SI Screw vs Locking Square Plate Fixation in Sacroiliac Joint Disruption on Composite Bone Models

By

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Declaration:

I, Frederik Jacobus Kloppers, declare that the coursework Master's Degree mini-dissertation that I herewith submit in a publishable manuscript format for the Master's Degree qualification MMed(Orth) at the University of the Free State is my independent work, and that I have not previously submitted it for a qualification at another institution of higher education.

All sources used and/or quoted have been indicated and acknowledged by means of complete references.

The author declares no conflict of interest.

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Abstract

Background: The aim of this study was to compare a locked square plate to a standard sacroiliac screw of the sacroiliac joint on a composite pelvis bone model to assess the ultimate load tolerated before failure of fixation and to describe the mode of failure of the construct.

Methods: Bilateral sacroiliac (SI) joint dislocations were created in 10 composite pelvic bone models. In this descriptive comparative study, the one SI joint was fixated using a 7.3mm cannulated screw and the contralateral side fixated using a 4-hole square locking plate. The pubic symphysis was not fixed. An upward vertical load was manually applied to each respective SI joint using a hook into the sciatic notch. The ultimate load to failure and the mode of failure was recorded for both groups.

Results: The mean load to failure for the SI screw group was 310 N and for the SI plate group 580 N. The ultimate load to failure was significantly lower in the SI screw group (p=0.0002). There were no hardware-related failures recorded in any of the fixations in the study. The SI screw group had failure through a fracture of the sacrum in all the specimens. In the SI plate group, fractures of the sacrum and ilium constituted, respectively, 60% and 40%.

Conclusion: A locked square plate fixation is superior to a single SI screw at the ultimate load to failure when a vertical load is applied to the sacroiliac joint in a composite bone model.

Keywords

Pelvic ring, pelvis trauma, SI joint, SI screw, sacroiliac plating, bone models

List of abbreviations

SI – sacroiliac

VS – vertical shear

APC – anteroposterior compression

ORIF – open reduction internal fixation

LC – lateral compression

CT – computerised tomography

AO-OTA - Association for Osteosynthesis-Orthopaedic Trauma Association

Chapter 1: Literature review

SI screw vs Locking Square Plate Fixation in Sacroiliac Joint Disruption on Composite Bone Models

1. Introduction

Pelvic trauma comprises up to 3% of all skeletal injuries. It mainly occurs in younger patients as a result of high energy trauma, road traffic accidents, falls from heights, or sport-related injuries. Morbidity rates associated with pelvic injury remain high, mainly due to intrapelvic haemorrhage. Ten to fifteen percent of patients arrive in the emergency department with signs of shock. Pelvic injuries are associated with mortality rates of as high as thirty percent[1].

2. Anatomy

The pelvic ring consists of two innominate bones and the sacrum. The pelvic ring is stabilised anteriorly by the pubic symphysis and pubic rami, while posterior stability relies on the posterior sacroiliac (SI) complex with its corresponding ligaments. Biomechanical studies have proven that the posterior sacroiliac complex contributes more to the stability of the pelvic ring if compared to the anterior structures. The anterior and posterior complex each contribute 40% and 60%, respectively[2].

3. Classification

Unstable injuries to the pelvis are associated with disruption of the posterior osteoligamentous structures. These injuries include the following: sacroiliac joint disruptions, sacral fractures, complete iliac fractures, crescent iliac fracture-sacroiliac joint dislocations, or a combination of the above[3].

According to the Association for Osteosynthesis-Orthopaedic Trauma Association (AO-OTA) classification, a type C pelvic ring injury is defined by the disruption of the posterior pelvic complex that results in a vertically and rotationally unstable pelvic ring[4]. Other predictive systems, such as the Young & Burgess[5] and Tile[2] classifications, can be used to classify pelvic ring injuries. Young & Burgess classified them according to the mechanism of injury and consist of a lateral compression (LC), anteroposterior compression (APC), vertical shear (VS), or combination type injuries. Tile classified pelvic fractures according to stability: A - stable, B - partially stable, or C - unstable with sub-classifications of each[2].

The advantage of the mechanism-guided fracture classifications, such as the Young & Burgess classification, is that they provide guidance for surgical indications and fixation of pelvic fractures[(1,3)].

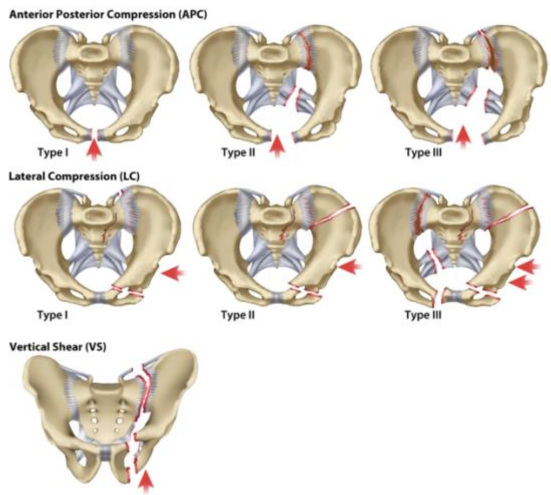

FIGURE 1: YOUNG AND BURGESS CLASSIFICATION [4]

4. Management

The initial treatment of unstable pelvic injuries is determined by the patient's overall condition and injury pattern. Circumferential pelvic binders or anterior external pelvic fixators can be used to stabilise the anterior pelvic ring in "open book" type injuries. Anterior external fixators may result in further displacement of the posterior complex in unstable pelvic ring injuries. The initial posterior pelvic reduction may improve with the use of a pelvic c-clamp or sacroiliac lag screws[1,3].

The definitive fixation of unstable pelvic injuries remains controversial in terms of timing. Current recommendations suggest that haemodynamically stable patients can be treated with a definitive internal pelvic fixation within 24 hours of the injury. Patients who are haemodynamically unstable or polytrauma patients with physiologically deranged parameters should be resuscitated and definitive fixation postponed until between day 4 and day 10 post-injury. The parameters used to assess if a patient is eligible for early total care include: normal temperature, absence of acidosis, normal lactate and the absence of coagulopathy[1,6].

Surgical fixation remains the definitive treatment of choice for unstable posterior pelvic injuries. However, to date, no fixation method is shown to be as stable as the intact pelvic ring[7].

4.1 Reduction accuracy

Anatomical reduction and fixation have shown improved overall construct performance, especially when compared to outcomes where non-anatomical reductions were obtained. Malreduction of the SI joint leads to loss of joint congruence and subsequently, a decrease in the contact area between the articular surfaces. Due to the shape of the SI joint, this will lead to decreased intrinsic stability of the joint. A non-anatomical reduction is associated with the development of chronic pain, leg length discrepancy, limb malalignment, and fracture non-union. Anatomical reduction of the SI joint will increase the fixation strength of the construct, prevent subsequent fixation failures and restore the limb malalignment[8].

Studies have proven that reduction within 1cm of combined residual displacement in posterior pelvic ring injuries leads to improved functional scores and clinical outcomes. It is also advised that posterior displacement should be less than 5mm. In pure SI joint dislocations, poor clinical outcomes were observed where the SI joint was not anatomically reduced. Favourable results were also reported at 1-year follow-up in patients treated with percutaneous fixation after obtaining an anatomical reduction[3,8].

4.2 Techniques

Several surgical techniques have been described in the literature for the treatment of posterior pelvic ring injuries. These techniques include anterior plating by ilioinguinal approach, open or closed reduction with percutaneous screw fixation, or posterior fixation using several different fixation techniques. Posterior fixation is usually done with the patient in a prone position and using one of the following fixation techniques: plate and screws, sacroiliac (SI) screws, or a lumbopelvic fusion using pedicle screws[6,9–12].

4.3 SI screw

Various sacroiliac screw techniques and positions have been described in the literature. *Van Zwienen et al.* compared a single S1 SI screw to two converging screws in S1 and one separate screw in S1 and S2, respectively. They concluded that adding a second screw significantly increases the rotational stiffness and load to failure compared to a single screw. Adding a second screw to S2, however, is more technically demanding and has an increased risk of iatrogenic nerve injury[7]. In a follow-up study, the authors compared a single to two SI screws again, using cyclic loading. They concluded that two sacroiliac screws had significantly more cycles as well as higher loads to failure. Both constructs failed within 700 applied cycles[13].

Finite element analysis of four different SI screw techniques by Zhang *et al.* concluded that a single SI screw fixation would be adequate for rotationally unstable dislocations. Adding a second screw in vertically and rotationally unstable dislocations would add biomechanical stability[14].

Lengthened sacroiliac screws have been shown to be superior to bidirectional sacroiliac screws in bilateral sacral fractures using finite element analysis[15]. Transiliac-transsacral lengthened screws have shown no differences in pain scores or functional scores when compared to unilateral sacroiliac screws[16].

In comparative biomechanical testing on posterior pelvic ring fixation, these fixations have also been described in terms of the construct's stiffness. In a study by Yinger *et al*. on synthetic pelvis models, a single SI screw was the least stiff construct of all tested. Two SI screws or a combination of two anterior SI plates combined with a SI screw proved to be the stiffest constructs. Anterior SI plating showed decreased stiffness when comparing SI joint rotation to SI joint gapping[17].

In a cadaver study by Sagi *et al.,* they found no statistically significant difference between one or two SI screws in controlling the rotational or linear displacement of an unstable hemipelvis alone. The addition of an anterior symphyseal plate in vertically unstable fractures decreased the displacement of the unstable hemipelvis in all planes, regardless of the posterior screw constructs used. They did not compare the load to failure of the constructs[18].

They attributed the differences in these results because of the different bone density areas found in the normal human sacrum whereas synthetic sacrum models are of uniform density. In a human sacrum, the greatest bone density is located in the anterior aspect of the promontory of S1. Lower bone densities are found at the posterior aspect of S1, the body of S2, and the sacral ala. Due to the relative osteopenia in S2 and the posterior aspect of S1, adding an additional screw in those regions will not likely add to the stability[18].

Current literature suggests that less experienced orthopaedic surgeons prefer closed reductions and percutaneous techniques compared to open reduction and internal fixation (ORIF) for pelvic ring fractures. Percutaneous performed cases have increased proportionally from 49% in 2003 to 79% in 2015[19].

Advantageously, percutaneous sacroiliac screw fixation has a shorter operative time, decreased intraoperative blood-loss, smaller wound size, and reduced length of hospital stay when compared to open anterior sacroiliac joint plate fixation[19,20].

4.4 Open reduction and approaches

Despite the popularity of closed reduction and percutaneous fixation techniques, some fractures and dislocations are not amenable to accurate reduction using these methods, and an open approach is sometimes required. Open reduction requires the direct visualization of the bony anatomy and can be done by using either the anterior or posterior approaches. The anterior approach allows better access to the superior SI joint and also allows better osseous exposure. The posterior approach allows better access to the inferior SI joint[11,21].

A study performed by Lindsay *et al.* proved that closed reduction could be as effective as open reduction through the posterior approach. The authors did not compare the accuracy of reduction using an anterior approach. The study was also performed by two different surgeons in two different centres each only performing either the closed reduction and percutaneous fixation or ORIF. This study was thus vulnerable to bias[22].

The posterior approach to the pelvis has a higher profile of complications compared to the anterior approach. This includes wound infection, skin necrosis, neurological injuries, post-operative lower back pain and sexual dysfunction[23].

Anterior plating of the SI joint is commonly performed with the use of a double plating technique. Fixation is achieved by using either a two-hole or three-hole plate. When using a three-hole plate, two screws are placed on the iliac side and a single screw on the sacral side. Parallel placement of the plates is weaker compared to double plates placed at 60 degrees to each other. When doing double plating at 60 degrees, it has shown greater strength and stability in biomechanical studies compared to two-hole plates and sacroiliac screws[23].

Anterior fixation with a square plate at the sacroiliac joint has shown promising clinical results in patients. Out of the 21 patients with 23 SI joint injuries, 18 patients had an excellent or good outcome at 5 years, and only 3 had poor outcomes. All patients had an open reduction using the anterior approach. This resulted in a perfect reduction or reduction within 5mm in 19 out of the 23 SI joints. The design of the square plate allows the screws to be inserted in close proximity to each other as well as close to the joint line[24].

Leighton *et al*. developed a four-hole anterior compression plate specific for sacroiliac joint fixation. They found that a flat plate that can easily be contoured could be used due to the relatively flat coronal plane bony architecture within 2cm either side of the sacroiliac joint. The deformation of 2.1cm was achieved when the intact pelvis was loaded to 1000N and was used as their control group. Posterior fixation with their four-hole plate and anterior symphyseal plates averaged a load of 320N to achieve 2.1cm deformation, and this construct failed at an averaged 428N in a cadaver model. They found no significant difference when comparing three posterior screws to the SI plate. This study confirmed again that no fixation method is as strong as the normal intact pelvis[25].

A study using synthetic pelvis models comparing posterior tension band plating through the S1 vertebra pedicles and sacroiliac screws bilaterally, concluded that bilateral single SI screws were superior to posterior tension band plating and S1 pedicle fixation. The study was divided into three groups. The average load to failure for the SI screw group was 2230N and for the posterior tension band group 1775N. For the group that combined the two constructs, the average load to failure was 2084N. The vertical force was applied to the S1 vertebral body while bilateral sciatic notches were stabilised using a specially designed metal interface[12].

