THE WRIST: FROM ANATOMY TO ARTHROSCOPY

Gregory Ian Bain, MBBS, FRACS, FA(Ortho)A

Clinical Lecturer

Discipline of Orthopaedics and Trauma

University of Adelaide, Australia

November 2007

Thesis by publication submitted for the degree of Doctor of Philosophy, University of Adelaide.

TABLE OF CONTENTS

COPYRIGHT LIST

The following items from the thesis are subject to copyright:

- All figures in the thesis, with the exception of figure 1.2.
- All tables within the thesis text.
- All appendices from chapter 4 of the thesis.
- All attachments (thesis text, pages 217-280), the 12 peer review publications.
- All videos supplied on the thesis CD and video images used in the thesis text.

Greg Bain
1.11.2007

ABSTRACT

The work described in this thesis was carried out by the author to address perceived deficiencies in the knowledge of wrist anatomy, imaging and arthroscopy that limited the surgical treatment of wrist disorders. The thesis encompasses studies of normal anatomy, imaging of the abnormal wrist and the development of wrist arthroscopy.

At the commencement of this work problem areas identified, which were addressed, included (i) the morphology and kinematics of the normal wrist, (ii) imaging of scaphoid deformity and the clinical application of fluoroscopy in the management of the wrist disorders, and (iii) surgery of the wrist, which was usually performed as an open procedure, and the clinical application of wrist arthroscopy, which was in its first decade of development.

To address these deficiencies, a radiological study was undertaken to determine how the morphology of the lunate affected the kinematics of the scaphoid. Lunate morphology was demonstrated to be associated with scaphoid kinematics. The result of this finding is that it is now possible to predict scaphoid kinematics because lunate type can be determined from plain radiographs. An anatomical study of the triquetro-hamate joint was undertaken to determine the morphology of this joint and whether it is related to the lunate morphology. Two types of triquetro-hamate joint were identified but these were not associated with the morphology of the lunate. One type had a helicoidal configuration and the other was relatively flat. These morphological differences are likely to have implications for wrist kinematics.

To image deformity of the scaphoid, a standardised method of longitudinal computed tomography was developed. An inter-observer reliability study was undertaken to compare the previously reported intra-scaphoid angle to newly developed methods of assessing the humpback deformity. The height-to-length ratio and dorsal cortical angle were found to be more reliable than the intra-scaphoid angle. The concepts of partial volume averaging for the assessment of scaphoid fracture union and pre-operative templating of correction of scaphoid deformity were described.

The role of arthroscopy was investigated in a number of clinical conditions. Patients with Kienböck's disease were assessed to determine whether characteristic patterns of articular changes could be identified at arthroscopy. Based on the findings, a classification of these arthroscopic findings was developed and used to direct future treatment. A study of arthroscopically assisted reduction of distal radius fractures was undertaken, which included development of new arthroscopically assisted and mini-open reduction and fixation techniques. Post-operative articular deformity was found to be associated with an increased incidence of pain. Arthroscopic debridement for scaphotrapezotrapezoidal joint arthritis was demonstrated to be a safe and effective treatment, with a lower complication and re-operation rate than with previously reported open procedures. New arthroscopic methods of capsular release of the wrist, arthroscopically assisted drilling of intra-osseous ganglion of the lunate and arthroscopic debridement of the ulnar styloid were developed. Fluoroscopy was valuable in pre-operative assessment as well as the intra-operative management using these new techniques.

In summary, the work described in this thesis increases the knowledge of the normal and abnormal wrist morphology and advances the role of arthroscopy in the treatment of wrist conditions.

STATEMENT OF ORIGINALITY

This thesis contains material that has been published in peer-reviewed medical journals.

This work has not been accepted for the award of any other degree or diploma in any other university or tertiary institution except where specifically identified. To the best of my knowledge and belief, this thesis contains no material previously published or written by another person, except where due reference has been made in the text.

I have been the first or principal author of the publications that form the main body of the thesis. Co-authors of any of the papers have provided support for papers to be included in this thesis. The individual statements of the contributions of jointly authored papers are in the section titled "Statement of authorship and contribution".

