

# Locked vs. Non-Locked Plating in Pelvic and Acetabular fractures

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## A Literature Review

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### Abstract

**Purpose:** Determine whether locked plating shows advantages over non-locked (conventional) plating in the treatment of pelvic and acetabular fractures. **Materials & Methods:** Systematic literature review via PubMed. **Results:** A total of 12 papers were included in this literature review - seven (7) on pubic symphysis disruptions and five (5) on acetabular fractures. Current literature does not indicate advantages for using locked vs. non-locked (conventional) plating in pelvic and acetabular fracture fixation. **Discussion & Conclusion:** Since the results of this review do not indicate advantages of using locked plating for the treatment of pelvic and acetabular fractures, the use of non-locked plates is well justified. Non-locked plates offer a large degree of possible screw angulation and highest flexibility in placing the screws for best bone purchase, e.g. following the infra-acetabular osseous path.

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## 1 Introduction and Purpose

Disrupted pubic symphysis and acetabular fractures have traditionally been treated with open reduction and internal fixation using conventional plating constructs [1] [2].

Over the last decade, surgical plating systems have been developed with the capability of locking the screw heads to the plate. The purpose of this literature review is to determine whether those locked plating systems offer advantages or disadvantages in the treatment of those pelvic injuries.

*fracture locking plate*. The resulting titles and abstracts were then screened to narrow down the selection. Studies dealing only with animals, not differentiating between fractures of the pelvis and of other sites, not differentiating between results achieved by locking and conventional plates or written in a language other than English were excluded at this stage. References of all selected papers were screened for further pertinent articles.

The collected information was then summarized in the following sections and in Table 2 (appendix).

## 2 Materials and Methods

A systematic literature search was performed in PubMed using the following key words: *pelvic fracture locked plating, pelvic fracture locking plate, pelvis locking plate, pelvic locking plate, pelvic locked plating, pelvis locked plating, Acetabulum locked plating, Acetabulum locking plate, pubis fracture locking plate, ischium fracture locking plate and ilium*

## 3 Results

A total of 12 papers were included in this literature review. Seven (7) studies focused on the fixation of the pubic symphysis, whereas the other five (5) focused on fixation of the acetabulum. Both biomechanical and clinical studies were included. Further information on study materials and methodology is given by Table 2 in the appendix.

### 3.1 Pubic Symphysis

#### 3.1.1 Biomechanical Studies

##### 3.1.1.1 Fixation strength and stability

In the study of **Prasarn et al.** [3] 4-hole symphysis plates with all locked or unlocked screws were compared. No significant difference in overall construct stiffness or in motion at the pubic symphysis or injured sacroiliac joint was found. Consequently, they concluded that locking plate and screw constructs have no apparent advantage over non-locking constructs for the fixation of the pubic symphysis.

**Daily et al.** [4] found no significant difference in superior and inferior symphysis gap displacement when they compared an anteriorly placed 4-hole locking construct to a non-locking construct. A potential advantage mentioned in this study was that a locked plating system may offer improved fixation in osteoporotic bone compared to a conventional plating system. However, contrary to this expectation, **Grimshaw et al.** [5] and **Moed et al.** [6], who used low bone mineral density samples in their studies, did not find a statistically significant difference between locked and unlocked plating of the pubic symphysis.

In a biomechanical study, **Moed et al.** [6] did not measure any statistically significant difference between locked and non-locked plating constructs of the pubis symphysis when comparing the number of completed cycles before failure and symphyseal widening after cyclic loading. Because of those findings, they consider their study as an indication that in the setting of an acute Type-C (OTA 61-C1.2) pelvic ring injury, pubic symphyseal locked plating does not offer any advantage over conventional non-locked plating. Thus, the authors recommended the continued use of standard non-locked plating techniques for a disruption of the pubic symphysis.

Using the same plate types, test setup and stressing protocol as **Moed et al.** [6], **Grimshaw et al.** [5] reached a similar conclusion for partially stable, open-book (OTA 61-B3.1) pelvic ring injuries in osteopenic bone. They also could not find any advantage of the locked plate construct.

In contrast to **Moed et al.** [6], **Grimshaw et al.** [5] and **Daily et al.** [4], **Pizanis et al.** [7] did find a biomechanical difference when comparing reduction and fixation capabilities of different plate techniques. In their synthetic Synbone composite pelvises with simulated OTA type 61 – B1.1 symphysis disruption, the best results with regard to compression and increased contact area were achieved with anatomically contoured plates combined with DC (dynamic compression) and locking screw capabilities. However, the use of locking screws without DC showed a significant loss of the initial compressive reduction force at the end of the experiment.

