angel, 1966: p34–44
Tooth wear (occlusal)	Evidence of loss of enamel and/or exposure of dentine on the occlusal surface	Macroscopic, LV Micro-CT	Category of tooth wear selected from Molnar's(1971) criteria chart.	Molnar, 1971
Dental trauma	Evidence of morphological damage to the tooth	Macroscopic, LV Micro-CT	An adaptation of the index by Winter and Brook (1989) was used to record trauma involving enamel only; enamel and dentine; or enamel, dentine, and pulp.	Winter & Brook, 1989
Caries	Evidence of decay – either involving the enamel surface, enamel and dentine or the enamel, dentine, and the pulp. Identification of a difference in radiolucency	Macroscopic, Radiographic, LV Micro-CT	Tooth type affected (FDI), the number, and location of carious lesions recorded. Dental probe was used for the macroscopic examination. ICDAS/ICCMS categories of radiolucency were selected from a visual chart for radiographic and digitally reconstructed radiographs (DDR) on Avizo 9 software.	Pitts & Ekstrand, 2013; International Caries Classification management System, 2022
Periodontal disease	(1) Alveolar bone status – evidence of changes in the structure of the buccal contours of the alveolar margins of the posterior teeth (2) Evidence of horizontal and/or vertical bone loss	Macroscopic, LV Micro-CT	(1) Alveolar bone status-inspection of the buccal contours of the alveolar margins of the posterior teeth. Scored as grade 1 to 4 using Ogden's (2008) system (2) Evidence of horizontal – measurement taken on the midline of the labial/buccal and lingual surfaces of the tooth, from the CEJ to the crest of the alveolar bone. A periodontal probe was used with 3-mm increments for the macroscopic examination.	(1) Ogden et al., 2007: p.283–307; Riga et al., 2021. (2) Perschbacher, 2014: p 302

TABLE 2 (Continued)

Categories measured	Identification criteria	Method/s to be used	System/s to be followed	Sources/references
Enamel hypoplastic defects	Evidence of enamel hypoplastic defect/s	Macroscopic, LV Micro-CT	Using an adaptation of the enamel defect index (EDI), the type of enamel hypoplastic defect/s, the number and location of defects were recorded. A measurement/s of the distance from hypoplastic defect/s to CEJ was taken.	Brook et al., 2001, Elcock et al., 2006
IGD (interglobular dentine)	Evidence of areas of defective mineralization in the dentine structure	LV Micro-CT	Recorded presence of IGD as yes/no	Colombo et al., 2019, Veselka et al., 2019
Dental age range estimation	Eruption rate and position of developing teeth in the alveolar	Macroscopic, Radiographic, LV Micro-CT	The London Atlas of Tooth Eruption and Development was used to identify the stage of eruption and tooth development.	AlQahtani, 2012, AlQahtani et al., 2010

Notes: FDI = Fédération Dentaire Internationale, ICCMS = International Caries Classification and Management System, CEJ = Cementum Enamel Junction, ICDAS = International Caries Detection and Assessment System.

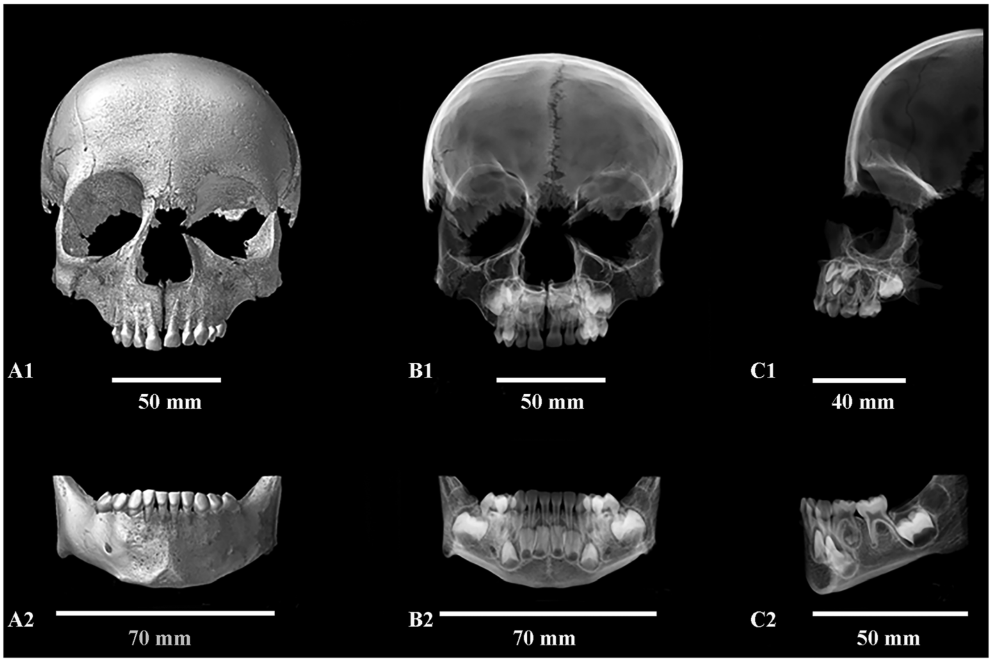

FIGURE 2 Large Volume Micro-CT. Sample SMB 4A – subadult (dental age range: 3.5 to 5.5 years; skeletal age range: 2–4 years). (cranium micro-CT scanned at 55 µm/pixel and mandible at 20 µm/pixel). (a1, a2) Anterior/labial view of the dentition in situ in the maxilla and mandible using the Avizo 3D image function. (b1, b2) Anterior/labial view of the same dentition using the Avizo digitally reconstructed radiograph (DRR) function (ThermoFisher Scientific, 2019). (c1, c2) Lateral view of the dentition using the clipping tool to remove one side of the jaw. (b, c) The DRR is showing the developing dentition in the alveolar bones. Images were created using volren with the Avizo 9 software (ThermoFisher Scientific, 2019). © Angela Gurr.

TABLE 3 The ability of each investigative method to provide data for the analysis of the categories studied for the health of the teeth and associated alveolar bone tissues.

Was the method capable of providing data for the following categories? Y/N	Methods		
	LV micro-CT	Macroscopic	Radiographic
Inventory	Y	Y	Y
Tooth wear	Y	Y	Y
Dental trauma	Y	Y	Y
Occlusion	Y	Y	***N***
Caries	Y	Y	Y
Alveolar status	Y	Y	***N***
Periodontal disease	Y	Y	***N***
Enamel hypoplasia	Y	Y	***N***
IGD (dentine defects)	Y	***N***	***N***
Dental age estimation	Y	Y	Y
Technical capabilities:			
Are internal structures visible?	Y	***N***	Y
Absence of superimposition problems?	Y	Y	***N***

Note: Y = yes; N = no. LV micro-CT = large volume micro-CT; IGD = interglobular dentine.

3.2 | Capacity for each method to provide data for the categories scored

Table 3 presents the results for each of the methods in determining the data required. The LV Micro-CT was the *only* technique to provide information for all of the categories. Macroscopic investigations could not provide data on the internal structures of the teeth (Table 3). Large volume Micro-CT and macroscopic examination were the only methods to provide information regarding the occlusion, as the maxillary and mandibular dentitions must be in their natural anatomical position (opposing each other) to score this category. The radiographic techniques did not provide data for at least 5 of the 10 investigated categories (Table 3). It was not possible to grade the alveolar bone status on the radiographs because of superimposition issues as this category examines small morphological changes in the structure of the buccal contours of the alveolar margins of the posterior teeth.

3.2.1 | Comparison of the level and range of results for the LV micro-CT, macroscopic and radiographic methods

Table 4 presents the level and range of results for each method. All three methods provided identical data for the in situ dental inventory. The estimation of the dental age range for each individual was similar when applying the London Atlas (AlQahtani, 2012; AlQahtani et al., 2010) with each method (Table 1).

Scores for the category of tooth wear for the radiographic method were consistently at least one category higher compared with the LV icro-CT and macroscopic examinations, but for dental trauma, the macroscopic technique identified the greatest number of episodes (Table 4).

The grades for alveolar bone status were scored higher for the LV micro-CT method compared with the macroscopic examination results. This category could not be scored on radiographs.

The distance from the Cemento-Enamel Junction (CEJ) on the teeth to the crest of the alveolar bone provided evidence of horizontal bone loss, an indication of periodontal disease; the measurements on the 3D images from the LV micro-CT were greater than those obtained using the macroscopic method. For example, using the LV micro-CT method, the ranges of measurements for horizontal bone loss for adult SMB 73 were 2.0 to 7.4 mm, compared with 2.0 to 6 mm using the macroscopic method.

The total number of carious lesions identified using the macroscopic method was higher than other methods (Table 4). Scoring of the category of radiolucency of carious lesions for the LV micro-CT and radiographic methods was identical (Table 4); this category could not be scored macroscopically.

More individuals were identified with evidence of EH defects by the LV micro-CT method (Figure 3), compared with the macroscopic examination (Table 4). As with the measurements for horizontal bone loss, using the LV micro-CT method the distance from the CEJ to the EH defect/s was greater than that obtained by the macroscopic examination. From the three methods compared, only the LV micro-CT technique provided data for the category of IGD.

Illustrative Case Study: Infant SMB 58, dental age range = 1–1.5 years (±3 months) (AlQahtani et al., 2010). The accuracy of the LV micro-CT method was tested with the fragmented cranium and mandible of infant SMB 58. The standard methods were applied and EH defects were identified macroscopically on the maxillary primary canines and the semi-erupted primary maxillary and mandibular second molars of this infant. The LV micro-CT technique identified further detailed evidence of EH defects on the primary maxillary and

TABLE 4 A comparison of the levels and range of results for LV micro-CT, macroscopic, and radiographic methods of examination of the dental and alveolar bone health categories.

	Methods used		
Categories measured	LV micro-CT	Macroscopic	Radiographic
Tooth wear Molnar (1971). Grades 1 to 8. Min. to max. range observed:	1 to 5	1 to 5	2 to 5
Dental trauma Winter and Brook, (1989) Total number of teeth affected:	9	17	10
Class of occlusion Angle, (1966) Range of classes: 1 to 3	Class 1	Class 1	N/A
Carious lesions [a]Total number of lesions observed:	56	80	41
Carious lesions ICDAS/ICCMS Categories of radiolucency: 0 to 6 Min. to max. range observed	1 to 4	N/A	1 to 4
Enamel hypoplastic defects Brook et al. (2001) Total number of teeth affected:	44	13	N/A
IGD (interglobular dentine) Colombo et al., (2019), Veselka et al., (2019) Total number of teeth affected:	7	N/A	N/A

LV Micro-CT = large volume micro-CT. N/A = not applicable – this method cannot be used to score the specific oral health category. IGD = Interglobular dentine, ICDAS = International Caries Detection and Assessment System; ICCMS, International Caries Classification and Management System.
[a]More than one carious lesion may be present on a tooth.

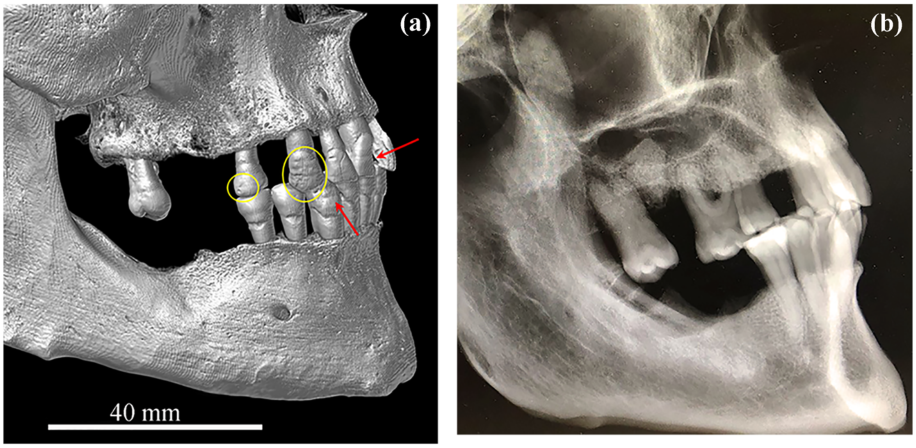

FIGURE 3 Sample SMB 73, adult male (dental age: over 23.5 years, skeletal age range: 30–39 years). (a) Large Volume Micro-CT-(skull scanned at 60 μm/pixel). Lateral view of the dentition in situ in the maxilla and mandible. Multiple examples of enamel hypoplastic (EH) defects (linear = *red arrows* and pits = *yellow circles*) are shown. The software "clipping" tool was used to remove half of the skull, therefore the upper first molar, seen on the radiograph (Figure 3b), is not visible. (b) Digitally reconstructed radiograph tool (DRR – Avizo 9 software) of the same individual. The EH defects cannot be observed on this radiograph; however, evidence of periodontal disease with generalized bone loss, most severe around the molar teeth, is visible. The bony outline of the mandible suggests that lower molars were lost because of periodontal disease. Images were created using volren with the Avizo 9 software (ThermoFisher Scientific, 2019). © Angela Gurr. [Colour figure can be viewed at wileyonlinelibrary.com]

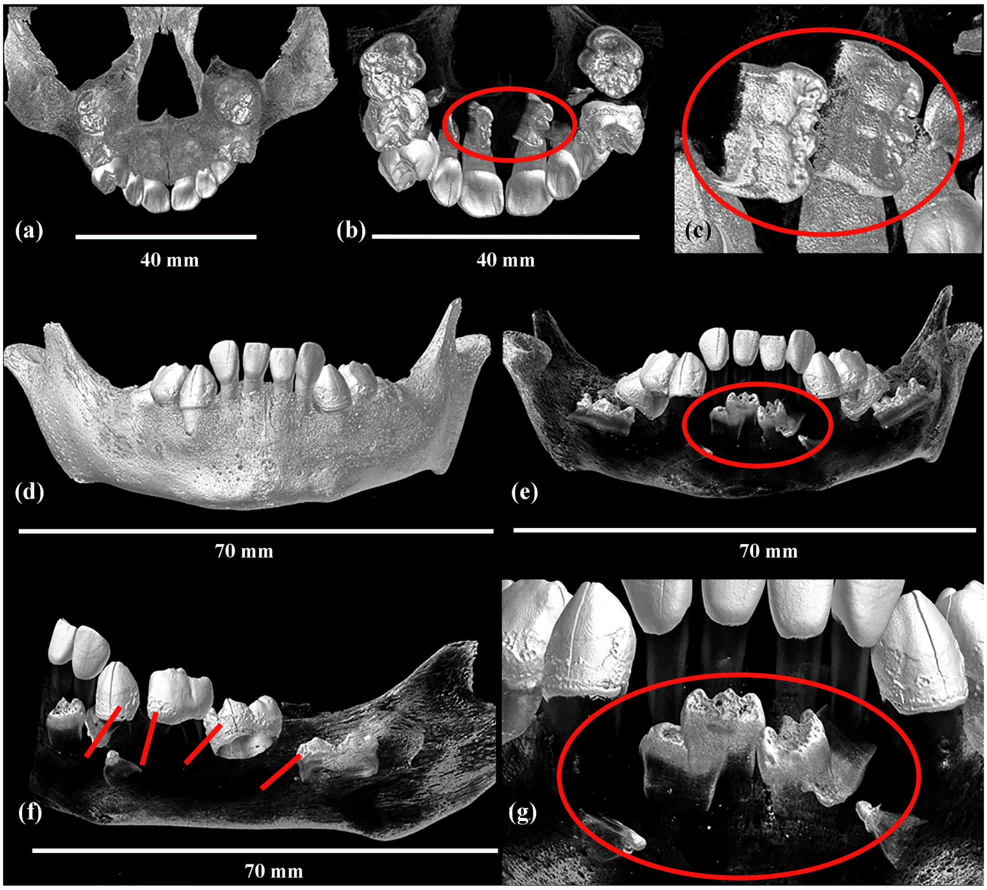

FIGURE 4 Large Volume Micro-CT. SMB 58 – Infant (dental age range 1–1.5 ± 3 months, skeletal age range 0–2 years of age). (cranium micro-CT scanned at 35 μm/pixel and mandible at 21 μm/pixel). (a and b) Posterior/lingual view of the maxilla. The bone density threshold level has been manipulated to reveal the developing teeth in the alveolar. The red oval shows the maxillary tooth germs of the permanent central incisors. Other teeth in the maxilla also have evidence of enamel hypoplastic defects. (c) Red oval – a close-up of Figure 4b, the maxillary permanent central incisor tooth germs, showing enamel hypoplastic defects. (d) Anterior/labial view of the mandible. (e–g) As with Figure 4b, the bone density threshold level was changed to show the developing teeth in the alveolar (red oval). (f) Lateral view of the mandibular dentition, the clipping tool was used to remove one side of the jaw. Red lines identify enamel hypoplastic defects on the erupted primary teeth and the semi-erupted primary second molar. Permanent teeth can be seen developing in the alveolar. (g) A close-up (from Figure 4e) of the mandibular permanent central and lateral incisor teeth developing (the red oval), and the tips of permanent canine teeth within the alveolar tissue. Images were created using the Volren function with the Avizo 9 software (ThermoFisher Scientific, 2019). © Angela Gurr. [Colour figure can be viewed at wileyonlinelibrary.com]

mandibular teeth in situ in the jaws (Figure 4), as well as on the erupting primary second molars. Extensive EH defects were also seen on the developing permanent tooth germs in the alveolar tissue (Figure 4). These enamel defects were not identified on the dental radiographs (Figure 5). Areas of IGD were identified (Figure 6) in all the teeth. These internal dentine defects (IGD) and the EH defects seen on the developing teeth within the alveolar tissue could not be identified macroscopically or radiographically (Figures 3, 5, and 6).

4 | DISCUSSION

This study demonstrated there are substantial differences between the methods, particularly in the levels and in the detail that they can be used to score each of the dental and alveolar bone health categories. These methods are considered in the order of the aims of the study.

4.1 | Aim 1 – Can LV micro-CT act as a single technique to provide a detailed analysis of the structures of the dentoalveolar complex in situ within archaeological human skull specimens?

The high-resolution, non-invasive LV micro-CT scanning method is capable of being a single technique for the analysis of the structures of the dentoalveolar complex in situ within a human archaeological skull specimen. This technique provided data for the full range of categories measured, (Tables 2–4), fulfilling the first aim of this study. The post-scan processing software (ThermoFisher Scientific, 2019) enabled specific and detailed measurements for the external and

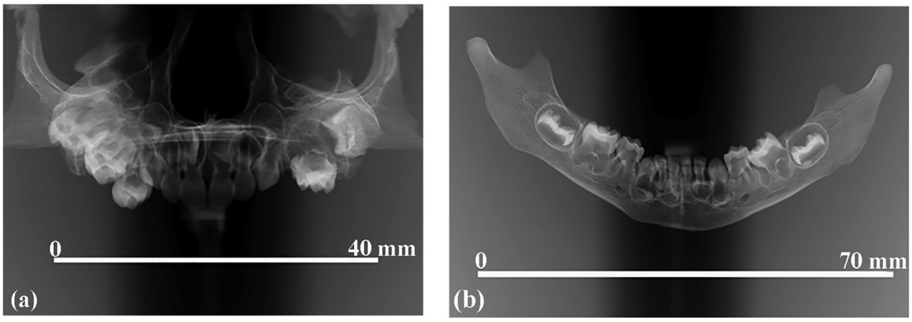

FIGURE 5 Dental radiographs. SMB 58 – Infant (dental age range 1–1.5 ± 3 months, skeletal age range 0–2 years of age). (a) Panoramic radiograph of the maxillary dentition, showing the erupted and semi-erupted primary teeth and the developing permanent teeth within the alveolar. (b) Panoramic radiograph of the mandibular teeth, similarly showing the erupted and semi-erupted deciduous teeth. The developing cusps of the permanent first molars can be clearly seen in the alveolar bone.

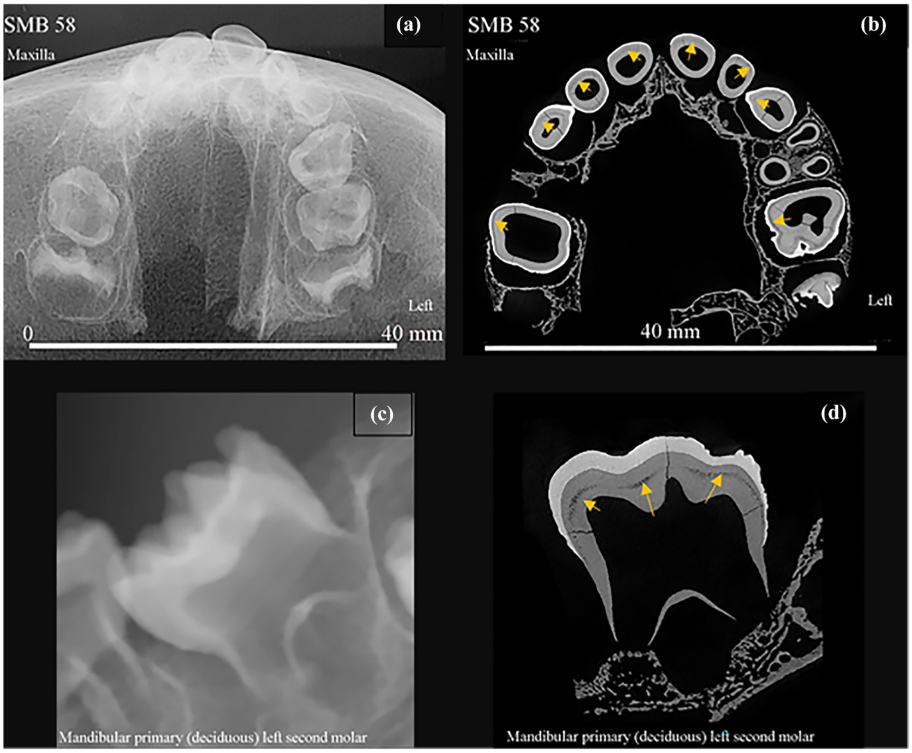

FIGURE 6 LV Micro-CT. SMB 58 – Infant (dental age range 1–1.5 ± 3 months, skeletal age range 0–2 years of age). (cranium micro-CT scanned at 35 μm/pixel and mandible at 21 μm/pixel). (a) Dental radiograph of the maxilla (vertex occlusal projection). The level of detail visible in this dental X-ray is less when compared with the micro-CT scan slice in Figure 6b. (b) Superior view of an internal slice from the LV micro-CT scan of the maxillary teeth. Orange arrows show areas of interglobular dentine. This mineralization defect was seen in all of the maxillary teeth and the majority of the mandibular teeth. (c) A dental radiograph of the lower left primary second molar (semi-erupted). (d) Sagittal slice from the micro-CT scan of the same mandibular tooth showing interglobular dentine (orange arrows). Micro-CT images were created using the orthoslice function with the Avizo 9 software (ThermoFisher Scientific, 2019). © Angela Gurr. [Colour figure can be viewed at wileyonlinelibrary.com]

internal structures of the dentoalveolar complex with the ability to scroll through the 3D image. With training, the software was easy to use for operators with a non-dental background.

The analysis of the LV micro-CT scan images provided insight into the changes and interactions that occur in the teeth and alveolar bone during development and disease. These data are important as the teeth and dental arches are parts of Complex Adaptive Systems of two or more structures (Brook, 2009, 2014; Brook et al., 2016). The age range and differing size for each individual were deliberately chosen to cover the dynamic interactions and changes that occur during development and to determine the value of the LV micro-CT technique for the analysis of in situ dentitions at different stages of development. For example, there was a marked difference/contrast seen in the density threshold level of the dentine and the enamel for the teeth from the adults compared with those from the subadults and infant. These variations in density levels were because of the differing stages of dental development and of mineralization of dentitions (Nanci, 2012).

This method can also provide data for an overall impression of general health as well as oral health through the examination of the cranium and the identification of co-morbidities, such as cribra orbitalia (Brickley, 2018; Godde & Hens, 2021; Walker et al., 2009) and caries sicca (Baker et al., 2020). Teeth developing during an extended period of disease or other insult can be affected, and the evidence of such a health insult may be seen as enamel and/or dentine defects (Figures 3–5) (Armelagos et al., 2009; Beaumont et al., 2018; Brickley et al., 2019; Brook et al., 1997; Brook & Smith, 1998; D'Ortenzio, Ribot, et al., 2018; Halcrow & Tayles, 2008; Hillson & Antoine, 2011; Kinaston et al., 2019; Mellanby, 1928, 1934; Nikiforuk & Fraser, 1979).

4.2 | Aim 2 – How findings from the LV micro-CT technique compare with standard methods?

Addressing the second aim, the LV micro-CT was the *only* technique to provide data for the complete analysis of the in situ dentoalveolar complex for the five individuals (Tables 3 and 4). The macroscopic method could not provide all data required for all the categories studied. The radiographic method provided the least amount of information to address the categories (Tables 3 and 4). By combining the macroscopic and the radiographic methods, a range of data could be provided for many but not all of the categories (Table 3).

Differences and similarities were seen in the "level" of scoring of data that was provided from the compared methods. All three techniques produced identical scores for the inventory of the in situ archaeological dentitions, which was to be expected as this category is not open to interpretation. The software ("volren" – Avizo 9) used with the reconstructed LV micro-CT scan data can adjust the density threshold level of the alveolar bone on the 3D images to reveal structures that are denser than the bone tissue, such as the enamel of developing tooth germs (Figure 4). Adjusting the bone density threshold levels and manipulating an image on the computer screen provided valuable additional information on morphology, position, and stage of development of primary and/or permanent teeth within the jaw; this adjustment and visualization of layers are not available on radiographs. The macroscopic method could only provide data for the dental age range category based on evidence of the external eruption of teeth.

The LV micro-CT and radiographic methods identified clinically significant carious lesions having marked demineralization and depth. Early caries with slight demineralization and staining can be scored macroscopically. This may be the reason for the higher caries score in this study with the macroscopic technique (Table 4), but these early reversible changes would have had no influence on the oral or general health of the individual.

The grades for the category of tooth wear were consistently higher on the dental radiographs compared with the other methods. This may have been because of problems associated with superimposition, that is, one structure being superimposed on top of another in the 2D radiographic image. Such distortion of the radiographic image can occur particularly in the cuspal regions of the premolars and molars. To overcome superimposition during the analysis of the Avizo 9 DRR images of the LV micro-CT scans, the clipping tool was used to remove a quadrant of the jaw or individual teeth (Figures 2c, 3, and 4f).

EH defects that were not observed during the macroscopic examination of the teeth of one subadult (SMB 52B) were identified during the 3D image analysis of the LV micro-CT scans. This method also identified a higher total number of EH defects, for all five individuals (Table 4), compared with the macroscopic analysis. The difference in the number of EH defects identified was probably related to the high-resolution images produced by the LV micro-CT system. In addition, an improved level of accurate measurable detail for the location of the EH defects was possible on the 3D image analysis of the LV micro-CT scans compared with the measurements taken during the macroscopic examination. Radiographically, EH is difficult to identify except in the most severe of cases (Figure 5).

For periodontal disease, an improved level of accuracy concerning measuring the distance between the CEJ and the alveolar bone was also provided using the LV micro-CT compared with the macroscopic method (Tables 2 and 4). The LV micro-CT allows for the precise location and size of the defect to be measured or to determine the extent of horizontal alveolar bone loss as evidence of periodontal disease. For example, there was a difference of 1.4 mm between the LV micro-CT measurement and the macroscopic measurement for the same tooth type in individual SMB 73.

4.3 | Illustrative case study: Infant SMB 58

The value of the LV micro-CT method was tested further with the investigation of the dentoalveolar complex in situ in the fragmented skull of infant SMB 58 (approximately 1.5 years of age) (Figures 4 and 6). EH defects were identified macroscopically on several of the erupted primary teeth. To investigate the full extent of this infant's dental and general health, the fragile cranium and mandible were LV micro-CT scanned. This method is ideal for this type of delicate specimen as it offers the least amount of handling of such fragmented remains (Figures 4 and 6).

A change in the bone density threshold levels of the maxilla and mandible on the LV micro-CT scans allowed the developing tooth germs within the alveolar to be analysed. Evidence of extensive EH defects was seen on the developing permanent teeth, the semi-erupted and erupted primary teeth (Figure 4). Examination of the dentine of the erupted and developing dentitions of this infant showed areas of IGD (Figure 6). These enamel secretion and dentine mineralization defects indicate that the ameloblast and the odontoblast (Hillson, 1996; Nanci, 2012) were affected by health insults during the development of the primary and permanent dentitions and reflect the general health status of infant SMB 58. An approximation of the timing of the health insults, during the development of the dentition (AlQahtani, 2012; AlQahtani et al., 2010), can be made by examining the location of the defects in relation to the CEJ. Health insults, such as a chronic systemic illness in the pregnant mother, can affect the primary and permanent dentitions of a baby in utero. Postnatally, the temporary immunity passed on to the newborn from its mother via the placenta and through breastfeeding (Jennewein et al., 2017) decreases, and the infant's immature immune system can struggle to overcome health issues. The location of the EH defects seen on the primary and developing permanent dentition of SMB 58 suggests that they could have suffered a health insult around the time of birth, and further illness affecting the developing teeth of this infant in the first year of life (AlQahtani et al., 2010; Nanci, 2012). The additional information gained from the LV micro-CT scan of the dentoalveolar complex of SMB 58 adds to the data from the macroscopic and radiographic methods (Figure 5) and illustrates the importance of this imaging technique.

4.4 | Advantages and limitations of the large volume micro-CT scanning method

The LV micro-CT scanning system is a valuable method that has shown it can be used as a single technique for the investigation of the dentoalveolar complex in situ in human archaeological skulls. Moreover, this micro-CT scanning system is considerably more time efficient for the amount of data received than by combining the macroscopic and radiographic methods.

Digital images (2D and 3D) created from LV micro-CT scans are permanent records that could be used to preserve rare and/or delicate archaeological human skull samples from individuals of different age groups as well as for data sharing for international collaboration, and/or for repeat scoring for reproducibility studies. Alternatively, micro-CT scan data sets can be converted to STL files for 3D printing. Ethical implications of digitalizing and/or replicating human remains must always be considered (Hirst et al., 2018).

4.5 | Alternative 3D image analysis techniques

An alternative CT technique that was not utilized for this investigation but could also be used for the study of the dentoalveolar complex in situ in human skull samples was the CBCT scanner. As previously mentioned, there is a difference in the size of the scan slice produced by the two techniques (Orhan, 2020; Orhan & Büyüksungur, 2019; Pour et al., 2016). However, depending on the type of anatomical or pathology structure to be studied, the CBCT scanner may be more readily available and a cheaper alternative to the LV micro-CT scanner (Lamira et al., 2022; Lozano et al., 2022). The 3D digital microscope (3D DM) could also provide high-quality images of dental defects on the external surfaces of the teeth. This equipment is suitable for teeth in situ in "small maxilla and mandible fragments or isolated teeth" (Lozano et al., 2022:3) but not an entire in situ dentoalveolar complex.

4.6 | Limitations of this study

The sample size for this study was dictated by the cost of the LV micro-CT technique. While at present the LV micro-CT is used for small numbers of rare samples, the cost is likely to reduce as the method becomes more widely applied. Statistical analysis (Gwet's AC and AC2) was affected by the sample size (Tables S3 and S4), with many results having a confidence interval of 1.00, which indicates a perfect agreement by the operators (raters).

5 | CONCLUSION

The LV micro-CT scanning technique was the only method to provide data for all the categories studied. This micro-CT scanning system provides accurate, detailed measurements of external and internal structures of the dentoalveolar complex in situ within archaeological human skull specimens. In this study, the LV micro-CT technique provided data that could not be obtained using macroscopic or radiographic methods and demonstrates that LV micro-CT scanning is an advance from standard non-invasive methods. This valuable technique allows fragile and rare archaeological human skull specimens to be examined, as the study of infant SMB 58 illustrated. The data that support the findings are available from the corresponding author upon reasonable request.

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CONFLICT OF INTEREST

The authors declare that they have no known competing financial interests or personal relationships that could have appeared to influence the work reported in this paper.

DATA AVAILABILITY STATEMENT

The data that support the findings of this study are available from the corresponding author upon reasonable request.

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SUPPORTING INFORMATION

Additional supporting information can be found online in the Supporting Information section at the end of this article.