To date, in the literature there are no comparative studies using a locked square plate fixation and a SI screw fixation. The choice of fixation method to use still remains multifactorial and needs to be individualised to the specific patient and injury factors.

4.5 Anatomical considerations for anterior plating

Complications associated with anterior SI joint plating include iatrogenic nerve injury to the nerve roots of L4 and L5. Anatomically, anterior plates can be used at the superior end of the SI joint. Visualisation of the joint to ensure anatomical reduction and good screw placement is achieved by exposing 2.5cm of the sacrum medially at the superior end and 1.5cm of the sacrum medially at the inferior third. Screws inserted on the sacral side should incline approximately 30 degrees medially to avoid entering the SI joint on the lateral side and the sacral foramina with its corresponding nerve roots on the medial side[26].

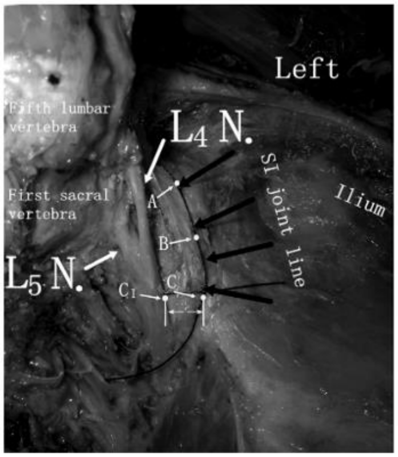

Fig. 1. The morphological observation of the SI joint of the corpse. The SI joint line was represented by the suture line which was marked by the black arrows. A: the highest point of SI joint line, C: the lowest point of SI joint line, B: the midpoint of SI joint line, C1: the intersection point of the lateral border of the anterior branches of L4 and the transverse plane passing point C. The vertical distance from the point C to the sagittal plane passing the point C1 was defined the horizontal distance between the L4 nerves and the SI joint on the plane C.

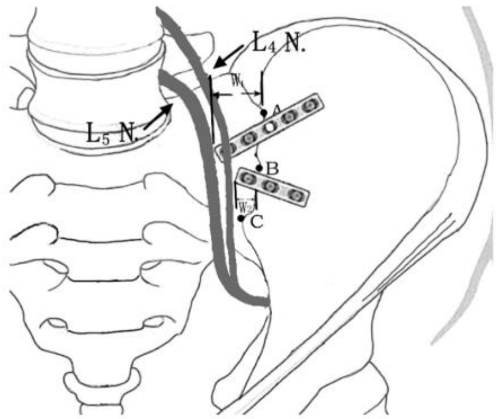

Fig. 7. The model diagram showing the surgical safe zone of the double plates fixation of the SI joint fracture. A: the highest point of SI joint line, C: the lowest point of SI joint line, B: the midpoint of SI joint line, W1: the limited sacral exposure range of 2.5 cm wide, W2: the limited sacral exposure range of 1.5 cm wide.

Above Figures: Anatomical evidence for anterior plate fixation of sacroiliac joint[26].

Navigation-aided visualisation of the lumbosacral nerves has also been used with success to recognise the at-risk areas for nerve injury in a patient where anterior sacroiliac plate fixation was needed. The authors used a pre-operative computerised tomography (CT) with an intra-operative 3D-fluoroscopy matching navigating system. Using this technology, they managed to identify the nerve roots at risk and subsequently could do an anterior sacroiliac plate fixation in a safe zone. However, it was only a single case, and the segmentation of the lumbosacral nerves could not be validated. Comparative studies quoted in this paper using 3D fluoroscopic navigation for percutaneous iliosacral screws have also shown decreased risks of screw penetration and subsequent complications[27].

5. <u>Use of bone models in research</u>

Composite bone models have evolved and became a suitable replacement for cadaver bone in many settings, including surgical education and orthopaedic biomechanical research. This has reduced the need for cadaveric bone in bone-related studies. The current fourth-generation composite bone models' biomechanical properties accurately reproduce that of human bone under different loads. They offer excellent anatomic detail and also offer consistency in terms of their biomechanical properties. Cadaver specimens show more inconsistency between different specimens and can also cost up to three times more than equivalent fourth-generation composite bone models. The bone quality of cadaveric specimens may also not represent that of the general orthopaedic population due to disproportionately representing the elderly.[28] Synthetic bone models have successfully been used in multiple biomechanical studies, specifically in the pelvic and acetabular regions[8,12,17,29,30].

6. Hypothesis

From the above literature review, we have learned that anatomical reduction and definitive surgical fixation of the sacroiliac joint is important to allow improved construct performance and functional outcomes in patients.

Many different techniques have been described to reduce and fixate the SI joint, and it is generally accepted that a percutaneous SI screw is currently the treatment of choice. In some cases and injury patterns, it is not possible to get an adequate closed reduction, and open reduction needs to be considered.

Anterior plating of the SI joint has been described in different plate types and configurations.

We could not find literature where a locked 4-hole plate and screw configuration was compared to a SI screw.

We suggest that a locking plate, placed in the safe zone over the SI joint and screws inserted under direct vision, when doing an open reduction, can be safely done. It will decrease the risk of neurologic injury when compared to doing an open reduction and percutaneous screw technique under fluoroscopy after an open reduction of the joint.

It is also generally accepted to use synthetic bone models for biomechanical research in orthopaedic surgery.

7. Research questions, aims, and objectives

The question we pose is whether a square-shaped locking plate is stronger than a standard SI screw at its ultimate failure point when a vertical load is applied to the sacroiliac joint in a composite bone model? The primary objective is to determine the ultimate load to failure of both fixation types in the context of a vertical external force applied in a composite bone model.

The secondary objective is the description of the fracture pattern observed in the model or the nature of the failure of the construct.

We hypothesise that the anterior square plate construct will be equal to or stronger than the SI screw fixation at the ultimate failure point.

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Chapter 2: Manuscript

SI screw vs Locking Square Plate Fixation in Sacroiliac Joint Disruption on Composite Bone Models

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Abstract

Background: The aim of this study was to compare a locked square plate to a standard sacroiliac screw of the sacroiliac joint on a composite pelvis bone model to assess the ultimate load tolerated before failure of fixation and to describe the mode of failure of the construct.

Methods: Bilateral sacroiliac (SI) joint dislocations were created in 10 composite pelvic bone models. In this descriptive comparative study, the one SI joint was fixated using a 7.3mm cannulated screw and the contralateral side fixated using a 4-hole square locking plate. The pubic symphysis was not fixed. An upward vertical load was manually applied to each respective SI joint using a hook into the sciatic notch. The ultimate load to failure and the mode of failure was recorded for both groups.

Results: The mean load to failure for the SI screw group was 310 N and for the SI plate group 580 N. The ultimate load to failure was significantly lower in the SI screw group (p=0.0002). There were no hardware-related failures recorded in any of the fixations in the study. The SI screw group had failure through a fracture of the sacrum in all the specimens. In the SI plate group, fractures of the sacrum and ilium constituted, respectively, 60% and 40%.

Conclusion: A locked square plate fixation is superior to a single SI screw at the ultimate load to failure when a vertical load is applied to the sacroiliac joint in a composite bone model.

Level of evidence: Level 3

Keywords: pelvic ring, pelvis trauma, SI joint, SI screw, sacroiliac plating, bone models

Introduction

Trauma to the pelvis comprises up to 3% of all skeletal injuries. It mainly occurs in younger patients as a result of high energy trauma, road traffic accidents, falls from heights, or sport-related injuries. These injuries are associated with increased morbidity and mortality rates[1].

Biomechanical studies have proven that the posterior sacroiliac (SI) complex contributes more to the stability of the pelvic ring if compared to the anterior structures. The anterior and posterior complex each contribute 40% and 60%, respectively[2].

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Surgical fixation remains the definitive treatment of choice for unstable posterior pelvic injuries. To date, no fixation method is as stable as the intact pelvic ring[7]. Anatomical reduction and fixation have shown improved overall construct performance, especially when compared to outcomes where non-anatomical reductions were obtained. The non-anatomical reduction is associated with the development of chronic pain, leg length discrepancy, limb malalignment and fracture non-union[8].

Studies have proven that reduction within 1cm of combined residual displacement in posterior pelvic ring injuries leads to improved functional scores and clinical outcomes. In pure SI joint dislocations, poor clinical outcomes were observed where the SI joint was not anatomically reduced. Favourable results were also reported at a one-year follow-up in patients treated with percutaneous fixation after obtaining an anatomical reduction[3,8].

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Current literature suggests that less experienced orthopaedic surgeons prefer closed reductions and percutaneous techniques compared to open reduction and internal fixation for pelvic ring fractures[19]. Despite the popularity of closed reduction and percutaneous fixation techniques, some fractures and dislocations are not amenable to accurate reduction using these methods and an open approach is sometimes required. The anterior approach allows better access to the superior SI joint and allows better osseous exposure than the posterior approach[11,21].

Advantageously, percutaneous sacroiliac screw fixation has a shorter operative time, decreased intraoperative blood-loss, smaller wound size, and reduced length of hospital stay when compared to open anterior sacroiliac joint plate fixation[19,20]. The posterior approach to the pelvis has a higher profile of complications compared to the anterior approach. It includes wound infection, skin necrosis, neurological injuries, post-operative lower back pain and sexual dysfunction[23].

Composite bone models have evolved and became a suitable replacement for cadaver bone in many settings, including surgical education and orthopaedic biomechanical research. The current fourth-generation composite bone models' biomechanical properties accurately reproduce that of human bone under different loads. They provide excellent anatomic detail and also offer consistency in terms of their biomechanical properties. Cadaver specimens can also cost up to three times more than equivalent fourth-generation bone models[28]. Synthetic bone models have successfully been used in multiple biomechanical studies, specifically in the pelvic and acetabular regions[8,12,17,29,30].

To date, we could not find comparative studies between a locked square plate and a SI screw for sacroiliac joint fixation.

This study's primary aim was to compare the ultimate load to failure of a square locking plate to a SI screw when a vertical load is applied to the SI joint. The secondary objective was to describe the mode of failure of the construct.

Materials and methods

Ten artificial pelvis models (Synbone AG, Switzerland, Model no: 4083) were used in this study. These models are specifically designed for orthopaedic training and research.

No biomechanical testing facility was available at the University of the Free State to assist with this study.

We simulated an unstable type C sacroiliac (SI) joint dislocation in the models by removing all attachments at the sacroiliac joint and pubic symphysis. The lower part of the sacrum and coccyx was removed using a jigsaw to allow sacrum fixation to a wooden block. The sacrum of the model was then secured to a wooden block using four 10mm threaded rods with washers and bolts through the sacral foramina of S1 and S2. In turn, the wooden block was then secured to a bench vice to keep it stable to the ground. The sacrum attached to the wooden block and bench vice allowed a stable base to work from.

Anatomical reduction of the SI joint was then performed using a toothed reduction clamp. The SI fixation type was grouped into two groups: a SI screw group and a SI plate group. The one side of the model was fixed using the screw and the other side using the plate. Sides were randomised so that both groups would have equal representation on either side of the sacrum in our study population. The pubic symphysis was not fixated in any of the specimens.

The SI screw group was fixated using a 90mm x 7.3mm stainless steel, partially threaded cannulated screw with a washer. After anatomical reduction, a threaded guidewire was inserted perpendicularly from the ilium over the SI joint into the body of S1. A cannulated drill bit was used and drilled until just medial to the SI joint. The screw with its washer was then inserted by hand and hand tightened using a two-finger tightening technique.

The SI plate group was fixed using a 4-hole, 35mm x 22mm x 2.5mm, titanium plate with fully threaded cancellous locking screws, 45mm x 7mm (Saspine Pty Ltd). The plate was placed on the superior surface of the SI joint with two screws on either side of the joint. Holes were drilled using a 4.2mm drill bit and the nearest cortex over drilled with a 5mm drill bit. The sacrum screws were directed medially parallel to the joint, avoiding penetration of the sacral foramina and SI joint. Iliac screws were directed posterolaterally aimed at the posterior inferior iliac spine. The screws were inserted and locked by hand.

An industrial hanging scale (ADAM Model: MIF200) with metal hooks was hooked into the test model's sciatic notch. The researcher applied a manual vertical force via the scale in a controlled manner until fixation failure occurred. Fixation failure was defined as the point where fracture of the model, screw pullout, or implant breakage occurred. A slow-motion video was taken during vertical force application to determine the ultimate load to failure accurately. The force needed to cause construct failure was recorded (kilograms converted to newtons). The models and implants were inspected after the test was done to assess the mode of construct failure.

Data was collected on a data form after each test. Data was then captured in the form of a Microsoft Excel spreadsheet and submitted to the Department of Biostatistics at the University of the Free State for analysis.

Results

In the SI screw group, the median load to failure was 310 N (range: 280 to 390 N) and in the SI plate group, the median load to failure was 580 N (range: 380 to 760 N). Ultimate load to failure was significantly lower in the SI screw group (p=0.0002). See table 1 for comparison of ultimate load to failure in the fixation types.

