The Effectiveness of Surgical versus Conservative Treatment for Symptomatic Unilateral Spondylolysis of the Lumbar Spine in Athletes.

A thesis submitted by

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Abstract

Background

Spondylolysis is a common cause of low back pain in athletes. It remains unclear whether athletes with unilateral spondylolysis who undergo surgical repair are able to return to the sports field as effectively or faster than if they had conservative treatment.

Objectives

To determine the effectiveness of surgical fixation, performed after a trial period of conservative management, compared to the effectiveness of conservative management only for unilateral spondylolysis in athletes.

Inclusion criteria

Types of participants

Athletes with symptomatic unilateral spondylolysis of the lumbar spine.

Types of intervention(s)

Surgical interventions which attempted a direct repair of the pars interarticularis, compared to conservative management.

Types of studies

Experimental and epidemiological study designs were considered for inclusion.

Types of outcomes

The primary outcome of interest in this review was the ability to return to sport. The effectiveness of surgery on pain and overall function were secondary outcomes of interest.

Search strategy

A three-step search strategy that aimed to find both published and unpublished studies was utilized. The search was limited to studies published in the English language between 1 January 1970 and 1 September 2013.

Methodological quality

The studies were critically appraised using one of the standardized critical appraisal

instruments from The Joanna Briggs Institute.

Data collection

Details describing each study and results on effectiveness in promoting the outcomes of interest were extracted from papers included in the review using the standardized data extraction tool from The Joanna Briggs Institute.

Data synthesis

Due to the heterogeneity of the included studies, the results for similar outcome measures were not pooled in statistical meta-analysis. A narrative and tabular format was used to synthesize the results of identified and included studies.

Results

Five studies reporting results for the outcomes of interest were critically appraised and included in the review. Due to the paucity of data, studies were included regardless of whether their participants were exclusively athletes with unilateral spondylolysis or adults (athletes and non-athletes) with unilateral and bilateral spondylolysis. Sub-group analysis was used to distinguish the findings for the main participant group of interest, namely athletes with unilateral spondylolysis.

Conclusions

The limited evidence on the effectiveness of surgical treatment versus conservative treatment for unilateral spondylolysis in athletes does not allow any conclusions to be drawn about the relative effectiveness of surgery versus conservative treatment for facilitating rapid return to sport or a high level of post injury sporting level/performance. It does suggest however, that for adult athletes for whom conservative treatment has not been successful, surgery is likely to enable return to sport, reduce pain and promote overall function.

Implication for practice

Adult athletes that have failed conservative treatment who suffer pain and compromised functionality (including inability to play regular sport) can consider surgery to reduce their pain, increase their function and enable return to sport (Grade B). It does however remain unclear as to what level of sport they will be able to return to post surgery (Grade B).

Implications for research

A prospective case series design focused specifically on unilateral spondylolysis is required. Future research needs to be more specific in identifying athletes and the specific sports they participate in. More clarity is also required when describing return to sport as an outcome measure.

Keywords

athletes, conservative treatment, pars interarticularis, spondylolysis, surgical treatment

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.

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Chapter 1: Background to the study / systematic review

1.1 Introduction

The systematic review which forms the basis for this thesis was developed using the Joanna Briggs Institute (JBI) systematic review methodology for reviewing evidence on the effectiveness of interventions. The question it addresses is what the best available evidence suggests about the effectiveness of surgical fixation, performed after a trial period of conservative management, compared to the effectiveness of conservative management only for unilateral spondylolysis of the lumbar spine in athletes.

The JBI methodology for systematic review is specifically tailored to identify and synthesize healthcare primary research. It sees the purpose of systematic review not only as an academic pursuit, designed to contribute to knowledge, but also as a tool to inform practice and thereby enhance health outcomes.

The purpose of his thesis is two-fold; firstly to meet the requirements for the Master of Clinical Science degree, and secondly to provide scientific evidence that may be used by clinician's to improve their understanding and thereby improve outcomes for athletes with unilateral spondylolysis of the lumbar spine.

The first chapter of the thesis describes the context and background of the review. Section 1.2 introduces the health condition focused on in the review, unilateral spondylolysis and the debate and knowledge over how to manage and treat the condition. Section 1.3 introduces the method – namely systematic review – used in the dissertation and locates it in the evidence-based healthcare movement. Section 1.4 describes the motivation for the review and presents the systematic review objective and questions. The chapter concludes by outlining the structure of the dissertation.

1.2 Spondylolysis and unilateral spondylolysis in adults and athletes

Spondylolysis is a common cause of low back pain in athletes, especially amongst adolescents. The incidence of the condition in the general population is between 6%-

8%[1, 2], however in the athletic population the incidence has been reported to be as high as 47% [3]. Spondylolysis refers to a defect or fracture of the pars interarticularis of vertebrae, which can be either unilateral or bilateral. The pars interarticularis is the junction of the pedicle, articular facet and lamina.

Historically, stress injuries of the pars interarticularis were thought to be mostly bilateral[4] and were noted in young athletes competing in sports requiring repetitive lumbar extension movements such as gymnastics and swimming[5]. The growth of professional sport has seen more athletes exposed at a younger age to the repetitive actions which can lead to this condition. This, combined with great advances in lumbar spine imaging in the past 20 years has led to the understanding that unilateral spondylolysis is more prevalent than originally thought and that in sports such as cricket unilateral spondylolysis may in fact be just as common as bilateral spondylolysis [6, 7]. Studies using Magnetic Resonance Imaging (MRI) or high resolution Computerized Tomography (CT) scanning have estimated that between 32% - 48% of all cases of radiologically confirmed spondylolysis in athletes are unilateral [8, 9]. In cricket it has been shown that up to 55% of young fast bowlers may suffer from unilateral spondylolysis [10]. If this injury is not managed appropriately the resulting pain and disability may limit players significantly throughout their sporting careers [10, 11]. A large proportion of the research regarding unilateral spondylolysis has involved this specific group of athletes [6, 7, 10-13].

Unilateral spondylolysis occurs when repetitive stresses are placed on the pars interarticularis. The specific combination of repetitive extension, rotation and side flexion causes micro trauma to the pars interarticularis. The above mentioned combination of movements lead to a shear force on the pars interarticularis which causes stretching of the pars and eventually stress micro fracture [4]. With ongoing stress an incomplete fracture occurs which can lead to chronic non-union. The condition occurs most commonly at the L5 vertebral level [8]. The injury can cause significant pain and activity limitation, which can lead to extensive time away from sport [5, 7].

Despite growing knowledge regarding the epidemiology and etiology of unilateral spondylolysis, the optimum management of athletes with this condition remains unclear. It has been recommended by several review articles examining the evidence on treatment of unilateral and bilateral spondylolysis that conservative management including rest, activity modification and physiotherapy facilitate a patient's return to sports over time [4, 5, 14]. A study by Blanda et al. demonstrated that a 6 month protocol of non-operative management led to apparent radiographic union of the unilateral pars interarticularis defect in 87% of patients, however little mention was made to return to sport or clinical outcome of this specific group of patients [15]. Sys et al. noted similar outcomes for a subgroup of 11 patients with unilateral spondylolysis treated with lumbar bracing for an average of 16 weeks. These patients all achieved CT proven osseous healing of the fracture with most of the athletes able to return to a previous level of sport [9]. These studies indicate that conservative treatment of up to 6 months achieves positive results in most patients. However it remains unclear if surgery or ongoing conservative treatment is more beneficial for patients who do not respond to conservative treatments within 6 months, or even whether it would potentially be more beneficial for patients to have surgical intervention immediately after the initial diagnosis of the injury.

Various methods of surgical fixation have been used to treat spondylolysis, with surgical fixation always attempted only after an initial period of conservative management [4, 5, 14]. The general aim of surgical intervention is a direct repair of the pars interarticularis. In the past, spinal fusion was used as the first line of surgical treatment; however internal fixation devices have superseded spinal fusion as the gold standard surgical treatment [14]. Despite technological advances the role of surgical intervention and its effectiveness remains controversial, and it remains unclear whether athletes with unilateral spondylolysis are able to return to the sports field as effectively or faster than if they had conservative treatment.

1.3 Systematic review background

1.3.1 The evolution of systematic reviews as part of the evidence based healthcare movement

Over the past few decades we have seen an increasing emphasis placed on evidence based healthcare. Clinicians rely heavily on published literature to guide them in their day-to-day decision making. Even though evidence based medicine has helped grow our understanding and provided guidance for the management of many medical problems there are unfortunately some limitations in health research, and if the clinician making use of the research information is not aware of these they may not be offering the best possible care to their patients. Some of these limitations and difficulties include sources of bias, poor interpretation of results and misleading conclusions. In an attempt to account for some of these limitations, reviews of the literature were developed to pull together all the findings regarding a specific topic, critique these and then synthesize them into clinically meaningful, clear recommendations.

Gathering research and synthesizing the findings is the essence of the science of literature reviews [(16)]. Even though the need for this synthesis was recognized as far back as the 18th century, it was not until the 20th century that researchers began to develop clear methods for literature reviews [(16)]. In recent years these literature reviews have developed to become a more rigorous and transparent process. There are numerous variations of literature reviews, with subtle variations mainly in the degree of process and rigor between review types[(16)]. Traditional literature reviews in themselves have major drawbacks such as heavy reliance on the authors knowledge and experience, are often predominantly subjective, and are based on selective references chosen from the evidence [(17)].

The natural progression of simple literature reviews led to the development of systematic reviews, which aim to provide a more comprehensive, unbiased synthesis of all the relevant studies in a single document [(17)].

1.3.2 Systematic review features

A key feature of a systematic review is that it attempts to uncover the relevant evidence in its entirety, as opposed to only focusing on a limited cross section of the available literature [16, 17]. Another is the conduct of critical appraisal of the literature. A third is in-depth reporting of the entire review process, which allows the results to be readily reproducible, reduces bias and increases validity of findings.

A recently published series of articles describing systematic review identifies the following "defining features" of a systematic review [17]:

- clearly articulated objectives and questions for the evidence review and commonly publication of a protocol for the review prior to its initiation
- inclusion and exclusion criteria, stipulated in the protocol that determine the eligibility of studies
- a comprehensive search to identify all relevant studies, both published and unpublished
- appraisal of the quality of included studies, assessment of the validity of their results and reporting of any exclusions based on quality
- analysis of data extracted from the included research
- presentation and synthesis of the finding extracted
- transparent reporting of the methodology and methods used to conduct the review

Many of the above mentioned steps are present in conventional literature reviews in one form or another. The in depth reporting and the critical appraisal are often what differentiates the systematic review from other types of literature reviews[16].

The systematic review methodology can be tailored to the underlying research paradigm most appropriate to answer the review question, which directs whether a quantitative or qualitative systematic review is undertaken. Quantitative research in the field of healthcare looks at the effectiveness of an intervention for a given population, while qualitative research focuses specifically on participants experiences related to a specific phenomena of interest. The review included in this thesis looks at the effectiveness of a specific intervention, and hence was

undertaken using quantitative systematic review methods. The following section (1.4) offers a brief description of the steps involved in a systematic review, with specific emphasis placed on quantitative research. This facilitates understanding the steps used in the review reported in this dissertation. Various organizations, including the Cochrane Collaboration (see http://handbook.cochrane.org), the Centre of Reviews and Dissemination (http://bit.ly/1g9WoCq) and the Joanna Briggs Institute (http://joannabriggs.org) publish guidelines for best practice systematic review conduct.