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4.4. Appendix to Paper 3 (Chapter 4) – Supporting Information

4.4.1. Table S1

Table S1. St Mary's Cemetery archaeological samples – manual measurements using craniometric landmarks of each skull, with the mandible in position if applicable, cranium without the mandible in place, due to bone fragmentation, and measurements for each mandible alone. All diameters in millimetres. Note: some measurements are not of the standard craniometric diameters, they were used merely to give an idea of the size of an object inserted into the scanner. All were measured as simple linear distances

			Skull/ cranium measurements			Mandible only measurements		
St Mary's ID	**Skeletal age** (years)	**Sex**	**Length** *g-op*	**Height** *mst-b*	**Width** *eu-eu*	**Length** *gn-go*	**Height** *go* to the condylion	**Width** *go-go*
SMB 73*	30-39	M	225	167	138	114	74	115
SMB 66B	30-39	F	179	140	153	103	55	118
SMB 52B*	8-12	U	208	154	130	94	55	99
SMB 4A	2-4	U	191	98	132	74	28	90
SMB 82	0-2	U	144	113	118	60	26	72

Notes: * - for these complete skulls the "length" was taken as the distance from gnathion to the opisthocranion, and the height was measured as the distance from gonion to bregma.

Craniometric abbreviations: *gn* - Gnathion; *op* - Opisthocranion; *g* - Glabella; *b* - Bregma; *mst* - Mastoidale; *eu* -Euryon; *go* - Gonion;

4.4.2. Table S2

Table S2. Large Volume Micro-CT. Settings used for scanning of the dentition in-situ in the dentoalveolar complex of the human skulls from the St Mary's Cemetery individuals, using the Nikon XT H 225 ST Micro-CT system.

Skeletal region LV Micro-CT scanned	**St Mary's** ID	**Pixel size** (µm)	**Source voltage** (kV)	**Source Current** (µA)	**Filter Type**	**Filter thickness** (mm)
Skull	**SMB 73**	60	190	220	Sn	0.1
	SMB 52B	60	190	220	Sn	0.1
Cranium only	**SMB 82**	40	190	220	Sn	0.1
	SMB 66B	50	190	220	Sn	0.1
	SMB 58	35	190	184	Sn	0.1
	SMB 4A	55	190	220	Sn	0.1
Mandible only	**SMB 82**	18	190	68	Al	0.5
	SMB 73	13	190	68	Al	0.5
	SMB 66B	13	190	68	Al	0.5
	SMB 58		190		Al	0.5
	SMB 52B	22	190	60	Al	0.5
	SMB 4A	22	190	68	Al	0.5

4.4.3. Table S3

Table S3. Statistical Analysis Summary- Results from tests of intra- and inter-operator reliability for each of the methods assessed.

Test	Comparison	Summary Results		
		Agreement	AC2	Percentage agreement
		Inventory		
Inter-operator	LV	Fair – Perfect	0.31 - 1.00	67 - 100
	Macro	Poor - Perfect	-0.01 - 1.00	56 - 100
	Radio	Substantial - Perfect	0.79 - 1.00	89 - 100
Intra-operator	LV	Perfect	All 1.00	All 100%
	Macro	Moderate - Perfect	0.53 - 1.00	67 – 100
	Radio	Substantial - Perfect	0.79 – 1.00	89 – 100
		Tooth wear		
Inter-operator	LV	Fair - Perfect	0.20 – 1.00	63 – 100
	Macro	Moderate - Perfect	0.53 – 1.00	75 – 100
	Radio	Moderate - Perfect	0.47 – 1.00	75 – 100
Intra-operator	LV	Perfect	All 1.00	All 100%
	Macro	Almost perfect	0.81 – 100	88 – 100
	Radio	Substantial - Perfect	0.78 – 1.00	88 – 100
		Alveolar status		
Inter-operator	LV	Poor – Perfect	-0.18 – 1.00	38 – 100
	Macro	Poor – Perfect	-0.43 – 1.00	38 – 100
Intra-operator	LV	Perfect	All 1.00	All 100%
	Macro	Fair – Perfect	0.20 – 1.00	50 – 100
		Dental trauma		
Inter-operator	LV	Substantial – Perfect	0.74 – 1.00	81 – 100
	Macro	Substantial – Perfect	0.74 – 1.00	81 – 100
	Radio	Substantial – Perfect	0.77 – 1.00	81 – 100
Intra-operator	LV	Substantial – Perfect	0.74 – 1.00	81 – 100
	Macro	Almost perfect	0.82 – 1.00	88 – 100
		Caries		
Inter-operator	LV	Poor – Perfect	-1.00 – 1.00	0 – 100
	Macro	Poor – Perfect	-0.45 – 1.00	0 – 100
	Radio	Poor – Perfect	-0.45 – 1.00	0 – 100
Intra-operator	LV	Fair – Perfect	0.20 – 1.00	50 – 100
	Macro	Fair – Perfect	0.27 – 1.00	50 – 100
	Radio	Fair – Perfect	0.20 – 1.00	50 – 100
		Enamel hypoplastic defects		
Inter-operator	LV	Poor – Perfect	-0.57 – 1.00	0 – 100
	Macro	Fair – Perfect	0.20 – 1.00	50 – 100
Intra-operator	LV	Fair – Perfect	0.20 – 1.00	50 – 100
	Macro	Fair – Perfect	0.27 – 1.00	50 – 100
		Periodontal disease		
			ICC	
Inter-operator	LV	Poor – Excellent	0.23 – 1.00	

	Macro	Poor – Excellent	0.21 – 1.00	
Intra-operator	LV	Poor – Excellent	0.46 – 1.00	
	Macro	Poor – Excellent	0.00 – 1.00	

Chapter 5. Introduction to Paper 4

5.1. Paper 4 - Overview

Papers 1 and 2 examined aspects of the skeletal health of St Mary’s individuals. Their oral health and how it could affect their general health status needed to be investigated. The introduction of a reliable and accurate non-invasive method, in paper 3 (LV Micro-CT), for the analysis of in-situ dentition and the alveolar bones, allowed an in-depth dental investigation of the St Mary’s individuals to be undertaken.

Multiple non-destructive methods were used in paper 4 (i.e., LV and SV Micro-CT, macroscopic examination and dental radiographs) to maximise data collection. Analysis of the findings established that the oral health of the St Mary’s cohort was poor. Extensive evidence of carious lesions, antemortem tooth loss, and periodontal disease was seen. These oral conditions would have affected their general health and worsened existing Co-Morbidities.

The presence of enamel and dentine defects showed that many of the adults in this group had survived one or more episodes of systemic ill health during the development of their dentition. It appears that systemic health insults in childhood to young adulthood, resulting in enamel hypoplastic defects, were a common occurrence as similar results were found in historic samples from NSW, Australia, New Zealand and the UK. Probable signs of systemic ill health were seen on some of the St Mary’s individuals. These could have been associated with health insults that produced enamel hypoplastic defects and areas of interglobular dentine.

Statement of Authorship

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Name of Principal Author (Candidate)	Angela Gurr		
Contribution to the Paper	Conceptualization, methodology, investigation, data curation, software, formal analysis, visualization, writing - original draft, and writing - review and editing. project administration. Submission of manuscript and acted as corresponding author.		
Overall percentage (%)	85%		
Certification:	This paper reports on original research I conducted during the period of my Higher Degree by Research candidature and is not subject to any obligations or contractual agreements with a third party that would constrain its inclusion in this thesis. I am the primary author of this paper.		
Signature		Date	08.03.2023

Co-Author Contributions

By signing the Statement of Authorship, each author certifies that:

i. the candidate's stated contribution to the publication is accurate (as detailed above);
ii. permission is granted for the candidate in include the publication in the thesis; and
iii. the sum of all co-author contributions is equal to 100% less the candidate's stated contribution.

Name of Co-Author	Maciej Henneberg		
Contribution to the Paper	Conceptualization, data curation, formal analysis, methodology, resources, supervision, validation, writing - original draft, and writing review and editing.		
Signature		Date	9 Feb '23

Name of Co-Author	Jaliya Kumaratilake		
Contribution to the Paper	Resources, Supervision, writing - original draft, and writing - review and editing, funding acquisition.		
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Contribution to the Paper	Conceptualization, methodology, investigation, formal analysis, visualization, writing - original draft, and writing - review and editing, funding acquisition.		
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5.3. The oral health of a group of 19th-century South Australian settlers in relation to their general health and compared with that of contemporaneous samples

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Article

The Oral Health of a Group of 19th Century South Australian Settlers in Relation to Their General Health and Compared with That of Contemporaneous Samples

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Abstract: The aims of this study are to determine the oral health status of a rare sample of 19th-century migrant settlers to South Australia, how oral conditions may have influenced their general health, and how the oral health of this group compares with contemporaneous samples in Australia, New Zealand, and Britain. Dentitions of 18 adults and 22 subadults were investigated using non-destructive methods (micro-CT, macroscopic, radiographic). Extensive carious lesions were identified in seventeen adults and four subadults, and from this group one subadult and sixteen adults had antemortem tooth loss. Sixteen adults showed evidence of periodontal disease. Enamel hypoplastic (EH) defects were identified in fourteen adults and nine subadults. Many individuals with dental defects also had skeletal signs of comorbidities. South Australian individuals had the same percentage of carious lesions as the British sample (53%), more than other historic Australian samples, but less than a contemporary New Zealand sample. Over 50% of individuals from all the historic cemeteries had EH defects, suggesting systemic health insults during dental development were common during the 19th century. The overall oral health of the South Australian settlers was poor but, in some categories, (tooth wear, periapical abscess, periodontal disease), better than the other historic samples.

Keywords: oral health; systemic health; colonial dental health

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1. Introduction

A skeletal sample of 19th-century migrant settlers to South Australia was investigated to understand their health status. There are few collections of skeletal remains from early migrants to Australia. The majority of the individuals from this South Australian sample were buried in the first three decades after the establishment of the colony in 1836. Skeletal abnormalities in these individuals have been examined and the findings in relation to the general health of the individuals have been published [1,2]. The dentoalveolar complexes of these skeletons were investigated in this study to expand our understanding of the health status of the individuals in relation to their dental and oral health.

Tooth enamel cannot be remodeled in life [3,4]. Dentine can be remodeled but only very slowly as a result of the aging process and/or due to dental caries or trauma [3,4]. Therefore, health insults that occur during dental development in utero and postnatally until young adulthood [5,6] can cause enamel and dentine defects such as enamel hypoplasia and interglobular dentine that remain throughout life [4]. This makes dentition an excellent model for the investigation of an individual's health history compared with bones, which become remodeled during life in response to changes in the forces acting on them [7]. Skeletal abnormalities that result from a health insult in early life may alter or change with the remodeling of the bone.

The presence of carious lesions, morphological changes to the alveolar bone, including its loss, and antemortem tooth loss due to extraction, disease, or trauma are all valuable sources of evidence. As a result of teeth being in direct contact with their environment, patterns of tooth wear from attrition, abrasion, and erosion can provide information regarding diet, lifestyle choices, oral hygiene, the use of teeth in daily activities, and the environment of the individual. Cultural practices affecting the oral environment may also leave their mark on dentition, for example, pipe mouthpieces or pins and nails habitually held between teeth by some tradespeople. The status of the oral health of this group of early settlers could also give an indication of the degree to which they had access to the available dental services [8].

The relationship between poor oral health and systemic ill health has been investigated [9–11]. Periodontal disease has links to many systemic illnesses, such as atherosclerotic cardiovascular disease [12–15], Type 2 diabetes [9,16], and bacterial pneumonia [17,18]. Considering the oral health of the St Mary's Cemetery sample, together with any skeletal signs of disease to indicate comorbidities [1,2], should provide the clearest possible insight into the health of these individuals.

Therefore, the aims of this study were to investigate (1) the oral health status of the individuals buried at the 'free ground' of St Mary's Anglican Church Cemetery, (2) how these oral conditions may have influenced their general health and, (3) how the oral health status of these colonial South Australian settlers compared with other historic samples in Australia, New Zealand, and Britain.

2. Materials and Methods

2.1. Materials—The Archaeological Sample

The 70 individuals in this sample were buried between 1847 and 1927, in an unmarked area of St Mary's Cemetery, referred to as the 'free ground', which was for people who had no funds to pay for their interment. These burials were paid for by the South Australian Government. Burials in the main section of the cemetery were paid for by the deceased or their family; these burials came with a gravestone [1].

To identify the individuals excavated from the free ground, each skeleton was assigned a site code and number (e.g., St Mary's Burial/number 58 = SMB 58). No other sections of the cemetery have been excavated. Relevant aspects concerning the excavation of this sample and the observed macroscopic skeletal abnormalities have been published [1,2,19,20]. Determination of the sex of each individual and an estimation of the age range at death, from the skeletal remains and macroscopic examination of tooth eruption, were recorded immediately after the excavation of each skeleton. [19].

2.1.1. The Archaeological Sample—Dentitions

The skeletal remains of 40 individuals where dentitions were preserved in a suitable state were selected for the study. This sample consisted of 18 adults (13 male and 5 female) and 22 subadults from the St Mary's Cemetery skeletal collection (total n = 70). The terms 'infant' and 'subadult' are used in this study to refer to individuals in the following age ranges: 0–2 years (infants); 3–5 years, 6–9 years, 10–15 years, and 16–19 years (all groups of subadults). Table S1 provides an example using these age categories.

The maxillary and mandibular bones of the remaining 30 individuals within this sample were highly fragmented and not suitable for analysis. The specimens investigated comprised dentitions in situ within the dentoalveolar complex of the skull and had lost teeth that had been displaced post-mortem. A dental inventory (number and type of teeth present), an estimation of the age range (assessment of the skeletal remains and dentitions), and the sex of each individual are presented in Table S1.

2.1.2. The Archaeological Sample—Ethics

The excavation of the free ground section of St Mary's Anglican Church Cemetery occurred upon the request of the Parish as they wished to re-use the area. Approval for the study of the skeletal remains was also granted by St Mary's Parish and the Flinders University Social and Behavioural Research Ethics Committee (SBREC project number 8169). Destructive analysis was not permitted during the investigation of this sample as the remains are of a rare historical nature.

2.2. Methods

Large Volume and Small Volume (LV or SV Micro-CT) scanning systems, macroscopic examination, and standard dental radiographs were used for the investigation of the structures of the dentoalveolar complexes of the selected human skulls from the St Mary's skeletal collection.

2.2.1. Large Volume Micro-CT

This technique allowed for the examination of 'large 'specimens such as dentitions that remain in situ within the skull that require minimal handling. This method provides rapid data acquisition at a high resolution of both the external and internal structures [21]. The dentoalveolar complexes in situ within the skulls of six individuals (two adults, SMB 66B and SMB 73; two subadults, SMB 04A and SMB 52B; and two infants SMB 58 and SMB 82) were scanned using the Nikon XT H 225 ST cabinet Micro-CT scanning system [22]. The pixel/voxel size (spatial resolution) used for each scan was different as these are relative to the size of the specimen. The settings used for each complete skull, cranium, or mandible alone are presented, with additional scanning information, in Table S2.

2.2.2. Small Volume Micro-CT

Teeth that had been displaced post-mortem from 21 individuals (n = 41 teeth) (Table S3) were investigated. The number of teeth and tooth types that were available for each individual varied. Individual tooth specimens were scanned using the desktop Bruker SkyScan 1276 [23], at a pixel size of 9.0 µm. Information regarding the SV Micro-CT scan settings is presented in Table S3.

2.2.3. Macroscopic Examination

Visual investigation of the structures of the dentoalveolar complexes was conducted in a dry laboratory with the aid of a table magnifying glass with enhanced lighting. A periodontal probe with incremental markings was used for measurements [24]. The Fédération Dentaire Internationale (FDI) World Dental Federation notation system [25,26] was used in this study to accurately record and distinguish between permanent and primary teeth.

2.2.4. Standard Dental Radiographs

Panoramic extraoral radiographs (crania and mandibles were imaged separately) and periapical intraoral radiographs were taken using Planmeca X-ray equipment [27]. Details of the radiographic equipment and the settings used are available in the supplementary material in Appendix A. Dental radiographs can only identify severe cases of interglobular dentine (IGD) or enamel hypoplastic (EH) defects, therefore these categories were not scored on those.

2.2.5. Scoring: Dental and Alveolar Bone Health Categories

The following dental and alveolar health categories were scored: dental inventory, dental age, tooth wear, presence of carious lesions, periodontal disease, enamel hypoplastic (EH) defects, and interglobular dentine (IGD). The identification criteria and scoring systems used for the above categories are listed in Table 1. Teeth with more wear could be suggestive of an older adult. Therefore, 11 adults from the St Mary's sample with permanent molars remaining in situ were scored using Miles's (1962) [28] tooth wear system for archaeological specimens. This system assesses the functional age of each molar and predicts the age of the subject [28]. To determine the extent of general tooth wear, Molnar's (1971) [29] system was also used for all individuals in the sample.

Avizo 9 data visualisation software [30] was used for image analysis of the reconstructed LV and SV Micro-CT scan data sets. The software (Avizo 9) provides digitally reconstructed radiographs (DRRs) from the LV and SV Micro-CT scans which were compared to the dental radiographs. The category of radiolucency of caries (Table 1) was scored on both the dental radiographs and the DRRs. This software was used to manipulate the bone density threshold levels of the specimens (i.e., reduce the density of the alveolar bone) to reveal developing teeth.

Alveolar bone loss, which was suggestive of periodontal disease, was scored using a measurement from the cementoenamel junction (CEJ) on a tooth to the crest of the alveolar bone [24]. This measurement was taken along the midline of the tooth on the labial/buccal and lingual/palatal surfaces. An increase in the distance measurement from the CEJ to the crest of the alveolar bone suggested that bone loss had occurred. Measurements of 4 mm or above are included in this analysis.

The St Mary's sample were examined for evidence of calculus deposits. Adult SMB 84 is edentulous (with dentures) and not included in this analysis. The presence and location of the calculus on the tooth (enamel or root) and the severity of the deposits (small/slight, medium, or large/considerable) were scored following the criteria set out by Connell and Rauxloh (2003) [31] and Powers (2012) [32] from the Museum of London Human Osteology Method Statement. These systems are developed from that of Brothwell (1963) [33].

It is difficult to differentiate areas of staining on the tooth that could be caused by the burial environment and/or taphonomic changes from developmental enamel opacities and/or variations in the mineralisation of the enamel [34–36]. Therefore, enamel opacities (hypo-mineralisation defects) were not investigated.

Table 1. Categories for scoring dental and alveolar bone health.

Categories to Be Investigated	Criteria for Identification	Scoring Systems	References
Dental Inventory	Total number of teeth in situ. Antemortem tooth loss: evidence of alveolar tissue healing. Postmortem tooth loss: open socket and no evidence of bone healing	Data were recorded on a visual chart representing the primary/permanent teeth using the FDI (ISO 3950) notation system. (i) tooth type present, (ii) location of healed alveoli, (iii) open socket—location in the alveolar process	[25,26,37–40]
Dental age range	Erupted tooth types present, semi-erupted, and developing teeth in alveolar bones Tooth wear—adult molars only	The London Atlas of tooth eruption and development was used with dental radiographs to identify the stage of eruption and tooth development (0–23.5 years). Adult age range: assessment of the functional age of each molar and the predicted age of the subject based on tooth wear scores set out by Miles (1962).	[5,6,28]
Tooth wear	Evidence of enamel loss and/or exposure of dentine on the occlusal surface of the teeth	Category of tooth wear selected from Molnar's (1971) and Miles's (1962) criteria charts.	[28,29]
Carious lesions (caries—cavity)	(1) Evidence of decay: (a) present on enamel surface only, (b) involving enamel and dentine, (c) decay involving the enamel dentine and the pulp. (2) Identify changes in radiolucency/density of the tooth	Score: (i) tooth type affected (FDI), (ii) location of the carious lesion in relation to the CEJ, (iii) ICDAS/ICCMS category of radiolucency-using dental radiographs and DRRs. Select a category from a visual chart.	[41]

Table 1. *Cont.*

Categories to Be Investigated	Criteria for Identification	Scoring Systems	References
Periodontal disease	(i) Evidence of alveolar bone loss (ii) Evidence of morphological changes in the margins of the contours of the alveolar bone of the posterior teeth (buccal surface only)	(i) Measurement taken from the CEJ to the crest of the alveolar bone on the midline of the crown surface (labial/buccal and lingual/palatal). (ii) Alveolar bone status: graded 0–4 using Ogden's (2008) system via inspection of the margins of the alveolar bone surrounding the posterior teeth.	[42–44]
Enamel hypoplastic defects (EH)	Evidence of lines or pits in the surfaces of the enamel	Scored using an adaptation of the Enamel Defect Index (EDI): (i) type of EH defect/s, (ii) number of EH defects on the enamel surface, (iii) location of EH defect/s—measurement of the distance of the defect/s in relation to the CEJ.	[45,46]
Interglobular dentine (IGD)	Evidence of changes in the density of the dentine structure	Record: the presence of IGD as Yes/No (Micro-CT only)	[47,48]

Notes: CEJ = Cemento-enamel Junction, FDI = Fédération Dentaire Internationale/World Dental Federation notation system, DRR = Digitally Reconstructed Radiographs using Avizo 9 software [30], ICDAS/ICCMS = International Caries Detection and Assessment System/International Caries Classification and Management System.

2.2.6. Scoring: Evaluation of Intra and Inter-Operator Variations

Intra-Operator Variation

The primary operator (AG) macroscopically examined and scored the images of teeth and alveolar tissues using dental radiographs and 2D and 3D images taken from the LV and SV Micro-CT scans using the Avizo 9 software [30]. A second data scoring session was carried out using the same specimens two weeks later for the evaluation of the intra-operator variability.

Inter-Operator Variation

Operators were trained and calibration sessions were carried out two weeks before these inter-operators independently scored the dental and alveolar bone health categories (Data S1 and Tables S4 and S5).

2.2.7. Statistical Analysis

All analyses were performed using Stata v17 computer software [49]. Assessments of the intra-operator and inter-operator reliability were made using Gwet's Agreement Coefficient (AC1), weighted Gwet's Agreement Coefficient (AC2), and Intraclass Correlation Coefficient (ICC) using a two-way random-effects model for absolute agreement, for binary and nominal scale data, and ordinal scale data and continuous data, respectively. Results are presented as AC1/AC2 with a 95% confidence interval (CI) and percentage agreement for non-continuous data and as the ICC with a 95% CI for continuous data. Interpretation of AC1 and AC2 was <0 = poor agreement; 0–0.2 = slight agreement; 0.21–0.4 = fair agreement; 0.41–0.6 = moderate agreement; 0.61–0.8 = substantial agreement; and >0.8 = almost perfect agreement [50]. Interpretation of ICC values was <0.50 = poor agreement; 0.50–0.75 = moderate agreement; 0.75–0.90 = good agreement; and >0.90 = excellent agreement [51].

2.3. Comparison of Historic Dental Samples from Australian, New Zealand, and British Cemeteries

Findings from the investigation of the dental and alveolar bone health categories for the St Mary's Cemetery sample were compared with data from two colonial Australian samples: Cadia Cemetery, NSW, 1864–1927 (n = 109) [52] and Old Sydney Burial Ground (OSBG), NSW, 1792–1820 (n = 10) [53]. Dental findings from Cadia Cemetery have not been previously published; therefore, permission was granted by the copyright holder, Newcrest Mining Ltd. and Dr. Edward Higginbotham and Associates Pty Ltd., the consultant archaeologist. The St Mary's findings were also compared with the published data from St John's Burial Ground, Milton, Otago, New Zealand, (1860–1926) ($n = 7$) [54] and a British sample from the Cross Bones Burial Ground, Southwark, London, UK (1800–1853) ($n = 83$) [55]. The category of tooth wear for each cemetery was scored using different systems; therefore, only scores that represented 'moderate to heavy' tooth wear were compared.

3. Results

3.1. Reproducibility—Standard Statistical Analysis

Due to the small sample size, many tests for intra-operator and inter-operator agreement achieved perfect agreement, resulting in all summary ranges, including perfect or excellent agreement [50,51]. For the inventory and tooth wear measurements, the inter-operator agreement was better when using the Macroscopic or Radiographic techniques; the results ranged from poor to perfect for the Macroscopic technique and substantial to perfect for the Radiographic technique, compared with fair to perfect for the LV Micro-CT technique; for both Macroscopic and Radiographic techniques combined, the results ranged from moderate to perfect, compared to fair to perfect for the LV Micro-CT technique (for inventory and tooth wear, respectively). For alveolar status, the inter-operator agreement was the same for both the LV Micro-CT and Macroscopic techniques. The LV Micro-CT method achieved the same level of agreement as the other techniques for all other measures when assessing both the inter- and intra-operator agreement. The Macroscopic method also had an almost perfect agreement. It should be noted though that the percentage agreement was very similar—between 81 and 100% agreement for the LV Micro-CT method and 88 to 100% agreement for the Macroscopic method.

A summary of the tests of intra- and inter-operator reliability for each of the methods investigated is presented in Table S4. A written summary with information on this statistical analysis follows Table S4. Additional data and the raw data can be found in Table S5 and Data S1, respectively.

3.2. Dental Inventory

A full dental inventory for each individual is presented in Table S1. Thirty-nine of the forty individuals had dentitions in situ. The total number of teeth present for the sample ($n = 40$) was 518 (175 primary and 343 permanent teeth). There were eight adults, and each had less than ten teeth present (Table S1). One adult female, SMB 84, was edentulous and had a full set of vulcanite dentures with porcelain teeth (Figure 1). The setup/fabrication of the dentures suggests that they were well made.

Dental Age Range

The estimated dental age range for each individual is presented in Table S1. The dental age range of the majority of individuals was similar to that assigned from the skeletal assessment (Anson, 2004). The dental age ranges of the two subadults (SMB 28, SMB 70) were different from the skeletal age range (Table S1). Subadult SMB 28: the dental age range was 15.5–16.5 years (±1 year) compared with the 12–13 years skeletal age range. The skeletal age was based on the incomplete fusion of the epiphyseal plates at the elbow [19]. Radiographically, there was no evidence of the mandibular third molars developing, and the alveolar tissue in this area was fragmented. The developing crowns of these molars were loose and had separated from the jaw. Subadult SMB 70: the dental age range was 11.5–12.5 years (±1 year), compared with the 8–9 years skeletal age range.

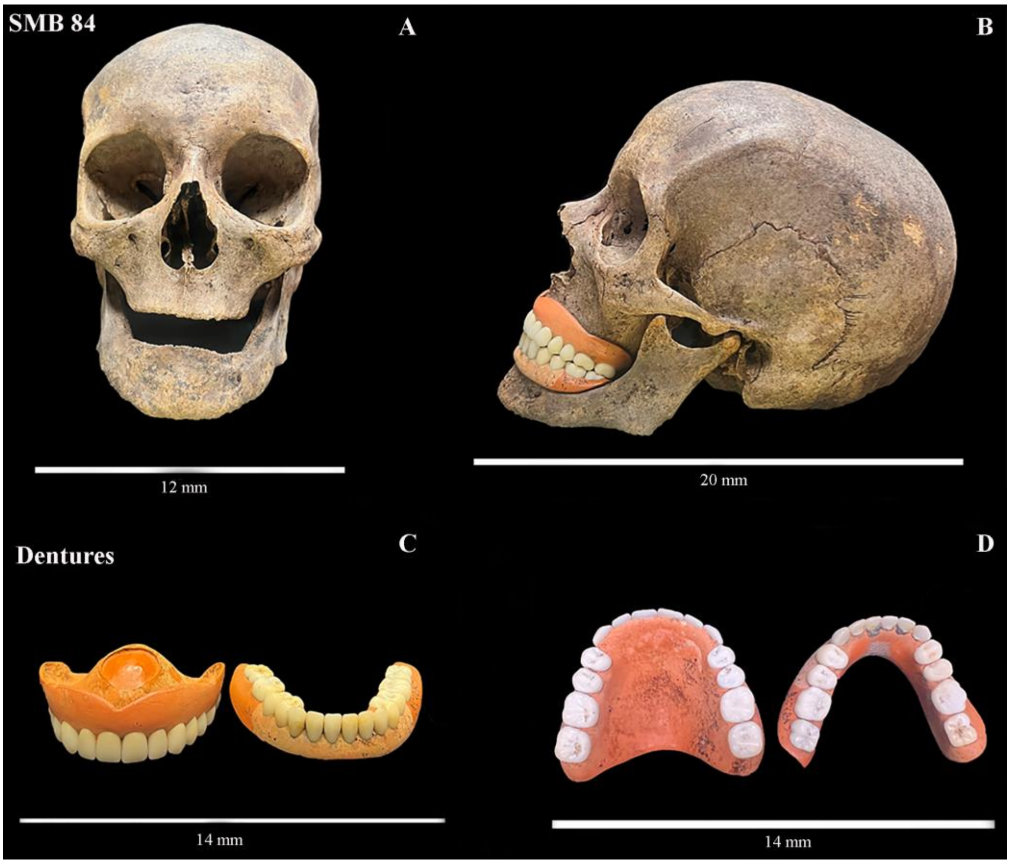

Figure 1. SMB 84—adult female (age range 50–59 years.). Vulcanite base dentures with porcelain teeth. Images show dentures in situ and removed from the maxilla and mandible. (**A**). Anterior view of the edentulous maxilla and mandible. (**B**). Left lateral view of the 'well-made' dentures with a class one occlusion in the jaw. (**C**,**D**). The vulcanite dentures with porcelain teeth—the maxillary denture shows a shield shape suction area on the superior surface of the plate. © Angela Gurr.

3.3. Tooth Wear

In scoring tooth wear, a higher category implies more wear [28,29]. The functional age of the permanent molars of 11 adults was scored to estimate the age range of each individual [28] (S6). Some of the age ranges predicted using Miles's (1962) system [28] were different from the age ranges assigned to the individuals based on the evidence of skeletal changes/maturity and dental eruption. Molnar's (1971) [29] system provided general tooth wear scores for each tooth present in all of the individuals in the sample (Tables S7a–c). The individuals with higher categories of tooth wear (categories 4–8) [29] were all adults (Table S7a). Analysis of the distribution of tooth wear for the different tooth types (i.e., incisors, canines, premolars, etc.) showed that more anterior teeth (central and lateral incisors as well as canines) were scored with category 4 and 5 tooth wear compared with premolars and molars (Table 2). The canine teeth of the St Mary's adults were the only anterior teeth to be scored with category 5 tooth wear, along with the molars (Table 2).

Three adult males (SMB 59, SMB 72, and SMB 78) showed patterns of tooth wear that suggest they had smoked a pipe for an extended period of time. The opposing upper and lower teeth, for example the maxillary and mandibular canines and first premolars, had a semi-circular pattern of tooth wear, suggesting these teeth could have gripped a pipe (Figure 2).

Table 2. The number of each tooth type for each category of tooth wear scored using Molnar's system [29] for the permanent dentition of the adults from the St Mary's sample, with the number of each tooth type for each category of tooth wear scored.

Type of Permanent Tooth	Number of Teeth with Cat. 4	Number of Teeth with Cat. 5	Number of Teeth with Cat. 6	Number of Teeth With Cat. 7	Number of Teeth With Cat. 8	Total Number of Each Tooth Type
Cent. Incisor	13	13	0	0	0	26
Lat. Incisor	22	18	0	0	0	40
Canine	16	14	3	0	0	33
P1	8	6	0	1	0	15
P2	9	1	2	1	0	13
M1	7	1	4	0	0	12
M2	7	3	3	1	0	14
M3	1	1	3	0	1	6
Total	**83**	**57**	**15**	**3**	**0**	

Notes: Cent. = central, Lat. = lateral, P1 = first premolar, P2 = second premolar, M1 = first permanent molar, M2 = second permanent molar, M3 = third permanent molar. Cat. = category of tooth wear.