In the SI screw group, all failures were due to a fracture of the sacrum. In the SI plate group, 60% (6 models) of the failures occurred due to fracture of the sacrum and 40% (4 models) due to fractures at the ilium. No hardware breakage or screw pullout was observed in any of the groups.

In the SI plate group, the median load to failure for an ilium fracture was 610 N (range 380 to 760 N) and for the sacrum fracture 490N (range 400 to 600 N).

Discussion

Surgical fixation remains the treatment of choice in various posterior pelvic injuries, which includes SI joint dislocation. Which technique to use remains multifactorial in terms of injury and patient factors.

It is generally accepted in various biomechanical and finite element analysis studies that adding a second screw to the SI joint fixation increases the biomechanical stability, load to failure and amount of cycles to failure compared to a standard single SI screw[3,6,7,13,14,17]. Transiliac-transsacral lengthened screws provide mechanical advantages over unilateral sacroiliac screws and also shows no differences in pain scores or functional scores when compared to unilateral sacroiliac screws[15,16]. Adding a second screw theoretically increases the risk for extraosseous screw penetration and subsequent iatrogenic nerve injury.

In a cadaver study by Sagi *et al.,* they found no statistically significant difference between one or two SI screws in controlling the unstable hemipelvis's rotational or linear displacement alone.

The addition of an anterior symphyseal plate in vertically unstable fractures decreased the displacement of the unstable hemipelvis in all planes, regardless of the posterior screw constructs used. They attributed these results because there are different bone density areas found in the normal human sacrum, whereas synthetic sacrum models are of uniform density. In a human sacrum, the greatest bone density is located in the anterior aspect of the promontory of S1. Lower bone densities are found at the posterior aspect of S1, the body of S2 and the sacral ala. Due to the relative osteopenia in S2 and the posterior aspect of S1, adding an additional screw in those regions will not likely add to the stability[18].

We opted to use a single SI screw in our study to limit variables in screw positioning and to compare a baseline screw fixation with the limited amount of bone models available to us. A theoretical higher risk of screw penetration and iatrogenic nerve injury when adding a second screw to the construct and the technical difficulty in inexperienced or low-volume surgeons also influenced this decision.

Anterior plating of the SI joint is commonly performed with the use of a double plating technique. When using a three-hole plate, two screws are placed on the iliac side and a single screw on the sacral side. Parallel placement of the plates is weaker compared to double plates placed at 60 degrees to each other[23].

Anterior fixation with a square plate of the sacroiliac joint has shown promising clinical results in patients. The square plate's design allows the screws to be inserted in close proximity to each other and close to the joint line[24]. The design allows placement in the "safe zone" around the SI joint, reducing the risk of iatrogenic nerve injury to the L4 and L5 nerve roots[26]. It also allows a relatively smaller dissection for plate placement compared to double plating. A relatively flat plate can be used due to the flat coronal plane bony architecture within 2cm either side of the SI joint. Leighton *et al.* developed a four-hole anterior compression plate for sacroiliac joint fixation. Posterior fixation with their four-hole plate and anterior symphysial plates failed at an averaged 428N in a cadaver model[25].

The design of the square plate with its large locking screws in our study allows a variable angle where the screws can be angled to prevent extraosseous penetration into the SI joint and sacral foramina. Screw pullout is reduced due to the locking mechanism in the plate and the screw with its cancellous thread also allows good bone purchase in cancellous bone. The larger core diameter of the screws also allows more resistance to bending forces and subsequently screw breakage.

There are some limitations to our study. A proper biomechanical testing facility would have allowed us a more accurate simulation of a vertical load to the SI joint. It would also enable cyclical loading to the respective constructs to determine specific failure points or displacement values. We would, however, argue that all specimens were stressed in the same manner and that the methodology is reproducible and cost-effective in a resource-constrained environment.

The most notable limitation was the use of synthetic bone models. Even though they cannot completely simulate human bone, they have comparable biomechanical properties when compared to cadaver specimens. They also allow consistent material properties between specimens and are most cost-effective[28]. Our sample size was also relatively small but is comparable to other similar biomechanical studies comparing posterior pelvic fixation techniques[7,8,12,13,17,23,29,30].

Conclusion

A locked square plate fixation is superior to a single SI screw at the ultimate load to failure when a vertical load is applied to the sacroiliac joint in a composite bone model. It may be considered an alternative to a percutaneous screw fixation when an open reduction of the sacroiliac joint is needed. Further biomechanical studies are required to compare a locked square plate to other SI joint fixation methods.

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Saspine (Pty) Ltd provided implants for use in this study.

Conflict of interest

The authors declare no potential conflicts of interest concerning the research, authorship and/or publication of this article. The authors did not receive any royalties and have no connections with Saspine (Pty) Ltd.

Ethics statement

The authors declare that this submission is in accordance with the principles laid down by the Responsible Research Publication Position Statements as developed at the 2nd World Conference on Research Integrity in Singapore, 2010.

Before the commencement of this study, ethics approval was obtained from the Ethics Committees of the University of the Free State ethics number: UFS-HSD2020/0157.

This article does not contain any studies with human or animal subjects.

Author contributions

FJK: Primary author, responsible for the literature review, study design, data collection and manuscript preparation.

JFVDM: Conceptualisation, study design, data collection and manuscript approval.

AAVZ: Conceptualisation, study design and manuscript approval.

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Figures

Figure 1: Sacrum secured to workbench and fixation of left SI joint using square plate

Figure 2: Anatomical fixation of left SI joint using square plate.

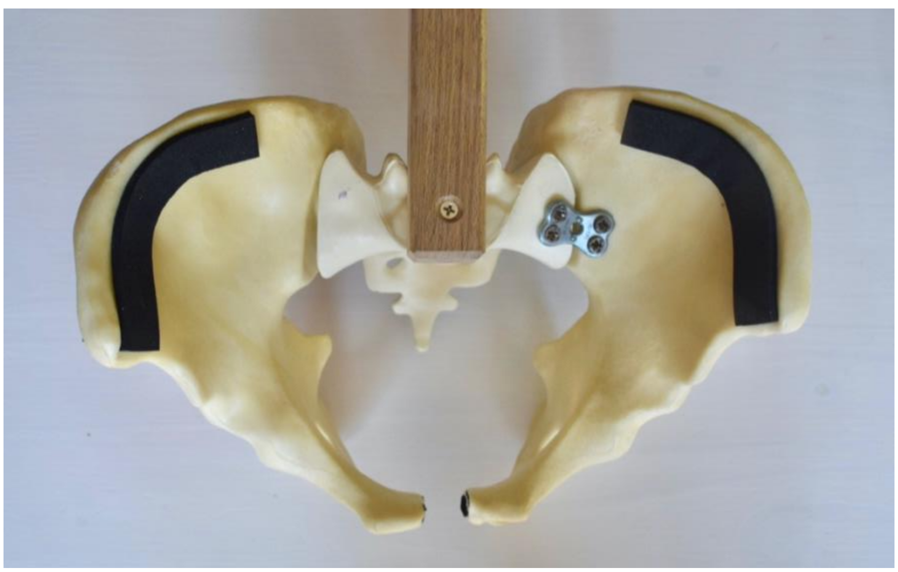

Figure 3: Square plate with locking screws illustrating variable locking angle of the screws

Figure 4: Manual vertical force applied to SI joint using a mechanical scale, hooked into the sciatic notch.

Tables

Table 1: Comparison of ultimate load to failure of SI screw and SI plate in Newtons(N)

Model number	SI screw	SI plate
1	310	400
2	280	410
3	300	760
4	330	600
5	320	620
6	390	560
7	350	600
8	290	380
9	310	420
10	310	600

Appendix A: Protocol

SI SCREW VS LOCKING SQUARE PLATE FIXATION IN SACROILIAC JOINT DISRUPTION ON COMPOSITE BONE MODELS

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INDEX

1. INTRODUCTION

Trauma to the pelvis occurs in 3% of all skeletal injuries. It occurs mainly in younger patients as a result of high energy trauma, sustained in road traffic accidents, falls from heights or sports related activities. Morbidity rates associated with pelvic injury remain high, particularly due to intrapelvic haemorrhage. Ten to fifteen percent of patients arrive in the emergency department with signs of shock. This contributes to a reported mortality rate of as high as 30 percent associated with pelvic injury[1].

Unstable injuries to the pelvis are associated with disruption of the posterior osteoligamentous structures. This includes disruption of the sacroiliac joint. According to the Association for Osteosynthesis-Orthopaedic Trauma Association (AO-OTA) classification, a type C pelvic ring injury presents with disruption of the posterior pelvic structures, which is both vertically and rotationally unstable[4]. Other predictive systems, including the Young and Burgess[5] and Tile[2] classifications respectively can be used to classify pelvic ring injuries.

Surgical fixation remains the treatment of choice for unstable posterior pelvic injuries. However, to date, no fixation method is shown to be as stable as the intact pelvic ring[7]. Exact anatomical reduction and fixation has shown improved overall construct performance, especially compared to outcomes where non-anatomical reductions were performed. Non anatomical reductions is associated with the development of chronic pain, leg length discrepancies, limb malalignment and fracture non-union[8].

Several surgical techniques have been described in the literature for the treatment of these injuries. These include anterior plating by ilioinguinal approach, either open or closed reduction with fluoroscopy guided percutaneous screw fixation or posterior fixation using several different techniques[6,9,10].

Biomechanical comparative testing on these fixation methods have been described in terms of stiffness of the construct, however the choice of method to use still remains multifactorial[17].

Current literature suggests that less experienced orthopaedic surgeons prefer closed reductions and percutaneous techniques compared to open reductions for pelvic ring fractures[19]. Despite the popularity of closed reduction and percutaneous fixation techniques, some fractures and dislocations are not amenable accurate reduction using these methods and an open approach is required[11,21].

Advantageously, percutaneous sacroiliac screw fixation has a shorter operative time, decreased intraoperative blood-loss, minor wound size and decreased length of hospital stay when compared to open anterior sacroiliac joint plate fixation[20].

Closed reduction has been proven to be as effective as open reduction of the sacroiliac joint in a prone position through the posterior approach[22]. The posterior approach to the pelvis has a higher profile of complications compared to the anterior approach. This includes wound infection, skin necrosis, neurological injuries, post-operative lower back pain and sexual dysfunction[23].

In contrast, the anterior approach allows improved visualisation of the superior SI joint and also a larger osseous exposure when compared to the posterior approach[21].

Anterior plating of the SI joint is commonly performed with the use of a double plating technique. Fixation is achieved with either a two-hole or three-hole plate. Parallel placement of the plates is weaker compared to plates placed at 60 degrees to each other. This construct has shown greater strength and stability in biomechanical studies[23].

Anterior fixation with a square plate of the sacroiliac joint has shown good clinical results in patients. The design of the square plate allows the screws to be inserted in close proximity to each other as well as close to the joint line([24].

Leighton et al developed a four-hole anterior compression plate. The construct failed at an averaged 428N in a cadaver model[25].

To date, there are no comparative studies using a locked square plate fixation and a SI screw fixation.

Complications associated with anterior SI joint plating include iatrogenic nerve injury to the nerve roots of lumbar nerves 4 and 5. Anatomically an anterior plate can be used at the upper end of the SI joint. Visualisation of the joint to ensure good screw placement is achieved by exposing 2.5cm of the sacrum medial at the upper end and at the lower third only 1.5cm of the sacrum medially. This in an effort to avoid iatrogenic nerve injury[26]. Navigation-aided visualisation of the lumbosacral nerves has also been used with success to recognise the at risk areas for nerve injury in a patient to where anterior sacroiliac plate fixation was needed[27].

Composite bone models have evolved and become a biomechanically relevant replacement for cadaver bone in many settings. This has reduced the need for cadaveric bone in bone related studies. The biomechanical properties of the current fourth generation composite bone models accurately reproduce that of human bone. Cadaver specimens can also cost up to three times more than equivalent fourth generation composite bone models[28].

2. RESEARCH QUESTIONS, AIMS AND OBJECTIVES

The question we pose is whether a square shaped locking plate is stronger than a standard SI screw at its ultimate failure point when a vertical load is applied to the sacroiliac joint in a composite bone model?

The primary objective is to determine the exact failure point at the sacroiliac joint of both fixation types in the context of vertical external force application in a composite bone model.

The secondary objective is the description of the fracture pattern observed in the model or the nature of the failure of the construct

We hypothesise that the anterior square plate construct will be equal to or stronger than the SI screw fixation at the ultimate failure point.

H0 – SI screw stronger at failure than SI plate
H1 – SI plate equal in strength to SI screw at failure

3. METHODOLOGY

3.1 Study design

Descriptive comparative study

3.2 Sample/ Study subjects

Ten composite pelvis bone models (Synbone) have been acquired. They have previously been sponsored as part of orthopaedic education and belong to the researcher.

Each composite pelvis will have a SI screw placed on a randomly assigned side and a plate fixation on the other.

Synthetic pelvis models have been used from 6 models per fixation up type to 12 models in biomechanical fixation studies for pelvic and acetabulum fixations[8,12,17,30].

We have access to ten models, which would give a good statistical yield.