1.4 Systematic review methodology: The essential steps

The conduct of a Systematic Review follows a step-wise process, starting with development of a review question. These steps are described below in more detail.

1.4.1 Developing the review question and inclusion criteria

The first step of a systematic review is the development of a clear research question. The research question sets the tone for the whole systematic review and guides the author in conducting the review [18]. The construction of the question will vary slightly, depending on whether quantitative or qualitative research is being reviewed. A widely accepted guide for assisting authors in developing a research question in quantitative effectiveness systematic reviews is the use of the mnemonic PICO, which includes four elements:

Population
Intervention
Comparison intervention
Outcomes

There are some variations of the PICO pneumonic available, including SPICE (Setting, Perspective, Intervention, Comparison, Evaluation) and SPIDER (Sample, Phenomenon of Interest, Design, Evaluation, Research Type) [19]. At JBI, PICO remains the preferred choice for question development. Table 1 provides an example of the application of the PICO pneumonic.

Table 1: An example of the use of the PICO pneumonic

Population	Athletes with unilateral spondylolysis of the lumbar spine
Intervention	Surgery
Comparison	Conservative treatment
Outcomes	Return to sport

In most quantitative reviews, the question asked is one of effectiveness. This generally involves looking at the effectiveness of a specific intervention, compared to the effectiveness of another intervention for a given medical problem in a specific population.

By setting the study up with a thorough and clear review question the researcher is then able to construct a review protocol. In the review protocol an overall plan that ensures scientific rigor and minimizes bias is laid out [18]. A key element of the protocol is defining the inclusion criteria for research articles. Clear and precise inclusion criteria need to be stipulated and justified to give the reader an understanding of the underlying processes and thoughts involved in the review [18]. As described by Stern et al. [18], and directed by the PICO research question, the following are elements which need to be considered and addressed when defining the inclusion criteria:

- types of studies to be included
- the intervention under investigation
- Any other interventions or treatments for comparison
- the outcomes
- the population
- publication language
- time period

An essential feature of the inclusion criteria is that it be as specific as possible which allows the research question to be accurately answered, but also allows replicability of the review [18].

1.4.2 Constructing a search strategy and searching for evidence

As a systematic review aims to incorporate *all* the evidence related to a specific research question, a clear, comprehensive and detailed search strategy is required. The search involves a standard process, and should look systematically across both published and unpublished literature [(20)].

The initial part of the search involves the running of multiple small searches using potential key words or phrases to test the potential outcomes of the search. By testing these search terms the author gets an idea of what literature is available which subsequently allows the author to maximize the search potential to obtain all the relevant evidence. This initial search is often broad and can be narrowed down as the search strategy is built further.

Developing a search strategy involves continual re-assessment and refinement [(20)]. It should be based on the research question and inclusion criteria, which then allows identification of the key terms. Once key words have been identified a logic grid can be set up where possible alternative terms for the key words can be identified. To conduct a comprehensive search, such as the one required in a systematic review, as many alternative terms as possible should be entered [(20)]. An example of a logic grid which was used in the systematic review for this thesis can be seen in Table 2. A separate logic grid needs to be created for every database that is searched. Once all the search terms have been collected the search can be undertaken across the selected databases.

Table 2: Example of a logic grid used during the literature search

Spondylolysis	Surgery	Lumbar Spine	Excluding	Limits
Spondylolysis[mh:noexp] OR pars interarticularis[tw] OR spondylolysis [tw] OR spondylolyses[tw]	repair[tw] OR fixation[tw] OR surgical*[tw] OR surgeon*[tw] OR surgery[tw]	Lumbar [tw]	Cervical[tiab] OR degener*[tiab] OR stenos*[tiab]	English humans 01/01/1970 - 07/09/2013

The comprehensive nature of a systematic review means that a search of a large number of databases should be undertaken. This usually starts with a search of the major databases related to the topic of interest, with further addition of other appropriate smaller databases. In a systematic review hand searching of reference lists of studies, or of specific journals are often used by authors to locate more studies which may be applicable to the research question [(20)]. In addition a comprehensive search should also conduct a search of the unpublished or *gray* literature.

As noted earlier a key feature of systematic reviews is the replicability of the study. Therefore a vital aspect is the reporting of the search strategy. Clear and transparent reporting of the search strategy should allow another researcher to follow the published search and arrive at similar results or conclusions [(20)]. The PRISMA guidelines (Preferred Reporting Items for Systematic Review and Meta-Analyses) is widely used as a guide for reporting search strategies [(20)], and this guideline dictates that the full search strategy for at least one major database be published along with the review.

1.4.3 Study selection and critical appraisal

Once the search for articles has been completed, study selection is the next major step. At this stage of the review articles that are relevant to the review question are screened and the relevant papers then critically appraised to ensure that any limitations of these are understood [21].

Study selection involves selecting the articles which merit critical appraisal from the citations found during the search. This is done using the pre-set inclusion and exclusion criteria [21]. Having a clearly defined research question and protocol assists in this stage and allows the researcher to more accurately select studies which are applicable to the topic. Once studies have been selected the full text of these are obtained and reviewed which allows thorough appraisal of the literature.

Critical appraisal has two main functions, firstly in excluding low quality studies, and secondly in identifying the strengths and weaknesses of the included studies [21]. At JBI several checklists have been designed and are used by researchers to ensure thorough and rigorous critical appraisal is completed. The strength and depth of critical appraisal is a significant indicator of quality in systematic reviews [21]. When looking at quantitative evidence the main aim of critical appraisal is to decrease the possibility of biased or misleading results. To help achieve this two reviewers often appraise the articles, and then discuss their findings, with the input of a third reviewer sought if there remains significant disagreements [21].

1.4.4 Data extraction and synthesis

After the appropriate studies have been identified from the literature and critically appraised the key data from the studies can be retrieved and then combined together to highlight findings. This process of data extraction and synthesis, combining findings from various studies, is another way in which systematic reviews extend beyond the simple subjective narrative reporting often seen in traditional literature reviews [22].

The extraction of data is done by reading the included articles and extracting the results relevant to the review question. To assist in this process standardized data

extraction tools are used to extract both descriptive and outcome data from the included studies [22].

In a systematic review, the synthesis makes up the results section of the review [22]. Where possible this is done as a meta-analysis in quantitative research. This involves statistically combining the results of a number of studies to calculate a single summary effect [22]. While this is preferred, it is not always possible especially if the studies vary significantly between each other, which is referred to as *heterogeneity*. When this is the case a narrative summary can be used to convey results and findings.

1.4.5 Presenting and interpreting findings

One of the main motivations for completing a systematic review is to allow the findings to have an impact on health care policy. For results and findings to be transferred from research to practice it needs to be presented in a clear and logical way. The readers of systematic reviews often have very different backgrounds and this needs to be taken into account when presenting the findings. As mentioned earlier, the PRISMA statement has become the international standard from presenting the finding of systematic reviews [23]. In line with the PRISMA statement two key features of the presentation of findings is the need for plain language and for transparency throughout the report [24]. This makes it easier for the reader to follow which can often be very technical details, and also shows clearly how the author came to their findings or conclusions.

1.4 Motivation and objectives

The main motivation for conducting this systematic review was to identify whether there is clear evidence regarding optimal management of unilateral spondylolysis of the lumbar spine in athletes, and more specifically whether either surgical or conservative management is more effective in managing the condition.

To reach this objective the following research questions were asked of the evidence in the review:

- Does surgical fixation of unilateral spondylolysis allow athletes to return to sports effectively?
- Does surgical fixation of unilateral spondylolysis allow athletes to return to sport faster than conservative management?

A search of the Cochrane Database of Systematic Reviews and CINAHL databases using the keywords unilateral spondylolysis, surgical versus conservative intervention and systematic review was undertaken to establish the existence of any recently published systematic review and/or protocols for review on the topic. No systematic reviews or protocols looking specifically at unilateral spondylolysis were identified. This systematic review therefore, provides sports rehabilitation practitioners, patients suffering the condition and other decision makers with the first synthesis of the available evidence on the effectiveness of surgical intervention compared to conservative management for unilateral spondylolysis in athletes.

Chapter 2: Method of the Systematic Review

As explained in chapter 1, best practice in systematic review methodology is to develop and publish a protocol for the review to be conducted. A protocol for the systematic review reported in this dissertation was developed and published in the Joanna Briggs Library of Systematic Reviews and Implementation Reports [25] and has been appended as Appendix 1.

The following chapter highlights and discusses the specific methods used in the systematic review on which this thesis is based, starting with the specific inclusion criteria and following through to a description of the search strategy and method of critical appraisal.

2.1 Inclusion criteria

2.1.1 Types of participants

This review considered studies in which participants were athletes with symptomatic unilateral spondylolysis of the lumbar spine. Due to the limited literature available, studies which stated explicitly that the participant population included both adult athletes with unilateral spondylolysis and athletes with bilateral spondylolysis were also considered for inclusion. Studies which did not specify whether spondylolysis was either unilateral or bilateral were not considered.

Athletes were defined as individuals under the age of 50 competing in regular organized sporting activities. Both professional and amateur athletes were considered. Studies with a mixed population group of athletes and non-athletes were considered for inclusion. Participant coverage was not restricted to any particularly type(s) of sport. For participants to be included in the review, unilateral spondylolysis had to be radiologically diagnosed in athletes with back pain using High Resolution CT scanning, MRI or by Single-photon Emission Computed Tomography (SPECT) scanning. An inclusive approach was adopted with respect to the geographical location of studies with participants from all countries and health care settings considered. Only studies where participants had first undergone a trial of

conservative treatment prior to surgical intervention were considered.

2.1.2 Types of intervention(s) and comparators

The interventions considered in the review were surgical interventions which attempted a direct repair of the pars interarticularis. Even though direct repair in the form of Buck's Repair is the most widely recommended surgical treatment for spondylolysis, other surgical techniques including segmental wire fixation and pediculolaminar hook screws also shown to be effective [(14)] were considered. Given that this is a rare procedure and that spondylolysis procedures are only completed in specialist spinal surgery units, it is natural that the surgeries will only be performed by highly qualified specialists and therefore no studies were excluded on the basis of who performed the surgery.

The comparator was conservative treatments commonly used to treat unilateral spondylolysis in athletes and allow return to sport including, but not limited to rest, activity modification, bracing, lumbar stability exercises, pharmacological treatment and physical therapy.

2.1.3 Types of studies

This review considered both experimental and epidemiological study designs including randomized controlled trials, non-randomized controlled trials, quasi-experimental, before and after studies, prospective and retrospective cohort studies, case control studies, and analytical cross sectional studies for inclusion.

This review also considered descriptive epidemiological study designs including case series, individual case reports and descriptive cross sectional studies for inclusion.

2.1.4 Types of outcomes

The primary outcomes of interest in this review were:

- ability to return to sport (including in particular the length of time between treatment – conservative treatment/operation and return to sport)
- return to pre-injury sporting level

All measures for these primary outcomes were considered, including subjective reporting from either the athlete or the researcher in response to the following question "Was the athlete able to return to sport?"