I give consent to a copy of this thesis being made available for loan and photocopying following its deposition in the university library.

Gregory Ian Bain 1st November 2007

DEDICATION

This thesis is dedicated to my wife Katherine for her support throughout my professional life. She has made a major sacrifice to allow me to proceed with my ongoing interest in my professional and academic career. My dedication extends to our three children, Madeleine, Jack and Annabel, who continue to inspire me throughout all aspects of my life.

NOTE: This figure is included on page ix of the print copy of the thesis held in the University of Adelaide Library.

My wife Katherine, Jack, Annabel and Madeleine

To my father for, teaching me the importance of self-involvement and a persistent commitment to one's chosen cause. To my mother for compassion and empathy as the core values of being a doctor. Professionally my dedication extends to the many teachers who have given time and effort to advance my knowledge. However, their greatest contribution has been teaching by example, the concepts of which I have feverishly tried to grasp. I have endeavoured to use these teachings as a surgeon and doctor, but more importantly as a human being. To all of you I owe so much, the challenge now is to give to the next generation as you have given to me.

ACKNOWLEDGEMENTS

I am grateful for the leadership and direction provided by Professor James Roth, who inspired me to become an academic surgeon, despite all of its challenges. To Professor Graham King for his academic wisdom.

Brigadier Robert Atkinson has provided a supportive structure at Modbury Hospital, which helped create an environment that could nurture research. To all the registrars and fellows for their assistance with research and co-authoring of the peer review papers.

To Professor Don Howie and Professor David Findlay who supported the culmination of my work as a thesis within the university's framework. Don Howie who assisted with the development of conceptual thinking and appropriate narrative required for the thesis. For future projects, I can see that this teaching will extend further my academic career. I thank David Findlay for his support, encouragement and insight in development of the thesis and Dr Oksana Holubowycz who assisted with understanding and working through the administration of the university.

I am indebted to Mr Ronald Heptinstall for performing the independent assessments and research assistance. He has supported me over more than a decade in my quest to advance the scientific knowledge base and to complete the thesis. To Mr Robert Maurmo for collating the narrative of the thesis and Elisabeth Heptinstall for grammatical editing of the narrative of the thesis.

I was most fortunate to have access to cadaveric material at the University of Adelaide. I thank the friends and families of the loved ones whose bodies were donated. For preparing and providing the materials I thank Mr Wesley Fisk and the staff at the Discipline of Anatomical Sciences.

STATEMENT OF AUTHORSHIP AND CONTRIBUTION

This section provides a statement of the contribution of each author for all the peer review publications in the thesis. All co-authors have signed the statement of contribution.

Signed statements follow.

HAND & UPPER LIMB SURGEON

196 Melbourne St
North Adelaide SA
5006 AUSTRALIA
p +61 8 8361 8399
f +61 8 8239 2237

greg@gregbain.com.au
www.gregbain.com.au

18th September 2007

Dear Dr

Please find below a letter which is required to be submitted with my Thesis for my PhD by publication. It is a letter which acknowledges you as a co-author in papers which are included in my thesis.

The letter outlines my understanding of the contribution of each of the authors to the paper. If you are happy to sign this please do so and return it to me.

If you believe the letter is incorrect then please makes the appropriate changes and return it to me.

I would be grateful if the letter could be faxed to me on 618 8239 2237 as I require to have a written confirmation of your support for this paper.

Yours sincerely

Greg Bain
Shoulder, Elbow
Wrist and Hand Surgeon

GB/kh/consentletters1297

NOTE: Statements of authorship appear in the print copy of the thesis held in the University of Adelaide Library.

THESIS ORGANISATION

The thesis is presented in the following sections.

Introduction

The introduction provides background information on the topic of the wrist. This section concludes with the aims of the thesis, significance of the aims of the thesis and a list of the objectives of the thesis.

Literature review

The literature review covers those areas relevant to the research performed. It is divided into the three sections: anatomy, imaging and arthroscopy. The deficiencies in knowledge relevant to the research performed are then listed. The section concludes with a discussion on the linkages within the thesis and between the research projects.