##### 3.1.1.2 Recorded Failure Modes

In the biomechanical study of **Moed et al.** [6], no catastrophic (i.e. abrupt and complete) failure of symphyseal or posterior fixation occurred during cyclic loading. Similarly, **Prasarn et al.** [3] and **Grimshaw et al.** [5] did not observe any catastrophic failure or screw pullout during testing and **Daily et al.** [4] and **Pizanis et al.** [7] did not mention any.

Consequently, **Grimshaw et al.** [5] concluded that any fear of catastrophic (i.e. abrupt and complete) failure of locked symphyseal plates appears to be unfounded for open-book injuries treated in patients with low bone density.

However, **Moed et al.** [6] and **Grimshaw et al.** [5] reported slight diastasis of the initial pubic symphysis reduction in all their specimens, regardless of the fixation method (**Moed et al.** [3] mean 1.0mm; range 0.2-1.7mm / **Grimshaw et al.** [5] mean 2.45mm; range 1.5 - 4.0mm). Both highlighted that this finding is common with standard unlocked plating techniques and shown to be clinically insignificant [3] [5].

**Grimshaw et al.** [5] also collected static testing failure data on one separate specimen of each plating group. Both specimens failed at 1985N. The one with standard non-locking screws failed anteriorly, fracturing through the right pubic ramus. The one with locked screws failed posteriorly with disruption through the sacroiliac joint.

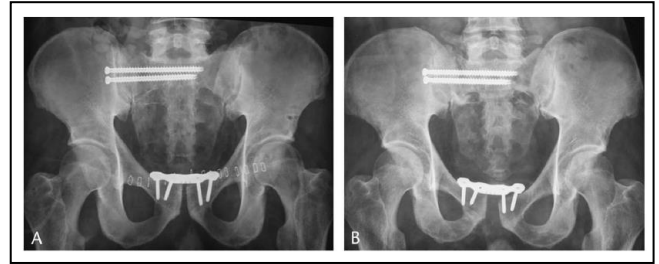
### 3.1.2 Clinical investigations and recorded failure modes

An overview of clinically observed failure modes is provided in Table 1.

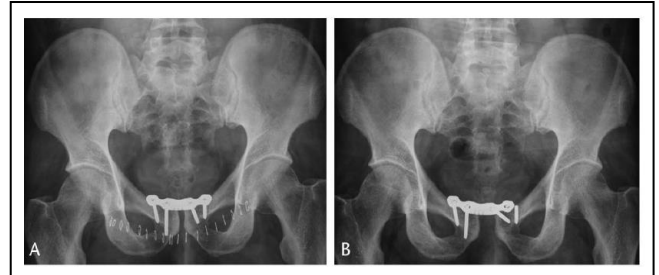
| Failure modes of metal hardware                                                                                                                                 | Time from fixation to failure [weeks] | No. of cases | Age of patients [years] | Source |
|-----------------------------------------------------------------------------------------------------------------------------------------------------------------|---------------------------------------|--------------|-------------------------|--------|
| Bone resorption at screw-bone interface and gapping of the pubic symphyseal reduction of about 10mm                                                             | 12/1/12                               | 3            | 44/54/64                | [8]    |
| Complete unilateral screw pullout from bone (Figure 1)                                                                                                          | <10                                   | 1            | 42                      | [8]    |
| Breakage of screws at screw-plate interface (in 4-hole plate) (Figure 2)                                                                                        | <12                                   | 1            | 40                      | [8]    |
| Unscrewing of the locked screws and pullout from bone (those locking screws were misaligned with the threads of the plate during surgical insertion) (Figure 3) | 3                                     | 1            | 45                      | [8]    |
| Loosening at screw bone interval, minor loss of post-operative reduction (gapping < 10mm)                                                                       | 3/11                                  | 2            | 68/29                   | [9]    |
| Unscrewing of locking screw / broken screw head, no significant loss of reduction                                                                               | 10                                    | 1            | 61                      | [9]    |
| Unscrewing of locking screw / no loss of reduction                                                                                                              | 5                                     | 1            | 19                      | [9]    |
| SIJ screw pullout / unscrewing of locking screw / broken screw head / loss of reduction                                                                         | 7                                     | 1            | 64                      | [9]    |
| None*                                                                                                                                                           | -                                     | 6            | 40/22/29/<br>14/58/58   | [9]    |

**Table 1:** List of failure modes reported for locked plating of Pubic Symphysis in patients. \*[8] present exclusively patients with failure of fixation. Total number of cases and percentage of cases with failure are not published in this paper.