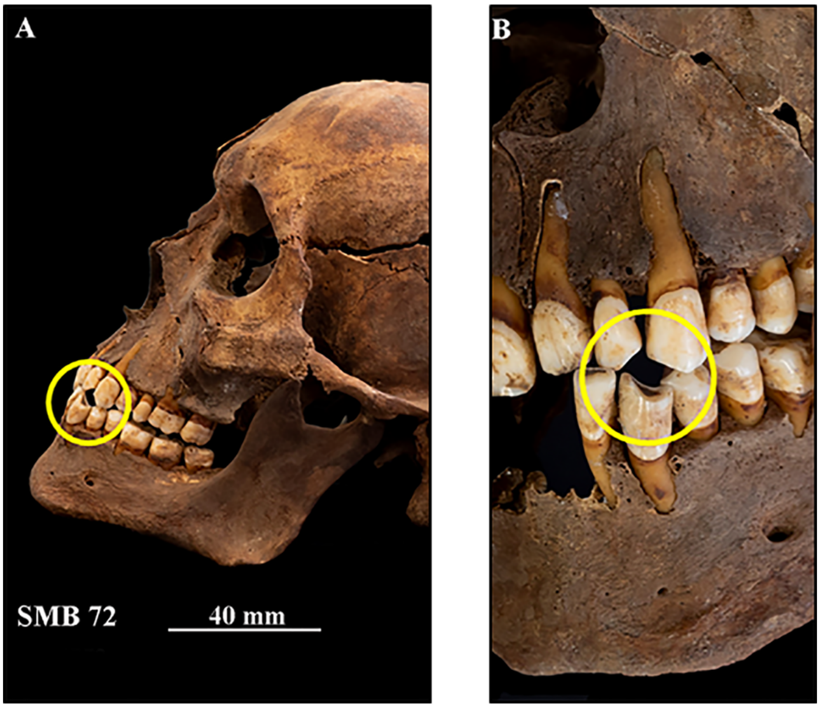

Figure 2. SMB 72. Adult male (age range 40–49 years). (**A**): Left lateral view of the dentition in situ in the skull. Yellow circle highlights a pattern of tooth wear often referred to as a 'pipe notch'. The teeth have become worn from the movement of and holding a smoking pipe between the teeth over an extended period of time. (**B**): A close-up view of the left maxillary and mandibular permanent lateral incisors and canines opposing each other. The yellow circle shows a clear semi-circular tooth wear pattern. © Angela Gurr.

3.4. Carious Lesions

Seventeen adults and four subadults (Table 3) had evidence of carious lesions on their dentitions (*n* = 21/40–53%). Seven individuals from this group had more than 60% of their teeth affected by caries (Table 3). The majority of the carious lesions were seen on the permanent teeth, except for the primary teeth of subadults SMB 19 (FDI tooth numbers 55 and 83) and SMB 70 (FDI tooth numbers 53 and 63). The total number and percentage of teeth affected by carious lesions are presented in Table 3. A greater number of lesions were located *on* the CEJ (46%) rather than above (42%) or below the CEJ (12%) (Table S8a), and a greater number of carious lesions was located on the mesial (29%) and distal (25%) surfaces of the teeth than on the occlusal (14%), the labial/buccal (21%), and the lingual/palatal (11%) surfaces (Table S8a). The extent of the carious lesions (e.g., how many involved the enamel only, the enamel and the dentine, or were extensive and approaching the pulp chamber) is presented in (Table S8b). The majority of carious lesions observed in the St Mary's sample involved the enamel only and had not extended to involve the dentine or pulp (Table S8b).

Table 3. Number and percentage of carious lesions identified for individuals from the St Mary's sample, with identification of teeth lost in life (antemortem).

St Mary's ID	Age Range	Sex	Total Number of Teeth Present	Permanent or Primary Dentition	* Total Number of Teeth Affected by Carious Lesions	Percentage of Teeth Affected by Carious Lesions	Total Number of Carious Lesions Present	** Antemortem Tooth Loss FDI Notation Number/s of Teeth Lost in Life
SMB 19	6–9	U	22	7 primary 15 Permanent	2	9%	3	None
SMB 70	6–9	U	8	2 primary 6 Permanent	2	25%	3	None
SMB 28	10–14	U	26	Permanent	1	4%	2	None
SMB 79	15–18	U	25	Permanent	8	32%	13	36
SMB 05	20–30	F	6	Permanent	4	67%	8	11, 12, 13, 14, 15, 16, 18, 21, 22, 23, 24, 25, 26, 27,28, 36, 37, 38, 45, 46, 47, 48
SMB 53C	30–39	F	9	Permanent	8	89%	12	15, 16, 17, 18, 24, 25, 27, 28, 31, 35, 36, 37, 38, 41, 44, 47, 48
SMB 66B	30–39	F	17	Permanent	11	65%	16	11 (root only), 13, 16, 18, 26, 28, 36, 37, 38, 46, 47, 48
SMB 73	30–39	M	19	Permanent	17	89%	39	15, 17, 18, 24, 26, 27, 36, 37, 38, 46, 47, 48
SMB 06	40–49	M	24	Permanent	12	50%	19	28, 34, 35, 36, 38, 48
SMB 09	40–49	M	22	Permanent	1	5%	11	11, 27, 38
SMB 57	40–49	M	25	Permanent	8	32%	12	25, 28
SMB 61	40–49	F	7	Permanent	4	57%	5	11, 12, 15, 16, 17, 18, 21, 22, 24, 26, 27, 28, 334,35, 36, 37,38, 43, 45, 46, 47, 48
SMB 72	40–49	M	29	Permanent	7	24%	15	None
SMB 78	40–49	M	4	Permanent	2	50%	3	11, 12, 15, 16, 17, 18, 21, 22, 23, 24, 25, 26, 27, 28, 31, 32, 36, 37, 38, 41, 42, 43, 44, 45, 46, 47, 48
SMB 83	40–49	M	16	Permanent	6	38%	7	16, 18, 26, 36, 45, 46
SMB 85	40–49	M	2	Permanent	1	50%	1	11, 12, 13, 14, 15, 16, 17, 18, 23, 24, 25, 26, 27, 28, 31, 35, 36, 37, 38, 41, 43, 44, 45, 46, 47, 48
SMB 14	50–59	M	2	Permanent	1	50%	1	12, 14, 15, 16, 17, 18, 21, 22, 24, 25, 26, 27, 28, 34, 36, 37, 38, 46, 48
SMB 23	50–59	M	21	Permanent	20	95%	54	48
SMB 59	50–59	M	15	Permanent	10	67%	10	14, 15, 24, 25, 47
SMB 63	50–59	M	3	Permanent	1	33%	3	11, 12, 14, 15, 16, 17, 21, 22, 24, 25, 26, 27, 28, 35, 36, 37, 38, 41, 42, 44, 46, 47, 48
SMB 68	50–59	M	19	Permanent	11	58%	14	15, 16, 36, 41, 46
TOTAL			**321**		**137**		**251**	

Notes: F = female, M = male, U = undetermined. * A tooth could have more than one carious lesion present. ** Antemortem tooth loss = evidence of healing or healed alveolar bone in the location of the absent tooth. FDI = Fédération Dentaire Internationale tooth identification notation system.

A large carious lesion was identified on the mesial/occlusal surface of the lower right permanent first molar (M1) of subadult SMB 79 (Figure 3a). Resorption of the alveolar bone surrounding this tooth exposed the majority of the buccal roots (Figure 3b). A localised periapical cavity was present with a circular hole (fistula) in the alveolar bone (3 mm in diameter) on the buccal surface, inferior to the mesial root of the M1 (Figure 3b,c). Evidence of changes in the texture of the alveolar bone surface (porosity) around this fistula was seen (Figure 3b). Radiographs showed the carious lesion had involved the enamel, dentine, and pulp of this tooth. The X-ray image also shows the extent and depth of the periapical cavity around the distal root of the M1 and the 'opening' in the alveolar bone adjacent to the apex of the mesial root (Figure 3c).

Figure 3. SMB 79, subadult (dental age range 15.5–16.5 years (±1 year)—skeletal assessment age range 16–18 yrs.). (**A**,**B**): Yellow circle shows caries in the mesial occlusal surface of the lower right permanent first molar (M1—FDI number 46). Yellow arrows indicate the periapical cavity and opening in the buccal surface of the alveolar bone. (**C**): Periapical dental radiograph of the mandible—yellow arrows show the extent of the cavity surrounding the roots of the M1 molar, and the 'opening' in the alveolar bone adjacent to the apex of the mesial root. The yellow circle highlights caries that extended to involve the pulp. © Angela Gurr.

3.5. Periodontal Disease

3.5.1. Alveolar Bone Loss

Nine out of forty adults (seven males: SMB 06, SMB 23, SMB 57, SMB 63, SMB 68, SMB 73, SMB 78, and two females: SMB 53C, SMB 66B) aged between 30–49 years old had a distance measurement from the CEJ to the crest of the alveolar bone of 4 mm or over (up to 10 mm) on three or more teeth, suggesting evidence of periodontal disease. Adult SMB 73 had 9 teeth with distance measurements ranging from 6 mm to 10 mm (other affected teeth measured from 4 to 5 mm). Two adults (SMB 14 and SMB 85, both male, aged between 40–59 years old) only had two teeth remaining having lost the majority of their teeth in life (antemortem). These teeth showed extensive horizontal alveolar bone loss (between 6–7 mm per tooth). The female with the dentures (SMB 84) (Figure 1) had complete resorption of alveolar processes.

3.5.2. Alveolar Bone Status:

Ogden's (2008) [42] system of assessment is as follows: grade 0 = unable to score, i.e., alveolar is missing, grade 1 = no disease and grade 4 = severe periodontitis. The higher grades (3 and 4) suggestive of evidence of periodontal disease are shown here.

Grade 3—*n* = three adults (males, SMB 72, SMB 73, and SMB 83), aged between 30–59 years old.

Grade 4—*n* = eight adults (seven males, SMB 06, SMB 09, SMB 23, SMB 57, SMB 63, SMB 68, and SMB 85, and one female, SMB 66B), aged between 30–39 years old.

The buccal contours of the alveolar margins of the posterior teeth for adult SMB 06 (aged between 40–49 years old) had the highest number of areas scored at grade 4. The remaining areas of alveolar bone for this individual were scored from grade 1 to 3, suggesting extensive periodontal disease.

3.5.3. Calculus

Calculus (calcified plaque) deposits were observed on the remaining dentitions of 11 of the 17 adults from the St Mary's sample; the full results per tooth are presented in Table S9. A total of 240 teeth were examined, with 79 teeth (33%) being affected by calculus (Tables 4 and S9). The calculus deposits observed were of small (slight)-to-medium amounts (Table S9). Five adults from the group of eleven had between 68% and 100% of their teeth affected by calculus (Table S9). The location of the calculus was predominantly on the enamel surface (60/79 teeth) (Table S9).

Table 4. Calculus—the percentage of individuals and the number of teeth with calculus deposits.

Dental Pathology: Calculus	Sample Size (Adults Only) *n* =	Percentage of Individuals Affected	Number of Teeth Present	Number of Teeth with Calculus Deposits	Percentage of Teeth with Calculus	Mean Number of Teeth Affected
	17	**65%**	**240**	**79**	**33%**	**7.2**

3.6. Enamel Hypoplasia (EH)

Fourteen adults and ten subadults showed evidence of one or more enamel hypoplastic defects on one or more of their teeth (Tables 5 and S10), representing over half of the total sample (n = 24/40–60%). Four adults and four subadults had EH defects on 60% or more of their teeth (Table 5). Adult SMB 73 had the highest percentage of teeth affected by EH defects (Table 5). More canine teeth were affected by EH defects than the incisors, premolars, or molars for both primary and permanent dentition (Tables 6 and S10); this was followed by the central and lateral incisors. The permanent third molars were the least affected tooth type (Table 6). Large Volume Micro-CT scans identified EH defects on the erupted primary teeth and the developing permanent teeth of infant SMB 58 (Figure 4) (Table 5). This infant also had evidence of EH defects on four primary canines, four primary second molars, and sixteen permanent teeth (central and lateral incisors, canines, and first molars), either starting to erupt or developing within the alveolae of the maxilla and mandible (Figure 4) (Tables 5 and S9). Details of the number of EH defects per tooth per individual are presented in Table S10.

Table 5. Number and percentage of enamel hypoplastic (EH) defects identified in the individuals from the St Mary's sample with antemortem tooth loss.

St Mary's ID	Age range (Skeletal and Eruption Findings) (Years)	Sex	Total Number of Teeth Present	Permanent and/or Primary Dentition	Tooth Type/s Affected by EH Defects FDI Notation	Total Number of Teeth with EH Defects	Percentage of Teeth Affected by EH Defects	Type of EH Defect/s Present
SMB 58	0–2	U	11	All primary teeth	51, 52, 54, 61, 62, 72, 74, 84	8	72%	Linear and pits
SMB 11	0–2	U	19	primary	53, 63, 73, 83	4	21%	Pits
SMB 04A	3–5	U	19	primary	71, 72, 81, 82	4	21%	Pits
SMB 35	6–9	U	11	primary	63	1	9%	Pits
SMB 19	6–9	U	22	Mixed 7 primary 15 Permanent	12, 13, 14, 15, 21, 22, 42, 83	8	36%	Linear and pit
SMB 51	10–15	U	16	1 primary 15 Permanent	12, 13, 14, 16, 22, 23 24, 25, 26, 34, 36	11	69%	Linear and pit
SMB 52B	10–15	U	17	2 primary 15 permanent	11, 12, 13, 16, 21, 23, 26, 31,32, 33, 36, 14, 42, 43	14	82%	Linear and pit
SMB 70	10–15	U	8	2 primary 6 Permanent	53, 21, 63, 26	4	50%	Linear and pits

Table 5. *Cont.*

St Mary's ID	Age range (Skeletal and Eruption Findings) (Years)	Sex	Total Number of Teeth Present	Permanent and/or Primary Dentition	Tooth Type/s Affected by EH Defects FDI Notation	Total Number of Teeth with EH Defects	Percentage of Teeth Affected by EH Defects	Type of EH Defect/s Present
SMB 28	10–15	U	26	All Permanent	11, 12, 15, 16, 22, 23, 25, 26, 27, 31, 32, 33, 34, 35, 41, 42, 43, 44, 45, 47	20	77%	Linear and pit
SMB 79	16–19	U	25	Permanent	13, 23, 27, 33,43	5	20%	Linear and pit
SMB 05	20–29	F	6	Permanent	41, 42	2	33%	Linear
SMB 53C	30–39	F	9	Permanent	11, 13, 14, 21, 23	5	56%	Linear and pit
SMB 66B	30–39	F	17	permanent	14, 17, 21, 23, 27, 34, 44, 45	8	47%	Pits
SMB 73	30–39	M	19	Permanent	11, 12, 13, 16, 21, 23, 25, 31, 32, 33, 34, 41, 42, 43, 44	15	79%	Linear and pits
SMB 06	40–49	M	24	Permanent	12, 31, 32, 41, 42	5	21%	Linear
SMB 09	40–49	M	22	Permanent	12, 13, 21, 22, 23, 32, 33, 43	8	36%	Linear and pit
SMB 57	40–49	M	25	Permanent	11, 12, 13, 14, 27, 32, 33, 35, 42, 43	10	40%	Linear and pit
SMB 72	40–49	M	29	Permanent	12, 13, 23, 24, 38, 43, 48	7	24%	Pits
SMB 83	40–49	M	16	Permanent	13, 21, 23, 27, 28, 33, 34, 42, 43	9	56%	Linear and pit
SMB 85	40–49	M	2	Permanent	33	1	50%	Linear and pit 2
SMB 23	50–59	M	21	Permanent	17, 18, 21, 31, 32, 33, 41, 42, 43	9	43%	Linear and pit
SMB 59	50–59	M	15	Permanent	11, 12, 13, 21, 22, 23, 35, 38, 41, 42, 44, 46	12	80%	Linear and pit
SMB 63	50–59	M	3	Permanent	32, 43	2	67%	Pits
SMB 68	50–59	M	19	Permanent	14, 23, 35, 43, 44, 45	6	42%	Pits

Notes: M = male, F = female, U = undetermined sex. EH = enamel hypoplastic defects. A tooth may have more than one EH defect. FDI = Fédération Dentaire Internationale tooth identification notation system.

Table 6. The different tooth types affected by enamel hypoplastic defects in the St Mary's Cemetery sample.

Tooth Type	Number of Primary Teeth with EH Defects	Number of Permanent Teeth with EH Defects	Total Number of Each Tooth Type
Cent. Incisor	4	32	**36**
Lat. Incisor	5	29	**34**
Canine	8	44	**52**
P1	n/a	18	**18**
P2	n/a	12	**12**
M1	3	10	**13**
M2	0	8	**8**
M3	n/a	5	**5**
Total	20	158	

Notes: EH = Enamel hypoplastic defects. Cent. = central, Lat. = lateral, P1 = first premolar, P2 = second premolar, M1 = first molar, M2 = second molar, M3 = third permanent molar.

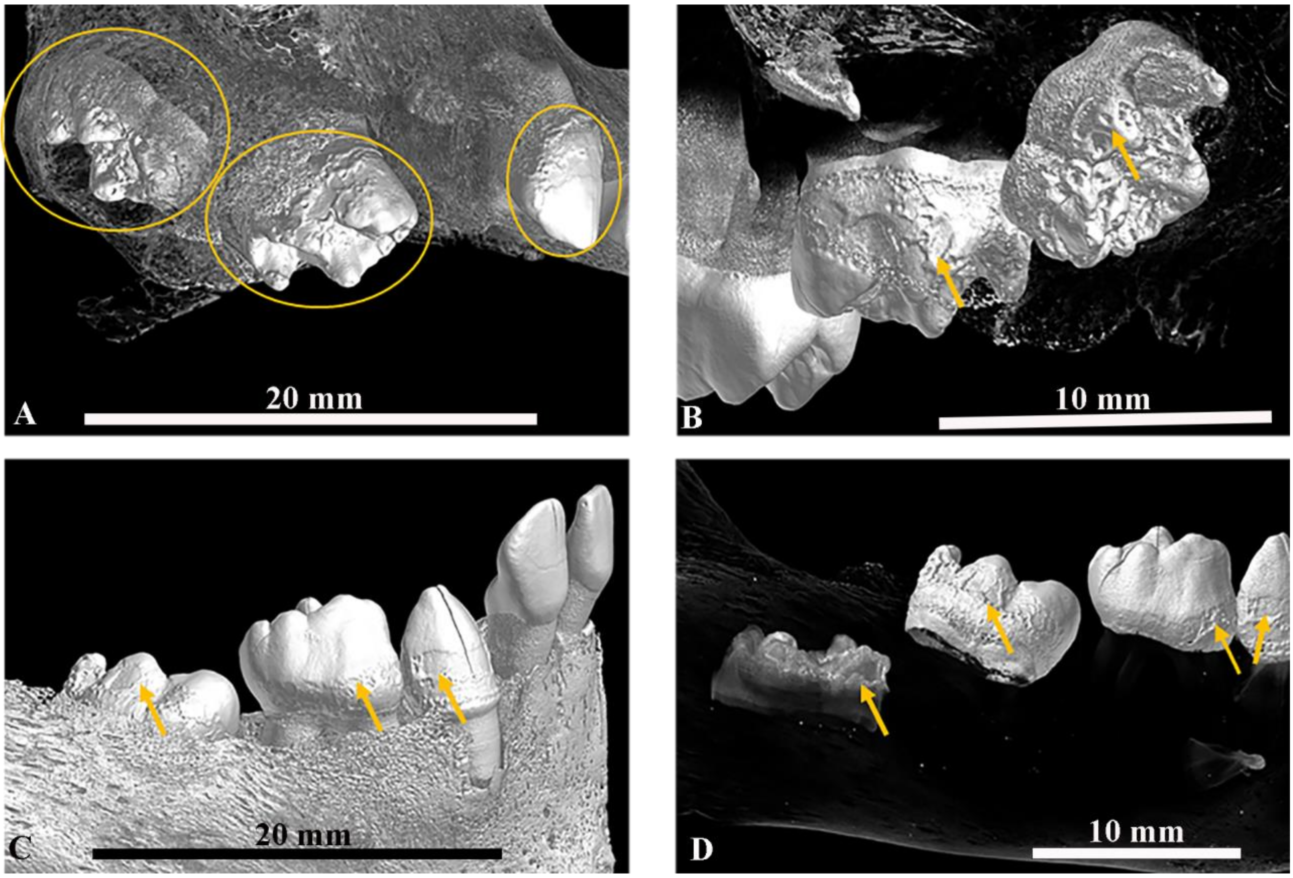

Figure 4. SMB 58—Infant (dental age range between 1–1.5 ± 3 months, skeletal assessment age range between 0–2. years of age). (Cranium—Large Volume Micro-CT scanned at 35 μm/pixel and mandible at 21 μm/pixel, Table S2). (**A**,**B**,**D**): Created using Avizo 9 software [30]; the bone density threshold level was manipulated/reduced to reveal the denser structures of the developing teeth within the alveolar bone. (**A**): Buccal view of the semi-erupted, upper-right primary canine and primary second molar; the first primary molar was lost post-mortem. Yellow circles show teeth affected by enamel hypoplastic defects, including the developing crown of the permanent upper right first molar within the alveolar bone. (**B**): Lingual/palatal view of the upper-left primary first and second molars and the crown of the permanent first molar within the alveoli. Yellow arrows highlight enamel hypoplastic defects. (**C**): Lateral view of the mandibular primary dentition. Yellow arrows indicate some enamel hypoplastic defects on the primary canine, first molar, and erupting second molar. (**D**): As with image B, the bone density threshold level was changed to show the developing teeth within the alveoli—yellow arrows show the enamel hypoplastic defects of the erupted primary teeth, semi-erupted primary second molar, and the cusps of the developing crown of the permanent first molar. © Angela Gurr.

3.7. Interglobular Dentine (IGD)

Two individuals (adult SMB 73 and infant SMB 58) of the six individuals that were scanned using the LV Micro-CT system showed areas of IGD. This mineralisation defect in the dentine was seen in all of the erupted and developing primary teeth of infant SMB 58 and of the permanent dentition within the alveolae (developing maxillary and mandibular teeth listed above) (Figure 5). Individual SMB 73 had IGD in 17 of his 19 permanent teeth. Three individuals (adults SMB 63 and 73 and subadult SMB 70) from the twenty-one individuals who had one or more loose teeth scanned using the Small Volume Micro-CT system (Table S3) showed IGD.

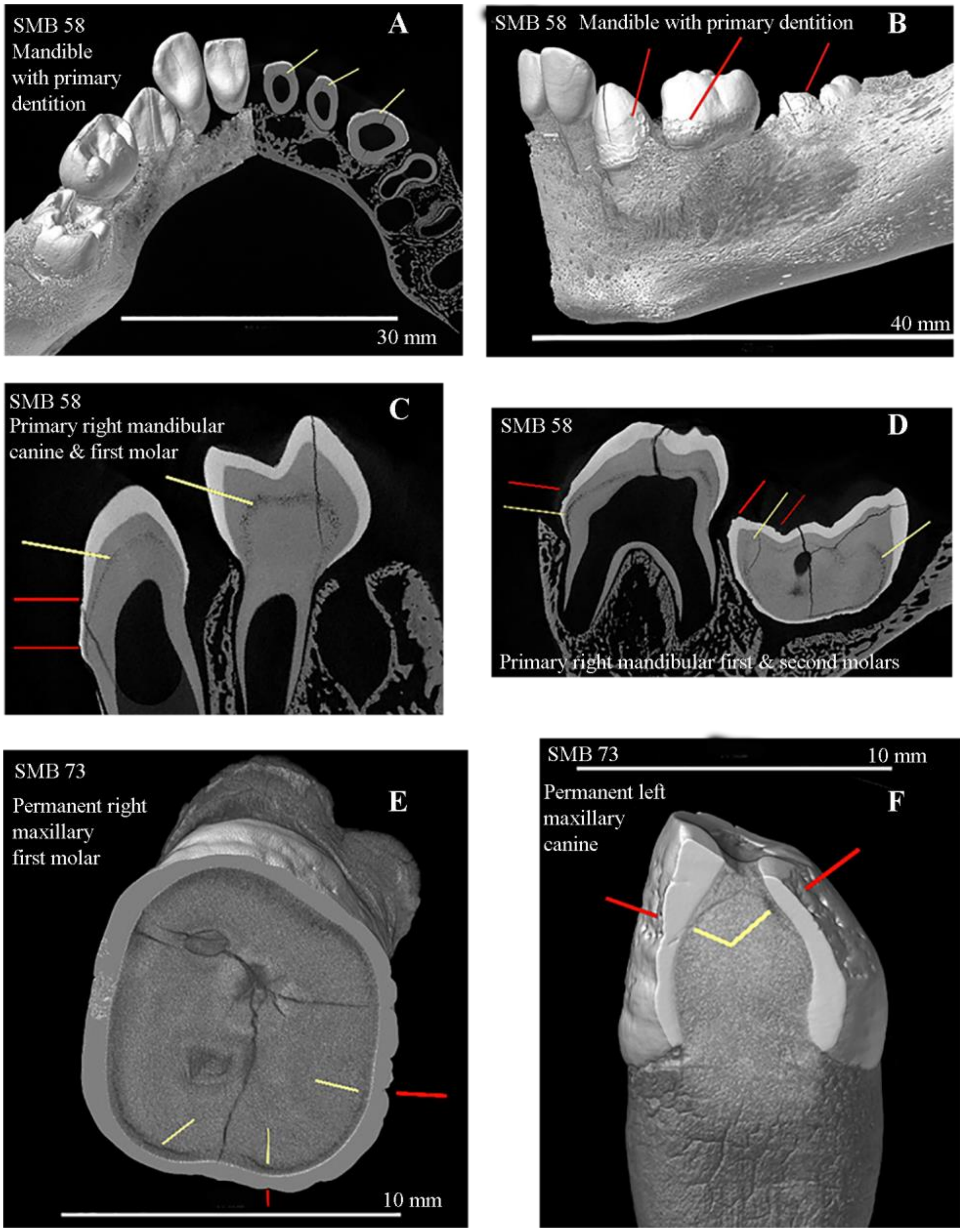

Figure 5. (**A**–**D**): SMB 58—infant (dental age range between 1–1.5 ± 3 months, skeletal age range between 0–2 years of age). Large Volume (LV) Micro-CT scanned at 21 µm/pixel (Table S2). (**A**): Superior/posterior view of the mandible and primary teeth. The left side of the jaw and teeth is shown in 3D and the right side is a 2D LV micro-CT slice of the teeth—yellow lines show interglobular dentine (IGD). (**B**): Lateral view of the mandibular primary dentition—red lines show enamel hypoplastic (EH) defects. (**C**,**D**): Sagittal slices from LV micro-CT scans of the mandibular dentition (Image C—FDI tooth numbers 83 and 84, Image D—FDI teeth 84 and 85). Yellow lines show areas of IGD in the internal structure of the teeth and the red lines show EH defects on the external structures of the teeth. (**E**,**F**): SMB 73—adult male, (skeletal age range: between 30–39 years). Individual tooth samples scanned with the Small Volume (SV) Micro-CT system at 9 µm/pixel (Table S3). (**E**): FDI tooth number 16; (**F**): FDI tooth number 23. Both images—yellow lines show areas of IGD and red lines show EH defects in the teeth and at a similar level. All images were created using Avizo software [30] Volren or Orthoslice functions from reconstructed LV and SV Micro-CT scan data. © Angela Gurr.

3.8. Comorbidities and Signs of Skeletal and Dental Changes

Twenty-five individuals from the St Mary's dental sample of forty had poor oral health. Their oral health findings are presented in Table 7. From this group, one infant, five subadults, and seven adults (n = 13/25) also had skeletal signs of one or more comorbidities and/or signs of skeletal abnormalities and/or evidence of dental changes, including indicators of lifestyle habits (Table 7). Some comorbidities are only evident in the soft tissue [9,12–16] and could not be identified in the skeletons of this sample. Seven adults had evidence of skeletal abnormalities such as Schmorl's nodes and vertebral osteophytes (Table 7) [1,2] and three adult males had dental changes due to tooth wear (pipe notch), which indicate smoking and an increased risk of poor oral health.

Table 7. Key individuals from the St Mary's Cemetery sample with a summary of their oral health findings. Many individuals had one or more skeletal signs of a comorbidity and/or signs of skeletal and dental changes.

St Mary's Burial I/D	Sex	Dental Age D = Skeletal Age S = (Years)	Inventory Number of Teeth Present de = Deciduous P = Permanent	Caries Number of Teeth Affected	Periodontal Disease		EH Number of Teeth Affected † Max:	IGD Number of Teeth Affected	Comorbidities Signs of Skeletal and Dental Changes
					Alveolar Bone Status Grade 1–4 Min–Max	Alveolar Bone Loss Number of Teeth Affected			
SMB 58	**U**	**D = 1–1.5 (±3 months) S = 0–2**	**10 de**	**0**	**1**	**0**	9/10	10/10	(i) Abnormal porosity of the cortical bones of the maxilla and mandible [1].
SMB 04A	U	D = 3.5–4.5 (±6 months) S = 2–4	19 de	0	1	0	4/19	0	(i) Cribra orbitalia Types 3–4 [1].
SMB 19	U	D = 7.5–8.5 (±1 year) S = 5–9	7 de 12 P	2/19	1–2	0	8/19	0	(i) Cribra orbitalia Types 3–4 [1].
SMB 70	U	D = 11.5–12.5 (±1 year) S = 8–9	2 de 6 P	6/8	1–2	0	4/8	2/2	(i) Congenital Syphilis, (ii) TB, (iii) mercury toxicity, (iv) abnormal porosity in the cortical bones of the greater wing of sphenoid, maxilla, scapulae, pelvic bones, bilaterally [1,19,56].
SMB 52 B	U	D = 10.5–11.5 (±1 year) S = 8–12	2 de 14 P	0	1	1/16	14/15	0	None seen.
SMB 51	U	D = 10–11. (±1 year) S = 8–12	14 de	0	1–3	0	10/14	0	None seen.
SMB 28	F	D = 15.5–16.5 (±1 year) S = 10–14	26 P	1/26	1–4	0	20/26	0	(i) Cribra orbitalia Type 4, (ii) Possible nutritional deficiency due to abnormal porosity of the cortical bones of the greater wing of the sphenoid and alveolar tissue of the maxilla—bilaterally [1].
SMB 79	U	D = 15–16 (±1 year) S = 16–18	25 P	13/25	1–2	0	5/25	0	(i) Spina bifida occulta, (ii) evidence of a dental abscess (Figure 3).
SMB 05	F	D = over 23.5 S = 20–29	6 P	4/6	1–2	0	2/5	0	None seen.
SMB 53 C	F	D = over 23.5 S = 30–39	9 P	8/9	2–3	8/9	5/9	0	(i) Pitting of the external surface of the Occipital bone, (ii) several vertebral osteophytes- [2].

Table 7. *Cont.*

St Mary's Burial I/D	Sex	Dental Age D = Skeletal Age S = (Years)	Inventory Number of Teeth Present de = Deciduous P = Permanent	Caries Number of Teeth Affected	Periodontal Disease		EH Number of Teeth Affected † Max:	IGD Number of Teeth Affected	Comorbidities Signs of Skeletal and Dental Changes
					Alveolar Bone Status Grade 1–4 Min–Max	Alveolar Bone Loss Number of Teeth Affected			
SMB 66 B	F	D = over 23.5 S = 30–39	17 P	12/17	1–4	12/17	8/17	0	None seen.
SMB 73	M	D = over 23.5 S = 30–39	19 P	17/19	1–3	15/19	18/19	7/19	(i) Torticollis, (iii) spina bifida occulta.
SMB 06	M	D = over 23.5 S = 40–49	24 P	12/24	1–4	22/24	5/24	0	(i) Posterior external surfaces of parietal bones—uneven thickening, possible mild caries sicca. (ii) Vertebral osteophytes and Schmorl's nodes [1,2,19].
SMB 09	M	D = over 23.5 S = 40–49	21 P	11/21	2–4	6/21	8/21	Not micro-CT scanned	(i) Spina bifida occulta.
SMB 57	M	D = over 23.5 S = 40–49	25 P	8/25	2–4	21/25	11/25	Not micro-CT scanned	(i) Vertebral osteophytes [2].
SMB 61	F	D = over 23.5 S = 40–49	6 P	4/6	2–3	3/6	0	Not micro-CT scanned	(i) Spina bifida occulta.
SMB 72	M	D = over 23.5 S = 40–49	31 P	7/31	2–3	2/31	0	0	(i) Evidence of pipe smoker's tooth wear pattern *. (Figure 2).
SMB 78	M	D = over 23.5 S = 40–49	4 P	2/4	0	4/4	0	Not micro-CT scanned	(ii) Vertebral osteophytes, (ii) bony growth 20 mm × 10 mm left fibular ossified haemorrhage [2].
SMB 83	M	D = over 23.5 S = 40–49	16 P	6/16	1–3	0	9/16	0	(i) Spina bifida occulta, (ii) vertebral osteophytes, (iii) bony thickening mid-shaft femur 20 mm × 3 mm, healed trauma antemortem [2].
SMB 85	M	D = over 23.5 S = 40–49	2 P	1/2	3–4	2/2	1/2	0	(i) Vertebral osteophytes, (ii) eburnation of multiple vertebral facet joints. [2]
SMB 14	M	D = over 23.5 S = 50–59	2 P	1/2	2–3	2/2	0	Not micro-CT scanned	(i) Multiple vertebral osteophytes, (ii) eburnation of multiple vertebral facet joints, the joints of the ulna, trochlear, and olecranon (bilaterally), femoral head, acetabulum, talus (head), and the navicular [2].
SMB 23	M	D = over 23.5 S = 50–59	21 P	20/21	3–4	10/21	9/21	0	None seen.
SMB 59	M	D = over 23.5 S = 50–59	16 P	10/16	3–4	8/16	12/16	Not micro-CT scanned	(i) Evidence of pipe smoker's tooth wear pattern. (Figure 2).