Research undertaken

The thesis is arranged into several chapters under the headings of anatomy, imaging and arthroscopy. Within each chapter the relevant published papers are separately discussed. The discussion of each individual publication commences with the stated aims and objectives. The principles of study methodology and the main findings of the research project are presented. This is not intended to be a detailed restatement of the published paper but does provide the main points of methodological interest. This section concludes with the linkages between the various papers that comprise the thesis.

Conclusion

The conclusion is an overarching discussion on the main features of the thesis. It includes the significance of the findings, problems encountered and future directions of the work.

Publications

This section includes all the peer review publications that have been included in the thesis.

Videos

An image capture (single frame) of the video is in the written document. The actual videos of are on a CD in the back cover of the written version of the thesis.

LIST OF TABLES

This section provides a list of all of the tables within the thesis.

LIST OF FIGURES

This section provides a list of all of the figures within the thesis. The first number is the chapter in which the figure is referenced.

Figure 2.6 - Histological view of the carpus including the scapho-lunate ligament. From – Fogg, 2004.

Figure 2.7a,b – Dorsal view of a right scaphoid. With the rotating scaphoid there is a single dorsal ridge for insertion of the radioscaphoid (RS) ligament. In the flexing scaphoid there are 3 ridges for insertion of the radioscaphocapitate (RSC) and dorsal intercarpal ligament (DIC). The middle ridge is for attachment of the radioscaphoid (RS) ligament. Adapted from – Fogg, 2004.

Figure 2.8 – Lateral 3-D view of right scaphoid. In the rotating scaphoid (left) the radioscaphoid (RS) ligament attaches to the dorsal ridge of the scaphoid. The radiocapitate (RC) and dorsal intercarpal ligament (DIC) bypass and encircle the scaphoid. These act like a pulley and help control the position of the scaphoid but allow rotation. In contrast, in the flexing scaphoid (right), the radioscaphocapitate (RSC) ligament attaches to the scaphoid as does the dorsal intercarpal ligament (DIC) and act as rotatory restraints but allow flexion. From – Fogg, 2004.

Figure 2.9 – Diagrams of a left scaphoid looking from the radial aspect. Stylised diagram of the rotating and flexing scaphoid. Note in the rotating scaphoid that the dorsal intercarpal ligament (DIC) and radioscaphocapitate (RSC) do not attach to the scaphoid but act as a pulley. The volar scapho-trapezo-trapezoidal (STT) ligament has a narrow base on the scaphoid which helps to act as a point of rotation around which the scaphoid rotates. In contrast with the flexing scaphoid, the STT ligament has a wide base on the scaphoid. The radioscaphocapitate ligament (RSC) has an attachment to the scaphoid waist, over which it flexes.

Figure 2.10 – Dorsal anatomical cadaveric dissection of a left scaphoid comparing the two types. In the rotating scaphoid the dorsal intercarpal ligament (DIC) has a loose membranous (M) attachment to the scaphoid before passing onto the trapezium (Tm). In contrast in the flexing scaphoid the DIC has a strong attachment to the scaphoid and does not extend to the trapezium. From – Fogg, 2004.

Figure 2.11 – Cadaveric coronal section of a right wrist. Type 1 lunate which articulates with a unicondylar mid-carpal joint. This is similar to a hip joint. From – Fogg, 2004.

Figure 2.12 – Cadaveric coronal section of a right wrist. Type 2 lunate with a radial facet which articulates with the capitate and the ulnar facet which articulates with the hamate. This creates a bicondylar mid-carpal joint which is similar to a knee joint. From – Fogg, 2004.

Figure 2.13 - Correlation of scaphoid inclination index to scaphoid flexion index. From - Garcia-Elias et al., 1995.

Figure 2.14 - Radiographic measurements obtained in order to calculate the scaphoid indices. From – Garcia-Elias et al., 1995.

Figure 2.15 – Radiographical views of the right scaphoid. Percutaneous electrical stimulation was used to achieve union in this angulated scaphoid fracture. Seven years later, significant degenerative change associated with pain and limited extension caused the patient to return for re-evaluation. **A**, Anteroposterior view, note retained stimulation wire; **B**, lateral view; **C**, lateral tomogram, note improved detail of scaphoid anatomy; **D**, one year after cheilectomy, patient had improved motion and less pain. From - Amadio et al., 1989.