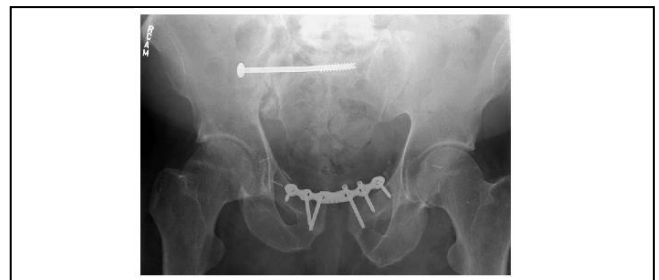
In contrast to the biomechanical findings of the previous paragraph, Moed et al. [8] and Hamad et al. [9] reported early failures of locked symphyseal plates in younger patients. **Moed et al.** [8] presented six patients (age: 40-64 years; mean 48 years) with failed locked plating fixation of the pubic symphysis. In 3 cases radiographic findings of bone resorption at screw-bone interface and gapping of the pubic symphyseal reduction (about 10 mm) were evident which did not produce any symptoms or elicit any complaints from the patients. In the other 3 cases, early and abrupt metal work failure occurred, resulting in complete loss of reduction.



**Figure 1:** Anteroposterior radiographs of Case 5 (Table 1 in [8]) showing (A) the immediate post-operative film and (B) when the patient returned for follow-up 10 weeks after surgery. [8]



**Figure 2:** Anteroposterior radiographs of Case 6 (Table 1 in [8]) showing (A) the immediate post-operative film and (B) when the patient returned for follow-up 12 weeks after surgery. [8]



**Figure 3:** Anteroposterior radiograph of Case 1 (Table 1 in [8]) obtained 3 weeks after surgery showing plate failure. [8]

**Hamad et al.** [9] performed a retrospective analysis on the subset of patients with locking symphyseal plates treating their pubic symphysis diastasis. This data was extracted from all pelvic fractures treated at their center between August 2008 and December 2011. A total of 11 patients were included (mean age 42 years; range 14-68 years).

In two patients, loosening at the screw-bone interface led to minor loss of post-operative reduction (gapping of < 10mm). In two other patients, locking screws unscrewed – in one of them a screw head broke in addition – but did not result in any significant loss of reduction. One patient had a significant radiological failure with SIJ screw pullout and fracture of symphyseal locking screws resulting in a malunion.

Since all patients were asymptomatic at last follow-up (10-54 weeks) and none required revision surgery, Hamad et al. [9] stated that locking plates across the pubic symphysis are safe with a low complication rate despite early weight bearing. However, they considered their sample size as too small for statistical conclusions with regards to the biomechanical efficacy of locking plates over their unlocking counterparts.

### 3.1.3 Summary of results from biomechanical and clinical studies

Biomechanical studies were performed on either cadaveric bones or synthetic pelvic bone models. No significant difference in mechanical performance between locked and non-locked plating of the pubic symphysis was found in three studies [3] [4] [6]. Grimshaw et al. [5] found minor diastasis of initial pubic symphysis reduction for both locked and unlocked plating.

In contrast to the other biomechanical evaluations, Pizanis et al. [7] investigated the compression of the symphysis and the maximal contact in the symphyseal gap on locked and non-locked plating constructs. These experimental results suggested a biomechanical advantage in using anatomically contoured plates compared to non-bent plates.

None of these studies reported catastrophic failure or screw pullout during testing, but contrary to these biomechanical investigations, two studies [8] [9] presenting a clinical case series of symphyseal diastasis managed with locking plates, found fixation failure in retrospective analysis.

Moed et al. [8] stated that failure mechanisms of locked design-specific plate fixation of the pubic symphysis include those seen with conventional uniplanar fixation as well as those common to locked plate technology. In contrast, Hamad et al. [9] found, that the use of locking plates across the pubic symphysis is safe with low complication rates. Nevertheless their sample size is too small for statistical conclusions with regards to the biomechanical efficacy of locking plates over their unlocking counterparts.

In summary, there was no evidence showing a substantial biomechanical or clinical advantage of locked pubis symphysis plating.