Table 7. *Cont.*

St Mary's Burial I/D	Sex	Dental Age D = Skeletal Age S = (Years)	Inventory Number of Teeth Present de = Deciduous P = Permanent	Caries Number of Teeth Affected	Periodontal Disease		EH Number of Teeth Affected † Max:	IGD Number of Teeth Affected	Comorbidities Signs of Skeletal and Dental Changes
					Alveolar Bone Status Grade 1–4 Min–Max	Alveolar Bone Loss Number of Teeth Affected			
SMB 63	M	D = over 23.5 S = 50–59	3 P	3/3	4	3/5	2/3	1/1	(i) Spina bifida occulta, (ii) concaved maxillary sinus with signs of new bone growth.
SMB 68	M	D = over 23.5 S = 50–59	19 P	11/19	2–4	15/19	8/19	0	(i) Eburnation of femoral head, acetabulum, talus, and calcaneus [2].

Notes: D = Dental age range, estimated using the London Atlas of Human Tooth Development and Eruption [5,6]. S = skeletal age range estimated from the assessment of skeletal changes/maturity [19]; U = undetermined sex, M = male, F = female. Periodontal disease includes (i) Alveolar Bone Status—Ogden's (2008) [42] screening system assigns a grade in relation to the condition of the buccal contours of the alveolar margins of the posterior teeth. A higher grade implies a more severe grade of periodontal disease; grades are between 0–4 (0 = unable to score, 1 = no disease, and 4 = severe periodontitis). Additionally, (2) horizontal alveolar bone loss measurements—the average distance measurement from the CEJ on a tooth to the crest of the alveolar bone that has not been affected by periodontal disease is ~2 mm. The higher distance measurement over this point suggests that horizontal alveolar bone loss has occurred. Measurements of 4 mm and over are included in Table 4. EH = Enamel hypoplasia; a category is assigned to each tooth for the presence or absence of EH defects. Table 4 shows the maximum number of EH defects identified. IGD = Interglobular Dentine—a mineralisation defect in the dentine of the tooth. A category was assigned to each tooth for the presences of this defect. Pipe notch/facet: a tooth wear pattern caused by a pipe stem held and moved between the maxillary and mandibular teeth—indicator of smoking. † A tooth may have more than one EH defect.

3.9. Comparison of Historic Dental Samples from Australian, New Zealand, and British Cemeteries

3.9.1. Demographic Profiles

The Australian, New Zealand, and British samples, compared with the St Mary's Cemetery sample, are presented in Tables 8 and 9. There were differences and similarities between the samples. For example, (a) no subadults were included in the dental sample from the Old Sydney Burial Ground (OSBG), NSW, or the St John's Burial Ground, NZ, (Table 8); (b) the percentage of subadults in the cemeteries of St Mary's, SA and Cadia, NSW, Cross Bones, UK was similar. The St Mary's and Cadia cemeteries had a slightly higher percentage of subadults (55% and 67%, respectively) than adults compared with the Cross Bones Burial Ground (Table 10).

Table 8. Demographic profiles of the subadults from St Mary's Cemetery, SA; Cadia Cemetery, NSW; Old Sydney Burial Ground, NSW; St Johns Burial Ground, NZ; and Cross Bones Burial Ground, UK.

Cemetery:	Total Dental Sample/Total Sample Size	Total Number of Subadults in Dental Sample	Preterm <37 Weeks	Foetal 40 Weeks Post-Partum	Infant 0–11 Months	Subadult 1–5 Years	Subadult 6–11 Years	Adolescent 12–17 Years	Subadult of Unknown Age
St Mary's Cemetery (SA) 1847–1927	40/70	**22/40 55%**	0	0	4	10	6	2	0
Cadia Cemetery (NSW)1864–1927	109/111	**73/109 67%**	0	15	25	17	3	4	9
Old Sydney Burial Ground (NSW)1792–1820	10/10	**0**	0	0	0	0	0	0	0
St John's Burial Ground (NZ)1860–1926	7/27	**0**	0	0	0	0	0	0	0
Cross Bones Burial Ground (UK)1800–1853	83/147	**39/79 47%**	0	0	8	26	2	1	2

Table 9. Demographic profiles of the adults from St Mary's Cemetery, SA; Cadia Cemetery, NSW; Old Sydney Burial Ground, NSW; St Johns Burial Ground, NZ; and Cross Bones Burial Ground, UK.

Cemetery:	Total Dental Sample/Total Sample Size	Total Number of Adults	Age Group 18–22 Years	Young Adult 23–35 Years	Middle Adult 35–50 Years	Old Adult 50+ Years	Adults of Unknown Age	Adult Male	Adult Female	Adults of Unknown Sex
St Mary's Cemetery (SA)1847–1927	40/70	**18/40 45%**	1	3	8	6	0	13	5	0
Cadia Cemetery (NSW)1864–1927	109/111	**36/109 33%**	0	7	18	10	1	23	14	0
Old Sydney Burial Ground (NSW)1792–1820	10/10	**10/10 100%**	N/A	N/A	N/A	N/A	10	0	4	6
St John's Burial Ground (NZ)1860–1926	7/27	**7/7 100%**	0	0	4	4	2	4	3	3
Cross Bones Burial Ground (UK)1800–1853	83/147	**44/83 53%**	3	4	18	14	5	12	27	5

Table 10. Comparison of findings for the oral health categories investigated between the St Mary's Cemetery sample and other 19th-century Australian, New Zealand, and British cemetery samples. The results presented in Table 8 are the number of individuals affected/number of individuals in the total sample for each cemetery, i.e., St Mary's $n = /n =$ followed by the percentage of affected individuals from that cemetery.

Cemetery:	Sample Size (Total Number of Individuals) $n =$	Dental and Alveolar Bone Health Categories Scored				
		Tooth Wear ‡ Moderate to Heavy	Carious Lesions Present	Periodontal Disease Interdental Alveolar Resorption	Periapical Abscess Present	Enamel Hypoplastic Defects Present
St Mary's Cemetery (SA) 1847–1927	**40**	14/40 35%	21/40 53%	9/40 23%	1/40 3%	24/40 60%
Cadia Cemetery (NSW) 1864–1927	**109**	Results not available	32/109 29%	Results not available	5/109 5%	Results not available
Old Sydney Burial Ground (NSW) 1792–1820	**10**	6/10 60%	4/10 40%	Results not available	Results not available	7/10 70%
St John's Burial Ground (NZ) 1860–1926	**7**	7/7 100%	6/7 86%	7/7 100%	5/7 71%	6/7 86%
Cross Bones Burial Ground (UK) 1800–1853	**83**	Results not available	44/83 53%	42/83 51%	15/83 18%	48/83 58%

Notes: ooth Wear ‡ Moderate to Heavy—This term was used as each skeletal sample used a different system to score tooth wear, i.e., for the St Mary's sample, tooth wear was scored using Molnar's (1971) [29] system; moderate-to-heavy = Category 5 and above; Cadia Cemetery was scored using Smith's (1984) [57] system; moderate-to-heavy wear = Category 5 and above; Old Sydney Burial Ground was scored using Littleton and Frohlich (1993) [58] and Scott's (1979) [59] systems; moderate-to-heavy wear = Category 7 or above; Cross Bones Burial Ground was scored for tooth wear using Buikstra and Ubelaker (1994) [60]; moderate-to-heavy wear = Category 5 and above. SA = South Australia, NSW = New South Wales, NZ = New Zealand, UK = United Kingdom.

3.9.2. Dental and Alveolar Bone Health Categories

A summary of the scores for the five oral health categories of St Mary's sample were compared with those of the Cadia Cemetery, Old Sydney Burial Ground (OSBG), St John's, and Cross Bones burial grounds (Table 10). All of the individuals from St John's were scored with 'moderate to high' tooth wear compared with 60% from OSBG and 35% of individuals from St Mary's (Table 10). Evidence of 'pipe facets' associated with long-term pipe smoking was seen in all seven of the New Zealand adults (sex unknown), two adult females from the OSBG sample, and three adult males from St Mary's (Figure 2). No information was available for the category of tooth wear from the Cadia or Cross Bones cemeteries.

St Mary's and Cross Bones had the same percentage of individuals with carious lesions present (53%) (Table 10). Cadia Cemetery had the smallest percentage of individuals with caries present and St John's had the highest (Table 10). Periodontal disease was identified in more individuals from St John's, NZ (100% of the sample) and Cross Bones, UK (58%) than in the St Mary's sample (23%) (Table 8). Data for this category were not available from Cadia Cemetery or the OSBG in NSW.

Evidence of one periapical lesion or more was seen in 18% of individuals from the Cross Bones Burial Ground compared with 5% and 3% of people from the Cadia and St Mary's samples, respectively (Table 10). St John's and the OSBG did not have data for this category. Enamel hypoplastic (EH) defects were identified in individuals from four of the five cemeteries (Table 10). Cadia Cemetery did not have specific data for this category. Statistical analyses carried out for the comparison of St Mary's findings with other samples used the standard error and confidence interval for each percentage.

4. Discussion

4.1. Multiple Methods for Additional Data

The validity and reproducibility of the methods used here for the investigation of bone and dental samples using LV and SV Micro-CT systems has been established [21]. The methods used in this study are non-invasive, as required for rare archaeological specimens such as the St Mary's sample. The 2D and 3D high-resolution images were produced from the reconstructed LV and SV Micro-CT scan data sets. These provided information that could not be obtained via the standard macroscopic and radiological investigations (Figure 5) [21]. For large specimens such as the dentoalveolar complex in situ within the human skull where minimal handling is required, the LV Micro-CT scanner is ideal. The SV Micro-CT is suitable for small specimens such as isolated individual teeth. The resolution of the Micro-CT scanning systems depends on the size of the specimen, i.e., the smaller the specimen, the higher the available resolution, and vice versa.

4.2. Aim 1—The Oral Health Status of St Mary's Cemetery Sample

There is a greater precision available with infants and subadults than with adults in assessing dental age based on the eruption and development of teeth [5,6]. Dental age and skeletal age are two different parameters that often do not coincide in an individual. For two subadults (SMB 28, SMB 70) the dental age range estimated by the London Atlas [5,6] using dental radiographs showed some variation from the assigned skeletal age range (Table S1). These subadults all had comorbidities (Table 6), which could have affected the timing of their dental development and eruption [61–63].

Verma et al. (2022) [28,64] reviewed multiple methods that can be used for the determination of the age of adults using dentition. Many of these methods, however, are destructive. The non-invasive methods set out by Miles (1962) and Molnar (1971) [29] and others like them, such as Smith (1984) [57], Littleton and Frochlich (1993) [58], and Scott (1979) [59], assess and score tooth wear (attrition) on the incisal/occlusal surface. These studies can give an indication of both the functional age of the teeth and a predicted age for the individual [28] as well as the severity of tooth wear [29]. Since tooth wear increases with age, older individuals in general will have had more wear. However, differences that were seen in the dental ages of the investigated adults from St Mary's using Miles's (1962) [28] system compared with their skeletal age range (Table S6) could be due to loss of molars in life. The scoring of the functional age of a tooth from tooth wear will be affected if it does not have an opposing molar and will thus affect the predicted age given for an individual.

The tooth wear scores for all tooth types [29] for the St Mary's sample showed that various teeth (i.e., central and/or lateral incisors and/or canines) had different degrees of wear (Table 2). This may have resulted from differences in diet and/or specific habits and/or the presence or absence of opposing teeth due to antemortem tooth loss. A specific example of the sort of diet that the St Mary's individuals may have had comes from a 19th-century coroner's report of a man who fell under the wheels of a bullock cart. The "deceased was sitting on the load, which consisted of tea/sugar and other stores" [65] after an annual trip to the City of Adelaide. A witness to the accident observed that "there was about a ton and a half in the dray", enough supplies for the extended family of the man in question [65].

4.2.1. Dental Pathologies

Loss of teeth in previous generations may have occurred due to poor oral health, such as extensive caries and/or periodontal disease [42,66]. In addition, due to the high cost of dental treatment, some people may have opted for the extraction of teeth in place of preventative and restorative dental treatments [67]. In some cultures and social classes, the tradition of removing a future bride's teeth and replacing them with dentures as a prenuptial gift was practiced [68,69]. This voluntary edentulism was to prevent the burden of costly dental treatments for the new husband's family. One adult female (SMB 84) was buried at St Mary's 'free ground' area with a full set of vulcanite and porcelain dentures (Figure 1). The background of this individual was unknown, but they appear to have had a downturn in their economic status before death, as the burial was at the expense of the South Australian Government.

Carious lesions were identified in more than half of the individuals from the St Mary's sample (*n* = 21/40—Table 3), the majority of whom were adults (*n* = 17/21—Table 3). Taking into account antemortem tooth loss that was mainly due to caries, notwithstanding non-clinical reasons, more teeth/individuals in this sample would have been affected. Most of the carious lesions were located *above or on* the cementoenamel junction (CEJ), rather than below (Table S8). A 'build-up' of dental plaque [3,38] within the interproximal area of the teeth may explain why a greater number of carious lesions were recorded on the mesial and distal surfaces of the teeth remaining in the jaw for the St Mary's individuals (Table S8). Extensive carious lesions on other surfaces of the tooth, such as the occlusal surface, may have resulted in its extraction. Calculus deposits seen on the tooth enamel at these locations for many adults from St Mary's (Tables 4 and S9) indicate the accumulation of plaque that had contained caries-producing bacteria, which was then calcified [66,70]. This is also indicative of a cariogenic diet high in carbohydrates and sugars, such as the consumption of bread made of refined flour and tea with sugar [71–75]. Inclusion of such dietary factors as described in the afore mentioned 1859 coroner's report [65] could have resulted in the high incidence of caries in the St Mary's sample. The 'Adelaide Commercial Report' for July 1853, published in a local newspaper [76], states that "business was exceedingly flat . . . for all description of goods, both colonial and imported, but tea, sugar and brandy were the exceptions, all of which are in demand at full rates".

A lack of knowledge and understanding of the effects of diet on oral hygiene [77,78] and the poor availability and/or affordability of dental services [8] could have also contributed to the poor oral health of several individuals from St Mary's. The periapical cavity (Figure 3) [79] surrounding the roots of the lower-right first permanent molar of subadult SMB 79, with an opening in the buccal surface of the alveolar bone, would have arisen from a large carious lesion that extended into the pulp of the tooth.

The 11 adults (*n*-11/18 adults in the sample) with horizontal bone loss (4 mm or more) from the CEJ to the crest of the alveolar bone and the 12 adults with morphological changes in the alveolar bone (grade 3 or above) [42] suffered from periodontal disease. Six individuals (SMB 14, SMB 53C, SMB 61, SMB 63, SMB 78, and SMB 85) with higher scores for these categories also had extreme antemortem tooth loss (Table 4), which is often seen with advanced periodontal disease.

Lifestyle habits such as smoking (Figure 2) have been linked to an increased risk of periodontal disease [80–84]. New migrants to the colony were encouraged to take up tobacco smoking, by advising them that "if they were in the bush, hungry, thirsty or tired" smoking would remedy the situation [85]. Tooth wear patterns indicating long-term pipe smoking were seen in three adult males (SMB 59, SMB 72, and SMB 78) from the St Mary's sample. Two of these individuals also had evidence of periodontal disease (Table 6).

4.2.2. Developmental Dental Defects

Extensive evidence of enamel hypoplastic (EH) defects was seen on the dentitions of 14 adults and 10 subadults (*n* = 24/40) (60%) (Tables 5 and S10). Eight individuals (four adults, four subadults) from this group had EH defects on more than 60% of their teeth, with some teeth having multiple defects (Tables 5 and S10). The presence of multiple EH defects on the teeth indicates that the individuals suffered repeated chronic health insults, which affected the developing teeth [5,6]. Recovery from these episodes of ill health in the colony, during voyaging, or before migration did occur as many of the individuals with EH defects in the St Mary's sample were adults (Tables 5 and S10). The canine teeth of these individuals were more affected by EH defects compared with the incisors, premolars, or molars (Tables 6 and S10), suggesting that many health insults occurred in childhood during the development of the primary and/or permanent canines, rather than in young adulthood [5,6].

Limited access to or the affordability of health services could have extended an illness. Infant SMB 58 and subadult SMB 70 both showed extensive enamel hypoplastic defects on both the primary and permanent dentitions [19,56,86,87] (Tables 5 and S10). The location of the EH defects on the erupted primary and developing permanent teeth of infant SMB 58 (Figure 4) (Tables 5 and S10) suggests that this infant suffered health insults around the time of birth as well as postnatally [4]. The pattern of enamel defects seen on the primary teeth of SMB 58 matches those found by Fearne et al. (1990) [88] in low-birth-weight children.

Dentine, like enamel, could be affected by health insults during dental development. Areas of defective mineralisation in the dentine are referred to as interglobular dentine (IGD) [4]. Such defects can occur in the same tooth in addition to EH defects [1,89,90]. Furthermore, these internal dentine defects can be seen at a similar level to the external EH defect (Figure 5) [1,91], suggesting that the same systemic health insult caused both defects. Areas of IGD and EH defects at a similar level in the tooth were seen in four individuals (one infant, SMB 58; one subadult, SMB 70; and two adults, SMB 63 and SMB 73 (Table 7 and Figures 4 and 5). No one in the St Mary's sample was observed with IGD alone. The clinical manifestations of dental defects are related to the severity and duration of the health insult and the degree of the host's response [92].

4.3. Aim 2: Oral Health Conditions and General Health Status

Evaluation of the oral health findings together with information regarding general health from the skeletal evidence for St Mary's sample [1,2] provided additional insight into the overall health and lives of these early colonists. Seven adults from this sample had less than ten teeth present, while four individuals in this group (SMB 14, SMB 63, SMB 78, and SMB 85) had just two to four teeth each (Tables 3, 7 and S1). This antemortem tooth loss indicates that their masticatory function was substantially reduced. Dental clinicians have indicated that "20 teeth, with nine to ten pairs of contacting units are necessary to maintain adequate masticatory efficiency" [93]. Therefore, many of the adults in the St Mary's sample would not have had a sufficient number of teeth to maintain adequate masticatory efficiency required for good general health and wellbeing [94].

Seven of the St Mary's adults had evidence of vertebral osteophytes, eburnation of the vertebral articular facets and other joints of the body (Table 7) [2]. These changes to the bones due to joint disease could have limited their dexterity and the ability to maintain good oral hygiene [10]. It has been established that there is a relationship between poor oral health and systemic disease [9,11–14,16,17,95,96]. Individuals from St Mary's showed extensive evidence of poor oral health such as carious lesions, periodontal disease, and antemortem tooth loss (Tables 3, 7 and S1), which would have affected their general health.

The St Mary's adults with extensive periodontal disease did not show evidence of pathological manifestations associated with systemic disease on their skeletons (Table 7). A lack of skeletal signs of chronic ill health near the time of death does not necessarily indicate an absence of comorbidities, or indeed a sign of previous good general health. The extensive dental disease seen in many of the St Mary's individuals could have increased the severity of some systemic health conditions such as atherosclerotic cardiovascular disease [12–15]. This cardiovascular disease only affects the soft tissues of the body and does not leave pathological manifestations on the skeleton [12–15], while others, for e.g., diabetes mellitus, can involve the skeleton [97–99]. However, the signs in the skeletal material may not be pathognomic, allowing for the identification of the specific aetiology.

Some chronic health insults suffered during development, for example nutritional deficiencies and/or infectious diseases such as treponemal disease (syphilis—congenital or acquired) and/or tuberculosis could produce dental defects (i.e., EH and IGD) as well as skeletal manifestations [1,100–103]. Twelve individuals from St Mary's had both developmental dental defects and skeletal signs of a comorbidity present (Table 7). The presence of specific EH defects with subadult SMB 70, (dental age between 11.5–12.5 years ±1 year) as well as IGD, together with evidence of the involvement of the skeleton, including an "osteoblastic lesion on the cranial vault", pathological changes to the clavicle, ribs, and vertebrae (Table 7) [56], all indicated that this subadult had suffered from congenital syphilis, tuberculosis, and mercurial toxicity [19,56,87]. This is an example of the multiple interactions between factors in oral health and in general health which are components in a multilevel complex interactive network that operated throughout the lives of these individuals.

4.4. Aim 3: St Mary's Oral Health Findings Compared with Australian, New Zealand, and British Historic Samples

Individuals from the 19th century in Cadia Cemetery, NSW, Australia [52] and St John's Burial Ground, Milton, Otago, New Zealand [54], represented contemporary communities (Tables 8 and 9) that could have had similar lifestyles and occupations (agricultural and industrial—mining, etc.) to the individuals buried at the St Mary's Cemetery 'free ground' (Tables 8 and 9). Individuals interred at the Old Sydney Burial Ground (OSBG), NSW [53], were not contemporaries of the St Mary's sample and could have come from different backgrounds, i.e., they could have been convicts or serving as sailors in comparison to the free settlers in South Australia. They could have also lived in different environmental conditions. However, as previously stated, there are only a few colonial Australian skeletal samples, and it was thought a worthwhile comparison. Cross Bones Burial Ground, London, UK, [55], was used for the poorest people in the 19th century Southwark community [104]. Individuals interred here did not have the money to pay for a burial or a headstone memorial, similar to those buried in the unmarked 'free ground' section at St Mary's Church Cemetery.

The outcome of the comparison of data between these historic cemeteries for five oral health categories found similarities and differences. Information on tooth wear was limited to the OSBG and St John's samples. Compared with these samples, there seems to be only a small number of individuals from St Mary's with 'moderate to high' wear on the occlusal surfaces of the dentition (Table 10). This may be due to a difference in diet, i.e., the individuals from NSW and NZ probably had a more abrasive diet. However, the numbers in the OSBG and St John's samples are small and therefore when statistics were applied, there was considerable overlap of confidence levels and no statistical significance.

Similarities were seen between St Mary's and Cross Bones Burial Ground (UK) for the categories of carious lesions and enamel hypoplastic (EH) defects (Table 10). In relation to developmental enamel defects, both the St John's and OSBG cemeteries had more individuals with EH present than the St Mary's or Cross Bones cemeteries (Table 10). Brook and Smith (1998) [105] investigated developmental defects in a 20th-century sample of East London school children. They found that 14.6% of the sample had enamel hypoplasia [105], which is markedly lower than any of the historic cemeteries compared in this study.

The same percentage of individuals with carious lesions (53%) for St Mary's and Cross Bones (Table 10) could suggest that the background of the early settlers to South Australia was similar to those buried at Cross Bones and that they continued with their oral hygiene and dietary habits.

Periodontal disease had a higher frequency in the British and New Zealand samples than St Mary's (Table 10). The individuals from St John's were all adults compared with St Mary's, which had a higher number of subadults (Table 8). Cross Bones had a similar percentage of subadults to the St Mary's sample, suggesting that many of the St Mary's individuals maintained a better standard of oral hygiene than the individuals from the British sample.

In summary, considering the limitations of the sample sizes and variations in the presentation and availability of data for analysis, the oral health of many individuals in the comparison samples was poor (Table 10), which would have affected their general health. The seven individuals from St John's Cemetery sample, NZ, appear to have had the worst oral health compared with data from the other historic samples, but the small sample size from this cemetery could have influenced these findings (Table 10). The oral health of individuals from St Mary's was poor but was better than the other cemetery samples for many of the oral health categories scored in this study (Table 10).

4.5. Limitations of This Study

The use of multiple non-invasive methods allowed detailed data to be collected. While the LV Micro-CT technique is ideal for high-resolution analysis of dentition in situ within archaeological human skull samples [21], the cost of this micro-CT system limited the number of individuals from the St Mary's sample that were scanned. The number of isolated individual tooth samples available for SV Micro-CT scanning from the St Mary's sample was also a limitation. As this equipment only scans small objects, teeth have to be separated from the jaw, and so destructive analysis was prohibited. The SV Micro-CT scanning method was included in this study even though the information obtained from an individual tooth is restricted. These data cannot infer the overall oral or general health of a person, but they can provide information on external and internal developmental defects.

Miles (1962) [28] acknowledges that the method of assessing the functional age of a tooth by tooth wear patterns, and thereby predicting the age of the subject, has limitations. The individuals studied [28] were derived from a different population (Anglo Saxon). These people could have had a different diet and a different caries rate to the 19th-century group, as they would have had less processed sugar. A lower caries rate meant less antemortem tooth loss, and so they could have retained their permanent teeth longer when compared with the adults from the St Mary's sample. A limitation that could have affected the results of the presence, location, and severity of calculus deposits [31–33] on the dentitions of the St Mary's adults was due to the partial removal of calculus from some of these skulls for previous studies [106].

5. Conclusions

The overall oral health of the settlers buried at the St Mary's Cemetery 'free ground' area was poor. Their inability to consume adequate amounts of nutritious foods due to extensive antemortem tooth loss would have exacerbated comorbidities and impacted their general health. The oral health of St Mary's settlers in relation to categories of tooth wear, periodontal disease, and periapical abscess was better than individuals from the comparison Australian, New Zealand, and British cemeteries. The St Mary's sample had similar findings for caries and enamel hypoplasia to the Cross Bones Burial Ground in London, suggesting that little improvement had occurred since arriving in the new colony. A high percentage of individuals from four of the five historic cemeteries (St Mary's; Old Sydney Burial Ground, NSW; St John's, NZ; and Cross Bones Burial Ground, UK) had enamel hypoplastic defects. This indicates that these individuals had suffered systemic health insults during dental development, which could have been commonplace during the 19th century.

Supplementary Materials: The following supporting information can be downloaded at: https://www.mdpi.com/article/10.3390/dj11040099/s1, Supplementary Data S1, Gurr.2022_RAWDATA_

StatisticalAnalysis_EXCEL; Supplementary Table S1. St Mary's Cemetery—dental inventory; Supplementary Table S2. Large Volume Micro-CT—scan settings for in situ dentition; Supplementary Table S3. Small Volume Micro-CT—scan settings for individual teeth; Supplementary Table S4. Statistical Analysis Summary; Supplementary Table S5. Additional information—statistical analysis of intra- and inter-operator reliability; Supplementary Table S6. Assessment of the functional age of each molar and the predicted age of the subject based on tooth wear scores set out by Miles (1962)—St Mary's Cemetery adult sample; Supplementary Table S7a. Summary of findings for St Mary's Cemetery adults using Molnar's (1971) categories of tooth wear; Supplementary Table S7b. Molnar's (1971) Category of tooth wear assigned to the maxillary dentition of the adults from the St Mary's sample; Supplementary Table S7c. Molnar's (1971) Category of tooth wear assigned to the mandibular dentition of the adults from the St Mary's sample; Supplementary Table S8a. St Mary's Cemetery Sample. Location of carious lesions on the surface/s of the teeth; Supplementary Table S8b. St Mary's Cemetery Sample. Number of carious lesions involving either the enamel only, the enamel and dentine, or the enamel, dentine or pulp; Supplementary Table S9. Dental calculus—an indication of the number and percentage of teeth affected by calculus with the location and severity of the deposit for the adults of the St Mary's Cemetery sample; Supplementary Table S10. Enamel Hypoplastic Defects _ St Mary Cemetery Sample [107,108].

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Appendix A. Standard Dental Radiographs—Summary of Equipment and Settings Used

Intraoral periapical and/or bitewing radiographs were taken using Planmeca X-ray equipment [27] with Phosphor Storage Plates (PSP) as the detectors with the following exposure settings: Tube voltage: 70 kV; Tube current: 6 mA, with an exposure time of 0.32 s. Panoramic extraoral dental radiographs were taken using orthopantomogram (OPG) X-ray equipment to rotate around the maxillary and mandibular dentitions if the maxilla and/or mandible were complete enough to use this equipment. The X-ray source used was a Kavo Pan eXam Plus. The tube type for this equipment was: a stationary anode; 65 kV; Tube current: 15 mA, with an exposure time of up to 16.4 s.

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5.4. Appendix to Paper 4 (Chapter 5) – Supporting Information

5.4.1. Table S1.

Table S1. St Mary's Cemetery - Dental inventory.

St Mary's Burial I/D	Sex	**†Dental age range** (months/years) London Atlas of human tooth development and eruption (AlQahtani et al., 2010)	**Skeletal age range** (years) (Anson, 2004)	**Number of primary and/ or permanent teeth present**	**Dental Inventory Tooth type present** ***FDI notation number/s**
SMB 66 A	U	7 mths-1 (+/- 3 mths)	0-2	6 *primary*	51, 52, 61, 62, 71, 81
SMB 40	U	10 mths-1 (+/- 3 mths)	0-2	6 *primary*	51, 61, 62, 71, 81, 82
SMB 32	U	10.5 mths-1 (+/- 3 months)	0-2	8 *primary*	51, 52, 61, 62, 71, 72, 81,82
SMB 41	U	1-1.5 (+/- 3 mths)	0-2	5 *primary*	54, 62, 64, 71, 81
SMB 08	U	1-1.5 (+/- 3 mths)	0-2	8 *primary*	51, 54, 61, 64, 71, 81, 82, 84
SMB 62	U	1-1.5 (+/- 3 mths)	0-2	10 *primary*	51, 52, 61, 64, 71, 72, 74, 81, 82, 84
SMB 82	U	1-1.5 (+/- 3 mths)	0-2	9 *primary*	51, 52, 54, 61, 62, 71, 74, 81, 84
SMB 24	U	1-1.5 (+/- 3 mths)	0-2	9 *primary*	51, 52, 54, 61, 62, 64, 74, 82, 84
SMB 27 B	U	1-1.5 (+/- 3 mths)	0-2	10 *primary*	51, 52, 54, 61, 71, 72, 74, 81, 82, 84
SMB 58	U	1-1.5 (+/- 3 mths)	0-2	11 *primary*	51, 52, 61, 62, 64, 71, 72, 74, 81, 82, 84
SMB 18	U	1-1.5 (+/- 3 mths)	0-2	1 *primary*	74
SMB 11	U	2-2.5 (+/- 3 mths)	0-2	19 *primary*	51, 52, 53, 54, 55, 61, 62, 63, 64, 71, 72, 73, 74, 75, 81, 82, 83, 84, 85
SMB 31	U	3-3.5 (+/- 6 mths)	3-5	17 *primary*	51, 53, 54, 55, 63, 64, 65, 71, 72, 73, 74, 75, 81, 82, 83, 84, 85
SMB 04A	U	3.5-4.5 (+/- 6 mths)	3-5	19 *primary*	51, 52, 53, 54, 55, 61, 62, 63, 64, 71, 72, 73, 74, 75, 81, 82, 83, 84, 85
SMB 75	U	5-6 (+/-1 yr)	6-9	14 *primary*	54, 55, 62, 63, 64, 65, 72, 73, 74, 75, 81, 83, 84, 85
SMB 35	U	6-7 (+/-1 yr)	6-9	11 *primary*	51, 52, 54, 63, 64, 65, 73, 74, 75, 84, 85

SMB 19	U	7.5-8.5 (+/-1 yr)	6-9	7 *primary* 15 permanent	11, 12, 13, 14, 15, 16, 21, 22, 24, 65, 26, 32, 73, 74, 75, 36,41, 42, 83, 84, 85, 46,
SMB 70	U	11.5-12.5 (+/-1 yr)	6-9	2 *primary* 6 permanent	53, 14, 15, 21, 63, 24, 25, 26
SMB 52 B	U	10.5-11.5 (+/-1 yr)	10-15	2 *primary* 16 permanent	11, 12, 13, 16, 21, 22, 23, 26, 31, 32, 33, 75, 36, 41, 42, 43, 85, 46
SMB 51	U	10-11 (+/-1 yr)	10-15	1 primary 15 permanent	12, 13, 14, 15, 16, 22, 23, 24, 25, 26, 31, 34, 36, 41, 42, 84,
SMB 28	F	15.5-16.5 (+/-1 yr)	10-15	26 permanent	11, 12, 14, 15, 16, 17, 22, 23, 24, 25, 26, 27, 31, 32, 33, 34, 35, 36, 37, 41, 42, 43, 44, 45, 46, 47
SMB 79	U	15.5-16.5 (+/-1 yr)	16-19	25 permanent	11, 13, 14, 15, 17, 21, 22, 23, 24, 25, 26, 27, 31, 32, 33, 34, 35, 37, 41, 42, 43, 44, 45, 46, 47
SMB 05	F	Over 23.5	20-29	6 permanent	32, 35, 41, 42,43, 44,
SMB 53 C	F	Over 23.5	30-39	9 permanent	11, 13, 14, 21, 23, 26, 34, 42, 46
SMB 66 B	F	Over 23.5	30-39	17 permanent	12, 14, 15, 17, 21, 22, 23, 27, 31, 32, 33, 34, 41, 42, 43, 44, 45
SMB 73	M	Over 23.5	30-39	19 permanent	11, 12, 13, 16, 21, 22, 23, 25, 28, 31, 32, 33, 34, 35, 41, 42, 43, 44, 45
SMB 06	M	Over 23.5	40-49	24 permanent	11, 12, 13, 14, 15, 16, 17, 22, 23, 24, 25, 26, 27, 31, 32, 33, 37, 41, 42, 43, 44, 45, 46, 47
SMB 09	M	Over 23.5	40-49	22 permanent	12, 13, 16, 21, 22, 23, 24, 25, 26, 31, 32, 33, 34, 35, 36, 37, 43, 44, 45, 46, 47, 48
SMB 57	M	Over 23.5	40-49	25 permanent	11, 12, 13, 14, 15, 16, 17, 18, 22, 26, 27, 32, 33, 34, 35, 36, 37, 41, 42, 43, 44, 45, 46, 47, 48,
SMB 61	F	Over 23.5	40-49	7 permanent	25, 32, 33, 35, 41, 42, 44
SMB 72	M	Over 23.5	40-49	29 permanent	11, 12, 13, 14, 15, 16, 17, 18, 21, 22, 23, 24, 25, 26, 27, 32, 33, 34, 35, 36, 37, 38, 42, 43, 44, 45, 46, 47, 48
SMB 78	M	Over 23.5	40-49	4 permanent	13, 14, 34, 35
SMB 83	M	Over 23.5	40-49	16 permanent	13, 14, 17, 21, 23, 24, 27, 28, 33, 34, 37, 38, 42, 43, 47, 48
SMB 85	M	Over 23.5	40-49	2 permanent	33, 34
SMB 14	M	Over 23.5	50-59	2 permanent	23, 35
SMB 23	M	Over 23.5	50-59	21 permanent	13, 14, 15, 17, 18, 21, 22, 23, 27, 28, 31, 32, 33, 34, 35, 37, 41, 42, 43, 44, 47
SMB 59	M	Over 23.5	50-59	15 permanent	11, 12, 13, 21, 22, 23, 34, 35, 37, 38, 41, 42, 44, 46, 48
SMB 63	M	Over 23.5	50-59	3 permanent	33, 34, 43
SMB 68	M	Over 23.5	50-59	19 permanent	13, 14, 17, 18, 23, 24, 25, 31, 32, 34, 35, 37, 38, 42, 43, 44, 45, 47, 48

SMB 84	F	Over 23.5	50-59	0	N/A
Total number of primary teeth present:				**175**	
Total number of Permanent teeth present:				**343**	
Grand Total of all tooth types present:				**518**	

5.4.2 Table S2.

Table S2. Large Volume Micro-CT. Settings used for scanning of the dentition in situ in the dentoalveolar complex of the human skulls from the St Mary's Cemetery individuals, using the Nikon XT H 225 ST Micro-CT system. In choosing the scanning settings, the transmitted signal intensity and source power settings were considered according to guidelines (Wearne et al 2022, du Plessis et al. 2017).