3.3 Measurement

3.3.1 Setting

Pre-existing workshop, equipped with a workbench at the residence of the supervisor. This setting provides an environment that limits environmental variables and ensures reproducibility in the testing on the composite bone model. It is anticipated that study will be executed and data collected between July and August 2020.

3.3.2 Team

The study will be conducted by both the researcher and research supervisor.

3.3.3 Equipment needed

The following equipment is needed for the completion of the study:

1. Orthopaedic implants
    a. 7.3 mm cannulated screws
    b. Square plates with accompanying locking screws
    c. Standard accompanying equipment including drill bits, guides etc (Provided by Saspine representatives)

2. Cordless drill (Provided by authors)

3. Industrial scale (Provided by authors)
4. Slow-motion video recording device - iPhone X (Provided by authors)
5. Composite pelvis bone models - Synbone (Provided by authors)

3.4 Procedure

Each composite pelvis bone model will be secured to a workbench. This will be achieved by attaching a wooden block to the sacrum through the sacral foramina using threaded rods with washers and bolts. The wooden block will be held in a bench vice.

The sacroiliac joints and symphysis pubis of each model will be totally loosened to simulate an unstable sacroiliac joint injury. Anatomical reduction of the sacroiliac joint will be performed and the fixation applied.

One side of the pelvis will be fixated with a single 7.3mm cannulated screw and a washer perpendicular to the joint line across the SI joint. The opposite hemipelvis to be fixated with the modified anterior square locking plate with four locking screws. Two of these screws will be medial to the SI joint and two screws will be lateral of the SI joint. The pubic symphysis will not be fixated.

A metal hook attached to the scale will be attached around the sciatic notch in the test model. An external vertical will be applied to the sacroiliac joint with the hook and scale. Sufficient force will be applied to cause failure of the construct on each side of the pelvis.

During external force application a slow motion video will be taken. This video will enable a retrospective review of the reading on the scale to determine the exact force at which failure of the construct occurs.

Once the data set has been obtained, a comparison can be compiled of the force applied at failure point of the constructs in order to compare the relative strengths of the different constructs. This will enable a direct comparison between the two different fixation methods.

The researcher will perform the fixation in all models. He will also apply the loads to eliminate inter-person variability in the execution of the study. An independent participant will capture the video during load application. The research supervisor will perform quality control during the different phases of the study execution. These will include the preparation of the models, reduction of the SI joint, application of fixation techniques, fixation of model to test bench, application of load and validation of data from the video recording.

3.5 Variables

- Ultimate strength at failure, measured in Newton (Numerical)

- Description of failure either fracture, screw pullout, breakage. (Categorical)

3.6 Methodological and measurement errors

Bias - Measurement bias

- Pulling scale
    - A pre-calibrated and validated scale will be used

- Camera
    - Slow motion camera to determine the exact failure point and time taken to achieve the failure

- Composite pelvis and implants
    - Similar batches for both pelvis specimens and respective implants will be sourced and used to eliminate intra-batch variability
    - Composite pelvis specimens have standardised anatomy and no differentiation between gender/anatomical variances or different bone qualities

- Unidirectional vertical load applied to produce a cost-effective, reproducible study

4. DATA CAPTURING AND ANALYSIS

All data will be collected on a data collection form and captured in a Microsoft Excel spreadsheet after collection. Captured data will then be analysed by the researchers and the department of Biostatistics at the University of the Free State.

Results will be summerised by means, standard deviations or percentiles (numerical variables) and by frequencies and percentages (categorical variables).

5. IMPLEMENTATION OF FINDINGS

This study forms part of the MMed curriculum and will be handed in to be marked as a MMed dissertation for the department of Orthopaedics, University of the Free State.

Should our findings provide us with significant information about the fixation strength comparing the SI screw and square locking plate, we intend to publish it in a reputable peer reviewed orthopaedic journal. Saspine only requires written acknowledgement of their involvement if study is published.

6. PROPOSED TIME SCHEDULE

Literature study	February – July 2019
Protocol writing	July – December 2019
Submission to Ethics Committee	June 2020
Data capturing	July – August 2020
Submission of data for analysis	September 2020
Submission of completed dissertation	January 2021

7. BUDGET

Item	**Cost**
Travel	R250
Eye protection	R100
Stationary	R250
Implants - Reused unless damaged	Donated
Composite bone models	Donated
Total	**R600**

Saspine (Pty) Ltd has agreed to supply plates screws and drillbits needed for use in this study at no cost to the researchers. Implants will be removed and re-used in different bone models, unless damaged or broken, to limit costs. In return Saspine (Pty) Ltd will receive written acknowledgement for their contribution in our published article.

Travel, eye protection and stationary expenses will be covered by the researcher.

Composite bone models have been donated to the researcher previously for education purposes and is the property of the researcher.

Adam industrial scale has been previously bought for other projects by the research supervisor.

No other expenses are budgeted for.

8. ETHICAL ASPECTS

The protocol will be submitted to the Health Sciences Research Ethics Committee of the University of the Free State.

Permission for this study has been obtained from Dr Steven Matshidza, Head of Department Orthopaedic Surgery, University of the Free State.

This study will be performed on inanimate, composite bone models. As a result there are no ethical issues pertaining to patient consent, confidentiality and medical records.

We do however pledge to act with integrity and honesty in the planning, execution and implementation of our research.

Equipment will be handled with adequate safety precautions. Every team member will be supplied with eye protection and other personal protective equipment during the study.

The duties related to service delivery in the daily employment of the research team will not be negatively influenced during the conduction of this study.

9. REFERENCES

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Appendix B: HOD Approval letter

UNIVERSITY OF THE FREE STATE
UNIVERSITEIT VAN DIE VRYSTAAT
YUNIVESITHI YA FREISTATA

UFS·UV
HEALTH SCIENCES
GESONDHEIDSWETENSKAPPE

2020/01/28

The Chair: Health Sciences Research Ethics Committee
Dr SM Le Grange
For Attention: Mrs M Marais
Block D, Room 104,
Francois Retief Building
Po Box 339 (G40)
Nelson Mandela Drive
Faculty of Health Sciences
University of the Free State
Bloemfontein
9300
2018/10/01

Dear Dr SM Le Grange

Dr FJ Kloppers
Student Number 2007109520

Research Title: SI Screw vs Locking Square-plate Fixation in Sacro-iliac Joint Disruption on Composite Bone Models

I, Dr Steven Matshidza hereby grant Dr FJ Kloppers permission to conduct the above mentioned research project. The research will be completed in accordance with myself as Head of Department of the Department of Orthopaedics at The University of the Free State and Dr JF van der Merwe as a co-investigator of this study.

Yours faithfully

Dr Steven Matshidza
HOD Department of Orthopaedics

29/01/2020
Date

Department of Orthopaedic Surgery
Tel: 051 401 7960

205 Nelson Mandela Drive/Rylaan
Park West/Parkwes
Bloemfontein 9301
South Africa/Suid-Afrika

PO Box/Posbus 339
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UNIVERSITY OF THE FREE STATE
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YUNIVESITHI YA FREISTATA

Appendix C: HSREC Approval

UNIVERSITY OF THE FREE STATE
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YUNIVESITHI YA FREISTATA

UFS·UV
HEALTH SCIENCES
GESONDHEIDSWETENSKAPPE

Health Sciences Research Ethics Committee

25-Jun-2020

Dear **Dr Frederik Kloppers**

Ethics Number: UFS-HSD2020/0157

Ethics Clearance: **SI screw vs Locking Square Plate Fixation in Sacro-iliac Joint Disruption on Composite Bone Models**

Principal Investigator: **Dr Frederik Kloppers**

Department: **Orthopaedics Department (Bloemfontein Campus)**

SUBSEQUENT SUBMISSION APPROVED

With reference to your recent submission for ethical clearance from the Health Sciences Research Ethics Committee. I am pleased to inform you on behalf of the HSREC that you have been granted ethical clearance for your request as stipulated below:

1. Saspine replaces De Puy Synthes as providers of the implants used in this study. They have a pre-manufactured square plate with locking screws and it does not require modification.

2. Saspine has provided a commitment letter to provide the implants at no cost to the research team. They only want written acknowledgement in final publication, regardless of the results. This will thus not bias the interpretation of results (see attached letter)

3.Study budget has been ammended to R600 total. Extra money set aside in budget to allow the purchase of eye protection for the researchers.

4.Composite bone models has been donated to the researcher and is the property of the researcher. Can thus be used for this study at no extra expense.

5. Implants and accompanying equipment provided by Saspine for use in this study at no cost to the researchers. Thus not indicated as an expense in the budget.

6. Proposed time schedule changed due to changes in the providers of the implants and to get the neccessary documentation and letters of commitment in place from Saspine. Time schedule moved on to allow for this delay.

The HSREC functions in compliance with, but not limited to, the following documents and guidelines: The SA National Health Act. No. 61 of 2003; Ethics in Health Research: Principles, Structures and Processes (2015); SA GCP(2006); Declaration of Helsinki; The Belmont Report; The US Office of Human Research Protections 45 CFR 461 (for non-exempt research with human participants conducted or supported by the US Department of Health and Human Services- (HHS), 21 CFR 50, 21 CFR 56; CIOMS; ICH-GCP-E6 Sections 1-4; The International Conference on Harmonization and Technical Requirements for Registration of Pharmaceuticals for Human Use (ICH Tripartite), Guidelines of the SA Medicines Control Council as well as Laws and Regulations with regard to the Control of Medicines, Constitution of the HSREC of the Faculty of Health Sciences.

For any questions or concerns, please feel free to contact HSREC Administration: 051-4017794/5 or email EthicsFHS@ufs.ac.za.

Thank you for submitting this request for ethical clearance and we wish you continued success with your research.

Yours Sincerely

Dr. SM Le Grange
Chair : Health Sciences Research Ethics Committee

Appendix D: Subsequent HSREC approval

UNIVERSITY OF THE FREE STATE
UNIVERSITEIT VAN DIE VRYSTAAT
YUNIVESITHI YA FREISTATA

UFS·UV
HEALTH SCIENCES
GESONDHEIDSWETENSKAPPE

Health Sciences Research Ethics Committee

02-Sep-2020

Dear **Dr Frederik Kloppers**

Ethics Number: UFS-HSD2020/015702

Ethics Clearance: **SI screw vs Locking Square Plate Fixation in Sacro-iliac Joint Disruption on Composite Bone Models**

Principal Investigator: **Dr Frederik Kloppers**

Department: **Orthopaedics Department (Bloemfontein Campus)**

SUBSEQUENT SUBMISSION APPROVED

With reference to your recent submission for ethical clearance from the Health Sciences Research Ethics Committee. I am pleased to inform you on behalf of the HSREC that you have been granted ethical clearance for your request as stipulated below:

- Addition of Dr AA van Zyl as a co-supervisor is acknowledged.

The HSREC functions in compliance with, but not limited to, the following documents and guidelines: The SA National Health Act. No. 61 of 2003; Ethics in Health Research: Principles, Structures and Processes (2015); SA GCP(2006); Declaration of Helsinki; The Belmont Report; The US Office of Human Research Protections 45 CFR 461 (for non-exempt research with human participants conducted or supported by the US Department of Health and Human Services- (HHS), 21 CFR 50, 21 CFR 56; CIOMS; ICH-GCP-E6 Sections 1-4; The International Conference on Harmonization and Technical Requirements for Registration of Pharmaceuticals for Human Use (ICH Tripartite), Guidelines of the SA Medicines Control Council as well as Laws and Regulations with regard to the Control of Medicines, Constitution of the HSREC of the Faculty of Health Sciences.

For any questions or concerns, please feel free to contact HSREC Administration: 051-4017794/5 or email EthicsFHS@ufs.ac.za.

Thank you for submitting this request for ethical clearance and we wish you continued success with your research.

Yours Sincerely

Dr. SM Le Grange
Chair : Health Sciences Research Ethics Committee

Health Sciences Research Ethics Committee
Office of the Dean: Health Sciences
T: +27 (0)51 401 7795/7794 | E: ethicsfhs@ufs.ac.za
IRB 00011992; REC 230408-011; IORG 0010096; FWA 00027947
Block D, Dean's Division, Room D104 | P.O. Box/Posbus 339 (Internal Post Box G40) | Bloemfontein 9300 | South Africa
www.ufs.ac.za

Appendix E: Data collection form

Test model number:_____

SI Screw		Plate	
Side		Side	
Newtons		Newtons	
Failure:		Failure:	
Sacrum fracture		Sacrum fracture	
Hardware breakage		Hardware breakage	
Hardware pullout		Hardware pullout	
Ilium fracture		Ilium fracture	

Appendix F: Author guidelines SAOJ

http://journal.saoa.org.za/index.php/saoj/information/authors

Criteria for publication

- The article falls within the scope of the journal.
- Methods, statistics, and other analyses are performed to a high technical standard and are described in sufficient detail.
- Results reported have not been published elsewhere.
- Conclusions are presented in an appropriate fashion and are supported by the data.
- The article is presented in an intelligible fashion and is written in standard English (British usage).
- The research meets all applicable ethical standards.
- The article adheres to guidelines provided in the instructions for authors section.