## 3.2 Acetabulum

### 3.2.1 Biomechanical Studies

#### 3.2.1.1 Fixation strength and stability

Zhang et al. [10] compared static fixation strength of three different fixation constructs (two interfragmentary screws alone, in combination with a conventional reconstruction plate or in combination with a locking reconstruction plate) for a simulated posterior wall fracture of the acetabulum in formalin preserved cadaveric pelvis. Measurements of the dislocation were taken at superior and inferior fracture site and no statistically significant difference between the three types of fixation was found. In each group, the vector dislocation at superior fracture site was significantly larger than the inferior one but all maximum vector displacements were below the clinically tolerable maximum value of 2mm. Zhang et al. [10] concluded that all three tested fixation constructs can provide sufficient stability for posterior wall acetabular fractures regardless the used reconstruction plate type.

Similar results were found by Marintschev et al. [11] for high anterior column fractures. The maximum fracture displacement under static loading was investigated on Synbone pelvis using three groups (two non-locking plates and one locking plate). The locking plate modality did not reduce the maximum fracture displacement. However, an additional infra-acetabular screw, independent of which type of plate technology was used, doubled the fixation strength. All measured vector displacements were smaller than the clinically tolerable maximum value of 2mm.

Khajavi et al. [12] used urethane foam hemipelvis with a transverse acetabular fracture and four different fixation techniques. The construct stiffness and fracture displacement of anterior column reconstruction plates with either locking or non-locking technology and two plates / lag screw combinations were investigated.

There was no statistical difference in stiffness between the single column fixation schemes using either locking or non-locking plates. However, the two column fixation constructs allowed about half the fracture displacement compared to single column fixation constructs. In conclusion, two column fixation provides the biomechanically stiffest construct for stabilization of transverse acetabular fractures.

Like Khajavi et al. [12], **Mehin et al.** [13] also considered a transverse acetabular fracture. They compared posterior column conventional fixation (interfragmentary lag screw along with a plate) to a locking plate construct in five paired fresh-frozen cadaveric acetabula. Each specimen was tested using a compressive cyclic loading followed by a static compression force until failure.

The results showed a trend favouring the conventional construct, however, there was no statistically significant difference found between the two groups in regards to stiffness and fracture gap displacement. Based on those results, Mehin et al. [13] concluded that the locking plate construct is as strong as the conventional plate with interfragmentary lag screw construct for fixing transverse acetabular fractures.

### 3.2.1.2 Recorded failure modes

The fracture displacements found by Zhang et al. [10] and Marintschev et al. [11] during simulation of clinical loading schemes were all below the clinically tolerable maximum value of 2mm.

With the exception of fracture displacement before and after loading, no specific mechanical failure was observed in three studies treating the acetabulum [10] [11] [12]. Mehin et al. [13] loaded the construct first until clinically failure (2mm fracture gap) and then until mechanical failure (end of the linear part of the force – displacement curve) but no specific failure modes were listed.

### 3.2.2 Clinical investigations and recorded failure modes

**Tadros et al.** [14] presented three patients, showing that the usage of locking reconstruction plates with monocortical screws for marginal posterior acetabular wall fracture fixation is clinically possible.

The 6-months follow up x-ray showed healed fractures with maintained fracture fragment alignment.

### 3.2.3 Summary of results from biomechanical and clinical studies

Studies on different acetabular fracture types were found. Zhang et al. [10] considered several posterior acetabular fracture fixation methods and found no statistically significant difference in fracture dislocation. Similar results were found by Marintschev et al. [11] for anterior column fracture fixation. In their study, the locking feature did not increase the strength of the fixation but the addition of an infra-acetabular screw significantly reduced the fracture displacement in all groups, independent of which plate system was used.

Khajavi et al. [12] and Mehin et al. [13] compared the fixation strength of conventional constructs (plate and lag screw constructs) to a locking plate construct in transverse acetabular fractures. Both studies showed that two column fixation provided a biomechanically equal or stiffer construct compared to single column fixation.

No benefit of locking plate fixation compared to the standard non-locking plate fixation was observed in those biomechanical studies.

One study [14] presenting a clinical case series of three marginal posterior wall fractures treated with locking plates did not show secondary displacement or nonunion.

## 4 Discussion and Conclusion

The common consent in this literature review is that experimentally, locked and non-locked plating of the assessed symphyseal and acetabular fracture types lead to statistically comparable interfragmentary stability when evaluated by static or cyclic loading.

The majority of published articles analyzing the biomechanical performance on the pubic symphysis showed evidence that symphyseal locked plating does not appear to offer any advantage over standard non-locked plating. Furthermore two clinical studies [8] [9] showed that failure mechanisms of locked plate

fixation include those seen with conventional fixations as well as those common to locked plating.