Skeletal region LV Micro-CT scanned	**St Mary's** ID	**Pixel size** (µm)	**Source voltage** (kV)	**Source Current** (µA)	**Source Power** (W)	**Rotation step**	**Exposure time** (seconds)	**Filter Type**	**Filter thickness** (mm)	**X-ray projections**	**Total acquisition time** (hours/minutes)
Skull	**SMB 73**	60	190	220	41	360º	1.42	Sn	0.1	3000	1 hr 10 mins
	SMB 52B	60	190	220	41	360º	1.42	Sn	0.1	3000	1 hr 10 mins
Cranium only	**SMB 82**	40	190	210	40	360º	1.42	Sn	0.1	3000	1 hr 10 mins
	SMB 66B	50	190	220	41	360º	1.42	Sn	0.1	3000	1 hr 10 mins
	SMB 58	35	190	184	35	360º	1.42	Sn	0.1	3000	1 hr 10 mins
	SMB 4A	55	190	220	41	360º	1.42	Sn	0.1	3000	1 hr 10 mins
Mandible only	**SMB 82**	18	190	68	12.9	360º	2	Al	0.5	3000	1 hr 40 mins
	SMB 73	13	190	68	12.9	360º	2	Al	0.5	3000	1 hr 40 mins
	SMB 66B	13	190	68	12.9	360º	2	Al	0.5	3000	1 hr 40 mins
	SMB 58	21	190	95	18	360º	2	Al	0.5	3000	1 hr 40 mins
	SMB 52B	22	190	68	12.9	360º	2	Al	0.5	3000	1 hr 40 mins
	SMB 4A	20	190	68	12.9	360º	2	Al	0.5	3000	1 hr 40 mins

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du Plessis, A., Broeckhoven, C., Guelpa, A., le Roux, S.G., 2017. Laboratory x-ray micro-computed tomography: a user guideline for biological samples, Gigascience 6, 1-11.

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5.4.3. Table S3

Table S3. Small Volume Micro-CT scanning of individual loose teeth, no longer in the jaws, from individuals of the St Mary's Cemetery sample. Additional SV Micro-CT scan settings follow this table.

St Mary's ID	**Dental age range** (years & months)	**Chronological Age range** (years)	**Sex**	**Permanent or *primary* Tooth Type** *with the FDI notation number*	**Total number of teeth SV Micro-CT scanned**
SMB 27B	1-1.5 (+/- 3 mths)	0-2	U	*primary* Low L M1 (74)	**1**
SMB 58	1-1.5 (+/- 3 mths)	0-2	U	*primary* Low L m1 (74)	**1**
SMB 82	1-1.5 (+/- 3 mths)	0-2	U	*primary* Upp R *cent incisor (51) *primary* Upp R lat incisor (52) *primary* Upp L cent incisor (61) *primary* Upp L lat incisor (62) *primary* Low R cent incisor (71) *primary* Low L cent incisor (81)	**6**
SMB 4A	3.5-4.5 (+/- 3 mths)	2-5	U	*primary* Upp R Lat Incisor (52) *primary* Upp R Canine (53) *primary* Upp L Cent Incisor (61) *primary* Upp L Canine (63)	**4**
SMB 19	7.5- 8.5 (+/- 6 mths)	6-10	U	Permanent Low L M1 (36)	**1**
SMB 70	11.5-12.5 (+/- 6 mths)	8-9	U	*primary* Low R m1 (74) Permanent Upp R M1 (16)	**2**
SMB 52B	10.5-11.5 (+/- 6 mths)	10-14	U	*primary* Low L m2 (75) Permanent Upp R Cent Incisor (11) Permanent Upp R lat Incisor (12)	**3**
SMB 51	10-11 (+/- 6 mths)	10-14	U	Permanent Low R M1 (46)	**1**
SMB 28	12-15 (+/- 6 mths)	12-16	U	Permanent Low L M1 (36)	**1**
SMB 79	15.5-16.5 (+/- 6 mths)	16-18	U (F?)	Permanent Upp L M1 (26)	**1**
SMB 05	Over 23.5	20-29	F	Permanent Low R Canine (43)	**1**
SMB 53C	Over 23.5	30-39	F	Permanent Upp R M1 (16)	**1**
SMB 66B	Over 23.5	30-39	F	Permanent Upp R lat incisor (12) Permanent Upp R P1 (14) Permanent Upp R P2 (15) Permanent Upp R M2 (17) Permanent Upp L canine (23)	**5**
SMB 73	Over 23.5	30-39	M	Permanent Upp R P1 (14) Permanent Upp R Cent Incisor (11) Permanent Upp R M1 (16) Permanent Upp L Canine (23) Permanent Upp L P2 (25) Permanent Upp L M3 (28)	**6**
SMB 6	Over 23.5	40-49	M	Permanent Upp L Canine (23)	**1**

SMB 72	Over 23.5	40-49	M	Permanent Low R M2 (47)	**1**
SMB 85	Over 23.5	40-49	M	Permanent Low L canine (33)	**1**
SMB 23	Over 23.5	50-59	M	Permanent Low R M2 (47)	**1**
SMB 63	Over 23.5	50-59	M	Permanent Low R Lat Incisor (42)	**1**
SMB 68	Over 23.5	50-59	M	Permanent Low R M3 (48)	**1**
SMB 83	Over 23.5	50- 59	M	Permanent Upp R M3 (18)	**1**
				Total number of teeth SV Micro-CT scanned:	**41**

5.4.4. Table S4

Table S4. Statistical Analysis Summary- Results from tests of intra- and inter-operator reliability for each of the methods assessed

Test	Comparison	Summary Results		
		Agreement	AC2	Percentage agreement
Inventory				
Inter-operator	LV	Fair – Perfect	0.31 - 1.00	67 - 100
	Macro	Poor - Perfect	-0.01 - 1.00	56 - 100
	Radio	Substantial - Perfect	0.79 - 1.00	89 - 100
Intra-operator	LV	Perfect	All 1.00	All 100%
	Macro	Moderate - Perfect	0.53 - 1.00	67 – 100
	Radio	Substantial - Perfect	0.79 – 1.00	89 – 100
Tooth wear				
Inter-operator	LV	Fair - Perfect	0.20 – 1.00	63 – 100
	Macro	Moderate - Perfect	0.53 – 1.00	75 – 100
	Radio	Moderate - Perfect	0.47 – 1.00	75 – 100
Intra-operator	LV	Perfect	All 1.00	All 100%
	Macro	Almost perfect	0.81 – 100	88 – 100
	Radio	Substantial - Perfect	0.78 – 1.00	88 – 100
Alveolar status				
Inter-operator	LV	Poor – Perfect	-0.18 – 1.00	38 – 100

	Macro	Poor – Perfect	-0.43 – 1.00	38 – 100
Intra-operator	LV	Perfect	All 1.00	All 100%
	Macro	Fair – Perfect	0.20 – 1.00	50 – 100
Caries				
Inter-operator	LV	Poor – Perfect	-1.00 – 1.00	0 – 100
	Macro	Poor – Perfect	-0.45 – 1.00	0 – 100
	Radio	Poor – Perfect	-0.45 – 1.00	0 – 100
Intra-operator	LV	Fair – Perfect	0.20 – 1.00	50 – 100
	Macro	Fair – Perfect	0.27 – 1.00	50 – 100
	Radio	Fair – Perfect	0.20 – 1.00	50 – 100
Enamel hypoplastic defects				
Inter-operator	LV	Poor – Perfect	-0.57 – 1.00	0 – 100
	Macro	Fair – Perfect	0.20 – 1.00	50 – 100
Intra-operator	LV	Fair – Perfect	0.20 – 1.00	50 – 100
	Macro	Fair – Perfect	0.27 – 1.00	50 – 100
Periodontal disease				
			ICC	
Inter-operator	LV	Poor – Excellent	0.23 – 1.00	
	Macro	Poor – Excellent	0.21 – 1.00	
Intra-operator	LV	Poor – Excellent	0.46 – 1.00	
	Macro	Poor – Excellent	0.00 – 1.00	

5.4.5. Table S5

Table S5. Additional Information from the Statistical Analysis of intra- and inter-operator reliability for each of the methods assessed

Test	**Comparison**	**Surface/Method**	**Summary Results**		
			Agreement	**AC2**	**Percentage agreement**
			Caries		
Inter-operator	LV	Radiolucency	Substantial – Perfect	0.71 – 1.00	79 – 100
		Caries - Present	Poor – Perfect	-1.00 – 1.00	0 – 100
		Caries on CEJ	Poor – Perfect	-0.33 – 1.00	0 – 100
		Caries above CEJ	Poor – Perfect	-0.45 – 1.00	0 – 100
		Caries below CEJ	Poor – Perfect	-0.33 – 1.00	0 – 100
		Caries on distal	Poor – Perfect	-0.33 – 1.00	0 – 100
		Caries on labial/buccal	Perfect	All 1.00	All 100%
		Caries on lingual	Perfect	All 1.00	All 100%
		Caries on mesial	Poor – Perfect	-0.45 – 1.00	0 – 100
		Caries on occlusal	Perfect	All 1.00	All 100%
	Macro	Caries - Present	Fair – Perfect	0.20 – 1.00	50 – 100
		Caries on CEJ	Poor – Perfect	-0.45 – 1.00	0 – 100
		Caries above CEJ	Poor – Perfect	-0.45 – 1.00	0 – 100
		Caries below CEJ	Fair – Perfect	0.27 – 1.00	50 – 100
		Caries on distal	Fair – Perfect	0.27 – 1.00	50 – 100
		Caries on labial/buccal	Poor – Perfect	-0.33 – 1.00	0 – 100
		Caries on lingual	Fair – Perfect	0.33 – 1.00	50 – 100
		Caries on mesial	Poor – Perfect	-0.45 – 1.00	0 – 100
		Caries on occlusal	Fair – Perfect	0.27 – 1.00	50 – 100
	Radio	Radiolucency	Substantial – Perfect	0.73 – 1.00	83 – 100
		Caries - Present	Poor – Perfect	-0.60 – 1.00	0 – 100
		Caries on distal	Poor – Perfect	-0.23 – 1.00	0 – 100
		Caries on mesial	Fair – Perfect	0.27 – 1.00	50 – 100
Intra-operator	LV	Radiolucency	Substantial – Perfect	0.77 – 1.00	83 – 100

		Caries - Present	Fair – Perfect	0.20 – 1.00	50 – 100
		Caries on CEJ	Fair – Perfect	0.38 – 1.00	50 – 100
		Caries above CEJ	Fair – Perfect	0.38 – 1.00	50 – 100
		Caries below CEJ	Fair – Perfect	0.27 – 1.00	50 – 100
		Caries on distal	Fair – Perfect	0.27 – 1.00	50 – 100
		Caries on labial/buccal	Perfect	All 1.00	All 100%
		Caries on lingual	Fair – Perfect	0.38 – 1.00	50 – 100
		Caries on mesial	Fair – Perfect	0.38 – 1.00	50 – 100
		Caries on occlusal	Fair – Perfect	0.38 – 1.00	50 – 100
	Macro	Radiolucency	Moderate – Perfect	0.53 – 1.00	67 – 100
		Caries - Present	Fair – Perfect	0.27 – 1.00	50 – 100
		Caries on CEJ	Fair – Perfect	0.27 – 1.00	50 – 100
		Caries above CEJ	Fair – Perfect	0.27 – 1.00	50 – 100
		Caries below CEJ	Fair – Perfect	0.27 – 1.00	50 – 100
		Caries on distal	Fair – Perfect	0.27 – 1.00	50 – 100
		Caries on labial/buccal	Fair – Perfect	0.27 – 1.00	50 – 100
		Caries on lingual	Fair – Perfect	0.38 – 1.00	50 – 100
		Caries on mesial	Fair – Perfect	0.27 – 1.00	50 – 100
		Caries on occlusal	Fair – Perfect	0.27 – 1.00	50 – 100
	Radio	Radiolucency	Substantial - Perfect	0.66 – 1.00	75 – 100
		Caries - Present	Fair – Perfect	0.20 – 1.00	50 – 100
		Caries on distal	Fair – Perfect	0.27 – 1.00	50 – 100
		Caries on mesial	Fair – Perfect	0.27 – 1.00	50 – 100

5.4.6. Table S6. Adults of St Mary's Cemetery sample. Assessment of the functional age of each molar and the predicted age of the subject based on tooth wear scores set out by **Miles (1962).** **Notes for abbreviations follow this table*

St Mary's ID	Age range (skeletal /eruption findings) (years)	Miles (1962) tooth wear (years)	Jaw and tooth identification, including FDI notation numbers:											
			MAXILLA						MANDIBLE					
			Upp R **M1** 16	Upp R **M2** 17	Upp R **M3** 18	Upp L **M1** 26	Upp L **M2** 27	Upp L **M3** 28	Low L **M1** 36	Low L **M2** 37	Low L **M3** 38	Low R **M1** 46	Low R **M2** 47	Low R **M3** 48
SMB 53C	30-39	Functional age of teeth	30	AMTL	AMTL	AMTL	AMTL	AMTL	AMTL	AMTL	AMTL	24	AMTL	AMTL
		Predicted age of subject	36	n/a	n/a	n/a	n/a	n/a	n/a	n/a	n/a	30	n/a	n/a
SMB 66B	30-39	Functional age	AMTL	7	AMTL	AMTL	12	AMTL	AMTL	AMTL	AMTL	AMTL	AMTL	AMTL
		Predicted age	n/a	18	n/a	n/a	26	n/a	n/a	n/a	n/a	n/a	n/a	n/a
SMB 73	30-39	Functional age	12	AMTL	AMTL	AMTL	AMTL	7	AMTL	AMTL	AMTL	AMTL	AMTL	AMTL
		Predicted age	18	n/a	n/a	n/a	n/a	24	n/a	n/a	n/a	n/a	n/a	n/a
SMB 06	40-49	Functional age	30	13	AMTL	36	32	PMTL	AMTL	28	Not erupted	36	20	Not erupted
		Predicted age	36	27	n/a	42	45	n/a	n/a	40	n/a	42	31	n/a
SMB 09	40-49	Functional age	18	PMTL	PMTL	12	PMTL	PMTL	15	7	AMTL	12	6.5	7
		Predicted age	24	n/a	n/a	18	n/a	n/a	21	19	n/a	18	18	25
SMB 57	40-49	Functional age	27	25	PMTL	24	25	AMTL	16	16	PMTL	23	20	7
		Predicted age	35	35	n/a	30	35	n/a	22	28	n/a	30	32	25
SMB 72	40-49	Functional age	12	5	14	12	5	AMTL	12	16	10	12	7	7
		Predicted age	18	17	26	18	17	n/a	18	27	25	18	18	24
SMB 83	40-49	Functional age	AMTL	AMTL	32	AMTL	26	24	AMTL	26	42	AMTL	26	35
		Predicted age	n/a	n/a	50	n/a	38	42	n/a	38	60	n/a	38	53
SMB 23	50-59	Functional age	PMTL	PMTL	28	PMTL	PMTL	7	AMTL	10	AMTL	AMTL	7	AMTL
		Predicted age	n/a	n/a	46	n/a	n/a	25	n/a	22	n/a	n/a	19	n/a
SMB 59	50-59	Functional age	AMTL	PMTL	PMTL	AMTL	PMTL	PMTL	PMTL	7	7	30	13	AMTL
		Predicted age	n/a	n/a	n/a	n/a	n/a	n/a	n/a	19	25	36	25	n/a
SMB 68	50-59	Functional age	AMTL	46	49	PMTL	PMTL	PMTL	AMTL	13	7	AMTL	20	24
		Predicted age	n/a	58	67	n/a	n/a	n/a	n/a	25	24	n/a	32	42

***Notes:** **Upp** = Upper jaw (maxilla), **Low** = Lower jaw (mandible), **R** = Right side of the jaw, **L** = left side of the jaw. **FDI** = Fédération Dentaire Internationale tooth identification notation system. **AMTL** = Antemortem tooth loss. **PMTL**= Post-mortem tooth loss. **N/A** = not applicable. Not erupted = the tooth had not erupted through the alveolar bone. The alveolar bone did not show signs of healing and dental radiographs confirmed that the tooth was *or* was not within the bone. '*Functional age of tooth'* was scored by the wear on the occlusal surface of the permanent **M1** (first molar), **M2** (second molar), and **M3** (third molar) following Miles's (1962) system. '*Predicted age of subject'* (individual person) following Miles's (1962) scoring system.

5.4.7. **Table S7a.** Summary of findings for St Mary's Cemetery adults using Molnar's (1971) categories of tooth wear

St Mary's Burial ID	Age range (years	Sex	Total number of permanent teeth present	Number of maxillary teeth	Number of mandibular teeth	Number of teeth with Cat 1-3	Number of teeth with Cat. 4	Number of teeth with Cat.5	Number of teeth with Cat. 6	Number of teeth with Cat. 7	Number of teeth with Cat. 8
SMB 05	20-29	F	6	0	6	4	2	0	0	0	0
SMB 53C	30-39	F	9	6	3	4	2	3	0	0	0
SMB 66B	30-39	F	17	8	9	9	7	1	0	0	0
SMB 73	30-39	M	19	9	10	6	12	1	0	0	0
SMB 06	40-49	M	25	13	12	1	10	8	5	1	0
SMB 09	40-49	M	22	9	13	14	4	4	0	0	0
SMB 57	40-49	M	25	11	14	3	10	12	0	0	0
SMB 61	40-49	F	6	2	4	4	1	0	0	1	0
SMB 72	40-49	M	30	15	15	16	11	3	0	0	0
SMB 78	40-49	F	4	2	2	1	0	2	1	0	0
SMB 83	40-49	M	15	7	8	2	7	4	2	0	0
SMB 85	40-49	M	2	0	2	0	0	2	0	0	0
SMB 14	50-59	M	2	1	1	0	1	0	1	0	0
SMB 23	50-59	M	21	10	11	8	6	6	0	0	1
SMB 59	50-59	M	16	6	10	5	5	1	4	1	0
SMB 63	50-59	M	3	0	3	0	1	2	0	0	0
SMB 68	50-59	M	19	7	12	5	4	8	2	0	0
		TOTAL	**241**	**106**	**135**	**82**	**83**	**57**	**15**	**3**	**1**

Table S7b. Molnar's (1971) Category of tooth wear assigned to the *maxillary* dentition of the adults from the St Mary's sample

St Mary's Burial ID	Age range (years	Sex	Jaw and permanent tooth identification, including FDI numbers Maxilla															
			Upp R Cent. Incisor 11	Upp R Lat Incisor 12	Upp R Canine 13	Upp R P1 14	Upp R P2 15	Upp R M1 16	Upp R M2 17	Upp R M3 18	Upp L Cent Incisor 21	Upp L Lat Incisor 22	Upp L Canine 23	Upp L P1 24	Upp L_ P2 25	Upp L M1 26	Upp L M2 27	Upp L M3 28
SMB 05	20-29	F	N/A	N/A	N/A	N/A	N/A	N/A	N/A	N/A	N/A	N/A	N/A	N/A	N/A	N/A	N/A	N/A
SMB 53C	30-39	F	5	N/A	4	N/A	N/A	5	N/A	N/A	5	N/A	2	2	N/A	N/A	N/A	N/A
SMB 66B	30-39	F	N/A	3	N/A	3	2	N/A	2	N/A	5	3	3	N/A	N/A	N/A	4	N/A
SMB 73	30-39	M	4	4	3	N/A	N/A	2	N/A	N/A	4	4	4	N/A	4	N/A	N/A	2
SMB 06	40-49	M	5	4	3	5	5	6	6	N/A	N/A	4	5	4	4	6	6	N/A
SMB 09	40-49	M	N/A	5	4	N/A	N/A	2	N/A	N/A	5	4	3	3	3	3	N/A	N/A
SMB 57	40-49	M	5	5	5	4	4	4	5	N/A	N/A	5	N/A	3	N/A	4	5	N/A
SMB 61	40-49	F	N/A	N/A	N/A	7	N/A	N/A	N/A	N/A	N/A	N/A	N/A	N/A	1	N/A	N/A	N/A
SMB 72	40-49	M	5	3	4	2	2	3	4	4	5	4	4	3	3	4	3	N/A
SMB 78	40-49	F	N/A	N/A	5	2	N/A	N/A	N/A	N/A	N/A	N/A	N/A	N/A	N/A	N/A	N/A	N/A
SMB 83	40-49	M	N/A	N/A	5	4	N/A	N/A	N/A	5	4	N/A	4	3	N/A	N/A	4	3
SMB 85	40-49	M	N/A	N/A	N/A	N/A	N/A	N/A	N/A	N/A	N/A	N/A	N/A	N/A	N/A	N/A	N/A	N/A
SMB 14	50-59	M	N/A	N/A	N/A	N/A	N/A	N/A	N/A	N/A	N/A	N/A	6	N/A	N/A	N/A	N/A	N/A
SMB 23	50-59	M	N/A	N/A	5	4	2	N/A	2	2	5	5	5	N/A	N/A	N/A	2	8
SMB 59	50-59	M	4	4	5	N/A	N/A	N/A	N/A	N/A	4	4	6	N/A	N/A	N/A	N/A	N/A
SMB 63	50-59	M	N/A	N/A	N/A	N/A	N/A	N/A	N/A	N/A	N/A	N/A	N/A	N/A	N/A	N/A	N/A	N/A
SMB 68	50-59	M	N/A	N/A	5	5	N/A	N/A	6	6	N/A	N/A	5	4	4	N/A	N/A	N/A

Table S7c. Molnar's (1971) Category of tooth wear assigned to the *mandibular* dentition of the adults from the St Mary's sample

St Mary's Burial ID	Age range (years)	Sex	Jaw and permanent tooth identification, including FDI numbers **Mandible** Low L Cent Incisor **31**	Low L Lat Incisor **32**	Low L Canine **33**	Low L P1 **34**	Low L P2 **35**	Low L M1 **36**	Low L M2 **37**	Low L M3 **38**	Low R Cent. Incisor **41**	Low R Lat Incisor **42**	Low R Canine **43**	Low R P1 **44**	Low R P2 **45**	Low R M1 **46**	Low R M2 **47**	Low R M3 **48**
SMB 05	20-29	F	4	N/A	1	2	N/A	N/A	N/A	N/A	3	4	N/A	2	N/A	N/A	N/A	N/A
SMB 53C	30-39	F	N/A	N/A	N/A	3	N/A	N/A	N/A	N/A	N/A	4	N/A	N/A	N/A	2	N/A	N/A
SMB 66B	30-39	F	4	4	4	3	N/A	N/A	N/A	N/A	4	4	4	3	3	N/A	N/A	N/A
SMB 73	30-39	M	4	4	5	2	4	N/A	N/A	N/A	4	4	3	3	4	N/A	N/A	N/A
SMB 06	40-49	M	5	4	4	5	N/A	N/A	7	N/A	4	4	5	4	4	6	5	N/A
SMB 09	40-49	M	5	5	3	3	3	4	4	N/A	N/A	N/A	3	2	2	3	3	3
SMB 57	40-49	M	N/A	5	5	5	4	4	4	N/A	5	5	5	4	3	4	4	3
SMB 61	40-49	F	N/A	3	4	N/A	2	N/A	N/A	N/A	N/A	2	N/A	N/A	N/A	N/A	N/A	N/A
SMB 72	50-59	M	4	4	5	2	2	3	3	2	N/A	4	4	2	2	4	3	2
SMB 78	40-49	F	N/A	5	6	N/A	N/A	N/A	N/A	N/A	N/A	N/A	N/A	N/A	N/A	N/A	N/A	N/A
SMB 83	40-49	M	N/A	N/A	5	5	N/A	N/A	5	6	N/A	4	4	N/A	N/A	N/A	4	6
SMB 85	40-49	M	N/A	N/A	5	5	N/A	N/A	N/A	N/A	N/A	N/A	N/A	N/A	N/A	N/A	N/A	N/A
SMB 14	50-59	M	N/A	N/A	N/A	N/A	4	N/A	N/A	N/A	N/A	N/A	N/A	N/A	N/A	N/A	N/A	N/A
SMB 23	50-59	M	5	5	4	4	2	N/A	2	N/A	4	4	4	3	N/A	N/A	2	N/A
SMB 59	50-59	M	N/A	N/A	N/A	6	7	6	N/A	2	3	3	N/A	6	4	2	N/A	2
SMB 63	50-59	M	N/A	N/A	5	5	N/A	N/A	N/A	N/A	N/A	N/A	4	N/A	N/A	N/A	N/A	N/A
SMB 68	50-59	M	5	4	N/A	3	3	N/A	3	3	N/A	5	4	5	2	N/A	5	5

Notes: M = male, **F** = female. A category was assigned to each tooth following **Molnar's (1971) categories of occlusal tooth wear**. A higher category implies more tooth wear.Category 1 =1, Category 2 =2, Category 3 =3, Category 4 =4, Category 5 =5, Category 6 =6, Category 7 = 7, Category 8 = 8. **Upp** = upper, **Low** = lower, **Cent.** = central, **Lat**. = lateral, **P1** = first premolar, **P2** = second premolar, **M1** = first permanent molar, **M2** = second permanent molar, **M3** = third permanent molar. **N/A** = not applicable – tooth either lost antemortem or post-mortem and could not be observed.

5.4.8. Table S8a. St Mary's Cemetery Sample. Location of carious lesions on the surface/s of the teeth

St Mary's ID	Estimation of age range skeletal & eruption findings (years)	Sex	*Total number of teeth present		**Caries *above* the CEJ	**Caries *on* the CEJ	**Caries *below* the CEJ		Location of caries: Mesial	Location of caries: Distal	Location of caries: Occlusal	Location of caries: Labial/ Buccal	Location of caries: Lingual/ Palatal	Total number of Carious lesions
SMB 19	6-10	U	22		2	1	0		2	0	0	1	0	3
SMB 70	8-12	U	8		2	1	0		1	1	1	0	0	3
SMB 28	10-14	U	26		2	0	0		0	0	1	1	0	2
SMB 79	15-18	U	25		11	1	0		8	4	0	1	0	13
SMB 05	20-29	F	6		5	1	3		2	3	0	1	2	8
SMB 53C	30-39	F	9		12	0	0		8	3	1	0	0	12
SMB 66B	30-39	F	17		7	7	2		6	4	2	3	1	16
SMB 73	30-39	M	19		5	31	3		12	14	5	4	4	39
SMB 06	40-49	M	24		9	1	9		3	1	5	4	6	19
SMB 09	40-49	M	22		11	0	0		5	6	0	0	0	11
SMB 57	40-49	M	25		4	5	3		2	1	3	6	0	12
SMB 61	40-49	F	7		5	0	0		0	3	1	1	0	5
SMB 72	40-49	M	29		5	8	2		2	0	5	5	3	15
SMB 78	40-49	M	4		0	3	0		2	1	0	0	0	3
SMB 83	40-49	M	16		7	0	0		1	2	4	0	0	7
SMB 85	40-49	M	2		1	0	0		1	0	0	0	0	1
SMB 14	50-59	M	2		1	0	0		0	0	0	0	1	1
SMB 23	50-59	M	21		15	34	5		16	16	4	10	8	54
SMB 59	50-59	M	15		2	6	2		2	2	0	6	0	10
SMB 63	50-59	M	3		2	1	0		2	0	0	1	0	3
SMB 68	50-59	M	19		6	8	0		2	4	2	6	0	14
TOTAL			**321**		**114**	**108**	**29**		**77**	**65**	**34**	**50**	**25**	**251**

Note: *A tooth may have more than one carious lesion present. † CEJ= Cementoenamel Junction. **More than one carious lesion may be present *above* and/ or *on* and /or *below* the CEJ.

Table S8b. St Mary's Cemetery Sample. Number of carious lesions involving either the enamel only, the enamel and dentine, or the enamel, dentine and pulp

St Mary's ID	Estimation of age range skeletal & eruption findings (years)	Sex	*Total number of teeth present		Total number of Carious lesions present		Carious lesions involving the enamel	Carious lesions involving the enamel & dentine	Carious lesions involving the enamel, dentine & pulp
SMB 19	6-10	U	22		3		3	0	0
SMB 70	8-12	U	8		3		3	0	0
SMB 28	10-14	U	26		2		2	0	0
SMB 79	15-18	U	25		12		11	1	0
SMB 05	20-29	F	6		9		7	2	0
SMB 53C	30-39	F	9		12		11	1	0
SMB 66B	30-39	F	17		16		14	2	0
SMB 73	30-39	M	19		39		39	0	0
SMB 06	40-49	M	24		19		19	0	0
SMB 09	40-49	M	22		11		11	0	0
SMB 57	40-49	M	25		12		9	3	0
SMB 61	40-49	F	7		5		1	2	2
SMB 72	40-49	M	29		15		15	0	0
SMB 78	40-49	M	4		3		3	0	0
SMB 83	40-49	M	16		7		7	0	0
SMB 85	40-49	M	2		1		1	0	0
SMB 14	50-59	M	2		1		1	0	0
SMB 23	50-59	M	21		54		50	2	2
SMB 59	50-59	M	15		10		9	1	0
SMB 63	50-59	M	3		3		2	0	1
SMB 68	50-59	M	19		14		14	0	0
		TOTAL	**321**		**251**		**232**	**14**	**5**

Note: *A tooth may have more than one carious lesion present.