Guidelines for authorship

- Each author should participate and is responsible for the content and design of the study, the preparation of the manuscript and its revisions, and final approval.
- Other "contributors" can be acknowledged at the end of the manuscript together with their contribution.
- Authors of manuscripts representing a multi-centre study may list members of the group in the footnote on the title page of the published article and their affiliations are listed in an appendix.
- The authors should clearly indicate the predominant surgeon or surgeons who have contributed patients.
- On submission of your article the ORCID (Open Researcher and Contributor ID) identifier of all authors will be required. ORCID provides a persistent digital identifier that distinguishes you from every other researcher and supports automated linkages between you and your professional activities ensuring that your work is recognized. To register and find more information please visit: http://orcid.org

Registration of clinical trials

- A clinical trial is defined as any research study that prospectively assigns human participants or groups of humans to one or more health-related interventions to evaluate the effects of health outcomes. Interventions include drugs, surgical procedures, devices, behavioural treatments, dietary interventions, and process-of-care changes.
- Clinical Trials should be registered in a public trials registry in accordance with International Committee of Medical Journal Editors.
- Trials must register and approved by the relevant authorities before the onset of patient enrolment.
- The Medicines Control Council (MCC) reference number and the SA National Clinical Trial Register (SANCTR) registration number should be included at the end of the abstract of the article.
- Purely observational studies (those in which the assignment of the medical intervention is not at the discretion of the investigator) will not require registration.

Reporting guidelines

All articles should be prepared in accordance with the guidelines relevant to the study design that was used (listed below).

- Randomised trials (CONSORT)
- Observational studies (STROBE)
- Systematic reviews (PRISMA)
- Case reports (CARE)
- Qualitative research (SRQR)
- Diagnostic/prognostic studies (STARD)
- Quality improvement studies (SQUIRE)
- Economic evaluations (CHEERS)
- Animal pre-clinical studies (ARRIVE)
- Study protocols (SPIRIT)

Randomised trials should be accompanied by a flow diagram that illustrates the progress of patients through the trial, including recruitment, enrolment, randomisation, withdrawal and completion, and a detailed description of the randomisation procedure.

Role of funding source

You are requested to identify who provided financial support for the conduct of the research and/or preparation of the article and to briefly describe the role of the sponsor(s), if any, in study design; in the collection, analysis and interpretation of data; in the writing of the report; and in the decision to submit the article for publication. If the funding source(s) had no such involvement, then this should be stated.

Formatting of submissions

Text formatting

- Use Arial font, size 11.
- 1,5 spacing throughout the document.
- Pages of the blinded manuscript should be numbered consecutively.
- Use the automatic page numbering function to number the pages.
- Use italics for emphasis.
- When referring to an article with multiple authors please use the following format: Rabinowitz *et al.* published their retrospective review.
- Do not use field functions.
- Use tab stops or other commands for indents, not the space bar.
- Use the table function, not spreadsheets, to make tables.
- Use the equation editor or MathType for equations.
- Save your file in docx format (Word 2007 or higher) or doc format (older Word versions).

Headings

Please use no more than three levels of displayed headings.

Abbreviations

Abbreviations and acronyms should be defined at first mention and used consistently thereafter.

Units

Follow internationally accepted rules and conventions: use the international system of units (SI). If other units are mentioned, please give their equivalent in SI.

Figures

- Figures should be numbered consecutively with illustration Arabic numbers 1, 2, 3 etc.
- The figure should be listed in the text as follows: ... wound irrigation and splinting (*Figure 1*).
- Figures should be clear and easily understandable with a full descriptive legend stating any areas of interest and explaining any markings, letterings or notations. All figures should be understandable without the main text.
- For radiographs please ensure you state view used and the time point at which it was taken, as well as the demographic details of the patient if applicable.
- Figures should not be imbedded in the text file, but should be submitted as separate individual files. Each figure should be a separate file, entitled Figure 1, Figure 2, etc.
- Remove all markings, such as patient identification, from radiographs before photographing.
- All line or original drawings must be done by a professional medical illustrator.
- We accept a maximum of 6 figures.
- Do not submit any figures, photos, tables, or other works that have been previously copyrighted or that contain proprietary data unless you have and can supply written permission from the copyright holder to use that content.
- Randomised trials should be accompanied by a flow diagram that illustrates the progress of patients through the trial, including recruitment, enrollment, randomisation, withdrawal and completion, and a detailed description of the randomisation procedure.

Tables

- Tables should carry uppercase Roman numerals, I, II, III, etc.
- Tables should always be cited in text in consecutive numerical order.
- The table should be identified in the text as follows: Details of results are listed in *Table I*. Or, alternatively, high-energy trauma that is often associated with these fractures (*Table II*).
- Tables should be used to present information in a clear and concise manner. All tables should be understandable without the main text.
- For each table, please supply a table caption (title) explaining the components of the table.

- Identify any previously published material by giving the original source in the form of a reference at the end of the table caption.
- Footnotes to tables should be indicated by superscript lower-case letters and included beneath the table body.
- Please submit tables as editable text and not as images. They should be created using the Table tool in Word.
- Table should not be imbedded in the text file, but should be submitted as separate individual files. Each table should be a separate file, entitled Table 1, Table 2, etc.
- We accept a maximum of 8 tables.
- Do not duplicate information given already in the text.
- Do not submit any figures, photos, tables, or other works that have been previously copyrighted or that contain proprietary data unless you have and can supply written permission from the copyright holder to use that content.

References

- References should be numbered consecutively in the order that they are first mentioned in the text and listed at the end in numerical order of appearance.
- Identify references in the text by Arabic numerals in superscript after punctuation.
- References should not be a listing of a computerised literature search but should have been read by the authors and have pertinence to the manuscript.
- Authors should add DOIs to all references in articles.
- Accuracy of references is the author's responsibility and the author is to verify the references against the original documents.
- Manuscripts in preparation, unpublished data (including articles submitted but not in the press) and personal communications may not be included in the reference listing. They may be listed in the text in parentheses only if absolutely necessary to the contents and meaning of the article.
- The titles of journals should be abbreviated according to the style used in Index Medicus, obtainable through the website http://www.nlm.nih.govshould
- The following format should be used for references:

Journal Articles:

Sidhu GS, Ghag A, Prokuski V, Vaccaro AR, Radcliff KE. Civilian gunshot injuries of the spinal cord: a systematic review of the current literature. Clin Orthop Relat Res 2013;471:3945-55.

Ideally, the names of all authors should be provided, but the usage of "et al" in long author lists (more than 6 authors) will also be accepted: Fong K, Truong V, Foote CJ, et al. Predictors of nonunion and reoperation in patients with fractures of the tibia: an observational study. BMC Musculoskelet Disord 2013;14:103.

On-line journal article:

Caetano-Lopes J, Lopes A, Rodrigues A, et al. Upregulation of inflammatory genes and downregulation of sclerostin gene expression are key elements in the early phase of fragility fracture healing. PLoS One 2011;6:e16947.

Web reference (with authors):

Cierny G, DiPasquale D. Adult osteomyelitis protocol.
http://www.osteomyelitis.com/pdf/treatment_protocol.pdf.
(date last accessed 05 March 2013).

Web reference (no authors listed):

No authors listed. International commission on radiological protection. http://www.icrp.org (date last accessed 20 September 2009).

Chapter in a book:

Young W. Neurophysiology of spinal cord injury. In: Errico TJ, Bauer RD, Waugh T (eds). Spinal Trauma. 3rd ed. Philadelphia: JB Lippincott; 1991: 377-94.

Dissertation:

Borkowski MM. Infant sleep and feeding: a telephone survey of Hispanic Americans [dissertation]. Mount Pleasant (MI): Central Michigan University; 2002.

Abstract:

Peterson L. Osteochondritis of the knee treated with autologous chondrocyte transplantation [abstract]. ISAKOS Congress, 2001.

Structure and content of submission

We accept a maximum of 3500 words including abstract, body of the text (excluding references). Exceptions to this rule may be made for systematic reviews and meta-analysis, at the discretion of the Editor-in-Chief.

Please follow the following structure when preparing your submission.

- Title page (Title, authors and affiliations, corresponding author and declarations)
- Blinded Manuscript (Abstract, key words, introduction, methods, results, discussion, funding sources, conflict of interest statement, ethical statement, acknowledgements and references)
- Tables (with headings), each as a separate file.
- Figures (with legends), each as a separate file.

Title page

Title

The title should be concise and informative.

Author names and affiliations:

Please provide the following information for each author:

- Full names and surname, as well as title (please check that all names are accurately spelled)
- Qualifications
- Affiliation and address (indicate all affiliations with a lower-case superscript letter immediately after the author's name and in front of the appropriate affiliation details)
- ORCID ID (see Article Submission section)

Provide the full postal address of each affiliation, including the country name and, if available, the email address of each author.

Corresponding author

Clearly indicate who will handle correspondence at all stages of refereeing and publication, also post-publication.

Ensure that the email address and permanent address is given and that contact details are kept up to date by the corresponding author.

Please note that the corresponding author’s contact details will be provided in the final article.

Please provide the following information for the corresponding author:

- Full names and title
- Affiliation
- Physical address
- Postal address
- Telephone Number
- Email address

Please provide the names and email addresses of two potential reviewers.

Declarations

Authors are to insert a section at the end of the title page entitled declarations. Following the declarations all authors need to sign the document (please provide name of author, signature and date). The following statements is required under the declarations section:

Authorship

The authors confirm that all authors have made substantial contributions to all of the following:

- The conception and design of the study, or acquisition of data, or analysis and interpretation of data.
- Drafting the article or revising it critically for important intellectual content.
- Final approval of the version to be submitted.
- Sound scientific research practice

The authors further confirm that:

- The manuscript, including related data, figures and tables has not been previously published and is not under consideration elsewhere
- No data have been fabricated or manipulated (including images) to support your conclusions
- This submission does not represent a part of single study that has been split up into several parts to increase the quantity of submissions and submitted to various journals or to one journal over time (e.g. “salami-publishing”).

Author contributions

Please state the contributions of each author

• For example: “A.B contributed to study conceptualization, design, data analysis and manuscript preparation. C.D. contributed to data collection and manuscript preparation. E.F. contributed to ....”

• The types of contributions are:

o Conceptualization and design

o Data collection or contribution

o Data analysis

o Manuscript preparation

o Other contribution (please specify)

Plagiarism:

- The authors confirm that the work submitted is original and does not transgress the plagiarism policy of the journal.
- No data, text, or theories by others are presented as if they were the author’s own.

- Proper acknowledgements of other's work has been given (this includes material that is closely copied, summarized and/or paraphrased), quotation marks are used for verbatim copying of material.
- Permissions have been secured for material that is copyrighted.

Conflict of interest statement

A conflicting interest exists when professional judgement concerning a primary interest (such as patient's welfare or the validity of research) may be influenced by a secondary interest (such as financial gain or personal rivalry). It represents a situation in which financial or other personal considerations from authors, reviewers or editors have the potential to compromise or bias professional judgment and objectivity. It may arise for the authors when they have financial interest that may influence their interpretation of their results or those of others. Examples of potential conflicts of interest include employment, consultancies, stock ownership, honoraria, paid expert testimony, patent applications/registrations, and grants or other funding. All potential conflicts of interest need to be declared. The conflict of interest statement should list each author separately by name, i.e.

"John Smith declares that he has no conflict of interest. Paula Taylor has received research grants from Drug Company A. Mike Schultz has received a speaker honorarium from Drug Company B and owns stock in Drug Company C."

If multiple authors declare no conflict, this can be done in one sentence

Funding sources

All sources of funding should be declared. Also define the involvement of study sponsors in the study design, collection, analysis and interpretation of data; the writing of the manuscript; the decision to submit the manuscript for publication. If the study sponsors had no such involvement, this should be stated.

Compliance with ethical guidelines

For all publications:

"The author/s declare that this submission is in accordance with the principles laid down by the Responsible Research Publication Position Statements as developed at the 2nd World Conference on Research Integrity in Singapore, 2010."

Available from: http://publicationethics.org/resources/international-standards-for-editors-and-authors

Institutional Review Board (IRB) ethical approval must have been given if the study involves human subjects or animals. Please provide the approval number. IRB documentation should be provided.

"Prior to commencement of the study ethical approval was obtained from the following ethical review board: *Provide name and reference number"*

For studies with human subjects include the following:

"All procedures were in accordance with the ethical standards of the responsible committee on human experimentation (institutional and national) and with the Helsinki Declaration of 1975, as revised in 2008."

"Informed written consent was or was not obtained from all patients for being included in the study."

For studies with animals include the following sentence:

"All institutional and national guidelines for the care and use of laboratory animals were followed."

For articles that do not contain studies with human or animal subjects:

"This article does not contain any studies with human or animal subjects."

If doubt exists whether the research was conducted in accordance with the Helsinki Declaration, the authors must explain the rationale for their approach, and demonstrate that the institutional review body explicitly approved the doubtful aspects of the study. If any identifying information about patients is included in the article, the following sentence should also be included: Additional informed consent was obtained from all patients for which identifying information is included in this article. The Helsinki Declaration 2008 can be found at http://www.wma.net/en/30publications/10policies/b3/

Blinded manuscript

Abstract

A structured abstract (maximum of 350 words), summarising the most important points in the article is required.