The effectiveness of surgery on pain and overall function were secondary outcomes of interest. This was measured using various validated functional pain or disability scales specific to low back injuries. The Oswestry Disability Index (ODI) is commonly used to review the effectiveness of interventions in subjects with low back pain. This comprehensive questionnaire looks at the impact of low back pain on all aspects of life including activities of daily living, social life, sleep and work capabilities[26]. The Short Form (SF) 36 Health Survey is a more global assessment of health and is not specifically focused on low back pain however is also widely used to quantify the impact of a specific injury (in this case spondylolysis) on the individual's overall sense of well-being[27]. Other measures of general function or health were also considered, including specific low back pain scales that are often created by subspecialist research groups or associations. Examples include the Japanese Orthopedic Association Score, The Quebec Back Pain Disability Scale and the Roland Morris Low Back Pain and Disability Questionnaire. As with the ODI, these tools measure the impact of the injury on various aspects of a patient's life with a general focus on activity limitation.

The literature suggests that the ideal follow-up period for accurate measurement of the outcomes of interest for the population of interest in this review is two years. In light of the small size of the evidence base identified to address the questions of the review, all studies that met the inclusion criteria described above were considered regardless of the follow up time and regardless of the scale used to measure the outcomes of interest.

2.2 Search strategy

A three-step search strategy that aimed to find both published and unpublished studies was utilized in the review. An initial limited search of PubMed and CINAHL was undertaken followed by analysis of the text words contained in the title and abstract, and of the index terms used to describe articles. Secondly, a search using all identified keywords and index terms was undertaken, across all databases. Thirdly, the reference lists of identified reports and articles were searched for additional studies.

The following databases were searched to identify studies published in the commercial literature (black literature):

PubMed

CINAHL

Cochrane (CENTRAL)

Scopus

Centre for Review and Dissemination databases

PEDro

EMBASE

To identify studies conducted but not published in the commercial literature (i.e. grey literature) the following were searched:

MedNar

ProQuest Dissertations and Theses

Given that the surgical techniques used today and considered in the review were developed in the early 1970's, the date limitation for the search of studies was 1 January 1970 - 1 September 2013.

Publication in the English language was a second limitation applied in the database searches.

Examples of initial keywords used in the exploratory stage of the search for studies

in electronic databases were: spondylolysis, pars interarticularis, stress injury, fracture, surgical treatment, conservative treatment, athletes.

Informed by the findings from the initial exploratory searches in the range of databases to be covered, further key words were identified and a detailed search strategy developed and implemented for each database. The search strategies used to search the leading databases is listed in Appendix II.

Using the search strategy, records were identified from the above mentioned databases. The results obtained from each database search were electronically imported into a citation manager (EndNote), where the results from all the databases were pooled together into a single library.

2.3 Assessment of quality of included studies

The methodological quality of considered studies was assessed by two independent reviewers using one of the standardized critical appraisal instruments from the Joanna Briggs Institute's Meta-Analysis of Statistics Assessment and Review Instrument (JBI-MAStARI) for appraising observational studies, namely the Descriptive / Case Series Studies tool (Appendix III). One of the studies included for appraisal was a before and after study[28] and was also appraised using the observational study appraisal tool in the absence of there being a JBI critical appraisal tool tailored for appraisal of before and after studies. Some may argue that it would have been more appropriate to appraise the before and after study with the tool for experimental and quasi-experimental study assessment. The classification of study designs and selection of appropriate appraisal tools for quasi-experimental studies and observational studies is often not a clear distinction. Had the before and after study been appraised using the JBI tool for assessing randomized controlled trials and quasi-randomized controlled trials, the study would have been classified as being of poorer quality. This would not have affected the results, conclusions or recommendations (for research and/or practice). Any disagreements that arose between the reviewers were resolved through discussion, with the input of a third independent reviewer for the resolution of any disagreements not required.

2.4 Data collection

Details describing each study and results on effectiveness in promoting the outcomes of interest were extracted from papers included in the review using the standardized data extraction tool from JBI-MAStARI (see Appendix IV). In addition to extraction of the results for outcomes relevant to the review objectives and questions the information extracted included details about the interventions, populations and method of the included studies. Where data was missing or unclear, authors were contacted. Three of the studies that were identified for inclusion in the review included athlete participants who had unilateral spondylolysis and athletes with bilateral spondylolysis in a single group and did not conduct sub-group analysis to distinguish the outcomes for the two groups. The authors of these were contacted and one of the authors for one of the studies provided the required data for the unilateral spondylolysis patients of interest in the review. There was no response from the other authors.

2.5 Data analysis and synthesis method

For studies reporting dichotomous outcome measures, data was extracted from the included studies on the number of athletes who were able to return to sport out of the total study sample and proportions calculated. Data was also extracted where possible on the length of time before return to sport post intervention. The lack of measurement of the level of activity/satisfaction with sport following intervention emerged as a major limitation of the studies included in the review, with no measures identified to address this aspect of the review question. For the outcomes expressed in continuous data, means and their 95% confidence intervals were extracted from included papers and analyzed. Due to heterogeneity in the included studies, the results for similar outcome measures were not pooled in statistical meta-analysis using JBI-MAStARI. Instead, a narrative and tabular format was used to display the results of this review.

With respect to sub-group analysis, as a number of the studies included in the review (2/5) included a mix of athletes and non-athlete participants with unilateral and bilateral spondylolysis, the analysis considered firstly the measures of effect for all

participants (unilateral and bilateral spondylolysis, athletes and non-athletes) and then secondly, for the patients that could be identified as athletes having only unilateral spondylolysis. The authors had intended to conduct sub-group meta-analysis to examine differences in the effectiveness of surgical treatment for unilateral spondylolysis for different kinds of athletes but data did not permit this analysis.

Chapter 3: Results from the Systematic Review

The objective of the review was to systematically review the evidence to determine the effectiveness of surgical fixation, performed after a trial period of conservative management, compared to the effectiveness of conservative management only for unilateral spondylolysis in athletes. The following chapter presented the findings of the review on the questions of: Firstly, is surgical intervention or conservative management more effective in supporting the athlete to resume pre-injury function?; Secondly, does surgical fixation of unilateral spondylolysis allow athletes to return to sport and return to sport faster when compared to conservative management?

The results on effectiveness, which are preceded by a description of the studies identified, are presented by outcome.

3.1 Description of studies

3.1.1 Search and study selection

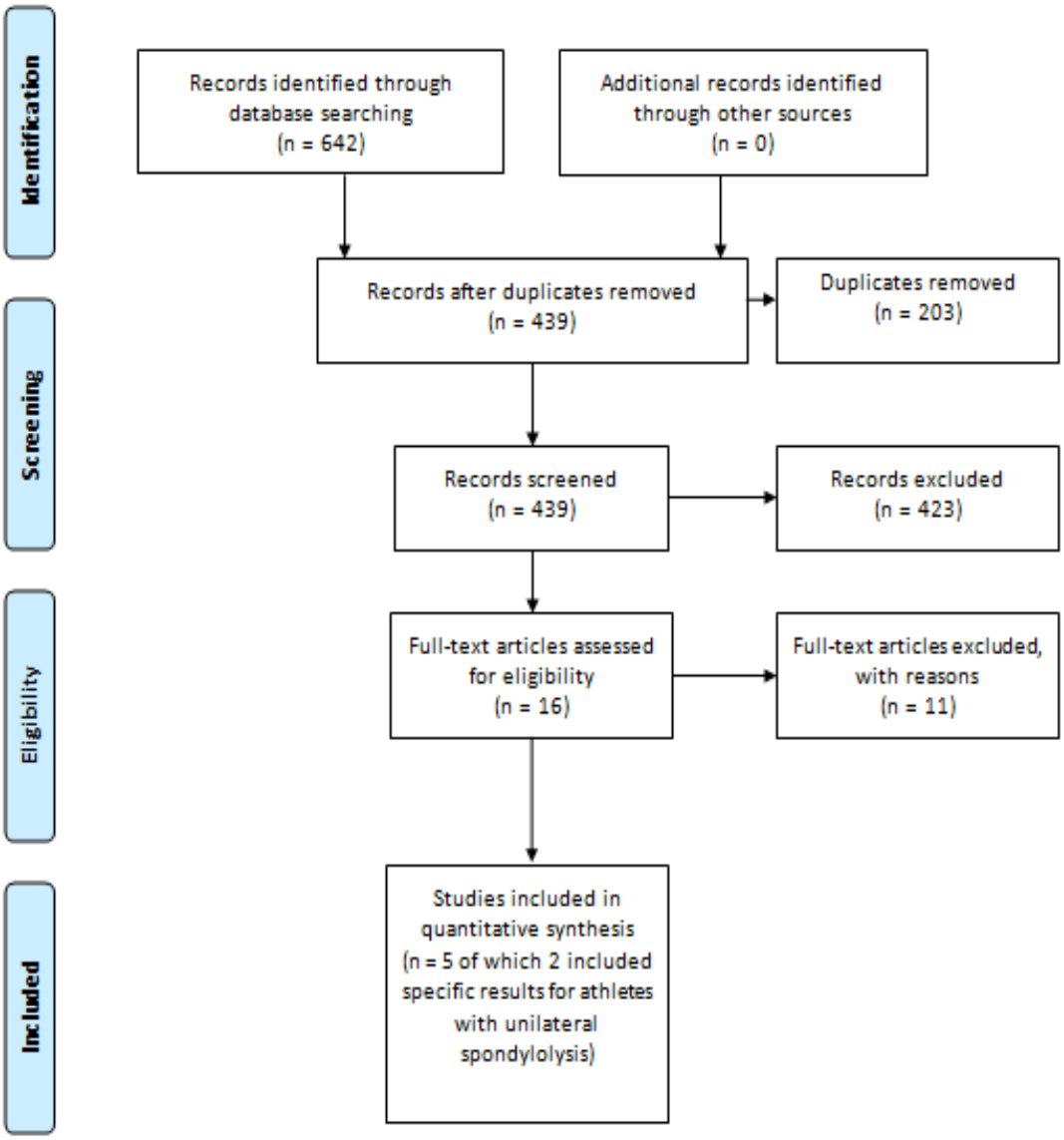
A total of 642 articles were identified from the search for commercially published literature in the selected databases and search for grey literature. After removal of 203 duplicates, 439 articles remained for title and abstract screening.

The screening process involved individually viewing the article title and/or abstract against the review inclusion criteria and excluding those records that clearly did not meet the inclusion criteria. A total of 423 records were excluded on screening leaving 16 for full text review. All 16 studies included athletes as at least a proportion of the participant population, and all participants had spondylolysis of the lumbar spine (either unilateral or bilateral). Following further review of the articles extracted for full text examination, 11 were excluded for not meeting the inclusion criteria leaving five studies [11, 28-31] for critical appraisal. Appendix V lists the 11 excluded studies and reasons for their exclusion. All five of the studies that were critically appraised were included in the review regardless of their methodological limitations, whether they focused exclusively on patients with unilateral spondylolysis or included both patients with unilateral and bilateral spondylolysis and whether they included

only athletes or a mix of athletes and non-athletes.

Figure 1 presents an overview of the search and selection process in the form of a PRISMA diagram.