5.4.9. Table S9 Dental calculus – an indication of the number, and percentage of teeth affected by calculus with the location and severity of the deposit for the adults of the St Mary's Cemetery sample

St Mary's Burial I/D	**Sex**	Estimation of age range skeletal & eruption findings (years)	Total number of permanent teeth present	**Number of Teeth with calculus**	**Percentage of teeth with calculus**	**Calculus Present** Tooth-type with calculus present FDI notation number/s	**Calculus Location** 1 = enamel surface only 2 = Root* (Brothwell, 1963; Connell and Rauxloh, 2003; Powers, 2012)	**Calculus Severity** 1 = small (slight) 2 = medium 3 = large (heavy/ considerable) (Brothwell, 1963; Connell and Rauxloh, 2003; Powers, 2012)
SMB 05	F	20-29	6	6	100%	32, 35 41, 42, 43, 44	All teeth = enamel	35, 44 = small (slight), 32, 41, 42, & 43 = medium
SMB 53 C	F	30-39	9	1	11%	42	42 = root	42 = small
SMB 66 B	F	30-39	17	6	35%	31, 32, 41, 42, 43, 44	All teeth = root	All teeth = small
SMB 73	M	30-39	19	0	0	N/A	N/A	N/A
SMB 06	M	40-49	24	14	58%	12, 16, 17, 23, 25, 26, 27, 32, 33, 37, 41, 44, 45, 47	12, 17, 23, 26, 32, 33, 37, 45 = enamel, 16, 25, 27, 47 = root	12, 17, 23, 25, 26, 27, 32, 33, 37, 44, 45, 47 = small, 16 = medium
SMB 09	M	40-49	22	15	68%	12, 13, 16, 26, 27, 31, 32, 36, 37, 43, 44, 45, 46, 47, 48	12, 13, 16, 22, 23, 24, 26, 31, 32, 36, 43, 44, 45, 46, 47, 48 = enamel, 26, 37 = root	All teeth = small
SMB 57	M	40-49	25	14	56%	15, 16, 17, 18, 22, 26, 27, 32, 33, 34, 35, 36, 44, 45	All teeth = enamel	All teeth = small
SMB 61	F	40-49	7	3	43%	32, 42, 44	32 & 42 = enamel, 44 = root	All teeth = small
SMB 72	M	40-49	29	2	7%	42, 43	42 & 43 = enamel	All teeth = small
SMB 78	M	40-49	4	4	100%	13, 14, 34, 35	All teeth = enamel	All teeth = small
SMB 83	M	40-49	16	14	88%	13, 14, 17, 23, 24, 27, 28, 33, 34, 37, 42, 43, 47, 48	14, 17, 23, 24, 27, 28, 42, 43, 47,48 = enamel, 13, 33, 34, 37, 42 = root	13, 14, 17, 28, 33, 34, 37 = small, 23, 24, 27, 42, 43, 47, 48 = medium
SMB 85	M	40-49	2	0	0	N/A	N/A	N/A
SMB 14	M	50-59	2	0	0	N/A	N/A	N/A
SMB 23	M	50-59	21	0	0	N/A	N/A	N/A
SMB 59	M	50-59	15	1	7%	46	46 = enamel	46 = small
SMB 63	M	50-59	3	0	0	N/A	N/A	N/A
SMB 68	M	50-59	19	0	0	N/A	N/A	N/A

Notes: F = female, M = male. † Dental eruption age range – "Over 23.5 years"= Estimation of dental age range is based on development and when this is complete. FDI = Fédération Dentaire Internationale tooth identification notation system. *Guidelines, system, and criteria followed as set out by Brothwell, 1963; Connell and Rauxloh, 2003; Powers, 2012, of the Museum of London.

References for section 5.4.9. Table S9 Dental calculus

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Powers, N. 2012. *Human Osteology Method Statement*. Museum of London: London.

5.4.10 Table S10. Enamel Hypoplastic Defects _ St Mary Cemetery Sample

St Mary's ID	Estimation of age (skeletal & eruption findings) (years)	Sex	Total number of teeth present	Permanent and/or primary dentition	Tooth type/s affected by EH defects (anatomical tooth classification)	Tooth type/s affected by EH defects (*FDI notation numbers)	Total number of teeth with EH defects	Percentage of teeth affected by EH defects	Type of EH defect/s present	Number of EH defects per tooth	Antemortem tooth loss (*FDI notation numbers) *(evidence of healing or healed alveolar bone in the original position of the tooth)*
SMB 58	0-2	U	11	*All primary* teeth	Upp R & L Cent I Upp R & L Lat I, Low L Lat I, Upp R m1, Low L & R m1	51, 52, 54, 61, 62, 72, 74, 84	8	72%	Linear & pits	51, 61 = 1 line, 52, 62 = 1 line & 1 pit, 54, 72, 84 = group of multiple pits,	None
SMB 11	0-2	U	19	primary	Upp R & L Canines Low R & L Canines	53, 63, 73, 83	4	21%	Pits	53, 63, 73 & 83 = group of multiple pits	None
SMB 04A	3-5	U	19	primary	Low R & L Cent I Low R & L Lat I	71, 72, 81, 82	4	21%	Pits	71, 72, 81 & 82 = small pits in a line	None
SMB 35	6-9	U	11	primary	Upp L Canine	63	1	9%	Pits	63= 1 pit	None
SMB 19	6-9	U	22	*Mixed dentition:* 7 primary 15 Permanent	*Primary teeth*: Low R canine *Permanent teeth*: Upp R & L Cent I, Canine, P1, P2, Upp L Lat I. Low R Lat I.	12, 13, 14, 15, 21, 22, 42, 83	8	36%	Linear & pit	12= 1 pit, 13 = 1 pit, 14 = 1 pit, 15 = group of multiple pits, 21 = 1 line, 22 = 1 pit, 42 =1 pit, 83= 1 pit	None
SMB 51	10-15	U	16	1 primary 15 Permanent	*Permanent teeth*: Upp R Cent I, Canine, P1, M1, Upp L Lat I, Canine, P1, P2, M1, Low L P1, M1	12, 13, 14,16, 22, 23,24, 25, 26, 34, 36	11	69%	Linear & pit	12, 13 = 2 lines, 14, 24, 36 = 1 line & 1 pit, 16 = 1 line & a group of multiple pits, 22, 23, 26 = 2 lines, 25 = 2 lines & a group of multiple pits, 34 = 3 lines	None
SMB 52B	10-15	U	17	2 primary 15 permanent	*Permanent teeth*: Upp R Cent I, Lat I, Canine, M1, Upp L Cent I, Canine, M1, Low L Cent I, Lat I, Canine, M1, Low R Cent I, Lat I, Canine	11, 12, 13, 16, 21, 23, 26, 31, 32, 33, 36, 14, 42, 43	14	82%	Linear & pit	11, 12, 23, 26, 31, 32, 43 = 1 line, 13, 33, 42 = 2 lines, 16, 21, 36 = 1 pit, 41 = 1 line & 1 pit	None
SMB 70	10-15	U	8	2 primary 6 Permanent	*Primary teeth:* Upp R & L Canines *Permanent teeth*: Upp L Cent I, M1.	53, 21, 63, 26	4	50%	Linear & Pits	53, 63, 26 = a group of multiple pits, 21 = 3 lines & a group of multiple pits	None

5.4.10 Table S10. Enamel Hypoplastic Defects _ St Mary Cemetery Sample

SMB 28	10-15	U	26	*All Permanent*	Upp R Cent I, Lat I, P2, M1,Upp L Lat I, Canine, P2, M1, M2, Low L Cent I, Lat I, Canine, P1, P2, Low R Cent I, Lat I, Canine, P1, P2, M2	11, 12, 15, 16, 22, 23, 25, 26, 27, 31, 32, 33, 34, 35, 41, 42, 43, 44, 45, 47	20	77%	Linear & pit	11, 16, 27, 47 = a group of multiple pits (in 2 lines), 12, 22 = 2 lines, 15, 25, 41 = 1 pit 23, 43 = 3 lines, 26 = 1 line & a group of multiple pits, 31, 32, 33, 34, 35, 42, 44, 45 = 1 line,	None
SMB 79	16-19	U	25	Permanent	Upp R Canine, Upp L Canine, M2, Low R & L Canines	13, 23, 27, 33, 43	5	20%	Linear & pit	13 = 1 pit, 23, 27 = a group of multiple pits, 33 = 2 lines, 43 = 1 line & a group of multiple pits	36
SMB 05	20-29	F	6	Permanent	Low R Cent I, Lat I	41, 42	2	33%	Linear	41, 42 = 1 line	11, 12, 13, 14, 15, 16, 18, 21, 22, 23, 24, 25, 26, 27,28, 36, 37, 38, 45, 46, 47, 48
SMB 53C	30-39	F	9	Permanent	Upp R Cent I, Canine, P1, Upp L Cent I, Canine	11, 13, 14, 21, 23	5	56%	Linear & pit	11 = 2 lines & a group of pits, 13, 14 = 2 lines, 21 = 1 line, 23 = a groupof multiple pits	15, 16, 17, 18, 24, 25, 27, 28, 31, 35, 36, 37, 38, 41, 44, 47, 48
SMB 66B	30-39	F	17	permanent	Upp R P1, M2, Upp L Cent I, Canine, M2, Low L P1, Low R P1, P2	14, 17, 21, 23, 27, 34, 44, 45	8	47%	Pits	14, 17, 21, 23, 27, 44 & 45 = a group of multiple pits, 34 = 1 pit	11 (root only), 13, 16, 18, 26, 28, 36, 37, 38, 46, 47, 48
SMB 73	30-39	M	19	Permanent	Upp R Cent I, Lat I, Canine, M1, UppL Cent I, Canine, P2, Low L Cent I, Lat I, Canine, P1, Low R Cent I, Lat I, Canine, P1	11, 12, 13, 16, 21, 23, 25, 31, 32, 33, 34, 41, 42, 43, 44	15	79%	Linear & pits	11, 21, 31, 32, 41 & 42= 2 lines & a group of multiple pits, 12 = 1 line, 13, 23 33 & 43 = 1 line & a group of multiple pits, 16, 44 = 1 pit & a group of multiple pits, 25 = 1 pit	15, 17, 18, 24, 26, 27, 36, 37, 38, 46, 47, 48
SMB 06	40-49	M	24	Permanent	Upp R Cent I, Low L Cent I, Lat I, Low R Cent I, Lat I	12, 31, 32,41, 42	5	21%	Linear	12 = 3 lines, 31, 32, 41,42 = 1 line,	28, 34, 35, 36, 38, 48
SMB 09	40-49	M	22	Permanent	Upp R Cent I, Canine, Upp L Cent I, Lat I, Canine, Low L Lat I, Canine, Low R Canine	12, 13, 21, 22, 23, 32, 33, 43	8	36%	Linear & pit	12, 13, 21, 22, 23, 32, 33, 43 = 1 line	11, 27, 38
SMB 57	40-49	M	25	Permanent	Upp R Cent I, Lat I, Canine, P1, Upp L, M2, Low L Lat I, Canine, P2, Low R Lat I, Canine	11, 12, 13, 14, 27, 32, 33, 35, 42, 43	10	40%	Linear & pit	11, 12, 32, 33 & 42 = 2 lines, 13 = 1 line & a group of multiple pits, 14, 27 & 35= a group of multiple pits, 43 = 3 lines	25, 28
SMB 72	40-49	M	29	Permanent	Upp R Lat I, Canine, Upp L Canine, P1, Low L M3, Low R Canine, M3	12, 13, 23, 24, 38, 43, 48	7	24%	Pits	12, 38, 48= 1 pit, 13, 23, 24, 43 = a group of multiple pits (in a line)	
SMB 83	40-49	M	16	Permanent	Upp R Canine, Upp L Cent I, Canine, M2, M3, Low L	13, 21, 23, 27, 28, 33, 34, 42, 43	9	56%	Linear & pit	13, 23 = 2 lines, 21, 33, 34, 42 = 1 line, 27, 28 = a group of multiple pits,	16, 18, 26, 36, 45, 46

5.4.10 Table S10. Enamel Hypoplastic Defects _ St Mary Cemetery Sample

					Canine, P1, Low R Lat I, Canine					43 = 2 lines & a group of multiple pits	
SMB 85	40-49	M	2	Permanent	Low L Canine	33	1	50%	Linear & pit2	33 = 1 line & a group of multiple pits	11, 12, 13, 14, 15, 16, 17, 18, 23, 24, 25, 26, 27, 28, 31, 35, 36, 37, 38, 41, 43, 44, 45, 46, 47, 48
SMB 23	50-59	M	21	Permanent	Upp R M2, M3, Upp L Cent I, Low L Cent I, Low R Cent I, Lat I, Canine	17, 18, 21, 31, 32, 33, 41,42, 43	9	43%	Linear & pit	17, 18, 21, 33, 43 = a group of multiple pits, 31, 32, 41, 42 = 1 line	48
SMB 59	50-59	M	15	Permanent	Upp R Cent I, Lat I, Canine, Upp L Lat I, Canine, Low L P2, M3, Low R Cent I, Lat I, P1, M1	11, 12, 13, 21, 22, 23, 35, 38, 41, 42, 44, 46	12	80%	Linear & pit	11, 42 = 2 lines, 12, 13, 22, 23, 35, 38, 44, 46 = a group of multiple pits, 21 & 41 = 3 lines	14, 15, 24, 25, 47
SMB 63	50-59	M	3	Permanent	Low L Lat I, Canine	32, 43	2	67%	Pits	32 = a group of multiple pits, 43 = 1 pit	11, 12, 14, 15, 16, 17, 21, 22, 24, 25, 26, 27, 28, 35, 36, 37, 38, 41, 42, 44, 46, 47, 48
SMB 68	50-59	M	19	Permanent	Upp R P1, Upp L, Canine, Low L P2, Low R Canine, P1, P2	14, 23, 35, 43, 44, 45	6	42%	Pits	14, 23, 35, 43, 44, & 45 = a group of multiple pits	15, 16, 36, 41, 46
Total number of primary teeth affected							20				
Total number of Permanent teeth affected							158				
Grand Total of teeth affected							178				

Notes: **M** = male, **F** = female, **U** = undetermined sex. **EH** = Enamel hypoplastic defects. **Upp** = upper jaw (maxilla), **Low** = lower jaw (Mandible), **Cent.** = central, **Lat.** = lateral, **I** = incisor, **P1** = first premolar, **P2** = second premolar, **m1** = first *primary* molar, **M1**= first *permanent* molar, **m2** = second *primary* molar, **M2** = second *permanent* molar, **M3** = third permanent molar.

*A tooth may have more than one EH defect. **AMTL**= antemortem tooth loss = evidence of healing or the alveolar bone has healed in the original position of the tooth. **FDI** = Fédération Dentaire Internationale tooth identification notation system

Chapter 6. General Discussion and Conclusion

6.1. Originality of the project

This research project has used an approach that was both deeper and broader than those used previously on the skeletal sample of the St Mary's Cemetery. This sample is from a specific segment of the 19th century South Australian settler community. The methods applied in the investigation of these skeletal remains were novel, non-destructive and in agreement with the conditions of the ethics approval. Results generated from this investigation were organised and analysed to seek associations between them (Fig. 6 of thesis introduction). From this, new knowledge was developed, as presented in each of the papers within this thesis. These papers were subjected to peer review and three of the investigations have been published. The fourth investigation is published online as a preprint and is under review by journal referees. New insights and understandings were developed from the findings of this project about the factors influencing the health and well-being of the St Mary's sample, who represented at the time of their death a particular stratum in a deliberately socially stratified population of the new colony of South Australia.

6.2. Key findings of this project

6.2.1. Papers 1 and 2 (Chapters 2 and 3): General health of St Mary's Cemetery settlers

The abnormal bone manifestations presented in papers 1 and 2 (Chapters 2 and 3), of the migrant settlers, buried in the free ground of St Mary's Cemetery, suggested that they were affected by the demands of the establishment of a new industrialised colony. The life expectancy of individuals buried in the free ground of St Mary's Cemetery was over 10 years less than those buried in the purchased and marked leased plots in the main section (Fig. 7, and Table 5 of paper 2 in Chapter 3).

Joint diseases and traumatic injuries seen on many of the skeletons from the St Mary's sample (Figs. 3-5, Table 2 of paper 2), could have been caused by extended periods of hard physical labour, such as the construction of buildings and roads, which would have been required to establish settlements and industries. Injuries sustained by two adult males in the St Mary's sample (SMB 59, SMB 83) (Figs.4 and 5 of paper 2), including the multiple fractures suggest that some of the work that was undertaken could have been hazardous and may well have been fatal.

The delay in the allocation of arable land, together with extreme heat and environmental conditions in South Australia could have led to short falls in food production (Pike, 1967; Price, 1929, 1973; South Australian Register, 1897). Abnormal skeletal manifestations seen on subadults from St Mary's sample indicated that they had suffered chronic metabolic disturbance resulting from vitamin C and/or iron deficiencies (Figs 5 and 6, Tables 3, 4, and S1 of paper 1). These could have been due to an inadequate intake of nutrients or the inability to absorb them (Ferguson et al., 1996; Godde and Hens, 2021; Snoddy et al., 2018; Stark, 2014; Stuart-Macadam, 1991; Weiss and Goodnough, 2005).

The health of the public would have been affected by drinking contaminated water, which was taken directly from rivers and creeks in the early years of the colony (Smith, 2007; Smith, et al., 2020; The South Australia Register,1847, 1873, 1898). Sewage drainage that could have improved public health by reducing the contamination of the water was not established in Adelaide until the 1880s (Burgess, 1978; Price, 1929). Areas away from the city of Adelaide relied on open 'long drop' toilets for the disposal of human waste. Gastrointestinal conditions were found to be the common cause of death for many of the subadults of the St Mary's sample. Health services available to the general public were minimal and were located in the city of Adelaide. Therefore, a gastrointestinal condition in a child living in regions like St Mary's, whose family did not have the means to travel and/or access health services, could have become fatal.

In summary, life was hard for many migrants to South Australia, especially for those without a family or financial support. The need for and establishment of the Destitute Asylum in 1849, less than 15 years from the foundation of the colony, demonstrates this point. The large number of burials in the free ground area of St Mary's Cemetery, between the 1840s and 1870s, (Fig. 2 of paper 1, and Figs. 2 and 6, Tables 3 and 4 of paper 2) at the expense of the government, also reflected the economic changes taking place in the colony, and how these changes affected the settlers of the St Mary's Church parish. These conclusions are supported by the findings presented in papers one and two.

6.2.2. Paper 3 (Chapter 4): Introduction of a new methodology

Paper 3, in Chapter 4, evaluated the reliability and accuracy of the Large Volume (LV) Micro-CT compared to other standard methods used for the analysis of the dentoalveolar complex in situ in archaeological skull samples. Data from the LV Micro-CT scans, dental radiographs and macroscopic examinations were scored and measured for the oral health categories studied and the results showed that the LV Micro-CT scanning method was the *only* technique that provided detailed data for all categories. Large Volume Micro-CT was the only method that could examine the internal structures of the teeth and identify areas of interglobular dentine in the dentition.

This non-invasive LV micro-CT scanning system has many advantages, as well as its volumetric capacity and production of high-resolution scan data sets in a short time. The data and images produced by this innovative method, allow the examination of multiple tissues of the teeth and the arches, and their relationships during development. This non-invasive method has major benefits for the analysis of in-situ dentition within fragile and/or valuable archaeological skull samples. The aims of this paper were fulfilled and the LV Micro-CT scanning technique has been shown to have the potential to provide a more in-depth study of oral hard tissues.

6.2.3. Paper 4 (Chapter 5): The Oral health of the St Mary's sample.

The investigation presented in Chapter 5 (paper 4) demonstrated that individuals from the St Mary's sample had poor oral health. Evidence of extensive carious lesions, antemortem tooth loss and periodontal disease was seen among the adults in this group (Tables 3, S1, S6, S8a, and S8b of paper 4 - Chapter 5).

Historical documents have shown that sugar was available to 19th-century settlers (The South Australia Register, 1859; Thearle, 1985; Wilkinson, 1853). A 'cuppa' tea with sugar was a dietary habit which migrated with the settlers and was considered "a prime necessity of life" (Barrow, 1858:7). Paper 4 showed that cariogenic foods were included in the diet of people from the St Marys-on-the-Sturt community. A witness statement, at a Coroner's inquest into the accidental death of a man run over by a bullock cart, describes the dray as carrying a large and heavy load which included sugar (The South Australia Register, 1859). Sugar was imported to South Australia from overseas and later from other regions of Australia including Queensland (Griggs, 2011).

Antemortem tooth loss was seen in a number of the St Mary's adults (Table S1 and S6 of paper 4). The loss of their permanent upper and/or lower molars did not seriously affect their ability to consume food. One adult male, SMB 73 (skeletal age range 30-39 years), was an example of an individual, who, lost all of his lower permanent molars and the majority of his upper permanent molars in life. According to Miles's (1962), tooth wear system, the tooth loss of the above adult occurred at the age of 18- 24 years, which was almost 20 years before his death (Table S6 of paper 4).

Periodontal disease affected many of the adults in the St Mary's sample (Table 6 of paper 4). This oral disease would have exacerbated any systemic health conditions that they had. Pathological manifestations associated with co-morbidities were seen on subadults in the St Mary's sample, but not on the adults with periodontal disease (Table 6 of paper 4). The adults could have suffered from systemic health issues, such as heart disease that only affected the soft tissues and did not leave observable skeletal signs (Beukers et al., 2017; Cullinan, et al., 2009; Desvarieux et al., 2003; Iwasaki et al., 2018; Scannapieco and Mylotte, 1996; Tavares, et al., 2014).

Application of the LV and SV Micro-CT scanning techniques to this investigation enabled an in- depth study of developmental dental defects i.e., enamel hypoplasia (EH) and interglobular dentine (IGD). Areas of interglobular dentine were identified for the first time in dentitions from St Mary's sample (Fig. 7 of paper 1, Fig. 5 of paper 4). In addition, individuals were seen with EH and IGD present, at similar developmental levels in the same one or more teeth (Fig. 7 of paper 1 and Fig. 5 of paper 4). The presence of developmental defects in the dentitions indicated that these settlers had suffered one or more episodes of ill health in childhood to young adulthood. These may have occurred before or after migration to South Australia. The defects seen in the dentitions of adults indicated that they survived their previous systemic ill health conditions.

6.3. Comparison of Skeletal Samples

Findings from papers 1, 2 and 4 for the individuals buried at St Mary's free ground, were compared with the published data of historic skeletal samples from Australia, New Zealand

and/or Britain. These were Cadia cemetery, NSW, Australia (1864-1927) (Higginbotham and Associates Pty Ltd., 2002), the Old Sydney Burial Ground, NSW, (1792-1820) (Donlon et al., 2017), and St John's Anglican Burial Ground, Milton, Otago, New Zealand (the 1860s-1890s) (Buckley et al., 2020). The British samples that were compared with St Mary's were St Martin's Cemetery, Birmingham, UK, (1810-1864) (Brickley et al., 2006), St Peter's Collegiate Church 'overflow' burial ground, Wolverhampton, UK, (1819-1900) (Adams and Colls, 2007; Arabaolaza et al., 2007), and Cross Bones Burial Grounds (1800-1853), Southwark, London, UK, (WORD database, 2022).

Collections of skeletal remains of migrant settlers to Australia and New Zealand during the 19th century are scarce. Therefore, a comparison with 'equivalent' skeletal samples was difficult. The unmarked 'free ground' area of St Mary's Cemetery was in use between 1847 and 1927. The date range of burials in the cemeteries used for comparison overlapped to a degree with that of St Mary's. Only one cemetery, the Cross Bones Burial Grounds, UK, (WORD database, 2022), had individuals buried in unmarked graves similar to those in St Mary's 'free ground' area (papers 2 and 4). Burials in the other comparison cemeteries were in leased plots that had been paid for by the deceased or their relatives/friends, with a memorial gravestone. This suggested that their background and their economic status could have been different from the settlers buried in free ground. Taking into account these issues, the comparisons of the St Mary's sample with other historic samples provided valuable new understandings. They have shown that the general and oral health of the St Mary's settlers were similar to those of the settlers in Australia, and New Zealand, and that their dietary and oral hygiene habits were comparable to their contemporaries in Britain.

6.4. Limitations

The limitations encountered during the investigations for papers 1 to 4 are considered below.

i) The fragmented state of some of the subadults skeletons in St Mary's sample limited the interpretation of pathological signs on the bones in paper 1.

ii) Ethics restriction did not allow destruction analysis (i.e., removal of teeth from the jaw for analysis or the use of destructive analytical methods such as histology), therefore only a small number of teeth that had been displaced post-mortem could be scanned with Small Volume micro-CT system for paper 1.

iii) Skeletal remains from some of the historical comparison cemeteries have been re-interred, e.g., the individuals from Cadia Cemetery were excavated due to construction work in the location of the cemetery (Higginbotham and Associates Pty Ltd., 2002). They were examined for identification purposes and general health assessments and have now been re-buried – papers 2 and 4.

iv) The small sample sizes of the Australian and New Zealand cemeteries or other contemporaneous skeletal samples limited the potential for meaningful statistical comparison – papers 2 and 4.

v) The Large Volume Micro-CT scanner required a licensed operator, which restricted the availability of the system. In addition, the high cost currently associated with this micro-CT method limited the number of individuals from the St Mary's sample that could have been scanned – papers 3 and 4.

vi) Methodological differences in the analysis of the teeth among between the Australian, New Zealand and British samples and St Mary's sample, did not allow the comparison of findings from the LV and SV Micro-CT scanning systems, and the dental radiographs for paper 4.

vii) The analysis of calculus deposits on teeth, for paper 4, had limitations due to the earlier removal of some of these deposits in another study (Skelly, 2019).

viii) Establishing a dental age range for adults from tooth wear using a non-destructive method, in paper 4, has substantial limitations. Hillson (1996:208), showed a comparison of various methods that can be used to estimate the age of an adult from skeletal materials. Hillson's (1996:242) correlations showed that "Miles's method performs at least as well as the alternatives for adult materials". Miles, (1962) examined the permanent molars and assigns a functional age for each tooth as an estimation of the age of the individual. This system has limitations (Miles, 1962). It was based on the tooth wear patterns of a sample of Anglo-Saxon adults, who would have had different diets and less refined sugars and starch than the 19th-century individuals of the St Mary's sample. Furthermore, the extensive antemortem tooth loss seen in many of the St Mary's adults, interfered with the estimation of a dental age range.

6.5. Summary of new findings demonstrated in this thesis

A summary of the original findings from the four investigations (papers 1-4) of the settlers buried in the free ground area of St Mary's Cemetery, that make up this thesis, is presented below:

1. Evidence of pathological manifestations on bones and/or skeletal abnormalities that were associated with:
    i. a disturbance of the metabolism such as deficiencies of vitamin C and/or iron (Figs. 5 and 6, Tables 3, 4 and S1 of paper 1).
    ii. joint diseases – such as vertebral osteophytes, eburnation of joints,

and/ or Schmorl's nodes - suggestive of extended periods of hard physical labour (Fig. 3, Table 2 of paper 2).

iii. traumatic injuries – antemortem and perimortem injuries including multiple fractures (Figs. 4 and 5 of paper 2)

were seen on the adults and subadults of this sample.

2. The life expectancy for adults interred at the free ground area was lower than for those buried in purchased leased plots in the main section of St Mary's Cemetery (Fig. 7, Table 5 of paper 2).
3. A high mortality rate for infant under one year of age was seen in the St Mary's sample (Fig. 7 of paper 1).
4. No trends relating to the seasonality of death were seen for individuals buried in the free ground (Fig. 3, Table 2 of paper 1).
5. The common causes of death for adults were pulmonary conditions and for subadults were gastrointestinal conditions (Fig. 7 of paper 2).
6. The number of burials in the unmarked free ground area of St Mary's Cemetery, between the 1840s-1870s was greater that the number of burials in purchased leased plots in the main section of this cemetery (Fig. 2 – paper 1, Fig. 6, Tables 3 and 4 of paper 2) (Raw data supporting these findings are given in Appendix 8.1.1 for paper 1).
7. The general health of the St Mary's sample was similar to their contemporaries in NSW, Australia, and the UK, which suggests that the St Mary's migrants were affected by economic hardship during the establishment of the new colony (papers 1 and 2).
8. The introduction of an innovative non-invasive methodology for the study of the

dentoalveolar complex in human archaeological specimens – the Large Volume Micro-CT scanning system, which has not been used before for this type of analysis (i.e., for in-situ dentition within archaeological skulls) – with a comparison to other standard non-destructive methods used for the analysis of archaeological dentitions (paper 3).

9. Evidence that poor oral was extensive in the adult population of the St Mary's sample (i.e., carious lesions Table 3, S8a and S8b, antemortem tooth loss Tables S1 and S6, periodontal disease Table S6 of paper 4).
10. An indication of the inclusion of sugar in the diet of early settlers', from primary sources including a 19th-century witness statement from a Coroner's inquest (paper 4).
11. The adults with poor oral health did not have skeletal signs of co-morbidities, whereas some subadults with evidence of dental developmental defects did (Table 6 of paper 4).
12. The identification of areas of interglobular dentine (IGD) for the first time in the St Mary's sample (Fig. 5 of paper 4).
13. The identification of two different dental developmental defects (i.e., IGD and EH) in the teeth of multiple individuals from St Mary's sample, and examples of EH and IGD at similar developmental levels in the same tooth (Fig. 5 of paper 4).
14. Dental developmental defects were present in the majority of individuals in St Mary's sample (Fig. 4, Tables 5a, 5b and S10 of paper 4).
15. Similar findings for dental developmental defects in the Australian, New Zealand, and British comparison samples suggests that ill health in childhood was common (Table 8 of paper 4).

16. The Oral health of St Mary's sample, while poor, was similar to the 19^{th}-century comparison samples (Table 8 of paper 4).

6.6. Information Relating to Supporting Data.Papers 1 to 4

Supporting Excel spreadsheets that contain data for papers 1 to 4 (Chapters 2 to 5), were too large to convert into Word document tables. Therefore, electronic links have been provided to simplify the viewing of this information in Chapter 8 : Appendix. The raw data from the survey of gravestones within the main section of St Mary's Anglican Church Cemetery are also provided in this appendix (8.1.1- paper 1), for other investigators and future studies.

6.7. Conclusion

In conclusion, the findings of this investigation largely fulfilled the initial aims. Our understanding of the extent to which conditions prevailing in the early colony of South Australia were detrimental to human health has increased. As has our knowledge of the likely factors that caused the pathological manifestations and/or abnormalities seen in bones and teeth of the individuals from the St Mary's sample. A multiple-method approach, to derive enhanced information from the dentoalveolar complex of the human skull, has been shown to be effective, whilst establishing a new methodology (LV Micro-CT) for the analysis of in situ dentition. Further, this investigation has digitally preserved data relating to this historical group of individuals for future comparisons

Chapter 7. References – Introduction and Discussion

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Chapter 8. Future work

Research topics that have arisen from this investigation for future works:

1. The application of Large Volume Micro-CT scanning as a single technique or used to complement a suite of other methods for the detailed investigation of oral health conditions and/or developmental defects using other archaeological samples.
2. Further investigations of the dental developmental defects, enamel hypoplastic (EH) defects and interglobular dentine (IGD) seen in human archaeological samples, are considered below:
   a) IGD and EH – when seen in the same tooth "which came first? Are ameloblasts or odontoblasts more sensitive to health insults during dental development? Investigate the timing of these developmental defect (EH and IGD) in the affected teeth. Do both tissues always respond?
   b) What is the frequency of these two dental developmental defects, seen separately or together in teeth, in other archaeological samples?
   c) Does the frequency of these dental developmental defects change over time (e.g., are there more examples of EH and IGD in 19^{th} century individuals from industrial backgrounds and environments compared with similar populations from a similar region such as the Romano-British people, centuries earlier?)
   d) How often do these two dental defects occur in the same teeth at a similar developmental level?

Chapter 9. Appendix:Excel - Supporting Data

Appendix: Excel - Supporting Data - Papers 1 to 4

(Chapters 2-5)

Supporting data, in the format of Excel spreadsheets, were too large to convert into Word document tables therefore, the following electronic links have been provided to simplify the viewing of this information.