The abstract consisting of four paragraphs with the subheadings:

- Background (must include the aim of the study)
- Patients and methods
- Results
- Conclusion

References should be avoided. Avoid uncommon abbreviations. If essential they must be defined at their first mention in the abstract itself

Keywords

Immediately after the abstract, provide a maximum of 6 keywords, using standard searchable terms. These keywords will be used for indexing purposes.

Level of evidence

Level 1 to 5.

Please follow the level of evidence guidelines provided by the Oxford Centre for Evidence-Based Medicine (OCEBM); version 2.1.

Available from: OCEBM Levels of Evidence Working Group. “The Oxford Levels of Evidence 2”.Oxford Centre for Evidence-Based Medicine. http://www.cebm.net/index.aspx?o=5653

Introduction

The introduction should contextualise the study by providing the background to the research; explain the problem that is to be addressed and provide the rationale for the study.

Briefly outline the relevance if the study in respect to the current literature. Avoid a detailed literature survey or a summary of the results.

The last sentence should outline the research question or hypothesis.

Patients (or Materials) and Methods

State the methods, outcome measures, and selection criteria. The following aspects needs to be described:

- The study design and research methodology.
- Whether randomization (with methods) was applied.
- If case controlled, how the controls were selected.
- The time period under review.
- Number of patients/subjects under investigation and why this number was chosen.
- Inclusion and exclusion criteria.
- Case and outcome definitions.
- Description of procedure or intervention, including post-operative protocol.
- The outcome measures or scores were used.
- The minimum follow-up period.
- A statistical analysis section should be included at the end of this section to detail statistical tests and package used, the reasons why these tests were used, and what p-value was considered statistically significant. A power analysis is recommended for studies comparing two or more groups.
- Provide sufficient detail so that another researcher can replicate the study.
- The reader should understand from this description all potential sources of bias such as referral, diagnosis, exclusion, recall, or treatment bias. This includes the manner in which investigators selected the patients. Consecutive inclusion implies all patients with a given diagnosis are included, while selective implies patients with a given diagnosis but selected according to certain explicit criteria (e.g. state of disease, choice of treatment).
- Do not describe standard procedure for common operations. Only include new procedures or adaptations to standard procedure.
- If you name any specific product, then it requires the name, city and state/country of the manufacturer.
- Present in narrative format and use past tense.
- Where relevant, tables or figures may be included to provide information more clearly.
- Generally, no data should normally be presented in this section.

Results

- Describe the relevant results and analysis thereof.
- Provide details of the number of patients included and excluded, as well as the reason for exclusion.
- It is important to state the follow-up period (mean and range).
- The results can be broken down into separate sections, e.g. Treatment, Functional outcome, Complications, etc.
- Tables may be used but avoid repeating data reported in the text in the tables.
- All appropriate data should be presented as means with ranges, not with standard deviations (SDs). Medians should only be used when the data is skewed, accompanied by an interquartile range (IQR).
- Avoid using percentages in studies involving well under 100 subjects.
- All results must be backed-up with p-values or survivorship analysis. All Kaplan-Meier data should be presented with the confidence intervals. Always present exact absolute p-values, whether significant or not, unless $p < 0.001$.
- However, p-values do not always convey the entire picture and where relevant the confidence interval will also be required (in addition to the power of the study reported in the methods section).

Discussion

- The question or hypothesis stated at the end of the introduction should be discussed and supported or rejected.
- The results must be interpreted clearly and any deficiencies expressed. All possible confounding factors, sources of bias, weaknesses in the study should be identified.
- Explore the significance of the results of the work, rather than repeating the results.
- The discussion must point out the relevance of the work described in the paper and its contribution to current knowledge.
- Explain what can be deduced from the results and how will it affect clinical practice should be clearly stated
- Should include a review of the relevant literature, placing the results of the study in the context of previous work in this area.
- Discussion of relevant prior research and references must be concise. Avoid extensive citations and discussion of published literature but put emphasis on previous findings that agree (or disagree) with those of the present study.
- Do not repeat the introduction.
- The limitations of the study must be presented and suggest how the study could have been improved for a future study.
- Authors should avoid making inferences from non-significant trends unless they believe their study is adequately powered to answer the question; in that case, provide a power analysis.

Conclusion

Summary statement which conveys the conclusions of the findings. Do not draw conclusions not supported by the data obtained from the specific study presented.

Conflict of interest

"Author A.B. (*use initials of relevant author, not full name in order for the document to remain blinded*) has received research grants from Company A. Author B.C. has received a speaker honorarium from Company X and owns stock in Company Y. Author C.D. is a member of committee Z."

If no conflicts of interest exists, please state this as follows: "The authors declare they have no conflicts of interest that are directly or indirectly related to the research."

Ethical statement

- For studies involving human subjects please include an ethical statement as follows: "All procedures performed in studies involving human participants were in accordance with the ethical standards of the institutional and/or national research committee and with the 1964 Helsinki declaration and its later amendments or comparable ethical standards."
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- If the study did not involve human or animal subjects state that: “This article does not contain any studies with human participants or animals performed by any of the authors.”
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Funding sources

List all funding sources as follows: “This work was supported by the xxxx (grant numbers xxxx, yyyy).”

When funding is from a block grant or other resources available to a university, college, or other research institution, submit the name of the institute or organization that provided the funding.

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Acknowledgements

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Author contributions

Please state the contributions of each author

• For example: “A.B contributed to study conceptualization, design, data analysis and manuscript preparation. C.D. contributed to data collection and manuscript preparation. E.F. contributed to ....”

• The types of contributions are:

o Conceptualization and design

o Data collection or contribution

o Data analysis

o Manuscript preparation

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Please refer to formatting of submissions section.

Tables and Figures

Table and figures should not be imbedded in the text file, but should be submitted as separate individual files. Each table should be a separate file, entitled Table I, Figure 2, etc.

Each table and figure should be provided with a heading or legend.

Please refer to the 'Formatting of Submission' section for further guidelines.

Current Concepts Review

Background

In November 2018 the SAOJ Editorial Board commissioned the inclusion of one "Current Concepts Review" paper per issue. All University departments will be scheduled to contribute one paper ever 2ndyear. The University via the Head of Department will the nominate expert author to be responsible for preparation the review article. We recommend that multiple authors are involved and in particular advocate collaborating with experts from other institutions to get a broader view on the topic.

General Guidelines

- A narrative review will suffice (and systematic or scoping review not necessary)
- A thorough literature review needs to be done prior to writing the manuscript to ensure that the author is well acquainted with the current concepts related to the topic (with emphasis on the most recent developments)
- A balanced and unbiased view of the current clinical aspects of the topic.
- Focus on clinical aspects like diagnosis and treatment.
- Discuss controversies and state both sides of the argument.
- Avoid extensive discussion of basic science (anatomy/physiology/pathology) aspects, except if there are some really novel and clinically-relevant new developments in the field.
- The topic may be adapted, but only with the permission of the Editor-in-Chief.

Outline of Article

- **Abstract =** One paragraph, no headings, ≤350 words.
- **Introduction =** Brief introduction to the topic
- **Contents =** Please use headings (in bold) and sub-headings (in italics) to structure to manuscript in reader-friendly manner
- **South African context =** Discuss matters which may be particularly relevant or unique to the South African clinical setting.
- **Learning points =** Make use of tables to summarize important learning points
- **Conclusion =** Brief evidence-based conclusion and summary
- **Conflict of interest statement**
- **Funding**
- **References =** As usual

Review Process

- Each submission will be peer-reviewed by 2 members of the editorial board

Appendix G: Turnitin plagiarism report

chapter 1

Chapter 1: Literature review

SI screw vs Locking Square Plate Fixation in Sacroiliac Joint Disruption on Composite Bone Models

Content:

1. Introduction

Pelvic trauma comprises up to 3% of all skeletal injuries. It mainly occurs in younger patients as a result of high energy trauma, road traffic accidents, falls from heights, or sport-related injuries. Morbidity rates associated with pelvic injury remain high, mainly due to intrapelvic hemorrhage. Ten to fifteen percent of patients arrive in the emergency department with signs of shock. Pelvic injuries are associated with mortality rates of as high as thirty percent. [1]

2. Anatomy

The pelvic ring consists of two innominate bones and the sacrum. The pelvic ring is stabilised anteriorly by the pubic symphysis and pubic rami, while posterior stability relies on the posterior sacroiliac (SI) complex with its corresponding ligaments. Biomechanical studies have proven that the posterior sacroiliac complex contributes more to the stability of the pelvic ring if compared to the anterior structures. The anterior and posterior complex each contribute 40% and 60%, respectively.[2]

3. Classification

Unstable injuries to the pelvis are associated with disruption of the posterior osteoligamentous structures. These injuries include the following: sacroiliac joint disruptions, sacral fractures, complete iliac fractures, crescent iliac fracture-sacroiliac joint dislocations, or a combination of the above [3].

According to the Association for Osteosynthesis-Orthopaedic Trauma Association (AO-OTA) classification, a type C pelvic ring injury is defined by the disruption of the posterior pelvic complex that results in a vertically and rotationally unstable pelvic ring[4]. Other predictive systems, such as the Young & Burgess [5] and Tile [2] classifications, can be used to classify pelvic ring injuries. Young & Burgess classified them according to the mechanism of injury and consist of a lateral compression (LC), anteroposterior compression (APC), vertical shear (VS), or combination type injuries. Tile classified pelvic fractures according to stability: A -stable, B - partially stable, or C - unstable with sub-classifications of each [2].

The advantage of the mechanism-guided fracture classifications, such as the Young and Burgess classification, is that they provide guidance for surgical indications and fixation of pelvic fractures. [(1,3)]

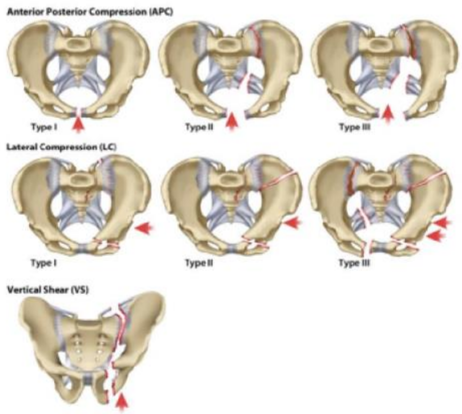

FIGURE 1: YOUNG AND BURGESS CLASSIFICATION (4)

4. Management

The initial treatment of unstable pelvic injuries is determined by the patient's overall condition and injury pattern. Circumferential pelvic binders or anterior external pelvic fixators can be used to stabilise the anterior pelvic ring in "open book" type injuries. Anterior external fixators may result in further displacement of the posterior complex in unstable pelvic ring injuries. The initial posterior pelvic reduction may improve with the use of a pelvic c-clamp or sacroiliac lag screws.[1,3]

The definitive fixation of unstable pelvic injuries remains controversial in terms of timing. Current recommendations suggest that haemodynamically stable patients can be treated with a definitive internal pelvic fixation within 24 hours of the injury. Patients who are haemodynamically unstable or polytrauma patients with physiologically deranged parameters should be resuscitated and definitive fixation postponed until between day 4 and day 10 post-injury. The parameters used to assess if a patient is eligible for early total care include: normal temperature, absence of acidosis, normal lactate and the absence of coagulopathy.[1,6]

Surgical fixation remains the definitive treatment of choice for unstable posterior pelvic injuries. However, to date, no fixation method is shown to be as stable as the intact pelvic ring [7].

4.1 Reduction accuracy

Anatomical reduction and fixation have shown improved overall construct performance, especially when compared to outcomes where non-anatomical reductions were obtained. Malreduction of the SI joint leads to loss of joint congruence and subsequently, a decrease in the contact area between the articular surfaces. Due to the shape of the SI joint, this will lead to decreased intrinsic stability of the joint. A non-anatomical reduction is associated with the development of chronic pain, leg length discrepancy, limb malalignment, and fracture non-union. Anatomical reduction of the SI joint will increase the fixation strength of the construct, prevent subsequent fixation failures and restore the limb malalignment. [8]

Studies have proven that reduction within 1cm of combined residual displacement in posterior pelvic ring injuries leads to improved functional scores and clinical outcomes. It is also advised that posterior displacement should be less than 5mm. In pure SI joint dislocations, poor clinical outcomes were observed where the SI joint was not anatomically reduced. Favourable results were also reported at 1-year follow-up in patients treated with percutaneous fixation after obtaining an anatomical reduction.[3,8]

4.2 Techniques

Several surgical techniques have been described in the literature for the treatment of posterior pelvic ring injuries. These techniques include anterior plating by ilioinguinal approach, open or closed reduction with percutaneous screw fixation, or posterior fixation using several different fixation techniques. Posterior fixation is usually done with the patient in a prone position and using one of the following fixation techniques: plate and screws, sacroiliac (SI) screws, or a lumbopelvic fusion using pedicle screws.[6,9–12]

4.3 SI screw

Various sacroiliac screw techniques and positions have been described in the literature. *Van Zwienen et al.* compared a single S1 SI screw to two converging screws in S1 and one separate screw in S1 and S2, respectively. They concluded that adding a second screw significantly increases the rotational stiffness and load to failure compared to a single screw. Adding a second screw to S2, however, is more technically demanding and has an increased risk of iatrogenic nerve injury[7]. In a follow-up study, the authors compared a single to two SI screws again, using cyclic loading. They concluded that two sacroiliac screws had significantly more cycles as well as higher loads to failure. Both constructs failed within 700 applied cycles[13].