Figure 1: PRISMA Flow Diagram of Search and Study Selection Process



3.1.2 Key characteristics of included studies

Below, the key characteristics of the five [11, 28-31] identified and included studies as a set are described. Table 3 provides a summary of the characteristics by study.

Table 3: Characteristics of included studies

Study	Design/Study Type	Outcomes Measured	Follow-up	Participants and Setting	Intervention and Comparison	Comment
Clegg, T. Carreon, L. Mutchnick, I. Puno, R., 2013	Descriptive Study: Retrospective case series review	Return to Sport ODI SF-36	21.7 months (SD = 5.5 months)	49 participants (25 male, 24 female) consisting of a mix of athletes and non-athletes. Mean age 17.7 years ranging from 10-22. Of the 49 patients, 8 had unilateral spondylolysis of the lumbar spine, while 41 had bilateral spondylolysis. Of the 8 patient with unilateral spondylolysis, 6 were athletes. Study was conducted at a specialist spinal surgery centre in Louisville, Kentucky, USA 2002-2009.	Surgical Repair (n=49). (Unilateral=8, bilateral =41) No Comparator group	Intervention group only, no comparator group. Population mix of athletes and non-athletes
Debnath, U. K. Freeman, B. J. Gregory, P. de la Harpe, D. Kerslake, R. W. Webb, J. K., 2003	Descriptive Study: Prospective case series	Return to sport ODI SF-36	2 years	22 athletes (15 male and 7 female). Mean age of 20.2, with a range from 15-34. Of the 22 patients in the study 15 had bilateral spondylolysis, and 7 had unilateral spondylolysis. Study was conducted at a university hospital in Nottingham, U.K 1994 - 1999.	Surgical Repair following trial of conservative treatment (n=22). (unilateral=7, bilateral=22) No Comparator group	Specific results for participants with unilateral spondylolysis who underwent surgical intervention not provided in the study. All follow-up results for unilateral spondylolysis and bilateral spondylolyis presented as a single cohort. Intervention group only, no comparator group.
Debnath, U., Freeman, D.,	Quasi-Experimental Study	Return to Sport	2 years	42 patients (31 male and	Surgical Repair following 6 months trial of conservative	Conservative group

Grevitt, M., Sithole, J., Scammell, B., Webb, J., 2007		ODI SF-36		11 female).Average age of 20 with a range from 14-35. 32 patients were involved with sporting activity at various levels, and 10 were not. All 42 participants had unilateral spondylolysis of the lumbar spine. Study setting was in a specialized spinal surgical centre, based at a university hospital in Nottingham, U.K 1995 - 2004.	treatment (n=8 athletes). (unilateral=8, bilateral=0) Conservative treatment only i.e. full recovery after 6 month trial of conservative measures (n= 24 athletes, n=10 non-athletes)	consisted of mix of athletes and non-athletes. Surgical group athletes only.
Hadcastle, P. H., 1993	Descriptive Study: Retrospective review of case series.	Return to sport (cricket)	At least 6 months post surgery, however not specified clearly	23 male cricket fast bowlers aged 15-25 (mean 20.9 years). Within the group 13 were managed with conservative treatment, and 10 underwent surgical repair. Of the 10 patients who underwent surgical repair 5 had bilateral defects and 5 had unilateral defects. Single author study based in Western Australia 1988 - 1991.	Surgical Repair following trial of conservative treatment (n=10). (Unilateral=5, bilateral=5). Conservative treatment only i.e. full recovery after 6 month trial of conservative measures (n=13)	Specific results for participants with unilateral spondylolysis who underwent surgical intervention not provided in the study. All follow-up results for unilateral spondylolysis and bilateral spondylolyis presented as a single cohort.
Ranawat, V., Dowell, J., Heywood-Waddington, M., 2003	Descriptive Study: Retrospective case series review	Return to Sport Subjective reporting of outcome categorized into excellent/good/poor based on stipulated criteria	Average of 5 years and 8 months (range 1 year 10 months - 10 years).	18 male professional cricketers contracted to a single English County Cricket Club. The average age of the patients was 20.8 (range18-31 years). 9 of the 18 patients had unilateral spondylolyis and 9 had bilateral spondylolysis. Study conducted via an Orthopaedic department in Essex, U.K. 1983-2001	Surgical Repair following trial of conservative treatment (n=10). (Unilateral=4, bilateral=5, other=1) Conservative treatment only i.e. full recovery after 6 month trial of conservative measures (n=8)	Specific results for participants with unilateral spondylolysis who underwent surgical intervention not provided in the study. All follow-up results for unilateral spondylolysis and bilateral spondylolyis presented as a single cohort.

3.1.2.1 Types of studies

All five of the identified and included studies were descriptive studies. One study [28] was a before and after study, while the other four [11, 29-31] were case series studies. Three [11, 29, 31] of the five studies involved a retrospective review of clinical data, while two [28, 30] were prospective studies.

Case series studies involve a detailed description of intervention and outcomes of participants with a particular condition of interest, which in this case was athletes (and non-athletes) with unilateral spondylolysis of the lumbar spine. Case series are useful for conditions which are not very prevalent, or when a very specific intervention is analyzed. Due to the specific nature of this injury and intervention it is not surprising that either case series, or single case reports dominated the research base found.

A strength of case series studies is that the relatively small number of participants facilitates detailed description of the specific outcomes for the participants. This is clearly evident in the selected studies. An example is the study by Clegg et al. [29] where the individual demographics and outcome data was available for analysis.

A weakness of case series and case studies is that they are characterized by multiple sources of bias, which is widely demonstrated throughout the included studies (see assessment of quality based on the JBI-MAStARI tool for appraising descriptive studies in Table 5). These include lack of blinding, self-reporting of results, lack of randomization and no standardized protocols. Case series does not always allow for a comparison to be made between groups. These limitations of case series are demonstrated in Table 5 which looks at critical appraisal of the studies using the JBI-MAStARI tool for appraising descriptive studies. Overall the five studies included for appraisal scored either poorly or 'not applicable' in Q1, Q5 and Q7 which related to randomization, and group comparison.

A further limitation of case series studies is that because the data is often retrospective there is not a clear protocol for the studies. An example of this in the

literature is the great variation seen with what was termed as conservative treatment by the studies. In addition, often outcome measures were not defined clearly, especially with regards to return to sport.

3.1.2.2 Participants and setting

Out of the five studies, only one [28] included participants with unilateral spondylolyis only. For the remaining four studies, only a proportion of the participants had radiologically proven unilateral spondylolyis while the remaining participants had either bilateral or non-specified spondylolysis. In one study [30], 7 of the 22 included participants had been diagnosed with unilateral spondylolyis. In another [29], 8 of 49 had unilateral spondylolysis, however the data and outcomes for this cohort of participants was obtained separately from the authors and hence the other participants who did not meet the systematic review criteria were not included in the analysis of results. In the third study [31], half (9/18) had unilateral spondylolysis and the fourth study [11] had 5 out of 10 patients in the surgical group who were diagnosed with unilateral spondylolysis, however the authors did not specify how many patients in the conservative group had unilateral spondylolysis.

Three [11, 30, 31] of the five studies included exclusively athletes as their participants. In one [28], 32 out of the 42 participants were athletes, however the outcomes of both the athletes and non-athletes were separately reported. In Clegg et al. 2013 [29], it was not clearly specified how many of the 49 participants were athletes, however upon contacting the author further information was obtained which indicated that of the eight participants with unilateral spondylolysis, six were in fact athletes, with the individual outcomes of these athletes made available by the authors for this review. Hence, looking across the studies as a whole, there were 113 participants of which 101 were identifiable as athletes and 71 had been diagnosed with unilateral spondylolysis. As indicated not all the participants from the studies included for data synthesis were athletes, however the specific results from those participants who underwent surgery could be obtained and hence athletes were isolated and included for sub-group analysis throughout the systematic review. This allowed specific conclusions regarding effectiveness of treatment to for athletes specifically to be made. The size of the participant samples ranged from 8 [29] to 42 [28].

The age of the athletes across the studies ranged from 10-35, with mean ages of 17.7[29], 20.2[30], 20[28], 20.9[11] and 20.8[31] respectively.

With respect to the kind of athletes in the participant populations of studies, in two of the studies [11, 31] the athletes were exclusively cricket players, more specifically cricket fast bowlers. In the remaining three studies[28-30], the athletes were involved in a wide variety of sports including cricket, football, gymnastics, tennis, hockey, golf and track and field athletics. The large number of athletes from a cricketing background was expected as cricket fast bowling closely reproduces the forces described in the background of this review required to cause injury to the pars interarticularis which leads to unilateral spondylolysis.

Of the 113 participants, 94 (83%) were male, compared to only 19 female participants (17%). This is also accounted for by the large proportion of cricket players which is largely a male dominated sport.

None of the studies made comment of specific medical co-morbidities of the subjects. This is unlikely to have impacted the results given the nature of the injury and the relatively young age of the subjects.

All five studies were performed in developed countries with well established health care systems. Three [28, 30, 31]were conducted in the United Kingdom, one [11] in Australia and one in the United States of America[29]. Three studies[28-30] were conducted through specialist spinal surgery centers, one through a hospital orthopedic department [31]while the other [11] was affiliated with a University department.

3.1.2.3 Interventions and comparators

In all five included studies the surgery involved direct repair of the pars interarticularis. In four [11, 28, 30, 31] all patients first underwent a trial of conservative management, lasting at least six months. If participants were able to functionally return to sport at this stage they were classified as the 'conservative treatment group'. If patients were not able to return to sport they proceeded to have surgical

intervention and were classified into the 'surgical group'. Hence, all participants in these four studies would have been in the 'conservative group' at commencement of the study, and then moved into the 'surgical group' if clinically indicated. In the fifth study [29] even though it was not explicitly reported that participants passed into the 'surgical' group if they could not return to sport, this process is assumed to have occurred especially as this is considered common practice for management of this condition and the fact that amongst the participants in their study the mean duration of symptoms prior to surgery was 28.8 months (SD=5 months). This common feature of the study designs meant that it was difficult to make a direct comparison between the outcomes of the surgical and conservative groups, as was hoped to achieve in the aims of this systematic review.

An additional feature of the interventions/comparators in the included studies, which also limited the ability to address the questions of the review, is that two [29, 30] of the five studies reported outcomes only for the surgical intervention group and had no comparator outcomes reported for the conservative treatment group.

3.1.2.4 Outcomes

A summary of the outcomes assessed in the studies is presented in Table 4. All of the studies reported on return to sport, with all studies giving an indication as to whether the athlete was able to return to sport six months following either initial injury in the case of the conservative groups, or six months following surgical intervention in the surgical groups. Unfortunately whilst the review sought measures on how successful the participants were in returning to sport, and time between surgery and return to sport none of the studies reported on these outcomes. Each study measured *return to sport* as return to previous sporting level, however no specific details were reported in the outcome measures regarding how successful the athlete was at returning, how long they were able to return for or how their pre-and post-injury sports performance compared.

In relation to the secondary functional outcomes of this review, the ODI, SF-36 Physical Component and SF-36 Mental Component were reported in three [28-30] out of the five studies. In Debnath et al. (2003 and 2007) this was reported pre- and post-intervention, whereas in Clegg et al. only post-intervention scores were

available. In one study, Ranawat et al., the Modified Henderson Assessment was used to review results of surgical treatment. This is a modified tool created by the authors of the paper whereby the patients subjectively categorize the outcome of their procedure into either excellent, good or poor based on a description of the classification related to pain, sporting function and occupational return[31].