9.1. Paper 1 (Chapter 2)

The following links will provide access to the Excel spreadsheets associated with paper 1.

- 9.1.1.Paper 1-S1 Excel Supporting Data. Observed skeletal manifestation seen on the skulls and post-cranial skeletons from St Mary's Cemetery sample: https://doi.org/10.1371/journal.pone.0265878.s002

- 9.1.2.Paper 1-S2 Excel Supporting Data – Summary - Enamel hypoplastic defects - macroscopic examination: https://doi.org/10.1371/journal.pone.0265878.s003

9.1.3. Paper 1- **St Mary's Cemetery Survey**

The raw data presented as tables in the following pages has been transferred from Excel spreadsheets. This information was collected from a survey of the memorial gravestones placed on the purchased 'leased' burial plots within the main section of St Mary's Anglican Church Cemetery, South Road, South Australia. This section of the cemetery is divided into four areas:Northeast, Northwest, Southeast and Southwest. The main section of this cemetery does not include the unmarked 'free ground' area. This raw data was analysed and the findings published (Paper 1- chapter 2).

DATA FROM A SURVEY OF ST MARY'S ANGLICAN CHURCH CEMETERY-'LEASED' PLOTS WITH GRAVESTONES 1847-1927

St Mary's Cemetery SECTION	ROW	GRAVE NUMBER	NUMBER OF BURIALS	FAMILY NAME	OTHER NAMES	DATE / DAY OF BIRTH	MONTH OF BIRTH	YEAR OF BIRTH	DATE/ DAY OF DEATH	MONTH OF DEATH	YEAR OF DEATH	AGE AT DEATH	INSCRIPTIONS	COMMENTS
North East	3	4	2	BALL	Ellen Florence	Unknown	Unknown	1879	13	5	1937	59	Wife of George Henry BALL	None
North East	3	4	2	BALL	George Henry	Unknown	Unknown	1876	2	11	1940	64	Husband of Ellen BALL	None
North East	2	5	2	BLYTHE	Rosena Sophia	Unknown	Unknown	1870	25	7	1935	65	Wife of Norman BLYTHE	None
North East	2	5	2	BLYTHE	Norman Robinson	Unknown	Unknown	1864	20	5	1939	75	Husband of Rosena BLYTHE	None
North East	1	12	2	BOUCAUT	Max Arthur	Unknown	Unknown	1870	23	8	1952	83	Husband of Laura, father t o Arthur	None
North East	1	12	2	BOUCAUT	Laura	Unknown	Unknown	1882	14	2	1970	88	None	None
North East	1	8	2	CLEMENT	Unknown	Unknown	Unknown	Unknown	Unknown	Unknown	Unknown		"In memory of our mum & dad"	Small stone heart NO DATES
North East	2	17	1	COFFEY	Alice	Unknown	Unknown	1886	8	1	1938	52	Wife of Leonard COFFEY	None
North East	1	11	2	COLEMAN	David. H.	Unknown	Unknown	Unknown	24	10	1934	Unknown	Husband & father	None
North East	1	11	2	COLEMAN	Ivy	Unknown	Unknown	1892	12	8	1969	77	Wife of David Coleman	None
North East	8	12	2	DAVIS	Sam Archibald	Unknown	Unknown	Unknown	8	1	1923	Unknown	None	None
North East	4	5	1	DEPLEDGE	William	Unknown	Unknown	1867	26	7	1932	65	None	None
North East	2	9	2	EATTS	Reginald Thomas	Unknown	Unknown	1899	22	3	1977	78	Husband of Rose EATTS	None
North East	2	9	2	EATTS	Rose Olive	Unknown	Unknown	1900	16	5	1984	84	Wife of Reginald EATTS	None
North East	1	1	2	FOX	Winifred	Unknown	Unknown	1881	13	1	1934	53	Wife of Robert Owen FOX	None
North East	1	1	2	FOX	Robert Owen	Unknown	Unknown	1876	Unknown	Unknown	1949	73	Husband of Winifred FOX	None
North East	2	2	1	GIBSON	Leah Ann Elizabeth	Unknown	Unknown	1882	1	2	1955	73	(Sis) Wife of E.W. GIBSON	None
North East	2	6	1	HEARD	Mary	Unknown	Unknown	Unknown	22	6	1936	Unknown	Wife of J.A.HEARD	None
North East	4	6	5	HILLMAN	William. J	Unknown	Unknown	1883	Unknown	Unknown	1937	54	None	None
North East	4	6	5	HILLMAN	Airlie. M.	Unknown	Unknown	1886	Unknown	Unknown	1943	57	None	None
North East	4	6	5	HILLMAN	Kevin. W	Unknown	Unknown	1929	Unknown	Unknown	1993	64	"Husband to Ismay, Father to Ismay"	Metal Plaques not stone markers
North East	4	6	5	HILLMAN	Melville John	5	3	1913	28	10	1994	81	None	None

DATA FROM A SURVEY OF ST MARY'S ANGLICAN CHURCH CEMETERY-'LEASED' PLOTS WITH GRAVESTONES 1847-1927

North East	4	6	5	HILLMAN	Ismay Airlie	2	5	1924	11	8	2014	90	Wife of Kevin	None
North East	1	9	2	HOFFMAN	August	Unknown	Unknown	Unknown	Unknown	Unknown	Unknown	Unknown	"Loving uncle & aunt of Laurel & Laurie"	NO DATES
North East	1	9	2	HOFFMAN	Amy	Unknown	Unknown	Unknown	Unknown	Unknown	Unknown	Unknown	"Loving uncle & aunt of Laurel & Laurie"	NO DATES
North East	3	6	1	HOLBROOK	Arthur	Unknown	Unknown	1863	6	6	1936	73	Husband of Anne HOLBROOK	None
North East	2	11 & 12	4	LEWIS	George	Unknown	Unknown	1857	11	1	1936	79	"Born Madeley, Shropshire, England"	None
North East	2	11 & 12	4	LEWIS	Lillian Constance	Unknown	Unknown	1890	5	11	1948	58	None	daughter?
North East	2	11 & 12	4	LEWIS	Alice Ann	Unknown	Unknown	1861	18	3	1952	91	Wife of George LEWIS	None
North East	2	11 & 12	4	LEWIS	Edith Averil	4	8	1891	23	1	1973	82	None	daughter?
North East	4	3 & 4	3	LEWIS	Elba	Unknown	Unknown	1923	25	5	1992	69	"nee McMILLAN"	None
North East	2	4	2	LOWE	Alice Jane	16	1	1867	16	3	1868	1.2	None	INFANT
North East	2	4	2	LOWE	Emma Salina	6	2	1858	24	4	1942	84	"Born Mt Pleasant, resident of this parish" (St Marys)	None
North East	1	4	2	MASON	Jane	Unknown	Unknown	1867	15	8	1934	67	Wife of Joseph MASON	None
North East	1	4	2	MASON	Joseph	Unknown	Unknown	1866	19	7	1954	88	Husband of late Jane MASON	None
North East	4	3 & 4	3	McMILLAN	Elba	Unknown	Unknown	1887	28	10	1958	71	"Nee BOUCAUT" Wife of Will McMILLAN	None
North East	4	3 & 4	3	McMILLAN	Will	Unknown	Unknown	1887	14	6	1968	81	None	None
North East	10	1	Unknown	NORRIS	Mary	Unknown	Unknown	1827	5	5	1902	75	Wife of JOSEPH	None
North East	1	2	1	NETTLETON	Mary Jane	Unknown	Unknown	1855	23	3	1934	79	None	None
North East	3	15	2	PERCY	Ethel May	Unknown	Unknown	1899	19	10	1992	93	None	None
North East	2	7 & 8	2	PETHICK	Sarah May	Unknown	Unknown	1876	20	9	1935	59	Wife of J.M.PETHICK	None
North East	2	7 & 8	2	PETHICK	John Mall	Unknown	Unknown	1858	6	8	1955	97	Husband of Sarah PETHICK	None
North East	3	16	1	RANDALL	Ernest (Ambrose)	Unknown	Unknown	Unknown	2	4	1940	Unknown	Husband of Eleanor RANDALL	None
North East	9	1	1	RICHARDSON	Margaret Lockyer	Unknown	JANUARY	1906	11	12	1907	1.11	Only child of W & H. RICHARDSON	Child

North East	3	10	2	RUSSELL	Thomas John	Unknown	Unknown	1878	7	2	1937	59	None	None
North East	3	10	2	RUSSELL	Elizabeth	Unknown	Unknown	Unknown	15	5	1944	Unknown	None	None
North East	3	5	2	SANDERSON	George	Unknown	Unknown	Unknown	Unknown	Unknown	Unknown	Unknown	Husband of Ethel SANDERSON, "Lovedparents"	NO DATES
North East	3	5	2	SANDERSON	Ethel	Unknown	Unknown	Unknown	Unknown	Unknown	Unknown	Unknown	Wife of George SANDERSON, "loved parents'	NO DATES
North East	1	5	3	SHEPARD STEEL	Unknown	Unknown	Unknown	1900	31	8	1934	34	"Mother of May, Nancy & Margaret"	Details of daughter May of plaque but not believed to be interned with her:May: DOB 26.06.1914 - Died 14.05.2003
North East	1	5	3	SHEPARD STEEL	Nancy	11	1	1922	16	7	2016	94	"Twins reunited with their mother on 17.08.2017"	None
North East	1	5	3	SHEPARD STEEL	Margaret	11	1	1922	31	7	2017	95	"Twins reunited with their mother on 17.08.2017"	None
North East	1	15	2	TAYLOR	Joseph	Unknown	Unknown	1882	9	7	1935	53	None	None
North East	1	15	2	TAYLOR	Elizabeth	Unknown	Unknown	1885	23	7	1955	70	Wife of Joseph Taylor	None
North East	3	7	2	THOMPSON	Edmund.W.J	Unknown	Unknown	1877	1	9	1936	59	Husband of Edith Alice THOMPSON	None
North East	3	7	2	THOMPSON	Edith Alice	Unknown	Unknown	1877	27	6	1954	77	Wife of Edmund THOMPSON	None
North East	1	3	2	TICKLE	Charles Edwin	Unknown	Unknown	1878	Unknown	Unknown	1934	56	Husband of Sarah TICKLE	None
North East	1	3	2	TICKLE	Sarah	Unknown	Unknown	1880	3	7	1957	77	Wife of Charles TICKLE	None
North East	3	3	2	TOMLINSON	Thomas.I	Unknown	Unknown	1877	31	10	1936	59	Husband of A.M TOMLINSON	None
North East	3	3	2	TOMLINSON	Alice Maude	Unknown	Unknown	1879	20	3	1950	71	wife of Thomas TOMLINSON	None
North East	3	12	1	WADE	John	Unknown	Unknown	1860	10	9	1937	77	None	None
North East	2	1	2	WIGHT	Robert	Unknown	Unknown	1865	12	1	1945	80	None	None
North East	2	1	2	WIGHT	Elizabeth	Unknown	Unknown	1871	11	7	1950	79	Wife of Robert WIGHT	None
North East	1	14	2	WILLIAMS	Lillian Jane	Unknown	Unknown	1891	22	5	1935	44	Wife of Roy Ernest Williams	None
North East	1	14	2	WILLIAMS	Roy Ernest	Unknown	Unknown	1890	14	8	1969	79	None	None

North East	2	15	1	WOOD	Elizabeth	Unknown	Unknown	1852	Unknown	Unknown	1937	85	"Mother"	None
North East	3	8 & 9	2	WOOD	Elizabeth Ann	Unknown	Unknown	1857	8	7	1938	81	Wife of Hohn WOOD	None
North East	3	8 & 9	2	WOOD	John	Unknown	Unknown	1848	20	7	1938	90	Husband of Elizabeth WOOD	None
North East	1	16	2	WRAIGHT	Ernie. E.G	Unknown	Unknown	1891	8	10	1936	45	None	None
North East	1	16	2	WRAIGHT	Jessie	Unknown	Unknown	1894	23	4	1970	76	Wife of Ernie. E.G WRAIGHT	None
North East	2	13	2	YOUNG	Mary Ann	Unknown	Unknown	1861	9	5	1938	77	Wife of James Henry YOUNG	None
North East	2	13	2	YOUNG	James Henry	Unknown	Unknown	1850	Unknown	12	1939	89	Husband of Minna YOUNG	None
North East	1	10	0	Unknown	Unknown	Unknown	Unknown	Unknown	Unknown	Unknown	Unknown	Unknown	Unknown	Empty
North East	1	13	0	Unknown	Unknown	Unknown	Unknown	Unknown	Unknown	Unknown	Unknown	Unknown	Unknown	Concrete surround no marker
North East	2	3	0	Unknown	Unknown	Unknown	Unknown	Unknown	Unknown	Unknown	Unknown	Unknown	Unknown	Plants only
North East	2	10	0	Unknown	Unknown	Unknown	Unknown	Unknown	Unknown	Unknown	Unknown	Unknown	Unknown	Empty
North East	2	14	0	Unknown	Unknown	Unknown	Unknown	Unknown	Unknown	Unknown	Unknown	Unknown	Unknown	Shrubs
North East	2	16	0	Unknown	Unknown	Unknown	Unknown	Unknown	Unknown	Unknown	Unknown	Unknown	Unknown	Empty
North East	3	1 & 2	0	Unknown	Unknown	Unknown	Unknown	Unknown	Unknown	Unknown	Unknown	Unknown	Unknown	Large Shrubs opposite church tower
North East	3	11	0	Unknown	Unknown	Unknown	Unknown	Unknown	Unknown	Unknown	Unknown	Unknown	Unknown	Empty
North East	3	13	0	Unknown	Unknown	Unknown	Unknown	Unknown	Unknown	Unknown	Unknown	Unknown	Unknown	Concrete surround no marker
North East	3	14	0	Unknown	Unknown	Unknown	Unknown	Unknown	Unknown	Unknown	Unknown	Unknown	Unknown	Empty
North East	4	1 & 2	0	Unknown	Unknown	Unknown	Unknown	Unknown	Unknown	Unknown	Unknown	Unknown	Unknown	Large Shrubs opposite church tower

DATA FROM A SURVEY OF ST MARY'S ANGLICAN CHURCH CEMETERY-'LEASED' PLOTS WITH GRAVESTONES 1847-1927

St Mary's Cemetery SECTION	ROW	GRAVE NUMBER	NUMBER OF BURIALS	FAMILY NAME	OTHER NAMES	DATE / DAY OF BIRTH	MONTH OF BIRTH	YEAR OF BIRTH	DATE/ DAY OF DEATH	MONTH OF DEATH	YEAR OF DEATH	AGE AT DEATH	INSCRIPTION	COMMENTS
North West	3	11	4	ACKLAND	WINIFRED			1897	UNKNOWN	UNKNOWN	1922	25	Daughter of Robert Boyley	Infant son of W & N. Ackland - age 3 weeks no date of death. Did the child die before or after the mother?
North West	6	4	3	ANDERSON	JAMES WALLACE	UNKNOWN	UNKNOWN	1897	28	5	1917	20	"Son of William & Euphemia Anderson	Killed in WWI?
North West	6	4	3	ANDERSON	EUPHEMIA	UNKNOWN	UNKNOWN	1861	10	8	1927	66	Wife of William Anderson	
North West	5	2 & 3	1	AYLIFFE	GEORGE HAMILTON	25	3	1840	2	5	1906	66	None	
North West	3	11	4	BOYLEY	ROBERT	UNKNOWN	UNKNOWN	1874	UNKNOWN	UNKNOWN	1914	40	None	
North West	2	6	4	BREYNARD	MARY	26	10	1845	17	5	1917	71	Wife of David. P. Breynard	
North West	2	6	4	BREYNARD	MARY ISOBEL	20	3	1883	26	7	1926	43	Daughter of Mary Breynard	
North West	1	3 & 4	4	BUGG	STEPHEN ERNEST	UNKNOWN	UNKNOWN	1894	24	1	1899	5	None	Child
North West	1	3 & 4	4	BUGG	HENRY JAMES	UNKNOWN	11	1899	15	3	1900	0.5	Belated son of E & C. Bugg	INFANT
North West	4	6	9	COLLINS	ALICE MARY	UNKNOWN	UNKNOWN	1872	3	2	1873	1.1	Beloved children of James & Catherine Collins	INFANT
North West	4	6	9	COLLINS	WILLIAM JAMES	UNKNOWN	UNKNOWN	1870	22	1	1873	3	Beloved children of James & Catherine Collins	INFANT
North West	4	6	9	COLLINS	JOHN	UNKNOWN	UNKNOWN	1805	7	2	1878	73	Grandparents of William, Alice & Percy Collins.	

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North West	4	6	9	COLLINS	ANN MARIA	UNKNOWN	UNKNOWN	1799	5	2	1883	84	Grandparents of William, Alice & Percy Collins	
North West	4	6	9	COLLINS	PERCY	UNKNOWN	UNKNOWN	1876	2	9	1893	17	"Beloved children of James & Catherine Collins"	
North West	4	2	6	COLLINS	MALCOLM FRANK	27	7	1906	30	8	1907	1.1	None	INFANT
North West	4	6	9	COLLINS	CATHERINE	UNKNOWN	UNKNOWN	1843	20	5	1915	72	Wife of James Collins	
North West	4	6	9	COLLINS	JAMES	1	7	1840	4	9	1916	76	Born in Carrington Tasmania	
North West	8	14	3	COWPER	WILLIAM HENRY	UNKNOWN	UNKNOWN	UNKOWN	17	4	1924	UNKNOWN	Husband of Kate Cowper	
North West	1	11	2	EVANS	ALICE JANE	29	8	1862	20	5	1915	52	Wife of James William Evans	
North West	4	11	1	FORBES	WILLIAM THOMPSON	UNKNOWN	UNKNOWN	UNKOWN	28	9	1924	UNKNOWN	None	
North West	1	10	2	FOXWELL	JOHN	UNKNOWN	UNKNOWN	1832	1	7	1912	80	None	
North West	1	10	2	FOXWELL	HARRIET	UNKNOWN	UNKNOWN		26	5	1917	74	Wife of JoHn Foxwell	
North West	2	4 & 5	3	GALE	H. J	UNKNOWN	UNKNOWN	1895	2	4	1917	22	"Killed in Action" "Pte" Rank of Private	
North West	2	4 & 5	3	GALE	ELIZABETH	UNKNOWN	UNKNOWN	1857	10	5	1926	69	Wife of John Gale	
North West	3	12	1	GENTLE	MARGERY	UNKNOWN	UNKNOWN	1895	3	3	1924	29	nee Williams	Childbirth?
North West	2	8	2	GIBSON	NICHOLAS	UNKNOWN	UNKNOWN	1855	25	10	1921	66	Husband of Ellen Gibson	
North West	2	8	2	GIBSON	ELLEN. S	UNKNOWN	UNKNOWN	1855	28	1	1924	69	Wife of Nicholas Gibson	
North West	1	1	2	HAESE	EDMOND	UNKNOWN	UNKNOWN	1897	UNKNOWN	UNKNOWN	1899	2	None	Child
North West	3	5	2	HAMS	ISABELLA	UNKNOWN	UNKNOWN	1835	1	5	1914	79	Wife of James Hams	
North West	2	13 & 14	2	HARRIS	BARBARA	UNKNOWN	UNKNOWN	1860	9	5	1925	65	Wife of Frederick Harris	

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North West	5	4	4	HILL	GARNET RANSOM	5	11	1915	22	3	1916	0.4	Child of William George & Ethel Hill	INFANT
North West	2	2	1	HILLIER	ARTHUR J.F	UNKNOWN	UNKNOWN	1880	17	10	1913	33	Son of Mrs E. Hillier	
North West	1	8	2	HIMMELREICH	DORIS	UNKNOWN	UNKNOWN	1898	6	11	1902	4	None	Child
North West	1	8	2	HIMMELREICH	HERMAN	UNKNOWN	UNKNOWN	UNKOWN	29	5	1904	UNKNOWN	None	
North West	1	9	1	HIMMELREICH	MARGARET	UNKNOWN	UNKNOWN	1863	5	8	1917	54	Wife of A.H.Himmelreich	
North West	3	8 & 9	4	HORSMAN	ELIZABETH. A. A	UNKNOWN	UNKNOWN	1883	20	1	1920	37	Wife of J.J. Horsman	
North West	5	6	3	McKENZIE	AUDREY ELLEN	UNKNOWN	UNKNOWN	1916	21	5	1919	3	"daughter of Alex & Nance McKenzie"	Child
North West	5	8	1	McNAMARA	CHARLOTTE ELIZABETH	UNKNOWN	UNKNOWN	UNKOWN	4	4	1922	UNKNOWN	Wife f John McNamara	
North West	4	7 & 8	4	MURPHY	FRED	UNKNOWN	UNKNOWN	1899	19	1	1918	19	"Third son of S.A & A. Murphy"	Killed in WWI??
North West	1	7	5	NESBITT	SARAH JANE	UNKNOWN	UNKNOWN	UNKOWN	29	8	1901	UNKNOWN	Daughter of late Samual Thomas Nesbitt	Child?
North West	1	7	5	NESBITT	SAMUEL THOMAS	UNKNOWN	UNKNOWN	UNKOWN	29	1	1903	UNKNOWN	None	
North West	1	7	5	NESBITT	SARAH JANE	UNKNOWN	UNKNOWN	UNKOWN	6	7	1905	UNKNOWN	Wife of Samual Thomas Nesbitt	
North West	1	7	5	NESBITT	MARY	UNKNOWN	UNKNOWN	1881	4	5	1924	43	Eldest daughter of Samuel Thomas Nesbitt & Sarah Jane Nesbitt	
North West	5	10 & 11	5	NOBLETT	DAVID JAMES	UNKNOWN	UNKNOWN	UNKOWN	5	4	1926	UNKNOWN	"Infant son of Edgar & May Noblett	INFANT
North West	2	9 & 10	2	PERCY	JAMES ERNEST	UNKNOWN	UNKNOWN	1863	30	1	1923	60	Husband of Ellen Emma Percy	
North West	2	1 & 2	3	RAGLESS	GEORGE	3	9	1823	19	8	1909	86	Born Battersea, Surrey. Died at Battersea Park, St Marys.	

													" a colonist of 71 years"	
North West	2	1 & 2	3	RAGLESS	GEORGE THOMAS	UNKNOWN	UNKNOWN	1861	15	12	1921	60	Husband of Marcella G. Ragless, & only son of George & M.A. Ragless	
North West	2	1 & 2	3	RAGLESS	MARY ANN	UNKNOWN	UNKNOWN	1834	23	9	1926	92	Wife of George Ragless Died at "Brievley" St Peters	
North West	2	3	1	SCHULZ	HARTLEY GLEN	UNKNOWN	UNKNOWN	1890	20	8	1914	24	None	
North West	4	9 & 10	2	SOPER	JOYCE MAUDE	UNKNOWN	UNKNOWN	1914	23	5	1922	8	"Daughter of H.H & M. Soper	Child
North West	4	12	3	STEER	THELMA MAVIS	UNKNOWN	UNKNOWN	1926	16	8	1926	0.2	"Daughter"	INFANT - 10 weeks
North West	5	5	2	STOLZ	SABRINA	UNKNOWN	UNKNOWN	1860	25	9	1916	56	Wife of George Stolz	
North West	3	6 & 7	4	SWIFT	DAVID	UNKNOWN	UNKNOWN	1856	29	1	1913	57	None	
North West	3	6 & 7	4	SWIFT	RAYMOND RALPH	UNKNOWN	UNKNOWN	1897	5	4	1918	21	? Died in France, ? Breslewood is he buried in France?	
North West	3	6 & 7	4	SWIFT	HERBERT JAMES	UNKNOWN	UNKNOWN	1886	27	2	1921	35		
North West	2	11 & 12	1	WEBB	CHARLES. L	UNKNOWN	UNKNOWN	1872	30	6	1923	51	Husband of Elizabeth . J. Webb	Difficult to read, this gravestone was worn
North West	3	13 & 14	4	WILLAN	MARGERY	UNKNOWN	UNKNOWN	1864	2	1	1927	63	Wife of John Willan	
North West	3	13 & 14	4	WILLAN	JOHN	UNKNOWN	UNKNOWN	1861	20	9	1927	66	Husband of Margery Willan	
North West	3	1,2 & 3	7	WYETT	ROBERT LIONEL QUENTIN	UNKNOWN	UNKNOWN	1888	9	8	1909	21	Eldest son of Robert & E. A. Wyett	Cause of death?

North West	3	1,2 & 3	7	WYETT	VICTOR. L	UNKNOWN	UNKNOWN	1890	13	10	1917	27	"Killed in Action" at Ypes Second son of Robert & E. A. Wyett
North West	4	17	3	YOUNG	HAROLD WILLIAM	UNKNOWN	UNKNOWN	1891	9	10	1917	26	"Killed in Action" in Belgium ANZAC

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South East	4	6	4	BOUCAUT	WINIFRED	24	7	1807	19	10	1883	76	"wife of Ray, daughter of James Penn	
South East	7	7	1	BOUCAUT	CHARLOTTE	UNKNOWN	UNKNOWN	UNKOWN	15	4	1905	UNKNOWN	Wife of Ray . P. Boucaut	
South East	4	6	4	BOUCAUT	JANET	UNKNOWN	UNKNOWN	UNKOWN	18	12	1912	UNKNOWN	None	
South East	3	9 & 10	3	BOUCAUT	JAMES PENN	UNKNOWN	UNKNOWN	1832	1	2	1916	84	"Sir James Penn Boucaut" K.C.M.G born in England, eldest son of Capt Ray Boucut, H.C.S born in Guernsey	
South East	4	7	4	BOUCAUT	HELEN MARIA	UNKNOWN	UNKNOWN	1854	14	6	1923	69	Wife of Hillary	
South East	4	7	4	BOUCAUT	HILLARY	UNKNOWN	UNKNOWN	1840	3	10	1927	87	Husband of Helen Maria	
South East	3	9 & 10	3	BOUCAUT	VIRGINIA	UNKNOWN	UNKNOWN	UNKOWN	2	6	18??	21	None	?
South East	6	3	5	CALLAGHAN	LAVINIA	UNKNOWN	UNKNOWN	1797	UNKNOWN	3	1853	56	Wife of P. Callaghan	
South East	6	3	5	CALLAGHAN	LAVINIA	UNKNOWN	UNKNOWN	1862	5	7	1894	32	Wife of John. C.Oliver	
South East	6	3	5	CALLAGHAN	PATRICK	UNKNOWN	UNKNOWN	1863	12	6	1911	48	None	
South East	6	3	5	CALLAGHAN	WILLIAM	UNKNOWN	UNKNOWN	1869	12	1	1927	58	Husband of Olive	
South East	3	6	2	CHOAT	HENRY JAMES	UNKNOWN	UNKNOWN	1827	22	1	1904	77	Husband of Caroline Choat	
South East	3	6	2	CHOAT	CAROLINE	UNKNOWN	UNKNOWN	1827	25	1	1904	77	Wife of Henry James	
South East	4	3	1	COCKING	RICHARD	UNKNOWN	UNKNOWN	1808	21	6	1859	51	None	
South East	4	4	1	COCKING	JULIA	UNKNOWN	UNKNOWN	1844	7	2	1914	70	None	
South East	3	1	4	CONWAY	LYDIA ELIZABETH	21	9	1839	30	3	1916	76	None	
South East	7	4	3	DAPPER	CATHERINE	UNKNOWN	UNKNOWN	1859	26	6	1907	48	None	
South East	7	4	3	DAPPER	JOSEPH	UNKNOWN	UNKNOWN	1886	11	3	1914	28	None	

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South East	5	6	1	HANCOX	JANE	UNKNOWN	UNKNOWN	1804	19	2	1861	57	Number 27 in booklet (a pioneer walk through St Mary's) head and foot stone Nee Pollard, married to William Hancox from Stratford upon Avon on 21/12/1840 Holy Trinity Church Adelaide? Lived in "stringybark forest" had a steam four mill in mid 1840s in Plympton. William Hancox may have name named St Marys on the sturt after Stratford	
South East	6	8	5	JOSE	CHARLES	UNKNOWN	UNKNOWN	1864	15	2	1892	28	"youngest son of T & M.A. Jose	
South East	6	8	5	JOSE	THOMAS	UNKNOWN	UNKNOWN	1819	18	9	1898	79	None	
South East	6	8	5	jOSE	MARY ANN	UNKNOWN	UNKNOWN	1821	30	7	1899	78	None	
South East	6	4	7	MATHIAS	WALLACE	UNKNOWN	UNKNOWN	1884	18	12	1890	5.5	Child of E.M & M. Mathias, Edwardstown.	Child
South East	6	4	7	MATHIAS	ETTY	UNKNOWN	UNKNOWN	1884	3	9	1891	7	Child of E.M & M. Mathias, Edwardstown	CHILD
South East	6	4	7	MATHIAS	MYRTLE	UNKNOWN	UNKNOWN	1902	7	12	1902	0.9	Child of E.M & M. Mathias,	INFANT
South East	7	3	3	MATHIAS	UNKNOWN	UNKNOWN	UNKNOWN	UNKOWN	UNKNOWN	UNKNOWN	1907	UNKNOWN	None	
South East	7	3	3	MATHIAS	GEORGIA	UNKNOWN	UNKNOWN	UNKOWN	3	1	1914	UNKNOWN	None	
South East	5	11	2	MITFORD	EUSTACE RAVELEY	UNKNOWN	UNKNOWN	1811	24	10	1869	58	Author of "Pasquin", a founder of St Mary's Church arrived in SA on the Katherine Stewart Forbes on 21/03/1939 His baby died on 04/01/1839 age 4 mths. Buried at sea.	