Finite element analysis of four different SI screw techniques by Zhang *et al.* concluded that a single SI screw fixation would be adequate for rotationally unstable dislocations. Adding a second screw in vertically and rotationally unstable dislocations would add biomechanical stability[14].

Lengthened sacroiliac screws have shown to be superior to bidirectional sacroiliac screws in bilateral sacral fractures using finite element analysis[15]. Transiliac-transsacral lengthened screws have shown no differences in pain scores or functional scores when compared to unilateral sacroiliac screws[16].

In comparative biomechanical testing on posterior pelvic ring fixation, these fixations have also been described in terms of the construct's stiffness. In a study by Yinger *et al.* on synthetic pelvis models, a single SI screw was the least stiff construct of all tested. Two SI screws or a combination of two anterior SI plates combined with a SI screw proved to be the stiffest constructs. Anterior SI plating showed decreased stiffness when comparing SI joint rotation to SI joint gapping[17].

In a cadaver study by Sagi *et al.* , they found no statistically significant difference between one or two SI screws in controlling the rotational or linear displacement of an unstable hemipelvis alone. The addition of an anterior symphyseal plate in vertically unstable fractures decreased the displacement of the unstable hemipelvis in all planes, regardless of the posterior screw constructs used. They did not compare the load to failure of the constructs[18].

They attributed the differences in these results because of the different bone density areas found in the normal human sacrum whereas synthetic sacrum models are of uniform density.

In a human sacrum, the greatest bone density is located in the anterior aspect of the promontory of S1. Lower bone densities are found at the posterior aspect of S1, the body of S2, and the sacral ala. Due to the relative osteopenia in S2 and the posterior aspect of S1, adding an additional screw in those regions will not likely add to the stability[18].

Current literature suggests that less experienced orthopaedic surgeons prefer closed reductions and percutaneous techniques compared to open reduction and internal fixation (ORIF) for pelvic ring fractures. Percutaneous performed cases have increased proportionally from 49% in 2003 to 79% in 2015[19].

Advantageously, percutaneous sacroiliac screw fixation has a shorter operative time, decreased intraoperative blood-loss, smaller wound size, and reduced length of hospital stay when compared to open anterior sacroiliac joint plate fixation.[19,20]

4.4 Open reduction and approaches

Despite the popularity of closed reduction and percutaneous fixation techniques, some fractures and dislocations are not amenable to accurate reduction using these methods, and an open approach is sometimes required. Open reduction requires the direct visualization of the bony anatomy and can be done by using either the anterior or posterior approaches. The anterior approach allows better access to the superior SI joint and also allows better osseous exposure. The posterior approach allows better access to the inferior SI joint. [11,21].

A study performed by Lindsay *et al.* proved that closed reduction could be as effective as open reduction through the posterior approach. The authors did not compare the accuracy of reduction using an anterior approach.The study was also performed by two different surgeons in two different centres each only performing either the closed reduction and percutaneous fixation or ORIF. This study was thus vulnerable to bias[22].

The posterior approach to the pelvis has a higher profile of complications compared to the anterior approach. This includes wound infection, skin necrosis, neurological injuries, postoperative lower back pain and sexual dysfunction[23].

Anterior plating of the SI joint is commonly performed with the use of a double plating technique. Fixation is achieved by using either a two-hole or three-hole plate. When using a three-hole plate, two screws are placed on the iliac side and a single screw on the sacral side. Parallel placement of the plates is weaker compared to double plates placed at 60 degrees to each other. When doing double plating at 60 degrees, it has shown greater strength and stability in biomechanical studies compared to two-hole plates and sacroiliac screws.[23]

Anterior fixation with a square plate at the sacroiliac joint has shown promising clinical results in patients. Out of the 21 patients with 23 SI joint injuries, 18 patients had an excellent or good outcome at 5 years, and only 3 had poor outcomes. All patients had an open reduction using the anterior approach. This resulted in a perfect reduction or reduction within 5mm in 19 out of the 23 SI joints. The design of the square plate allows the screws to be inserted in close proximity to each other as well as close to the joint line.[24]

Leighton *et al.* developed a four-hole anterior compression plate specific for sacroiliac joint fixation. They found that a flat plate that can easily be contoured could be used due to the relatively flat coronal plane bony architecture within 2cm either side of the sacroiliac joint. The deformation of 2.1cm was achieved when the intact pelvis was loaded to 1000N and was used as their control group. Posterior fixation with their four-hole plate and anterior symphyseal plates averaged a load of 320N to achieve 2.1cm deformation, and this construct failed at an averaged 428N in a cadaver model. They found no significant difference when comparing three posterior screws to the SI plate. This study confirmed again that no fixation method is as strong as the normal intact pelvis.[25]

A study using synthetic pelvis models comparing posterior tension band plating through the S1 vertebra pedicles and sacroiliac screws bilaterally, concluded that bilateral single SI screws were superior to posterior tension band plating and S1 pedicle fixation. The study was divided into three groups. The average load to failure for the SI screw group was 2230N and for the posterior tension band group 1775N. For the group that combined the two constructs, the average load to failure was 2084N. The vertical force was applied to the S1 vertebral body while bilateral sciatic notches were stabilised using a specially designed metal interface.[12]

To date, in the literature there are no comparative studies using a locked square plate fixation and a SI screw fixation. The choice of fixation method to use still remains multifactorial and needs to be individualised to the specific patient and injury factors.

4.5 Anatomical considerations for anterior plating

Complications associated with anterior SI joint plating include iatrogenic nerve injury to the nerve roots of L4 and L5. Anatomically, anterior plates can be used at the superior end of the SI joint. Visualisation of the joint to ensure anatomical reduction and good screw placement is achieved by exposing 2.5cm of the sacrum medially at the superior end and 1.5cm of the sacrum medially at the inferior third. Screws inserted on the sacral side should incline approximately 30 degrees medially to avoid entering the SI joint on the lateral side and the sacral foramina with its corresponding nerve roots on the medial side.[26]

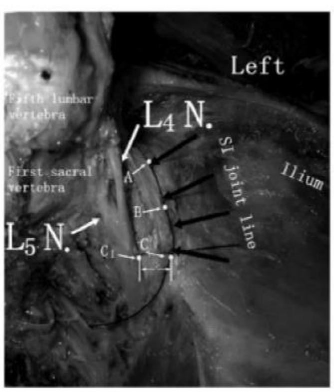

Fig. 1. The morphological observation of the SI joint of the corpse. The SI joint line was represented by the suture line which was marked by the black arrows. A: the highest point of SI joint line, C: the lowest point of SI joint line, B: the midpoint of SI joint line, C1: the intersection point of the lateral border of the anterior branches of L4 and the transverse plane passing point C. The vertical distance from the point C to the sagittal plane passing the point C1 was defined the horizontal distance between the L4 nerves and the SI joint on the plane C.

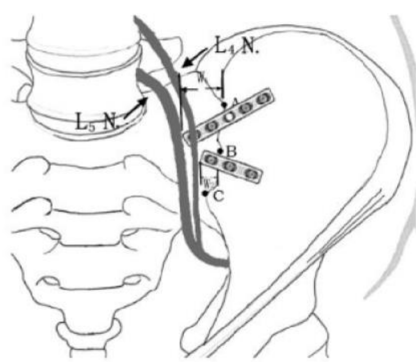

Fig. 7. The model diagram showing the surgical safe zone of the double plates fixation of the SI joint fracture. A: the highest point of SI joint line, C: the lowest point of SI joint line, B: the midpoint of SI joint line, W1: the limited sacral exposure range of 2.5 cm wide, W2: the limited sacral exposure range of 1.5 cm wide.

Above Figures: Anatomical evidence for anterior plate fixation of sacroiliac joint[26]

Navigation-aided visualisation of the lumbosacral nerves has also been used with success to recognise the at-risk areas for nerve injury in a patient where anterior sacroiliac plate fixation was needed. The authors used a pre-operative computerised tomography(CT) with an intra-operative 3D-fluoroscopy matching navigating system. Using this technology, they managed to identify the nerve roots at risk and subsequently could do an anterior sacroiliac plate fixation in a safe zone. However, it was only a single case, and the segmentation of the lumbosacral nerves could not be validated. Comparative studies quoted in this paper using 3D fluoroscopic navigation for percutaneous iliosacral screws have also shown decreased risks of screw penetration and subsequent complications. [27]

5. Use of bone models in research

Composite bone models have evolved and became a suitable

replacement for cadaver bone in many settings, including surgical education and orthopaedic biomechanical research. This has reduced the need for cadaveric bone in bone-related studies. The current fourth-generation composite bone models' biomechanical properties accurately reproduce that of human bone under different loads. They offer excellent anatomic detail and also offer consistency in terms of their biomechanical properties. Cadaver specimens show more inconsistency between different specimens and can also cost up to three times more than equivalent fourth-generation composite bone models. The bone quality of cadaveric specimens may also not represent that of the general orthopaedic population due to disproportionately representing the elderly.[28]

Synthetic bone models have successfully been used in multiple biomechanical studies, specifically in the pelvic and acetabular regions. [8,12,17,29,30]

6.

From the above literature review, we have learned that anatomical reduction and definitive surgical fixation of the sacroiliac joint is important to allow improved construct performance and functional outcomes in patients.

Many different techniques have been described to reduce and fixate the SI joint, and it is generally accepted that a percutaneous SI screw is currently the treatment of choice. In some cases and injury patterns, it is not possible to get an adequate closed reduction, and open reduction needs to be considered.

Anterior plating of the SI joint has been described in different plate types and configurations.

We could not find literature where a locked 4-hole plate and screw configuration was compared to a SI screw.

We suggest that a locking plate, placed in the safe zone over the SI joint and screws inserted under direct vision, when doing an open reduction, can be safely done. It will decrease the risk of neurologic injury when compared to doing an open reduction and percutaneous screw technique under fluoroscopy after an open reduction of the joint.

It is also generally accepted to use synthetic bone models for biomechanical research in orthopaedic surgery.

7. **Research questions, aims, and objectives**

The question we pose is whether a square-shaped locking plate is stronger than a standard SI screw at its ultimate failure point when a vertical load is applied to the sacroiliac joint in a composite bone model?

The primary objective is to determine the ultimate load to failure of both fixation types in the context of a vertical external force applied in a composite bone model.

The secondary objective is the description of the fracture pattern observed in the model or the nature of the failure of the construct.

We hypothesise that the anterior square plate construct will be equal to or stronger than the SI screw fixation at the ultimate failure point.

Article Error

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chapter 1

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chapter 1

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Chapter 2

by Frederik Kloppers

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SI screw vs Locking Square Plate Fixation in Sacroiliac Joint Disruption on Composite Bone Models

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Abstract

Background: The aim of this study was to compare a locked square plate to a standard sacroiliac screw of the sacroiliac joint on a composite pelvis bone model to assess the ultimate load tolerated before failure of fixation and to describe the mode of failure of the construct.

Methods: Bilateral sacroiliac (SI) joint dislocations were created in 10 composite pelvic bone models. In this descriptive comparative study, the one SI joint was fixated using a 7.3mm cannulated screw and the contralateral side fixated using a 4-hole square locking plate. The pubic symphysis was not fixed. An upward vertical load was manually applied to each respective SI joint using a hook into the sciatic notch. The ultimate load to failure and the mode of failure was recorded for both groups.

Results: The mean load to failure for the SI screw group was 310 N and for the SI plate group 580 N. The ultimate load to failure was significantly lower in the SI screw group (p=0.0002). There were no hardware-related failures recorded in any of the fixations in the study. The SI screw group had failure through a fracture of the sacrum in all the specimens. In the SI plate group, fractures of the sacrum and ilium constituted, respectively, 60% and 40%.

Conclusion: A locked square plate fixation is superior to a single SI screw at the ultimate load to failure when a vertical load is applied to the sacroiliac joint in a composite bone model.