As described earlier the studies contained a mixture of participants with both unilateral and bilateral spondylolyis. Only Debnath et al. 2007 and Clegg et al. gave specific results at follow-up related to those with unilateral spondylolysis, while the other three studies [11, 30, 31] reported the follow-up results for unilateral spondylolysis and bilateral spondylolyis as a single cohort.

Table 4: Outcome measures in included studies

Domain	**Outcome measured**	**Approach**	**Study/Citation**
Return to Sport	Participant return to sport	Author reported based on follow-up of the participant	Debnath et al 2003 Debnath et al 2007 Clegg et al 2013 Ranawat et al 2003 Hardcastle 1993
Overall Function and Pain	Oswestry Disability Index	Questionnaire	Debnath et al 2003 Debnath et al 2007 Clegg et al 2013
	SF - 36 Physical Health Component	Questionnaire	Debnath et al 2003 Debnath et al 2007 Clegg et al 2013
	SF - 36 Mental Health Component	Questionnaire	Debnath et al 2003 Debnath et al 2007 Clegg et al 2013
	Modified Henderson Assessment	Subjective reporting by patients	Ranawat et al 2003

3.1.2.5 Length of follow-up

For the two prospective studies [28, 30] follow-up was carried out at regular intervals up to two years post-surgery. None of the remaining three retrospective studies [11, 29, 31] specified a pre-set follow-up time, and in these studies the follow-up usually continued until patients returned to sport, after which no further follow-up was carried out. Subsequently the follow-up of individual patients ranged from six months [11, 29] up to ten years[31].

3.1.3 Methodological quality of included studies

The results of the quality assessment using the JBI-MAStARI appraisal tool for descriptive and case series studies are presented in Table 5. As may be seen from Table 5, measured using the quality criteria for descriptive studies, four[11, 28-30] of the five studies may be described as moderate to high quality and one[31] of poorer methodological quality. However, as explained above, the study design used by all five of the studies is characterized by a number of biases which undermines drawing any firm conclusions from the results of the included studies on the questions about relative effectiveness of surgical versus non-surgical treatment posed by the review.

Table 5: Results of critical appraisal based on JBI MASTARI tool for appraising descriptive studies

Citation	Q1 Randomization	Q2 Clearly defined inclusion criteria	Q3 Confounding factors accounted for	Q4 Objective assessment	Q5 Description of groups	Q6 Appropriate follow-up time	Q7 Withdrawals accounted for	Q8 Reliable outcome measures	Q9 Appropriate statistical analysis	Total
Clegg,T. Carreon,L. Mutchnick,I. Puno,R., 2013	N	Y	Y	Y	N/A	Y	N/A	Y	Y	6/7
Debnath, U. K. Freeman, B. J. Gregory, P. de la Harpe, D. Kerslake, R. W. Webb, J. K., 2003	N	Y	Y	Y	N/A	Y	N/A	Y	Y	6/7
Debnath, U., Freeman, D., Grevitt, M., Sithole, J., Scammell, B., Webb, J., 2007	N	Y	Y	Y	Y	Y	N/A	Y	Y	7/8
Hadcastle, P.H., 1993	N	Y	Y	Y	N/A	Y	Y	Y	N/A	6/7
Ranawat, V., Dowell, J., Heywood-Waddington, M., 2003	N	Y	Y	N	N/A	Y	N/A	N	N/A	3/6
%	0	100	100	80	100	100	100	80	100	

None of the participants in any of the studies underwent randomization to a specific treatment group. This is mainly due to the underlying nature of treatment for unilateral spondylolysis, where as described earlier, patients will always be treated conservatively first, and only be recommended by experts to progress to surgical treatment if this treatment fails. Given that three [11, 29, 31] of the studies were retrospective case series, randomization was not possible.

All the studies were very clear in identifying the inclusion criteria and accounting for confounding factors. The inclusion criteria in all the studies clearly stipulated radiologically proven (CT or MRI) spondylolysis in individuals with symptomatic back pain. Given that detailed radiological examination of the injured area was performed all other confounding injuries such as lumbar disc herniation or facet joint injury were identified, and these subjects were subsequently excluded from the studies.

Four[11, 28-30] of the five included studies used objective assessment to assess progress, while only one[31] relied on subjective reporting. The prospective studies[28, 30] had an appropriate pre-set follow-up period of two years, while the retrospective studies[11, 29, 31] followed patients until they were able to return to sport.

3.2 Findings

The findings from the five studies included in the review in response to the questions are presented below, first for the primary outcomes of interest relating to return to sport, and secondly for the secondary outcomes of interest, namely overall function and pain. For each outcome, the results are presented:

(i) for participants overall (athletes and non-athletes) with unilateral spondylolysis or bilateral spondylolysis of the lumbar spine.

(ii) for participants with unilateral spondylolysis, all of whom were athletes.

3.2.1 Return to sport

The primary question to be addressed in this review as per the protocol related to the athletes ability to return to sport, which consisted of two important aspects; both time of return and the quality of performance following return. Due to the nature of the studies available in this field it was not possible to completely answer these

questions. Four [11, 28, 30, 31] out of the five studies included measured and reported return to sport. Clegg et al. did not measure and report on this outcome. However, when the authors were contacted they were able to provide the data for the specific cohort of athletes in their group with unilateral spondylolysis.

The studies included only whether an athlete was able to return to sport or not within a period of six months from either initial injury in the case of the conservative group, or six months from intervention in the case of the surgical group, with no specific focus on quality of return. Table 6 gives an overview on the total ratio of participants (all participants grouped together and those who were specifically athletes with unilateral spondylolysis) who were able to return to sport as reported in each individual study.

Table 6: Ratio of study participants able to return to sport following surgical and conservative treatment

	All participants (ratio of patients able to return to sport within 6 months of intervention)		**Athletes with unilateral spondylolysis** (ratio of patients able to return to sport within 6 months of intervention)	
Study	Surgical Group	Conservative Group	Surgical Group	Conservative Group
Clegg,T. Carreon, L. Mutchnick, I. Puno, R., 2013	Data not available	No conservative treatment group	5/6	No conservative treatment group
Debnath, U., Freeman, D., Grevitt, M., Sithole, J., Scammell, B., Webb, J., 2007	6/8	24/24	6/8	24/24
Debnath, U. K. Freeman, B. J. Gregory, P. de la Harpe, D. Kerslake, R. W. Webb, J. K., 2003	18/22	No conservative treatment group	N/A	N/A

Ranawat, V., Dowell, J., Heywood-Waddington, M., 2003	9/9	8/8	N/A	N/A
Hadcastle, P. H., 1993	9/10	12/13	N/A	N/A

In total, 49 patients underwent surgical repair, and 42 of these were able to return to sport six months following the surgery (86%). This is compared to 44 out of the 45 patients in the conservative group being able to return to sport (98%). As explained above, in all of the studies the whole population started off in the conservative group, and then they automatically progressed into the surgical group if treatment failed, hence by definition all of the patients in the conservative group who did not progress on to surgical management would have made a successful return to sport. The one exception noted from Table 6 is in the Hardcastle study in which case 12/13 patients in the conservative group were able to return to sport, the one patient opted to not have surgery and retire from sport rather than progress to surgery. None of the studies prospectively looked at two separate randomized groups which would have allowed a direct head-to-head comparison of the treatment effectiveness.

In two of the studies [28, 29] it was possible to obtain the specific results for those athletes with unilateral spondylolysis as opposed to the combined group results. For this sub-group, which was the main group of interest in the review, 11 out of the 14 patients who underwent surgery were able to return to sport within six months of intervention. This equates to 79%, slightly lower than the 86% achieved for the total participant group, with unilateral and bilateral spondylolysis. Of these 14 athletes who had unilateral spondylolysis and who were able to return to sport, there were four soccer players, three cricketers, two basketball players and one athlete each involved with gymnastics, American football, baseball, golf and non-specific sports respectively. The three athletes who were not able to return to sport successfully within six months of their surgery were involved in cricket, non-specific sports and soccer respectively.

3.2.2 Overall pain and function

As explained above, overall pain and function was measured in four [28-31] of the five

included studies, using either the ODI, SF-36 measures of physical and mental health, or the Modified Henderson Assessment.

3.2.2.1 Oswestry Disability Index Measure (ODI)

The ODI is a comprehensive questionnaire which looks at the impact of low back pain on all aspects of life including activities of daily living, social life, sleep and work capabilities and gives an indication of a person's overall functional capacity[26]. Lower scores on this scale equate to better overall function. Three studies [28-30] looked at this questionnaire; the results are recorded in Table 7. The study by Clegg et al. was a retrospective study where no pre-intervention data was recorded, however the study did include ODI measures post-intervention.

Table 7: Results for all patient in studies where ODI was included as an outcome measure

	All participants			Athletes with unilateral spondylolysis		
Study	**Number of Participants (n)**	**Average Pre-Intervention score**	**Average Post-Intervention score**	**Number of Participants (n)**	**Average Pre-Intervention score**	**Average Post-Intervention score**
Clegg,T. Carreon, L. Mutchnick, I. Puno, R., 2013						
Surgical Group	42	N/A	10.2 (SD=15)	4	N/A	14.45
Conservative Group	N/A	N/A	N/A	N/A	N/A	N/A
Debnath, U., Freeman, D., Grevitt, M., Sithole, J., Scammell, B., Webb, J., 2007						
Surgical Group	8	39.1 (SD=3.6)	6.4 (SD=5.2)	8	39.1 (SD=3.6)	6.4 (SD=5.2)
Conservative Group	34	36 (SD=10.5)	6.2 (SD=8.2)	24	N/A	N/A
Debnath, U. K. Freeman, B. J. Gregory, P. de la Harpe, D. Kerslake, R. W. Webb, J. K., 2003						
Surgical Group	22	39.5 (SD=8.7)	10.7 (SD=12.9)			
Conservative Group	N/A	N/A	N/A			

In total 72 patients completed a post-surgical ODI questionnaire. The post-operative ODI scores ranged from an average of 6.4 (SD=5.2) to 10.7 (SD=12.9). This is in comparison to the average pre-intervention scores which ranged from 39.1 (SD=3.6) to 39.5 (SD=8.7), hence surgery was found to improve overall function. These findings are similar to those seen in athletes with unilateral spondylolyis where the post-operative ODI ranged from 6.4 (SD=5.2) to 14.5, compared to a pre-intervention ODI of 39.1 (SD=3.6) in the one group were this measure was available.

When using the ODI scoring system to analyze the results, these post surgery changes are clinically significant as a score in the range of 21-40 is interpreted as indicating moderate disability where patient experiences pain and difficulty with sitting, lifting and standing participation in travel and social life and may result in patients being disabled from work. In contrast scores from 0-20 indicate minimal disability where the patient can cope with most living activities and usually according to the interpretation of the ODI scoring system no treatment is indicated apart from advice on lifting, sitting and exercise.