Figure 2.16 - Intrascaphoid angle. Lateral diagram of left wrist. A perpendicular line is drawn to the proximal and distal articular surfaces and the resulting angle is measured. From - Amadio et al., 1989.

Figure 2.17 - Photograph of operating room set-up for performing wrist arthroscopy. Image from private file.

Figure 2.18 - Dorsal wrist arthroscopy portals. The convention is to describe portals according to their anatomic location. The radiocarpal portals are numbered according to their relation to the extensor compartments, e.g. the 3 4 portal is situated between the third and fourth extensor compartments; the 6R compartment is on the radial side (R) of the Extensor Carpi Ulnaris tendon (sixth compartment). A=artery; DRUJ = distal radioulnar joint; MCR = mid-carpal radial; MCU = mid-carpal ulnar. From - Bain et al., 1997.

Figure 3.1 - Demonstrates the results obtained from the author's patient population. It is interesting to compare the author's results with those published by Garcia Elias (Figure 2.13) SII (scaphoid inclination index), SFI (scaphoid flexion index) The results for each individual are marked with a number to represent the lunate type, i.e. 1, 2 or 3 (intermediate). Red line is the correlation of the total group. The thin red line is for the correlation of the type 1 lunate wrists and thin black line is for the correlation of the type 2 lunate wrists.

Figure 3.2 - Hamate, dorsal view (A) a right type I hamate and (B) a type 2 hamate. The type 1 hamate with a deep hamate groove and a distinct distal ridge. The type 2 hamate has a shallow hamate groove and no distal ridge.

Figure 3.3 - Triquetrum, mid-carpal view (A) right type A triquetrum and (B) a type B triquetrum. The type A triquetrum has a helicoidal shape. The type B triquetrum has a flat dish shape.

Figure 3.4 - Triquetro-hamate joint, volar view (A) Type TqH-1 joint. Note the biconcave articulation between a type A triquetrum and type I hamate. (B) Type TqH-2 joint. Note the dish shaped articulation between a type B triquetrum and type II hamate.

Figure 4.1 - Longitudinal CT scan of the scaphoid with the wrist held in radial deviation. From - (Bain et al., 1995).

Figure 4.2 – The target sign. Longitudinal CT scan of the left wrist. The head of the capitate is between the proximal and distal poles of the scaphoid. It is objective evidence that the scan is along the longitudinal axis of the scaphoid. From - Bain et al., 1995.

Figure 4.3 - Humpback deformity. Longitudinal CT scan of the right wrist. The proximal pole of the scaphoid is extended and the distal pole flexed. It produces carpal shortening. From - Bain, 1999.

Figure 4.4 - Height-to-length ratio. A baseline is drawn along the volar aspect of the scaphoid. The length of the scaphoid along the baseline is measured, as is the height of the scaphoid perpendicular to the baseline. The height-to-length ratio is recorded as a percentage. From - Bain et al., 1998.

Figure 4.5 - Dorsal cortical angle. A line is drawn along the dorsal cortex of the proximal and distal halves of the scaphoid and the angle between these lines is measured. From - Bain et al., 1998.

Figure 4.6 - Partial volume averaging. A three-dimension "slice" of tissue is computed to produce a two-dimensional image. A non union which passes obliquely through a "slice" may appear united as there is some bone within the slice which will appear on the two-dimensional image as an incomplete union. From - Bain, 1999.

Figure 4.7 – Diagram demonstrating a longitudinal CT scan representation of right wrist. Pre-operative CT scan "template”. The trapezoidal bone graft and screw in situ is useful to determine the need for a structural bone graft, the preferred fixation screw, and to assess whether it should be inserted via a volar or dorsal approach. From - Bain, 1999.

Figure 5.1 - Arthroscopic classification of articular changes of Kienböck’s disease. Grade 0: All articular surfaces functional but may have synovitis. Grade 1: Non-functional articular surface in the proximal lunate. Grade 2: A non-functional articular surface of the proximal lunate and lunate facet. Grade 2b: Non-functional proximal and distal lunate. Grade 3: Non-functional proximal and distal articular surfaces of the lunate and lunate facets of the radius. Grade 4: All four surfaces are non-functional. From - Bain et al., 2006.