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South East	5	11	2	MITFORD	ELIZA	UNKNOWN	UNKNOWN	UNKOWN	24	6	1893	UNKNOWN	Widow of Eustace Raveley Mitford. arrived in SA on thr Katherine Stewart Forbes on 21/03/1939 Her baby died on 04/01/1839 age 4 mths. Buried at sea.	
South East	7	7 & 8	1	MOORE	WILLIAM SAMUEL (REV)	UNKNOWN	UNKNOWN	UNKOWN	17	7	1901	UNKNOWN	"Rector of South Road, Goodwood & O'Halloran Hill"	
South East	3	1	4	NICHOLLS	MARY LETITIA	UNKNOWN	UNKNOWN	1849	15	6	1849	0.3	None	INFANT
South East	3	1	4	NICHOLLS	JOHN WARNER	UNKNOWN	UNKNOWN	1798	18	4	1880	82	None	
South East	3	1	4	NICHOLLS	EANNY	UNKNOWN	UNKNOWN	1809	2	6	1902	93	Wife of John Warner Nicolls	
South East	7	9,10 & 11	5	QUICK	CAROLINE ADELAIDE	UNKNOWN	UNKNOWN	1857	5	6	1885	28	Wife of Arthur Quick	
South East	7	9,10 & 11	5	QUICK	MARIA	UNKNOWN	UNKNOWN	1861	15	8	1901	40	Wife of Arthur Quick	
South East	7	9,10 & 11	5	QUICK	CLARRISSA HAWTHORNE	28	1	1892	29	11	1913	21	None	
South East	4	1	3	ROWLAND	JANE	UNKNOWN	UNKNOWN	1789	28	2	1867	78	Wife of Charles Rowland	
South East	4	1	3	ROWLAND	CHARLES	UNKNOWN	UNKNOWN	1789	11	8	1881	92	Husband of Jane	
South East	4	1	3	ROWLAND	MARY ELLEN	UNKNOWN	UNKNOWN	1824	30	11	1911	87	Daughter of Charles and Jane Rowland	

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South West	5	8	2	SADDLER (BOOKLET) (UNREADABLE)-	(UNREADABLE) RICHARD	UNKNOWN	UNKNOWN	1810	23	2	1872	62	Marker broken - fallen- names unreadable. **Booklet number 9:** STATES RICHARD WAS A BRICKLAYER & POST MAN. MARRED TO HARRIET	
South West	5	8	2	SADDLER (BOOKLET) (UNREADABLE)-	(UNREADABLE) HARRIET	UNKNOWN	UNKNOWN	1816	UNKNOWN	UNKNOWN	1903	87	Marker broken - fallen- names unreadable. Booklet number 9: STATES HARRIET WAS MARRIED TO RICHARD WHO WAS A BRICKLAYER & POST MAN. HARRIET KEPT A SHOP	
South West	8	5 & 6	2	AKHURST	EMMA	UNKNOWN	UNKNOWN	1829	7	6	1895	66	MEMORIAL BROKEN & MISSING PARTS	
South West	3	2	2	BABBAGE	B. HERSCHELL	UNKNOWN	UNKNOWN	1814	22	10	1878	64	Husband of Laura, "of St Marys", number 10 in booklet his uncle W.W. Whitmore was a founder of SA arrived in 1851, he worked for the water works and reported on the Adelaide water supply. Also, appointed to build the railway from the city to Port Adelaide in 1856. St Mary's church warden & lay reader. Bought property off J.W. Daw in 1851 built a castle near St Marys street off Daw's road. grew grapes on his 223 acres.	
South West	3	2	2	BABBAGE	LAURA	UNKNOWN	UNKNOWN	1817	22	7	1899	82	Wife of Benjamin Herschel	
South West	6	18	1	BEAN	ROSA	UNKNOWN	UNKNOWN	UNKOWN	10	6	1917	UNKNOWN	None	
South West	4	5	1	BOWDEN	HANNAH NORTON	18	3	1842	5	9	1909	64	Wife of Hopkin Bowden	
South West	8	3 & 4	1	BURNER	CHARLES	UNKNOWN	UNKNOWN	1859	22	6	1882	23	Husband of Mary Burner	Young adult
South West	4	6	2	BURTON	LOUISA	UNKNOWN	UNKNOWN	1816	7	5	1858	42	Wife of Richard Francis	
South West	4	6	2	BURTON	RICHARD FRANCIS	UNKNOWN	UNKNOWN	1810	24	2	1874	64	Husband of Louisa	
South West	7	12	3	CARD	JOHN	UNKNOWN	UNKNOWN	1800	25	10	1872	72	Grandfather of Emily Mary Hooper	
South West	3	7	1	CATOR	HENRIETTA	UNKNOWN	UNKNOWN	1830	18	9	1852	22	Wife of Albemarle Bertle Cator Esq, number 13 in booklet: " died in or shortly after childbirth". Daughter of N.A. Knox a solicitor. Married on 23/12/1851 gave birth to a daughter (also Henrietta) on 12/09/1852 & died 6 days later. Her daughter survived	Died 6 days after childbirth
South West	8 & 9	15 & 16	6	CHALK	FANNY	UNKNOWN	UNKNOWN	1870	13	10	1891	21	None	

DATA FROM A SURVEY OF ST MARY'S ANGLICAN CHURCH CEMETERY-'LEASED' PLOTS WITH GRAVESTONES 1847-1927

South West	8 & 9	15 & 16	6	CHALK	GEORGE . E	UNKNOWN	UNKNOWN	1879	28	5	1904	25	None	
South West	8 & 9	15 & 16	6	CHALK	THOMAS	UNKNOWN	UNKNOWN	1874	17	12	1907	33	None	
South West	8 & 9	15 & 16	6	CHALK	MARY JANE	UNKNOWN	UNKNOWN	1836	28	6	1923	87	Wife of Thomas William	
South West	8 & 9	15 & 16	6	CHALK	THOMAS WILLIAM	UNKNOWN	UNKNOWN	UNKOWN	9	8	1927	UNKNOWN	husband of Mary Jane	
South West	4	10	2	DAW	WILLIAM	UNKNOWN	UNKNOWN	1793	3	4	1851	58	"Unfortunately Killed by a horse & dray", husband of Mary Ann, who was also killed by a horse & dray one year later.	**Accidental death** Headstone facing east in a north facing row, seemed to be propped up not in original location??
South West	4	10	2	DAW	MARY ANN	UNKNOWN	UNKNOWN	1805	4	3	1852	47	"Killed in a like manner" i.e., her husband William was killed by a horse & dray one year earlier	**Accidental death** Headstone facing east in a north facing row, seemed to be propped up not in original location??
South West	4	12 & 13	2	DAW	JOHN WICKHAM	UNKNOWN	UNKNOWN	1796 (OR 1805)	2	7	1872	(67 OR) 76	Plaque on path opposite grass, ROW 3 GRAVE 12 - Number 17 in booklet: gave land for the first church in 1842. Born in Kensington, London in 1796? ALSO, STATES DIED AGED 67 IN BOOKLET BUT GRAVESONE STATES 76 YEARS**.** Arrived at Glenelg on the Winchester in 23/09/1838 with his wife Ellen and 6 children. In London he bought 1000 acres of land in SA at one pound sterling per acre. by 1842 owned 40 cattle & horse on his land. Named St Mary's after St Mary's Abbots in Kensington.	REPEATED INFO ON PLAQUE & GRAVE STONE IN DIFFERENT AREAS OF CEMETERY!
South West	4	12 & 13	2	DAW	ELLEN ORIANNA	UNKNOWN	UNKNOWN	1806	27	4	1873	67	ALSO-Plaque on path opposite grass, ROW 3 GRAVE 12- wife of John Wickham Daws, arrived at Glenelg on the Winchester in 23/09/1838 with husband and 6 children.	REPEATED INFO ON PLAQUE & GRAVE IN DIFFERENT AREAS OF CEMETERY!
South West	9	16	1	DAW	ALFRED DONALD	UNKNOWN	UNKNOWN	UNKOWN	1	1	1911	UNKNOWN	None	
South West	5	4	1	DRAYTON	H.J.T	UNKNOWN	UNKNOWN	1845	11	4	1884	39	None	
South West	7	6 & 7	3	DUNMORE	GEORGE WILLIAM	UNKNOWN	UNKNOWN	1911	14	12	1923	11.9	son of J.E & E.I. DUNMORE	CHILD
South West	6	16	1	FYFFE	HENRY GEORGE	UNKNOWN	UNKNOWN	UNKOWN	10	1	1898	UNKNOWN	None	
South West	9	1 & 2	4	GRANT	JAMES BANNERMAN	UNKNOWN	UNKNOWN	1810	11	8	1887	77	Father of Robert Sinclair Grant	
South West	9	1 & 2	4	GRANT	ROBERT SINCLAIR	UNKNOWN	UNKNOWN	1864	11	4	1900	36	son of James Bannerman Grant	

South West	9	1 & 2	4	GRANT	MARGARET STUART	UNKNOWN	UNKNOWN	1825	29	1	1910	85		
South West	3	8 & 9	3	HAMILTON	RICHARD	UNKNOWN	UNKNOWN	1792	30	8	1852	60	"Leaving issue by Ann, six sons & three daughters" husband of Ann number 14 in booklet: Arrived in 1837. Established famous name in wine, arrived with 8 of 9 children on first voyage of Katherine Stewart Forbes. "father of SA wine industry"	
South West	3	8 & 9	3	HAMILTON	ANN	UNKNOWN	UNKNOWN	1789	30	4	1886	97	Wife of Richard, mother of 6 sons & 3 daughters	
South West	3	8 & 9	3	HAMILTON	ALFRED	UNKNOWN	UNKNOWN	1832	19	3	1895	63	"survived by wife Mary"	
South West	10	7	2	HAWKINS	HENRY GEORGE	UNKNOWN	UNKNOWN	1904	UNKNOWN	UNKNOWN	1914	10	None	Child
South West	10	7	2	HAWKINS	GWENDOLIN GRACE	UNKNOWN	UNKNOWN	1908	UNKNOWN	UNKNOWN	1916	8	None	Child
South West	8	19 & 20	2	HERRING	NIGEL CHARLES	14	4	1840	23	9	1893	53	Husband of Anna Lititia	
South West	4	9	1	HIRTLE	JAMES	UNKNOWN	UNKNOWN	1836	UNKNOWN	UNKNOWN	1857	21	Number 15 in booklet: buried on 27/03/1857: Lived in Marion, no other information.	
South West	6	11	3	HOOPER	MARY	UNKNOWN	UNKNOWN	1858	20	5	1868	10	NUMBER 4 IN BOOKLET: Daughter of Henry & Emma Hooper (died 14/09/1885 aged 62) he was employed (engaged) by the Weaver family? To accompany them to SA aged 16 yrs. Also, a 16 yr. old boy called Charles Mount Stephen was engaged to go to SA with this family. Married Emma. Hotel keeper of Bay road. Emma remembers him as "a kind and affectionate father" She is NOT buried in St Mary's	Child
South West	6	11	3	HOOPER	THOMAS	UNKNOWN	UNKNOWN	1879	15	1	1881	3	NUMBER 4 IN BOOKLET: SON of Henry & Emma Hooper (died 14/09/1885 aged 62) he was employed (engaged) by the Weaver family? To accompany them to SA aged 16 yrs. Also, a 16 yr. old boy called Charles Mount Stephen was engaged to go to SA with this family. Married Emma. Hotel keeper of Bay road. Emma remembers him as "a kind and affectionate father" She is NOT buried in St Mary's	Child
South West	6	11	3	HOOPER	HENRY	UNKNOWN	UNKNOWN	1823	11	9	1885	62	MARRIED TO EMMA, FATHER TO MARY & THOMAS. NUMBER 4 IN BOOKLET: (BURIED 14/09/1885 aged 62) he was employed (engaged) by the Weaver family? To accompany them to SA aged 16 yrs. Also, a 16 yr old boy called Charles Mount Stephen was engaged to go to SA with this family. Married Emma. Hotel keeper of Bay road. Emma remembers him as "a kind and affectionate father" She is NOT buried in St Mary's	
South West	7	12	3	HOOPER	EMILY MARY	UNKNOWN	UNKNOWN	1867	6	4	1890	23	Granddaughter of John Card	

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South West	3	18	4	HUMBERSTONE	WILLIAM (HENERY) (sic)	UNKNOWN	UNKNOWN	1800	UNKNOWN	UNKNOWN	1856	56	Plaque on path opposite grass. Number 19 in booklet states buried 10/03/1856 aged 56 years. WAS THIS THE SON? Married to Elizabeth Vanstone Humberstone, and Buried in the plot of Willian (royal navy) Humberson too? Had seven children	Conflicting information REPEATED INFO ON PLAQUE & GRAVESTONE IN DIFFERENT AREAS OF CEMETERY!
South West	3	18	4	HUMBERSTONE	ELIZABETH	UNKNOWN	UNKNOWN	1818/ 1819/ 1820?	5	5	1858	39/40/41?	Plaque on path opposite grass. Number 19 in booklet states buried 05/05/1858! PLAQUE STATES 1818 TO 1857 and ALSO... GRAVESTONE AT ROW 4 GRAVE 11: states died 05/05/1857 aged 41 yrs married to William Humberstone. WAS THIS THE DAUGHTER in law OF William senior (Elizabeth Vanstone Humberstone, and Buried in their plot too? Had seven children. MARRIED TO WILLIAM HENERY	Conflicting information REPEATED INFO ON PLAQUE & GRAVESTONE IN DIFFERENT AREAS OF CEMETERY!
South West	3	18	4	HUMBERSTONE	WILLIAM (Royal Navy)	UNKNOWN	UNKNOWN	1776 or 1785	8	3	1856	71 or 80	Plaque on path opp grass. STATES 1776 TO 1856 = 80 Yrs. **ALSO ...GRAVESTONE AT ROW 4 GRAVE 11**: states died 08/03/1856 aged 71! Number 19 in booklet. Also in booklet: lived at "Humberville", which was near Tonsley. Arrived in 1840, he was a ship carpenter & married to Mary.	Conflicting information REPEATED INFO ON PLAQUE & GRAVESTONE IN DIFFERENT AREAS OF CEMETERY!
South West	3	18	4	HUMBERSTONE	MARY	UNKNOWN	UNKNOWN	1795	2	4	1875	80	Wife of William (royal Navy) lived at "Humberville", near Tonsley. Arrived in 1840, husband was a ship carpenter	
South West	7	22	1	JAFFERY	ALEX	UNKNOWN	UNKNOWN	1806	27	3	1867	61	None	
South West	9	17	1	JAMES	DAVID MOSTYN	5	1	1914	24	9	1914	0.9	None	INFANT
South West	4	7 & 8	9	KELLY	WILLIAM	UNKNOWN	UNKNOWN	UNKOWN	21	2	1856	UNKNOWN	Son of James & Anna Maria	?
South West	4	7 & 8	9	KELLY	MARIA ANNA	UNKNOWN	UNKNOWN	UNKOWN	9	9	1860	UNKNOWN	Grandchild of James & Anna Maria	?
South West	4	7 & 8	9	KELLY	JAMES	UNKNOWN	UNKNOWN	UNKOWN	25	1	1872	UNKNOWN	Husband of Anna Maria	
South West	4	7 & 8	9	KELLY	EDITH	UNKNOWN	UNKNOWN	UNKOWN	15	3	1872	UNKNOWN	Grandchild of James & Anna Maria	?
South West	4	7 & 8	9	KELLY	ANNA MARIA	UNKNOWN	UNKNOWN	UNKOWN	29	8	1883	UNKNOWN	Wife of James	
South West	5	12	2	KUSCHE	MATILDA	UNKNOWN	UNKNOWN	1865	5	11	1869	4	DAUGHTER OF GUSTUV & WILHELMINE?	CHild
South West	5	12	2	KUSCHE	GUSTUV	8	2	1820	18	9	1909	89	Husband of Wilhelmine	
South West	7	18 & 19	2	LAFFER	EMMA	UNKNOWN	UNKNOWN	1827	11	6	1879	52	Wife of James Number 3 in Booklet:	
South West	7	18 & 19	2	LAFFER	JAMES	UNKNOWN	UNKNOWN	1800	15	3	1889	89	Husband of Emma Number 3 in Booklet: states arrived in 1849? Then states he was one of 200 passengers on Fairlee arrived 07/07/1840! Bought "Fairford" after the death of William Trimmer. Property id bounded by Sturt river, Marion & South Rd near Tonsley. No mention of wife or children.	

South West	6	13	2	MACKLIN	WILLIAM	UNKNOWN	UNKNOWN	1808	10	2	1873	65	Husband to Hannah	
South West	6	13	2	MACKLIN	HANNAH	UNKNOWN	UNKNOWN	1816	3	5	1875	59	Wife of William	
South West	9	8	2	MACKLIN	ROSE. H	UNKNOWN	UNKNOWN	1843	14	4	1902	59	wife of E.W.Macklin	
South West	9	8	2	MACKLIN	EDWARD	UNKNOWN	UNKNOWN	1839	29	12	1913	74	husband of Rose. H	
South West	8	9 & 10	4	McROSTIE	ALEXANDER JAMES	UNKNOWN	UNKNOWN	1861	1861	6	1921	60	Husband of Martha	
South West	8	9 & 10	4	McROSTIE	QUEEN	UNKNOWN	UNKNOWN	1889	26	6	1926	37	Daughter of Alexander James	
South West	8	13	1	MERRIFIELD	UNKNOWN	UNKNOWN	UNKNOWN	1835	4	11	1887	52	Youngest son of John Merrifield Esq of Brighton England	
South West	7	1 & 2	5	MILLER	JANE	UNKNOWN	UNKNOWN	1824	8	10	1890	66	Wife of James	
South West	7	1 & 2	5	MILLER	JAMES	UNKNOWN	UNKNOWN	1818	9	2	1894	76	Husband of Jane	
South West	6	1	5	MILLER	ELIZABETH JANE	UNKNOWN	UNKNOWN	1896	3	4	1898	2.2	Daughter of S & A. Miller	Child
South West	6	1	5	MILLER	ELLE MAUDE	UNKNOWN	UNKNOWN	1886	9	12	1904	18	Daughter of S & A. Miller	YOUNG ADULT
South West	7	1 & 2	5	MILLER	JOHN JAMES	UNKNOWN	UNKNOWN	1861	2	7	1914	53	Third son of late James & Jane, died at Claremont	
South West	6	1	5	MILLER	ANN	UNKNOWN	UNKNOWN	1863	15	5	1916	53	Wife of Stanley Miller	
South West	3	21	1	MOODY	ROSETTA	UNKNOWN	UNKNOWN	1832	UNKNOWN	UNKNOWN	1853	21	Plaque on path opposite grass. Number 21 in booklet states buried:11/053/1853. A servant girl arrived in 1850 on the Sultana. Travelled with her sisters Elizabeth age 22, and Barbara, 20 yrs. Elizabeth employed by Mr & Mrs Stevenson of North Adelaide for 3 mths. at 6 shillings a week. Barbara, employed by Mr Robershan? in Sturt at 5 shillings a week (both with food and lodgings) Rosetta had to stay in lodgings at 5 shillings a week with Mrs Laws of Albertson until she became strong enough to take employment.	Died young adult
South West	7	9 & 10	2	O'HALLORAN	GEORGE GREY	29	10	1846	3	6	1849	2.8	Youngest child of William. L. O'Halloran of clan Fergeal & wife Eliza. Number 5 booklet: Father of child: Captain William Littlejohn O'Halloran founder of the parish. Booklet states George Grey buried on 16/11/ 1869. He was originally buried at Christ Church, O'Halloran Hill but was exhumed and buried at St Mary's in 1869. also, gravestone states died in JUNE but booklet states November.	INFANT

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South West	7	9 & 10	2	O'HALLORAN	CAPTAIN WILLIAM	5	5	1806	15	7	1885	79	Number 5 booklet: WILLIAM Littlejohn was one of 15 children of Major General Sir Joseph O'Halloran & wife Frances. Born in Bengal. Married to Eliza. Arrived in Adelaide in the Lalla Rook on 09/08/1840. Founder of stringybark church in 1841. He & Dr Handasyd carted the materials for the church & raised the money (90 pounds). He may have been responsible for the parsonage house in 1848. Clerk of the Legislative Council & Auditor General. Family moved to the plain & lived at Clan Feargeal on Goodwood Rd. An obituary state "a vivid recollection of his tall & upright figure, whose military bearing & courteous address marked him out for what he was .a soldier & gentleman", Eliza died in London visiting their daughter 14/12/1884. They had eight children.
South West	8	11 & 12	2	OVENS	HARRY	UNKNOWN	UNKNOWN	1810	4	2	1885	75	Husband of Elizabeth
South West	8	11 & 12	2	OVENS	ELIZABETH	UNKNOWN	UNKNOWN	1811	7	11	1886	75	Wife of Harry
South West	6	21	2	PINCHBECK	JAMES	UNKNOWN	UNKNOWN	1819	3	1	1876	57	Husband of Sarah painter
South West	6	21	2	PINCHBECK	SARAH PAINTER	UNKNOWN	UNKNOWN	1819	31	10	1891	72	Wife of James
South West	7 & 8	24 & 25	6	RAGLESS	ELIZA	UNKNOWN	UNKNOWN	1832	12	7	1896	64	"FOUNDER & SUCCEEDING OWNERS - TONSLEY FARM, SOUTH ROAD 1869-1955"
South West	7 & 8	24 & 25	6	RAGLESS	RICHARD	UNKNOWN	UNKNOWN	1818	19	4	1901	83	"FOUNDER & SUCCEEDING OWNERS - TONSLEY FARM, SOUTH ROAS\D 1869-1955" number 29 booklet. Arrived with his parents & siblings in 1838. son of Elizabeth & John Ragless arrived on the EDEN 26/02/1838. In 1869 purchased "Findon" previously belonged to Henry WATTS (1839 - 1855) Renamed it TONSLEY PARK. His brother George is buried by the main gate of the Churchyard
South West	7	1 & 2	5	RODGERS	ELIZABETH	UNKNOWN	UNKNOWN	1819	10	5	1878	59	wife of Thomas
South West	7	1 & 2	5	RODGERS	THOMAS	UNKNOWN	UNKNOWN	1820	30	11	1886	66	Husband of Elizabeth
South West	9	11, 12 & 13	7	ROGERS	SAMUEL	UNKNOWN	UNKNOWN	1843	13	7	1891	58	"Third son of William& Ann of Tusmore Estate. Pioneer settlers at 'Ynoo' sheep station central Yorke Peninsular in 1851- Maitland streets are named after his family"
South West	9	11, 12 & 13	7	ROGERS	MARY JANE	UNKNOWN	UNKNOWN	1839	11	1	1898	60	Wife of T.W. Rogers
South West	9	11, 12 & 13	7	ROGERS	W.R..S.	UNKNOWN	UNKNOWN	1865	30	12	1901	36	Son of Mary Jane & T.W Rogers
South West	9	11, 12 & 13	7	ROGERS	T.W	UNKNOWN	UNKNOWN	1825	UNKNOWN	11	1901	76	Husband of Mary Jane

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South West	3	19	1	SLADDEN	BETSY NICHOLLS	UNKNOWN	UNKNOWN	1821	UNKNOWN	UNKNOWN	1853	32	Plaque on path opposite grass. Number 20 in booklet states buried: 26/05/1853. WIFE TO BAZEL. Kept the "Kangaroo Inn" on South Rd (now State Bank of SA). Arrived on The CYGNET via Kangaroo Island . Arrived at Nepean Bay, KI on 11/09/1837 from London on 20/03/1837. Arrived before the Buffalo ship. Had a son called Basel born 28/11/1848 & baptised at St Mary's 17/12/1848.	
South West	8	21	1	SMYTHE	WILLIAM CAVENDISH	UNKNOWN	UNKNOWN	1861	5	7	1926	65	None	
South West	8	7	2	STRANGEWAYS	THOMAS BEWES	UNKNOWN	UNKNOWN	UNKOWN	23	1	1859	UNKNOWN	Husband of Lavina Albina	
South West	8	7	2	STRANGEWAYS	LAVINA AlBINA	UNKNOWN	UNKNOWN	UNKOWN	22	10	1883	UNKNOWN	Wife of Thomas Bewes	
South West	8	17 & 18	2	STUART	ALEXADER	UNKNOWN	UNKNOWN	UNKOWN	12	11	1893	UNKNOWN	None	
South West	8	17 & 18	2	STUART	ROBERT	UNKNOWN	UNKNOWN	UNKOWN	27	8	1897	UNKNOWN	None	
South West	3	10	1	SWEETMAN	ANN	UNKNOWN	UNKNOWN	1813	UNKNOWN	UNKNOWN	1853	40	Previous married name or maiden name may have been Thomas. Number 16 in booklet: Killed by a falling tree while gathering firewood on her property opposite St Mary's church. Married to James. From Cornwall, arrived via Dublin on the William Nichol in July 1840 already a widow. She met her future second husband James on the ship, but he was married at the time. His wife died and so he marred Ann on 03/10/1843. They had five children, the youngest was 6 months old at the time of the accident. She was a servant to DR & Mrs Duncan before her marriage.	Accidental death Plaque on pathway opp grass
South West	6	6	3	THOMPSON	JOHN	UNKNOWN	UNKNOWN	1826	3	8	1875	49	NUMBER 7 IN BOOKLET: Lived at "Arnwood" on Marion Rd. Married to Elizabeth. Three daughters, Eliza born 1857, Ellen born 1863 & Carlotta born 1871. Burial records show that all of the girls died at the age of 19 in 1876, 1882 & 1889 respectively.	
South West	6	6	3	THOMPSON	ELIZA	UNKNOWN	UNKNOWN	1857	UNKNOWN	UNKNOWN	1876	19	"Beloved daughters of John & Elizabeth Thompson, died in the flower of their youth". Lived at "Arnwood" on Marion Rd. Had sisters: Ellen born 1863 & Carlotta born 1871. Burial records show that all of the girls died at the age of 19 in 1876, 1882 & 1889 respectively.	Young adult
South West	6	6	3	THOMPSON	ELLEN	UNKNOWN	UNKNOWN	1863	UNKNOWN	UNKNOWN	1882	19	"Beloved daughters of John & Elizabeth Thompson, died in the flower of their youth". Lived at "Arnwood" on Marion Rd. Had sisters: ELIZA BORN 1857 & Carlotta born 1871. Burial records show that all of the girls died at the age of 19 in 1876, 1882 & 1889 respectively.	Young adult

South West	6	6	3	THOMPSON	CARLOTTA	UNKNOWN	UNKNOWN	1871	UNKNOWN	UNKNOWN	1889	19	"Beloved daughters of John & Elizabeth Thompson, died in the flower of their youth". Lived at "Arnwood" on Marion Rd. Had sisters: ELIZA born 1857.& Ellen born 1863 .Burial records show that all of the girls died at the age of 19 in 1876, 1882 & 1889 respectively.	Young adult
South West	7	3,4 & 5	4	TOPHAM	ROBERT PETER	UNKNOWN	UNKNOWN	1882	22	1	1883	0.9	Son of J.J & E.J Topham	INFANT
South West	7	3,4 & 5	4	TOPHAM	JOHN JAMES	UNKNOWN	UNKNOWN	1852	3	11	1922	70	Husband of E.J Topham	
South West	4	1 & 2	3	TROTT	HANNAH	UNKNOWN	UNKNOWN	1821	5	1	1872	53	Wife of Charles	
South West	4	1 & 2	3	TROTT	EMILY	UNKNOWN	UNKNOWN		25	8	1875	14.8	Daughter of Charles & Hannah	Child
South West	4	1 & 2	3	TROTT	CHARLES	UNKNOWN	UNKNOWN	1815	6	8	1880	65	Husband of Hannah	
South West	7	14 & 15	1	WAITE	DAVID	12	5	1831	26	6	1901	70	Born in Fife, Scotland. Died at Malvern, Adelaide	
South West	5	14 & 15	8	WALKER	JAMES	UNKNOWN	UNKNOWN	1854	31	5	1865	11	Son of Robert & Caroline Walker of Spring bank (now called Pasadena)	Child
South West	5	14 & 15	8	WALKER	ROBERT	UNKNOWN	UNKNOWN	UNKOWN	UNKNOWN	UNKNOWN	1875	UNKNOWN	Father of James and husband of Caroline	
South West	5	14 & 15	8	WALKER	CHARLES NYBERG	UNKNOWN	UNKNOWN	UNKOWN	UNKNOWN	UNKNOWN	1879	UNKNOWN	Son in law to Robert & Caroline Walker	If son in law, why has he got the same surname?
South West	5	14 & 15	8	WALKER	CAROLINE	UNKNOWN	UNKNOWN	UNKOWN	UNKNOWN	UNKNOWN	1886	UNKNOWN	Wife of Robert	
South West	9	3 & 4	4	WEAVER	FANNY JANE	17	1	1883	9	4	1884	1.3	Child of A.F & Fanny Weaver	INFANT
South West	9	5 & 6	3	WEAVER	ALFRED	UNKNOWN	UNKNOWN		17	6	1891	89.6	"Arrived in SA in March 1839", husband of Jane	
South West	9	5 & 6	3	WEAVER	JANE	11	10	1804	19	5	1899	94.7	wife of Alfred	INFANT
South West	9	3 & 4	4	WEAVER	ALFRED FRANCIS	UNKNOWN	UNKNOWN	1832	27	4	1912	80	Husband of Fanny	
South West	9	3 & 4	4	WEAVER	FANNY	UNKNOWN	UNKNOWN	1841	30	12	1915	74	Wife of Alfred & mother of A.C & F.F Weaver	
South West	6	7	1	WILLIAMS	WILLIAM DARCES	UNKNOWN	UNKNOWN	1817	UNKNOWN	UNKNOWN	1867	50	"Priest of St Mary's 1863 to 1867" Number 8 in booklet: from publican to priest- arrived in WA in 1841 kept a tavern at Australind. Later also in Perth. Gave it all up to be lay preacher & total abstinence society. Made Deacon in Adelaide by the Bishop in 01/05/1852. ordained priest by 27th of same month. After his wife’s death (no name!) left boys school in WA moved to Adelaide with his daughter Isabella to be priest at St Mary's.	
South West	7	23	2	WILLSHIRE	JAMES DOUGHTY	UNKNOWN	UNKNOWN	1821	13	10	1897	76	Husband of Emily	
South West	7	23	2	WILLSHIRE	EMILY	UNKNOWN	UNKNOWN	1823	19	7	1899	76	Wife of James Doughty	
South West	5	14 & 15	8	WILSON	BILL	UNKNOWN	UNKNOWN	1895	9	8	1925	30	Husband of Ruby & Father of Elaine	?

South West	5	14 & 15	8	WILSON	CAROLINE	UNKNOWN	UNKNOWN	1857	12	4	1925	68	Daughter of late Robert & Caroline Walker	
South West	8	1 & 2	2	WOOD	JOSEPH	UNKNOWN	UNKNOWN	1805	19	6	1882	77	NUMBER 1 in booklet: Husband of Rebecca, who was a teacher at the school in the church. arrived in Adelaide on Brothers in 1850. Joe was a blacksmith. lived in a two-room dwelling close to the 1841 church	
South West	8	1 & 2	2	WOOD	REBECCA	UNKNOWN	UNKNOWN	1808	26	2	1888	80	NUMBER 1 in booklet: WIFE OF JOSEPH. A pioneer teacher. Paid from pew rents and a small charge to the pupils. Started after the first teacher George Gordon Wise in 1850. another teacher was Jim Willshire who arrived from NSW in 1844, taught at Darlington, Buried at ST Mary's. school was originally in the church and later in a schoolroom. was open util 1916. Arrived in Adelaide on Brothers in 1850. Joe was a blacksmith. lived in a two-room dwelling close to the 1841 church	
South West	3	1	2	WOOLDRIGE	HENRY JAMES (F.R.S.England)	UNKNOWN	UNKNOWN	1811	11	7	1902	91	Husband of Emily Georgina	
South West	3	1	2	WOOLDRIGE	EMILY GEORGINA	UNKNOWN	UNKNOWN	UNKOWN	25	3	1926	UNKNOWN	Wife of Henry James	Wife must have been a lot younger than husband if he died in 1902 at 91 years and she dies some 24 yrs. later
South West	5	13	2	WYLE	MARY	UNKNOWN	UNKNOWN	1881	28	12	1881	0.7	Daughter of Mary Ann & A.J Wyle	INFANT Did mother die after childbirth 7 months earlier??
South West	5	13	2	WYLE	MARY ANN	UNKNOWN	UNKNOWN	1854	23	5	1881	27	Wife of A.J. Wyle, youngest daughter of William & Hannah Macklin.	Childbirth?? Baby dies 7 months later
South West	7	16	2	YEO	JOHN STEVENS	UNKNOWN	UNKNOWN	1809	29	5	1875	66	FATHER OF John Benjamin	
South West	7	16	2	YEO	JOHN BENJAMIN	UNKNOWN	UNKNOWN	1842	2	8	1878	36	Son of John Stevens Yeo	
South West	9	7	1	YOUNG	FLORENCE ETHEL	16	3	1886	9	12	1886	0.9	None	
South West	5	1	5	YOUNG	ROSE ETHEL	UNKNOWN	UNKNOWN	1881	12	11	1902	21	"Eldest daughter of J.W & F. Young"	Young adult
South West	5	1	5	YOUNG	JOHN	UNKNOWN	UNKNOWN	UNKOWN	UNKNOWN	UNKNOWN	UNKNOWN	0.1	"Also, darlings babes of J.W & F. Young" No date of death but as eldest daughter died in 1902. Strong chance the "babes" died before 1927/ Also Gravestone in old section of the cemetery.	INFANT
South West	5	1	5	YOUNG	ALFRED	UNKNOWN	UNKNOWN	UNKOWN	UNKNOWN	UNKNOWN	UNKNOWN	0.4	"Also, darlings babes of J.W & F. Young" No date of death but as eldest daughter died in 1902. Strong chance the "babes" died before 1927/ Also Gravestone in old section of the cemetery.	INFANT

South West	5	1	5	YOUNG	CHARLES	UNKNOWN	UNKNOWN	UNKOWN	UNKNOWN	UNKNOWN	UNKNOWN	0.8	"Also, darlings babes of J.W & F. Young" No date of death but as eldest daughter died in 1902. Strong chance the "babes" died before 1927/ Also Gravestone in old section of the cemetery.	INFANT
South West	5	1	5	YOUNG	LILY	UNKNOWN	UNKNOWN	UNKOWN	UNKNOWN	UNKNOWN	UNKNOWN	1.3	"Also, darlings babes of J.W & F. Young" No date of death but as eldest daughter died in 1902. Strong chance the "babes" died before 1927/ Also Gravestone in old section of the cemetery.	INFANT

8.2. Paper 2 (Chapter 3)

Paper 2 did *not* have Excel supporting data.

8.3. Paper 3 (Chapter 4)

The following link will provide access to the Excel spreadsheets associated with paper 3.

- 8.3.1. Paper 3- S1 Excel supporting Data - Statistical Analysis: https://doi=10.1002%2Foa.3204&file=oa3204-sup-0001-Data_S1.xlsx

8.4. Paper 4 (Chapter 5)

Paper 4 did *not* have Excel supporting data.

All supporting information associated with paper 4 can be found in Chapter 5, section 5.4. 'Appendix to paper 4', pages 148-167, of this thesis.