Only one study[28] made a direct comparison between the ODI scores of the surgical and conservative groups, which showed an improvement in ODI scores of 32.7 in the surgical group and improvement of 29.8 in the conservative group, implying that surgical intervention may have been more effective than conservative treatment alone. These results need to be interpreted with caution however, as no comment was made on statistical significance, and in addition the surgical group had a slightly higher baseline ODI score of 39.1 compared to 36 in the conservative group.

3.2.2.2 Short Form 36 Survey (SF-36)

The SF-36 is a global assessment of health and looks at the impact of an intervention on the different components of health. The studies included for analysis have looked at the Physical and Mental component of health. A higher score indicates better overall function. These finding are present in Tables 8 and 9.

Table 8: Results for all patients in studies where SF-36 Physical Component of Health was included as an outcome measure

	All participants			Athletes with unilateral spondylolysis		
Study	**Number of Participants (n)**	**Average Pre-Intervention score**	**Average Post-Intervention score**	**Number of Participants (n)**	**Average Pre-Intervention score**	**Average Post-Intervention score**
Clegg,T. Carreon, L. Mutchnick, I. Puno, R., 2013 Surgical Group Conservative Group	42 N/A	N/A N/A	51.4 (SD=9.7) N/A	6 N/A	N/A N/A	48.5 N/A
Debnath, U., Freeman, D., Grevitt, M., Sithole, J., Scammell, B., Webb, J., 2007 Surgical Group Conservative Group	8 34	29.6 (SD=4.4) 30.7 (SD=3.2)	49.2 (SD=6.2) 53.5 (SD=6.5)	8 N/A	29.6 (SD=4.4) N/A	49.2 (SD=6.2) N/A
Debnath, U. K. Freeman, B. J. Gregory, P. de la Harpe, D. Kerslake, R. W. Webb, J. K., 2003 Surgical Group Conservative Group	19 N/A	27.1 (SD=5.11) N/A	47.8 (SD=7.75) N/A			

Table 9: Results for all patients in studies where SF-36 Mental Component of Health was included as an outcome measure

	All participants			Athletes with unilateral spondylolysis		
Study	**Number of Participants (n)**	**Average Pre-Intervention score**	**Average Post-Intervention score**	**Number of Participants (n)**	**Average Pre-Intervention score**	**Average Post-Intervention score**
Clegg,T. Carreon, L. Mutchnick, I. Puno, R., 2013						
Surgical Group	42	N/A	51.5 (SD=11.4)	6	N/A	54.2
Conservative Group	N/A	N/A	N/A	N/A	N/A	N/A
Debnath, U., Freeman, D., Grevitt, M., Sithole, J., Scammell, B., Webb, J., 2007						
Surgical Group	8	37.7 (SD=1.9)	54.5 (SD=6.4)	8	38.7 (SD=1.9)	54.5 (SD=6.4)
Conservative Group	34	39 (SD=4.1)	56.5 (SD=3.9)	N/A	N/A	N/A
Debnath, U. K. Freeman, B. J. Gregory, P. de la Harpe, D. Kerslake, R. W. Webb, J. K., 2003						
Surgical Group	19	39 (SD=3.97)	54 (SD=6.36)			
Conservative Group	N/A	N/A	N/A			

The results from the measurement using the SF-36 Survey show that surgery led to an improvement in overall function as indicated by the Physical and Mental component of health on the SF-36. In total, 69 patients completed a post-surgical SF-36 questionnaire. The post-surgical SF-36 scores for the physical component of health ranged from an average of 47.8 (SD=7.75) to 51.4 (SD=9.7), which is an improvement from the average pre-intervention scores which ranged from 27.1 (SD=5.11) to 29.6 (SD=4.4), however once again no comment was made on the statistical significance of the results.

In the studies which looked at athletes with unilateral spondylolyis a similar improvement in the average scores was noted, with the average post-intervention scores ranging from 48.5 to 49.2 (SD=6.2) compared to an average of 29.6 (SD=4.4) in the one group were this measure was available. Similar results are seen for the SF-36 Mental Component of Health. On this scale the average pre-intervention scores ranged from 51.5 (SD=11.4) to 54.5 (SD=6.4) which indicated an improvement from the pre-intervention range of 38.7 (SD=1.9) to 39.0 (SD=3.97). No authors reported results that allowed for comparing the magnitude of the effect in the conservative and surgical management groups.

3.2.2.3 Modified Henderson Assessment

One study, Ranawat et al. used the Modified Henderson Assessment to assess their operative results. This was a modification of a subjective assessment previously described by another author where patients were asked to grade the outcome of their surgery as either excellent, good or poor based on a description of the grades incorporating pain, return to occupation and sport. No data was available for those patients managed conservatively, and for the nine patients who underwent primary repair (four of which were athletes with unilateral spondylolysis) all reported 'excellent' results.

Chapter 4: Discussion

4.1 Summary of findings

The aim of this systematic review was to assess the ability of athletes with unilateral spondylolysis to return to sport following surgical treatment compared to conservative treatment. The effectiveness of surgical treatment compared to conservative treatment in improving pain and overall function in athletes (aged under 50) with unilateral spondylolysis of the lumbar spine was a secondary outcome of interest. The small number of studies identified (five), the nature of their study designs – descriptive case series which are characterized by a high level of bias – and the mix of unilateral and bilateral spondylolysis participants in the studies all undermined the ability to adequately address the questions posed by the review.

The main finding from this systematic review of the evidence on the effectiveness of surgical versus conservative management of spondylolysis is that the best available evidence suggests that for the majority of athletes who fail conservative treatment, surgery may be an effective option for facilitating return to sport and improving pain and overall function. However, whilst the evidence suggests that surgery may be effective for improving these outcomes, no firm conclusions can be drawn due to the limited size of the available evidence base and methodological weaknesses in the studies. Regarding the methodological weaknesses the main limitations were lack of randomization, and insufficient time between intervention and outcome measurement (less than two years when two years is regarded as best practice).

The evidence base available does not allow any conclusions to be drawn about the relative effectiveness of surgery compared to conservative treatment on the outcome of interest. In this regard, a finding of note that emerged from one study [28] was that the post-intervention ODI scores for both surgical and conservative groups was notably lower than those seen in other studies. Interestingly this study contained only participants with unilateral spondylolysis, suggesting potentially that patients with unilateral spondylolysis may do better as a whole than those with bilateral

spondylolysis.

4.2 Knowledge gaps

Upon review of the results of this systematic review there remains some specific gaps in our knowledge regarding unilateral spondylolysis of the lumbar spine in athletes. It is evident that surgery is an option for those patients with unilateral spondylolysis of the lumbar spine, however it remains unclear as to whether it may in fact lead to a more rapid recovery when compared to conservative treatments. At the outset of this thesis it was hoped that this could be determined, which in turn would have a significant impact on current practice. However given the current philosophy of treatment where conservative measures are always taken first, with subsequent progression to surgical treatment if these fail, this remains difficult to determine.

A further gap in our knowledge is whether there is clinically a significant difference in outcomes between unilateral and bilateral spondylolysis, or between athletes and non-athletes. To date no clear comparison has been made in head to head studies between these groups.

The current evidence shows that most athletes are able to return to sport following unilateral lumbar spondylolysis, regardless of whether they have surgical or conservative treatment. However, it remains unclear as to how effective athletes are when returning to sport. We do not know if they are able to return to the same level of their previous sporting ability, what the re-injury rates are or for how long they are able to return to sporting activity. These are all aspects which are very important to athletes themselves, however given that much of the measurement of how well an athlete is performing can be a very subjective matter this may be difficult to quantify or measure in a research setting.

4.3 Limitations

As has been highlighted throughout the review there are some clear limitations to note when interpreting the findings and drawing inferences for practice. The main limitation is that not all the participants included for analysis had the specific

underlying pathology of interest. The main reason for this is paucity of data which led the reviewer to include these studies as part of the analysis. Through the literature search only one study [28] was identified where the total participant population exclusively had unilateral spondylolysis. In the other four studies [11, 29-31] it was specified in the methods of the study that a certain number of patients had unilateral spondylolysis (with a specific number given). These were identified by high resolution imaging at the beginning of the study. Unfortunately for these four studies when results were reported they were reported as a total group only, and no specific indication of those with unilateral spondylolysis only was given. The reviewer attempted to obtain this data from the authors of these four studies however this was only possible for one study which gave the specific follow-up data for that trial. Due to the overall paucity of data the decision was made to include all five of these studies for data synthesis with the knowledge that the results included those for participants with not only unilateral spondylolyis, but also bilateral spondylolyis, however it was guaranteed that at least a certain proportion of the participants did actually have unilateral spondylolysis. To address the questions for the specific group of interest in this review, the results were first analyzed and synthesized for all participants and then separately for the small number of athletes for whom it could be identified with certainty that they had unilateral spondylolysis.

A second limitation of the review related to the study population in that not all the participants from the studies included for data synthesis were athletes. In both the studies where unilateral data was specifically available not all the participants were athletes. However, fortunately in both these studies the results for those in the surgical group could be reviewed and those who were athletes isolated and included for sub-group analysis. This allowed specific conclusions regarding effectiveness of treatment for athletes specifically to be made.

A further limitation is in the reporting of the results where the studies do not quantify specifically how well athletes returned to sport (i.e. level of performance and satisfaction) or exactly how long it took them to return. This made it near impossible

to address the primary question of the review. A possible reason for the relative neglect of the level of return to sport in the studies conducted to date is that this may be a difficult outcome to measure/ quantify. How well athletes are able to return to sport is often a very opinionated / subjective matter which may vary greatly from one person to the next dependent on personal bias. Secondly the exact time a person is able to return to sport can also be difficult to quantify accurately as this can be affected by aspects as simple as whether it is off-season for the sport or not. Return may also be dependent on external factors such as coaches who may feel that the athlete is not 'fit' to return to sport as yet even though the athlete may feel that they are.

A final limitation of the review to note, which has implications for interpreting the results is that the majority of studies included for review were retrospective studies (3/5 studies), which translated into lack of clear protocols for the studies and limited description of the nature of the conservative treatment. There may therefore have been substantial differences in what was termed “conservative treatment”.

4.4 Reflection on the results of this review compared to similar reviews

To the authors knowledge there have been no previous systematic reviews which have looked specifically at unilateral spondylolysis of the lumbar spine. A systematic review by Iwamoto et al.[32] in 2010 looked at whether athletes were able to return to sport following surgical or conservative treatments. The review did not differentiate between unilateral or bilateral spondylolysis, and looked only at the proportion of athletes who were able to return to sport and the time taken following intervention. They found that following conservative and surgical treatment the percentages of athletes who returned to sports activities ranged from 80.0% to 89.3% and from 81.9% to 100%, respectively, and the intervals until their return ranged from 5.4 to 5.5 months and from 7 to 12 months, respectively. These findings are similar to those seen in this review where as described earlier 86% were able to return to sport six months following the surgery, compared to 98% in the conservative group. Significantly however Iwamoto et al. found a longer recovery period following surgery

before return to sport. That was not evaluated in this review as return to sport was assessed at the six months post-intervention. In addition, similar to this review there was no clear indication on how effective athletes where in their return to sports.