Level of evidence: Level 3

Keywords: pelvic ring, pelvis trauma, SI joint, SI screw, sacroiliac plating, bone models

Introduction

Trauma to the pelvis comprises up to 3% of all skeletal injuries. It mainly occurs in younger patients as a result of high energy trauma, road traffic accidents, falls from heights, or sport-related injuries. These injuries are associated with increased morbidity and mortality rates.[1]

Biomechanical studies have proven that the posterior sacroiliac (SI) complex contributes more to the stability of the pelvic ring if compared to the anterior structures. The anterior and posterior complex each contribute 40% and 60%, respectively. [2]

Unstable injuries to the pelvis are associated with disruption of the posterior osteoligamentous structures.[3] According to the Association for Osteosynthesis-Orthopaedic Trauma Association (AO-OTA) classification, a type C pelvic ring injury is defined as the presence of disruption of the posterior pelvic complex that results in a vertically and rotationally unstable pelvic ring.[4] The Young & Burgess[5] and Tile[2] classifications can also be used to classify pelvic ring injuries. The advantage of mechanism guided fracture classifications is that they provide a guide for surgical indications and fixation of pelvic fractures.[1]

Surgical fixation remains the definitive treatment of choice for unstable posterior pelvic injuries. To date, no fixation method is as stable as the intact pelvic ring.[6] Anatomical reduction and fixation have shown improved overall construct performance, especially when compared to outcomes where non-anatomical reductions were obtained. The non-anatomical reduction is associated with the development of chronic pain, leg length discrepancy, limb malalignment and fracture non-union.[7]

Studies have proven that reduction within 1cm of combined residual displacement in posterior pelvic ring injuries leads to improved functional scores and clinical outcomes. In pure SI joint dislocations, poor clinical outcomes were observed where the SI joint was not anatomically reduced. Favourable results were also reported at a one-year follow-up in patients treated with percutaneous fixation after obtaining an anatomical reduction.[3,7]

Several surgical techniques have been described in the literature for the treatment of posterior pelvic ring injuries. They include anterior plating by ilioinguinal approach, open or closed reduction with percutaneous screw fixation, or posterior fixation using several different fixation techniques.[3,8–12]

Current literature suggests that less experienced orthopaedic surgeons prefer closed reductions and percutaneous techniques compared to open reduction and internal fixation for pelvic ring fractures.[13] Despite the popularity of closed reduction and percutaneous fixation techniques, some fractures and dislocations are not amenable to accurate reduction using these methods and an open approach is sometimes required. The anterior approach allows better access to the superior SI joint and allows better osseous exposure than the posterior approach.[11,14]

Advantageously, percutaneous sacroiliac screw fixation has a shorter operative time, decreased intraoperative blood-loss, smaller wound size, and reduced length of hospital stay when compared to open anterior sacroiliac joint plate fixation[13,15] The posterior approach to the pelvis has a higher profile of complications compared to the anterior approach. It includes wound infection, skin necrosis, neurological injuries, post-operative lower back pain and sexual dysfunction.[16]

Composite bone models have evolved and became a suitable replacement for cadaver bone in many settings, including surgical education and orthopaedic biomechanical research. The current fourth-generation composite bone models' biomechanical properties accurately reproduce that of human bone under different loads. They provide excellent anatomic detail and also offer consistency in terms of their biomechanical properties. Cadaver specimens can also cost up to three times more than equivalent fourth-generation bone models.[17] Synthetic bone models have successfully been used in multiple biomechanical studies, specifically in the pelvic and acetabular regions.[7,12,18–20]

To date, we could not find comparative studies between a locked square plate and a SI screw for sacroiliac joint fixation.

This study's primary aim was to compare the ultimate load to failure of a square locking plate to a SI screw when a vertical load is applied to the SI joint. The secondary objective was to describe the mode of failure of the construct.

Materials and methods

Ten artificial pelvis models (Synbone AG, Switzerland, Model no: 4083) were used in this study. These models are specifically designed for orthopaedic training and research.

No biomechanical testing facility was available at the University of the Free State to assist with this study.

We simulated an unstable type C sacroiliac (SI) joint dislocation in the models by removing all attachments at the sacroiliac joint and pubic symphysis. The lower part of the sacrum and coccyx was removed using a jigsaw to allow sacrum fixation to a wooden block. The sacrum of the model was then secured to a wooden block using four 10mm threaded rods with washers and bolts through the sacral foramina of S1 and S2. In turn, the wooden block was then secured to a bench vice to keep it stable to the ground. The sacrum attached to the wooden block and bench vice allowed a stable base to work from.

Anatomical reduction of the SI joint was then performed using a toothed reduction clamp. The SI fixation type was grouped into two groups: a SI screw group and a SI plate group. The one side of the model was fixed using the screw and the other side using the plate. Sides were randomised so that both groups would have equal representation on either side of the sacrum in our study population. The pubic symphysis was not fixated in any of the specimens.

The SI screw group was fixated using a 90mm x 7.3mm stainless steel, partially threaded cannulated screw with a washer. After anatomical reduction, a threaded guidewire was inserted perpendicularly from the ilium over the SI joint into the body of S1. A cannulated drill bit was used and drilled until just medial to the SI joint. The screw with its washer was then inserted by hand and hand tightened using a two-finger tightening technique.

The SI plate group was fixed using a 4-hole, 35mm x 22mm x 2.5mm, titanium plate with fully threaded cancellous locking screws, 45mm x 7mm (Saspine Pty Ltd). The plate was placed on the superior surface of the SI joint with two screws on either side of the joint. Holes were drilled using a 4.2mm drill bit and the nearest cortex over drilled with a 5mm drill bit. The sacrum screws were directed medially parallel to the joint, avoiding penetration of the sacral foramina and SI joint. Iliac screws were directed posterolaterally aimed at the posterior inferior iliac spine. The screws were inserted and locked by hand.

An industrial hanging scale (ADAM Model: MIF200) with metal hooks was hooked into the test model's sciatic notch. The researcher applied a manual vertical force via the scale in a controlled manner until fixation failure occurred. Fixation failure was defined as the point where fracture of the model, screw pullout, or implant breakage occurred. A slow-motion video was taken during vertical force application to determine the ultimate load to failure accurately. The force needed to cause construct failure was recorded (kilograms converted to newtons). The models and implants were inspected after the test was done to assess the mode of construct failure.

Data was collected on a data form after each test. Data was then captured in the form of a Microsoft Excel spreadsheet and submitted to the Department of Biostatistics at the University of the Free State for analysis.

Results

In the SI screw group, the median load to failure was 310 N (range: 280 to 390 N) and in the SI plate group, the median load to failure was 580 N (range: 380 to 760 N). Ultimate load to failure was significantly lower in the SI screw group (p=0.0002).

In the SI screw group, all failures were due to a fracture of the sacrum. In the SI plate group, 60% (6 models) of the failures occurred due to fracture of the sacrum and 40% (4 models) due to fractures at the ilium. No hardware breakage or screw pullout was observed in any of the groups.

In the SI plate group, the median load to failure for an ilium fracture was 610 N (range 380 to 760 N) and for the sacrum fracture 490N (range 400 to 600 N).

Discussion

Surgical fixation remains the treatment of choice in various posterior pelvic injuries, which includes SI joint dislocation. Which technique to use remains multifactorial in terms of injury and patient factors.

It is generally accepted in various biomechanical and finite element analysis studies that adding a second screw to the SI joint fixation increases the biomechanical stability, load to failure and amount of cycles to failure compared to a standard single SI screw.[3,6,8,18,21,22] Transiliac-transsacral lengthened screws provide mechanical advantages over unilateral sacroiliac screws and also shows no differences in pain scores or functional scores when compared to unilateral sacroiliac screws.[23,24] Adding a second screw theoretically increases the risk for extraosseous screw penetration and subsequent iatrogenic nerve injury.

In a cadaver study by Sagi *et al.* , they found no statistically significant difference between one or two SI screws in controlling the unstable hemipelvis's rotational or linear displacement alone. The addition of an anterior symphyseal plate in vertically unstable fractures decreased the displacement of the unstable hemipelvis in all planes, regardless of the posterior screw constructs used. They attributed these results because there are different bone density areas found in the normal human sacrum, whereas synthetic sacrum models are of uniform density. In a human sacrum, the greatest bone density is located in the anterior aspect of the promontory of S1. Lower bone densities are found at the posterior aspect of S1, the body of S2 and the sacral ala. Due to the relative osteopenia in S2 and the posterior aspect of S1, adding an additional screw in those regions will not likely add to the stability.[25]

We opted to use a single SI screw to limit variables and to compare a baseline screw fixation in our study with the limited amount of bone models available to us.

Anterior plating of the SI joint is commonly performed with the use of a double plating technique. When using a three-hole plate, two screws are placed on the iliac side and a single screw on the sacral side. Parallel placement of the plates is weaker compared to double plates placed at 60 degrees to each other.[16]

Anterior fixation with a square plate of the sacroiliac joint has shown promising clinical results in patients. The square plate's design allows the screws to be inserted in close proximity to each other and close to the joint line.[26] The design allows placement in the "safe zone" around the SI joint, reducing the risk of iatrogenic nerve injury to the L4 and L5 nerve roots.[27] It also allows a relatively smaller dissection for plate placement compared to double plating. A relatively flat plate can be used due to the flat coronal plane bony architecture within 2cm either side of the SI joint. Leighton *et al.* developed a four-hole anterior compression plate for sacroiliac joint fixation. Posterior fixation with their four-hole plate and anterior symphysial plates failed at an averaged 428N in a cadaver model.[28]

The design of the square plate with its large locking screws in our study allows a variable angle where the screws can be angled to prevent extraosseous penetration into the SI joint and sacral foramina. Screw pullout is reduced due to the locking mechanism in the plate and the screw with its cancellous thread also allows good bone purchase in cancellous bone. The larger core diameter of the screws also allows more resistance to bending forces and subsequently screw breakage.

There are some limitations to our study. A proper biomechanical testing facility would have allowed us a more accurate simulation of a vertical load to the SI joint. It would also enable cyclical loading to the respective constructs to determine specific failure points or displacement values. We would, however, argue that all specimens were stressed in the same manner and that the methodology is reproducible and cost-effective in a resource-constrained environment.

The most notable limitation was the use of synthetic bone models. Even though they cannot completely simulate human bone, they have comparable biomechanical properties when compared to cadaver specimens. They also allow consistent material properties between specimens and are most cost-effective.[17] Our sample size was also relatively small but is comparable to other similar biomechanical studies comparing posterior pelvic fixation techniques.[6,7,12,16,18–21]

Conclusion

A locked square plate fixation is superior to a single SI screw at the ultimate load to failure when a vertical load is applied to the sacroiliac joint in a composite bone model. It may be considered an alternative to a percutaneous screw fixation when an open reduction of the sacroiliac joint is needed. Further biomechanical studies are required to compare a locked square plate to other SI joint fixation methods.

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Conflict of interest

The authors declare no potential conflicts of interest concerning the research, authorship and/or publication of this article. The authors did not receive any royalties and have no connections with Saspine (Pty) Ltd.

Ethics statement

The authors declare that this submission is in accordance with the principles laid down by the Responsible Research Publication Position Statements as developed at the 2nd World Conference on Research Integrity in Singapore, 2010.

Before the commencement of this study, ethics approval was obtained from the Ethics Committees of the University of the Free State ethics number: UFS-HSD2020/0157.
This article does not contain any studies with human or animal subjects.

Author contributions

FJK: Primary author, responsible for the literature review, study design, data collection and manuscript preparation.
JFVDM: Conceptualisation, study design, data collection and manuscript approval.
AAVZ: Conceptualisation, study design and manuscript approval.

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Chapter 2

PAGE 1

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Sp. This word is misspelled. Use a dictionary or spellchecker when you proofread your work.

Article Error You may need to use an article before this word.

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Prep. You may be using the wrong preposition.

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Article Error You may need to use an article before this word.

Sp. This word is misspelled. Use a dictionary or spellchecker when you proofread your work.

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Missing "," Review the rules for using punctuation marks.

PAGE 4

Sp. This word is misspelled. Use a dictionary or spellchecker when you proofread your work.

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Article Error You may need to remove this article.
Article Error You may need to use an article before this word.

Wrong Article You may have used the wrong article or pronoun. Proofread the sentence to make sure that the article or pronoun agrees with the word it describes.

PAGE 5

Sp. This word is misspelled. Use a dictionary or spellchecker when you proofread your work.

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Run-on This sentence may be a run-on sentence.

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Prep. You may be using the wrong preposition.

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Sp. This word is misspelled. Use a dictionary or spellchecker when you proofread your work.

P/V You have used the passive voice in this sentence. You may want to revise it using the active voi

Proofread This part of the sentence contains an error or misspelling that makes your meaning unclear.

Sp. This word is misspelled. Use a dictionary or spellchecker when you proofread your work. **P/V**

You have used the passive voice in this sentence. You may want to revise it using the active voi

Prep. You may be using the wrong preposition.

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PAGE 8

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Prep. You may be using the wrong preposition.

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Missing "," Review the rules for using punctuation marks.

Sp. This word is misspelled. Use a dictionary or spellchecker when you proofread your work.

Sentence Cap. Review the rules for capitalization.

Sp. This word is misspelled. Use a dictionary or spellchecker when you proofread your work.

PAGE 9

Missing "," Review the rules for using punctuation marks.

Sp. This word is misspelled. Use a dictionary or spellchecker when you proofread your work.

Sp. This word is misspelled. Use a dictionary or spellchecker when you proofread your work.

PAGE 10

Article Error You may need to use an article before this word.

Frag. This sentence may be a fragment or may have incorrect punctuation. Proofread the sentence be sure that it has correct punctuation and that it has an independent clause with a complete subject and predicate.

Sp. This word is misspelled. Use a dictionary or spellchecker when you proofread your work.

Frag. This sentence may be a fragment or may have incorrect punctuation. Proofread the sentence to be sure that it has correct punctuation and that it has an independent clause with a complete subject and predicate.

Sp. This word is misspelled. Use a dictionary or spellchecker when you proofread your work.

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