Figure 5.2 –The intra-articular fragments can be manipulated by 1) the arthroscopic probe, 2) K-wires introduced into the fragment and 3) intra-focal wires used to buttress the fragment. From – Mehta et al., 2000.

Figure 5.3 - London Technique. The articular surface is reduced, under arthroscopic vision, with “joysticks” and the arthroscopic probe. K-wires are advanced through the distal ulnar and into the subchondral level of the distal radius. The wires are removed from the radial side of the radius. From – Mehta et al., 2000.

Figure 5.4 - Mini-open volar approaches. Incision on the radial side of the wrist through the floor of the FCR tendon sheath. Incision on the ulnar side of the wrist was between the long flexor tendons and the ulnar neurovascular bundle. Retraction of the longitudinal structures allows the volar aspect of the distal radius to be identified so that K-wires can be advanced across the distal radius to provide stability.

Figure 5.5 – Arthroscopic view of distal radius fracture with intra-articular step. From – Bain et al., 1997.

Figure 5.6 – Arthroscopic view of distal radius fracture following reduction of the articular step. From – Bain et al., 1997.

Figure 5.7 – Arthroscopic view of the mid-carpal joint with probe in scapho-lunate interval to assess instability as reported by Geissler. From – Bain et al., 1997.

Figure 5.8 – Cadaveric coronal section of a left wrist with the arthroscopic portal in the STT joint. Note the close proximity of the radial artery.

Figure 5.9 - Cadaveric specimen demonstrating the dorsal STT portal ulnar to the EPL tendon. Note the radial nerve and radial artery to the radial side of EPL tendon.

Figure 5.10 - Arthroscopic view of the articular surface of the trapezium and trapezoid, with the cartilage seen between these 2 bones. From – Ashwood et al., in press.

Figure 5.11 - Arthroscopic debridement of the STT joint with a motorised resector. From – Ashwood et al., in press.

Figure 5.12a, b – Intra-osseous ganglion. Lateral view of left wrist (A) and AP view of left wrist (B). CT scan of the lunate demonstrating the exact position of the ganglion and a small cortical breach from which the ganglion arises. From – Ashwood et al., 2003.

Figure 5.13 – Interligamentous sulcus. Wrist arthroscopic view showing long radiolunate ligament (LRL) on the left and radioscaphocapitate (RSC) ligament on the right. From – Bain et al., 1997.

Figure 5.14 - Fluoroscopic confirmation of drill placement into the lunate (small arrow, drill in cannula; large arrow, arthroscope). From – Ashwood et al., 2003.

Figure 5.15 - Arthroscopic view of a burr in position to perform an arthroscopic debridement of the prominent ulnar styloid.

Figure 6.1 – Mechanism of injury. A flexing scaphoid with its rotational restraints. The mechanism of injury is a rotational injury to tear the rotational restraints.

Figure 6.2 - Plain radiograph of type 2 lunate wrist with STT joint degenerative arthritis.

Figure 6.3 - Fluoroscopic images of wrist. Type 1 lunate wrist on the top and type 2 on the bottom. The left images are in radial deviation, middle in neutral and right in ulnar deviation. The capito-hamate articulation is co-linear with the luno-triquetral articulation in ulnar deviation in the type 1 lunate wrist. In contrast, the capito-hamate articulation is co-linear with the luno-triquetrial articulation in ulnar deviation in the type 2 lunate wrist.

Figure 6.4 – Fetal wrist. A 45mm crown-rump fetal wrist with what appears to be a type 2 lunate, which articulates with the capitate and hamate. From Berger, 1998.

Figure 6.5 - The dorsal cortical percentile. A baseline is drawn along the volar aspect of the scaphoid. Perpendicular lines are drawn at the proximal and distal limits of the scaphoid. A dorsal line completes the box. A line is drawn through the fracture. Where the fracture line intersects, the dorsal line is identified. The distance from the proximal line to the fracture line (P) is measured. The distance from the fracture line to the distal line is measured (D). The dorsal cortical percentile is calculated and recorded as a percentage. (P/P+D). Image from Michael Smith.