Chapter 5: Conclusion: Implications for practice and research

The limited evidence on the effectiveness of surgical treatment versus conservative treatment for unilateral spondylolysis in athletes does not allow any conclusions to be drawn about the relative effectiveness of surgery versus conservative treatment for facilitating rapid return to sport or a high level of post injury sporting level/performance. However, It does suggest that for athletes for whom conservative treatment has not been successful, surgery is likely to facilitate return to sport, reduce pain and promote overall function. However, when making these conclusions it has to be taken into account that the literature is clearly limited by the small number and low participant sample of the existing studies as well as the methodological weaknesses of the included studies.

5.1 Implications for practice

The evidence suggests that practitioners may advise adult athletes that have failed conservative treatment who suffer pain and compromised functionality (including inability to play regular sport) to consider surgery to reduce their pain, increase their function and enable return to sport (Grade B).

In making a recommendation for surgery, clinicians/practitioners should inform patients suffering unilateral spondylolysis who are considering surgery that it is unclear what level of sport they will be able to return to post surgery (Grade B).

5.2 Implications for research

Future primary research addressing the question of whether surgical intervention or conservative management is more effective in supporting the athlete to resume pre-injury function needs to be focused specifically on the underlying pathology of interest i.e. unilateral spondylolysis of the lumbar spine. More research needs to be done where the participant population has unilateral spondylolysis only, and is not grouped together with participants who have bilateral spondylolysis. More clarity in identifying athletes and the specific sports they participate in is also required. The latter will facilitate understanding how the efficacy of surgery varies across athlete

types and making appropriate recommendations for athletes involved in specific sporting activates. It would also be useful for primary research to test efficacy of surgery and surgery versus conservative treatment for females compared to males.

In terms of study design a prospective case series is an appropriate design. Given the relatively rare incidence of the injury and the current treatment regimens it would not be feasible to randomize patients into a controlled trial. A case series looking at a specific cohort of athletes where there is likely to be a high incidence of unilateral spondylolysis of the lumbar spine would be desirable. An example of this would be recruiting a group of professional cricket fast bowlers, determining their pre-injury sports status and objectively measuring their overall function as a baseline, then subsequently following-up on with those who develop the injury of interest. Within this design there needs to be a stringent protocol where all athletes follow the same conservative recovery program and if they reach a pre-set time (likely 6 months) without making a successful return to sport they proceed to having surgical intervention.

In terms of outcome measures, for future research more clarity is required when describing return to sport. This is potentially a very opinionated matter and future studies in this area need to clearly define what is termed a successful return to sport and by whom this is judged.

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Appendices

Appendix I: Published Systematic Review Protocol

Review title

The Effectiveness of Surgical versus Conservative Treatment for Unilateral Spondylolysis of the Lumbar Spine in Athletes: A systematic review protocol

Reviewers

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Review question/objective

To systematically review evidence to determine the effectiveness of surgical fixation, performed after a trial period of conservative management, compared to the effectiveness of conservative management only for unilateral spondylolysis in athletes.

The questions to be asked in the review are:

- Does surgical fixation of unilateral spondylolysis allow athletes to return to sports effectively?
- Does surgical fixation of unilateral spondylolysis allow athletes to return to sport faster than conservative management?

Background

Spondylolysis is a common cause of low back pain in athletes, especially amongst adolescents. The incidence of the condition in the general population is between 6%-8% [(1, 2)], however in the athletic population the incidence has been reported as high as 47% [(3)]. Spondylolysis refers to a defect or fracture of the pars interarticularis of vertebrae which can be either unilateral or bilateral. The pars interarticularis is the junction of the pedicle, articular facets and lamina. Up to five types of spondylolysis have been descried including dysplastic, isthmic, degenerative, traumatic and pathological [(5, 14)]. This review will focus on the effectiveness of surgical treatment versus ongoing conservative management of isthmic spondylolyis which results from fatigue fractures.
Historically stress injuries of the pars interarticularis were thought to be mostly bilateral [(4)] and were noted in young athletes competing in sports requiring repetitive lumbar extension movements such as gymnastics and swimming [(5)]. The growth of professional sport has seen more athletes exposed at a younger age to the repetitive actions which can lead to this condition. This, combined with great

advances in lumbar spine imaging in the past 20 years has led to the understanding that unilateral spondylolysis is more prevalent than originally thought and demonstrated that in sports such as cricket unilateral spondylolyis may in fact be just as common as bilateral spondylolysis [6, 7]. Studies using MRI or high resolution CT scanning have estimated that between 32% - 48% of all cases of radiologically confirmed spondylolysis in athletes are unilateral [8, 9]. In cricket it has been shown that up to 55% of young fast bowlers may suffer from unilateral spondylolysis [10]. If this injury is not managed appropriately it significantly limits players continuing their careers [10, 11]. A large amount of research regarding unilateral spondylolyis has involved this specific group of athletes [6, 7, 10-13].

Unilateral spondylolysis occurs when repetitive stresses are placed on the pars interarticularis. The specific combination of repetitive extension, rotation and side flexion causes microtrauma to the pars interarticularis. The above mentioned combination of movements lead to a shear force on the pars interarticularis which causes stretching of the pars and eventually stress microfracture [4]. With ongoing stress an incomplete fracture occurs which can lead to chronic non-union. The condition occurs most commonly at the L5 vertebral level [8]. A spondylolytic injury can have massive impact on athletes, regardless of their sport. The injury can cause significant pain with subsequent activity limitation, and arguably is more damaging it can lead to significant time away from sport [5, 7].

Despite growing knowledge regarding the epidemiology and aetiology of unilateral spondylolysis, the optimum management of athletes with this condition still remains unclear. It has been recommended by several review articles on spondylolysis that conservative management including rest, activity modification and physiotherapy allows patients to return to sports over time [4, 5, 14]. A study by Blanda et al demonstrated that a 6 month protocol of non-operative management led to apparent radiographic union of the unilateral pars interarticularis defect in 87% of patients, however little mention was made to return to sport or clinical outcome of this specific group of patients [15]. Similar outcomes were noted by Sys et al. where a subgroup of 11 patients with unilateral spondylolyis treated with non-operatively with lumbar bracing for a average of 16 weeks. These patients all achieved CT proven osseous healing of the fracture with most of the athletes able to return to a previous level of sport [9]. These studies indicate that conservative treatment of up to 6 months achieves positive results in most patients. However it remains unclear if surgery or ongoing conservative treatment is more beneficial for patients who do not respond to conservative treatments within 6 months, or even whether it would potentially be more beneficial for patients to have surgical intervention immediately after the initial diagnosis of the injury.

Various methods of surgical fixation have also been described, with surgical fixation always attempted only after an initial trial period of conservative management [4, 5, 14]. The general aim of surgical intervention is a direct repair of the pars interarticularis. In the past spinal fusion was used as the first line of surgical treatment, however internal fixation devices have superseded spinal fusion as the gold standard surgical treatment [14]. Despite technological advances the role of surgical intervention and its effectiveness remains controversial, and it remains unclear whether athletes with unilateral spondylolysis are able to return to the sports field effectively or faster.

A search of the Cochrane(CENTRAL) and CINAHL databases using the keywords unilateral spondylolysis surgical versus conservative intervention and systematic review was undertaken to establish the existence of a recently published systematic review and/or protocols for review on the topic. No systematic reviews or protocols looking specifically at unilateral spondylolysis were identified. This explains the value of the proposed research which will provide sports rehabilitation practitioners with the first synthesis of the available evidence on the effectiveness of surgical intervention compared to conservative management for unilateral spondylolysis in athletes.

Inclusion criteria

Types of participants

This review will consider studies in which participants were athletes with unilateral spondylolysis of the lumbar spine. As the review aims to provide a comprehensive synthesis of the evidence on the effectiveness of surgical versus conservative management of unilateral spondylolyis of the lumbar spine for return to sport participant coverage will not be restricted to any particularly type(s) of sport or athlete age group. An inclusive approach will be adopted with respect to the geographical location of studies with participants from all countries and health care settings to be considered. Only studies where participants have first undergone a trial of conservative treatment prior to surgical intervention will be considered, as this is the currently widespread clinical practice.

Types of intervention and comparators

Surgical interventions which attempt a direct repair of the pars interarticularis will be considered for this review. Even though direct repair in the form of Buck's Repair is most the widely recommended surgical treatment for spondylolyis, other surgical techniques including segmental wire fixation and pediculolaminar hook screws have also been shown to be effective and will hence be included in the review [14]. Given that this is a rare procedure and that spondylolyis procedures are only completed in specialist spinal surgery units it is natural that the surgeries will only be performed by highly qualified specialist and therefore no studies will be excluded on the bases of whom is undertaking the surgery.

The comparators are the conservative treatments commonly used to treat unilateral spondylolyis in athletes and allow return to sport including but not limited to rest, activity modification, bracing, lumbar stability exercises, pharmacological treatment and physical therapy.

Types of outcomes

The focus of this review is the athletic population hence the ability to return to pre-injury sporting level will be the main outcome measure. This will be further expanded by examining firstly whether athletes are able to return to sport and subsequently whether they are able to return to faster and/or more effectively following surgical treatment when compared to ongoing conservative management.

The secondary outcomes are overall function as reported by various functional pain or disability scales which are specific to this injury. The Oswestry Disability Index is commonly used to review the effectiveness of interventions in subjects with low back pain. This comprehensive questionnaire looks at the impact of low back pain on all aspects of life including activities of daily living, social life, sleep and work capabilities. The Short Form (SF) 36 Health Survey is a more global assessment of health and is not specifically focused on low back pain however is also widely used to quantify the impact of a specific injury (in this case spondylolyis) on well-being. Other measures of general function or health which will be included are specific low back pain scales which are often created by subspecialist research groups or associations. Examples include the Japanese Orthopaedic Association Score, The Quebec Back Pain Disability Scale and the Roland Morris Low Back Pain and Disability Questionnaire. As with the Oswestry Disability Index these tools measure the impact of the injury on various aspects of a patient's life with a general focus on activity limitation.

Types of studies

This review will consider both experimental and epidemiological study designs including randomised

controlled trials, non-randomised controlled trials, quasi-experimental, before and after studies, prospective and retrospective cohort studies, case control studies and analytical cross sectional studies for inclusion.

This review will also consider descriptive epidemiological study designs including case series, individual case reports and descriptive cross sectional studies for inclusion.

To be considered for inclusion the studies most have examined the effectiveness of a surgical method or conservative treatment of unilateral spondylolyis in athletes. Due to the potential paucity of data studies that clearly report data on a subgroup of subjects with unilateral spondylolyis as part of a wider study on spondylolyis will retrieved and reviewed for possible inclusion in data synthesis.

Search strategy

The search strategy aims to find both published and unpublished studies. A three-step search strategy will be utilized in the review. An initial limited search of MEDLINE and CINAHL will be undertaken followed by analysis of the text words contained in the title and abstract, and of the index terms used to describe articles. Second, a search using all identified keywords and index terms will then be undertaken, across all databases. Thirdly, the reference list of identified reports and articles will be searched for additional studies.

The following databases will be searched to identify published studies:

PubMed

CINAHL

Cochrane (CENTRAL)

Scopus

Centre for Review and Dissemination databases

Turning Research into Practice TRIP

EMBASE

EBM Reviews

To identify unpublished studies the following will be searched:

Online clinical trials registers

MedNar

ProQuest Dissertations

Theses

Given that surgical techniques still used today that were developed in the early 1970's studies published between 1970 and 2013 be considered for inclusion in this review. With respect to language, only studies published in English language will be considered for inclusion.

Examples of initial keywords that will be used in the exploratory stage of the search for studies in electronic databases are: spondylolysis, unilateral, pars interarticularis, stress injury, fracture, surgical

treatment, conservative treatment, athletes.

Informed by the findings from the initial exploratory searches in the range of databases to be covered, further key words will be identified and a detailed search strategy will be developed and implemented for each database.

Assessment of methodological quality

Methodological quality of considered studies will be assessed by two independent reviewers for methodological validity prior to inclusion in the review using standardised critical appraisal instruments from the Joanna Briggs Institute Meta Analysis of Statistics Assessment and Review Instrument (JBI-MAStARI) (Appendix II). Any disagreements that arise between the reviewers will be resolved through discussion, or with a third reviewer.

Data collection

Details describing each study and results on effectiveness in promoting the outcomes of interest will be extracted from papers included in the review using the standardised data extraction tool from JBI-MAStARI (Appendix II). In addition to extraction of the results for outcomes relevant to the review question and specific objectives the information extracted will include details about the interventions, populations and method of the included studies.

Data synthesis

Quantitative data will, where possible be pooled in statistical meta-analysis using JBI-MAStARI. All results will be subject to double data entry. Effect sizes expressed as odds ratio (for categorical data) and weighted mean differences (for continuous data) and their 95% confidence intervals will be calculated for analysis. Heterogeneity will be assessed statistically using the standard Chi-square and also explored using subgroup analyses based on the different study designs included in the review and the sub-questions (or objectives) of the review. Where heterogeneity implies that statistical pooling is not possible the findings will be presented in narrative form of tables and figures.

Conflicts of interest

There are no conflicts of interest to report.

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Appendix II: Search strategy
Database Search Results

PubMed

Search Number	Parameters	Results
1	spondylolysis[mh:noexp] OR pars interarticularis[tw] OR spondylolysis [tw] OR spondylolyses[tw]	1587
2	(repair[tw] OR fixation[tw] OR surgical*[tw] OR surgeon*[tw] OR surgery[tw])	2453662
3	Lumbar [tw]	85351
4	(Cervical[tiab] OR degener*[tiab] OR stenos*[tiab])	411291
5	((((spondylolysis[mh:noexp] OR pars interarticularis[tw] OR spondylolysis [tw] OR spondylolyses[tw])) AND ((repair[tw] OR fixation[tw] OR surgical*[tw] OR surgeon*[tw] OR surgery[tw]))) AND Lumbar [tw]) NOT ((Cervical[tiab] OR degener*[tiab] OR stenos*[tiab]))	263
6	((((spondylolysis[mh:noexp] OR pars interarticularis[tw] OR spondylolysis [tw] OR spondylolyses[tw])) AND ((repair[tw] OR fixation[tw] OR surgical*[tw] OR surgeon*[tw] OR surgery[tw]))) AND Lumbar [tw]) NOT ((Cervical[tiab] OR degener*[tiab] OR stenos*[tiab])) Filters: Publication date from 1970/01/01 to 2013/09/07	260
7	((((spondylolysis[mh:noexp] OR pars interarticularis[tw] OR spondylolysis [tw] OR spondylolyses[tw])) AND ((repair[tw] OR fixation[tw] OR surgical*[tw] OR surgeon*[tw] OR surgery[tw]))) AND Lumbar [tw]) NOT ((Cervical[tiab] OR degener*[tiab] OR stenos*[tiab])) Filters: Publication date from 1970/01/01 to 2013/09/07;	235

	Humans	
8	((((spondylolysis[mh:noexp] OR pars interarticularis[tw] OR spondylolysis [tw] OR spondylolyses[tw])) AND ((repair[tw] OR fixation[tw] OR surgical*[tw] OR surgeon*[tw] OR surgery[tw]))) AND Lumbar [tw]) NOT ((Cervical[tiab] OR degener*[tiab] OR stenos*[tiab])) Filters: Publication date from 1970/01/01 to 2013/09/07; Humans; English	190

CINAHL

Search Number	Parameters	Results
1	spondylolysis OR pars interarticularis OR spondylolyses	298
2	repair OR fixation OR surg* OR operat*	243500
3	lumbar	9937
4	cervical	18123
5	S1 AND S2 AND S3	48
6	(S1 AND S2 AND S3) NOT S4	48

Cochrane (CENTRAL)

Search Number	Parameters	Results
1	Spondylolysis OR pars interarticularis OR spondylolyses	12

Scopus

Search Number	Parameters	Results
1	TITLE-ABS-KEY(spondylolysis OR pars interarticularis OR spondylolyses)	515
2	TITLE-ABS-KEY-AUTH(repair OR fixation OR surg* OR operat*)	5115437
3	TITLE-ABS-KEY-AUTH(lumbar)	111286
4	TITLE-ABS-KEY-AUTH(cervical)	212031
5	(TITLE-ABS-KEY(spondylolysis OR pars interarticularis OR spondylolyses)) AND (TITLE-	144

	ABS-KEY-AUTH(repair OR fixation OR surg* OR operat*)) AND (TITLE-ABS-KEY-AUTH(lumbar)) AND NOT (TITLE-ABS-KEY-AUTH(cervical))	
6	(TITLE-ABS-KEY(spondylolysis OR pars interarticularis OR spondylolyses)) AND (TITLE-ABS-KEY-AUTH(repair OR fixation OR surg* OR operat*)) AND (TITLE-ABS-KEY-AUTH(lumbar)) AND NOT (TITLE-ABS-KEY-AUTH(cervical)) AND (LIMIT-TO(LANGUAGE, "English"))	121

Centre for Review and Dissemination databases

Search Number	Parameters	Results
1	spondylolysis OR pars interarticularis OR spondylolyses	8

PEDro

Search Number	Parameters	Results
1	spondylolysis	5
2	spondylolysis - limit English	4

EMBASE

Search Number	Parameters	Results
1	'spondylolysis'/exp OR spondylolysis OR pars AND interarticularis OR spondylolyses	519
2	repair OR fixation OR surg* OR operat*	5511475
3	lumbar	111478
4	cervical	208960
5	1 AND #2 AND #3	204
6	#1 AND #2 AND #3 NOT #4	197

ProQuest Dissertations and Theses

Search Number	Parameters	Results
1	((spondylolysis OR pars interarticularis OR spondylolyses) AND (repair OR fixation OR surge* OR operate*) AND (lumbar)) NOT cervical, limit English	62

Appendix III: MAStARI critical appraisal tool for descriptive / case series studies

JBI Critical Appraisal Checklist for Descriptive / Case Series

Reviewer _____ Date _____

Author _____ Year _____ Record Number _____

	Yes	No	Unclear	Not Applicable
1. Was study based on a random or pseudo-random sample?	☐	☐	☐	☐
2. Were the criteria for inclusion in the sample clearly defined?	☐	☐	☐	☐
3. Were confounding factors identified and strategies to deal with them stated?	☐	☐	☐	☐
4. Were outcomes assessed using objective criteria?	☐	☐	☐	☐
5. If comparisons are being made, was there sufficient descriptions of the groups?	☐	☐	☐	☐
6. Was follow up carried out over a sufficient time period?	☐	☐	☐	☐
7. Were the outcomes of people who withdrew described and included in the analysis?	☐	☐	☐	☐
8. Were outcomes measured in a reliable way?	☐	☐	☐	☐
9. Was appropriate statistical analysis used?	☐	☐	☐	☐

Overall appraisal: Include ☐ Exclude ☐ Seek further info ☐

Comments (Including reason for exclusion)

Appendix IV: JBI MASTARI Data Extraction Tool

JBI Data Extraction Form for Experimental / Observational Studies

Reviewer _____ Date _____

Author _____ Year _____

Journal _____ Record Number _____

Study Method

RCT	☐	Quasi-RCT	☐	Longitudinal	☐
Retrospective	☐	Observational	☐	Other	☐

Participants

Setting

Population

Sample size

Group A _____ Group B _____

Interventions

Intervention A

Intervention B

Authors Conclusions:

Reviewers Conclusions:

Study results

Dichotomous data

Outcome	Intervention ( ) number / total number	Intervention ( ) number / total number

Continuous data

Outcome	Intervention ( ) number / total number	Intervention ( ) number / total number

Appendix V: List of studies excluded at full text examination with reasons

Brennan RP, Smucker PY, Horn EM. Minimally invasive image-guided direct repair of bilateral L-5 pars interarticularis defects. Neurosurgical focus. 2008;25(2):E13
- Bilateral spondylolysis only

Hioki A, Miyamoto K, Sadamasu A, Nozawa S, Ogawa H, Fushimi K, et al. Repair of pars defects by segmental transverse wiring for athletes with symptomatic spondylolysis: relationship between bony union an postoperative symptoms. Spine. 2012 Apr 20;37(9):802-7.
- Not specified whether unilateral or bilateral spondylolysis

Lundin DA, Wiseman D, Ellenbogen RG, Shaffrey CI. Direct repair of the pars interarticularis for spondylolysis and spondylolisthesis. Pediatric Neurosurgery. 2003 //;39(4):195-200.
- Bilateral spondylolysis only

Nozawa S, Shimizu K, Miyamoto K, Tanaka M. Repair of pars interarticularis defect by segmental wire fixation in young athletes with spondylolysis. American Journal of Sports Medicine. 2003 //;31(3):359-64.
- Not specified whether unilateral or bilateral spondylolysis

Ogawa H, Nishimoto H, Hosoe H, Suzuki N, Kanamori Y, Shimizu K. Clinical outcome after segmental wire fixation and bone grafting for repair of the defects in multiple level lumbar spondylolysis. Journal of spinal disorders & techniques. 2007 Oct;20(7):521-5.
- Bilateral spondylolysis only

Reitman CA, Esses SI. Direct repair of spondylolytic defects in young competitive athletes. The spine journal: official journal of the North American Spine Society. 2002 Mar-Apr;2(2):142-4.
- Not specified whether unilateral or bilateral spondylolysis

Roca J, Moretta D, Fuster S, Roca A. Direct repair of spondylolysis. Clinical orthopaedics and related research. 1989 Sep(246):86-91.
- Not specified whether unilateral or bilateral spondylolysis

Sairyo K, Sakai T, Yasui N. Minimally invasive technique for direct repair of pars interarticularis defects in adults using a percutaneous pedicle screw and hook-rod system: Technical note. Journalof Neurosurgery: Spine. 2009;10(5):492-5.
- Bilateral spondylolysis only

Salib RM, Pettine KA. Modified repair of a defect in spondylolysis or minimal spondylolisthesis by pedicle screw, segmental wire fixation, and bone grafting. Spine. 1993 Mar 15;18(4):440-3.
- Bilateral spondylolysis only

Sutton JH, Guin PD, Theiss SM. Acute lumbar spondylolysis in intercollegiate athletes. Journal of Spinal Disorders and Techniques. 2012 //;25(8):422-5.
- Not specified whether unilateral or bilateral spondylolysis

Widi GA, Williams SK, Levi AD. Minimally invasive direct repair of bilateral lumbar spine pars defects in athletes. Case Reports in Medicine. 2013;2013
- Bilateral spondylolysis only