Figure 6.6 – Normal scaphoid bone. Histology of osteocytes can be visualized within the lacunae. The fatty marrow between the trabeculae is structurally intact and viable. Image from Chris Carter.

Figure 6.7 - AVN scaphoid. Histology of necrotic scaphoid bone as indicated by empty lacunae, appositional new bone growth and granulation tissue replacing the marrow. Image from Chris Carter.

Figure 6.8 – Bridging trabeculi. CT scan with some bridging trabeculae between the proximal and distal fracture fragments.

Figure 6.9 – Pseudo-arthrosis of the scaphoid. Clearly separate fragments with no bridging trabeculi. Note increased radio-density of proximal pole.

Figure 6.10 - Fluoroscopic image confirms position of the drill bit, which has been placed into the lunate under arthroscopic vision.

Figure 6.11 – "Box concept". The arthroscopic 3D box with the multiple arthroscopic portals for viewing and instrumentation. This allows therapeutic surgery in any part of the joint. Image from private file.

Figure 6.12 - Cross-sectional anatomy of the wrist at the level of radial tuberosity with relationship of major nerves, UN, ulnar nerve; MN, median nerve (just distal to pronator quadratus). From – Verhellen et al., 2000.

Figure 6.13 - Nylon tape used to retract the extensor tendon off the dorsal capsule. Image from private file.

LIST OF VIDEOS

This section provides a list of all of the videos within the thesis. The first number is the chapter in which the video is referenced. The videos are contained in the CD in the back-cover of the thesis.

Video 2.1 - Arthroscopy of a patient with a partial deep tear of the TFCC. Note the superficial surface of the TFC, which provides a suspicion of the diagnosis. This was managed an arthroscopic debridement of the deep surface of the TFC within the DRUJ.

Video 2.2 - Infiltration of the mid-carpal joint with saline. Leakage of the saline from the 6R portal is due to leakage of the intracarpal ligaments (scapho-lunate or lunotriquetral ligaments).

Video 5.1 - Kienböck disease: Wrist arthroscopy view of the left wrist with a soft floating proximal pole of the lunate with adjacent synovitis. Full thickness cartilage defect of the lunate facet.

Video 5.2 – Wrist arthroscopy demonstrating a distal radius fracture. The radiocarpal joint is lavaged and a motorised resector is used to debride the clot and synovitis from the joint. The articular fragments are manipulated with the arthroscopic probe. In the background, the radial styloid can be seen to be manipulated with a pre-placed K-wire. Once an anatomic articular reduction is obtained, the 1.6mm K-wire is advanced into the cortex on the ulnar aspect of the metaphyseal radius. Further K-wires are used to stabilise the distal radius.

Video 5.3 – Scapho-lunate stabilisation. Arthroscopic view of the mid-carpal joint with scapho-lunate interval being reduced and stabilised with percutaneous K-wires.

Video 5.4 - STT arthritis. Arthroscopic view of the STT joint with eburnated bone on the distal aspect of the scaphoid and on the proximal aspect of the trapezium and trapezoid. A synovectomy of this joint can be performed with the aid of a motorised resector.

Video 5.5 – Inside-out volar radial portal technique: Wissenger rod is introduced through interligamentous sides to the radial side of FCR tendon.

Video 5.6 - Volar capsular release. Pre-operative range of motion of wrist contracture.

Video 5.7 - Volar capsular release video. Arthroscopic view showing volar synovitis is debrided to expose the volar capsule, which is released with cautery. The radial side of the RSC ligament is preserved to prevent ulnar-translocation.

Video 5.8 - Volar capsular release. Post-release manipulation.

Video 6.1 - Dorsal capsulectomy. Dorsal capsule being excised with the aid of basket forceps. In the background can be seen the white nylon tape retracting the extensor tendons.

Video 6.2 - Radiocarpal fusion. Bone graft harvested from distal radius and placed into debrided radiocarpal and mid-carpal joints. Steinman pin advanced from 3rd metacarpal into radius.