Transverse acetabular fractures were considered in two publications [12] [13] where a conventional plate with interfragmentary lag screw construct was compared with a locking plate construct. Results showed no statistical difference in stiffness or fracture gap opening. For both high anterior column and posterior wall acetabular fractures, studies [10] [11] pointed out that locking feature did not decrease the fracture displacement. However, an additional infra-acetabular screw, independently of which type of plate technology was used, showed a positive influence on reduction of fracture displacement. The use of non-locked plates with large degree of possible screw angulation offers highest flexibility in placing the screw for best bone purchase, e.g. following the infra-acetabular osseous path. This concept, which is utilized in the PRO quadrilateral surface plates, is an opportunity to increase the fracture fixation strength, which has been confirmed by Kistler et al. [15] in a biomechanical study.

## Résumé

In the light of the presented clinical and biomechanical studies, which did not indicate any significant advantages in using locked plating vs. non-locked plating in pelvic and acetabular fracture fixation, Stryker decided that the novel SOMA-designed pre-contoured PRO quadrilateral surface (QLS) plates are presented as non-locking plates in order to provide adequate stiffness and allow for secure fixation without any limitations in screw angulation caused by a locking screw mechanism.

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## 6 Appendix

Table 2: Overview and extracted meta-data of the studies included in this review

| 1 <sup>st</sup> author<br>Year | Type of Study         | Injury                                                                                                                                                                                                                                    | # of Patients (Female : Male) or # and type of specimens                     | Mean Age (range) / Mean bone density                                                                                         | Plating system(s) Group I, II, III...                                                                                                                                                                                                                                                                                                                                                                       | Test method                                                                                            | Failure modes / Results                                                                                                                                                                                                                                                                               | Differences between locked and non-locked plating                                                                                                                                                                                                                                                                               | Interesting points                                                                                                                                                                                                                               |
|--------------------------------|-----------------------|-------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------|------------------------------------------------------------------------------|------------------------------------------------------------------------------------------------------------------------------|-------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------|--------------------------------------------------------------------------------------------------------|-------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------|---------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------|--------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------|
| Prasarn 2012 [3]               | Biomechanical         | Completely unstable pelvic injuries, created by disrupting pubic symphysis and left sacroiliac joints                                                                                                                                     | 2 x 5 Pelves, cancellous core and hard cortical shell (Model 1301, Sawbones) | n/a                                                                                                                          | 4-hole, precontoured 3.5mm pubic symphysis plate (Synthes) placed superiorly; 5 pelves with 4 locking screws 5 pelves with 4 unlocked screws In all samples sacroiliac joint fixed with 7.3mm cannulated lag screw (Synthes) into the sacroiliac body                                                                                                                                                       | Compressive loading in single limb stance<br>1. cyclic compression 15N to 150N<br>2. side load of 100N | No catastrophic failure or screw pullout was observed                                                                                                                                                                                                                                                 | No significant difference between the two fixation methods in overall construct stiffness and motion at the pubic symphysis or injured sacroiliac joints.                                                                                                                                                                       | Measured also rotations at pubic symphysis joint and sacroiliac joint, not only translations                                                                                                                                                     |
| Daily 2012 [4]                 | Biomechanical         | Rotationally unstable (Tile B) pelvis injury                                                                                                                                                                                              | 5 (1:4) fresh frozen nonpreserved cadaveric pelvis                           | 70.6 years (55-81 years) /<br>1000 mg/cm <sup>2</sup> (641 mg/cm <sup>2</sup> - 1316 mg/cm <sup>2</sup> )                    | Each pelvis tested in the following order:<br>1. without fixation<br>2. with 4-hole 3.5mm pubic symphysis locking plate (PSLP; Synthes) and unicortical 3.5mm self-tapping screws (28mm length)<br>3. with 4-hole 3.5mm PSLP and bicortical self-tapping screws (85mm length)<br>4. with 4-hole 4.5mm Burgess dynamic compression plate (BDGP; Synthes) and bicortical 4.5mm fully threaded cortical screws | Compressive cyclic loading in 2-legged stance, 40N to 400N at 1 Hz                                     | Symphysis pubis displacement                                                                                                                                                                                                                                                                          | No statistically significant difference in stability (superior and inferior symphysis gap displacement) between the anteriorly placed 4-hole locking plate and non-locking plate constructs.<br><br>No statistically significant difference in pelvic ring stability between unicortical and bicortical locking screw fixation. | Advantages of unicortical screw placement: decreased surgical exposure, decreased exposure to ionizing radiation from fluoroscopy, decreased operative time, decreased blood loss, less risk for morbidity from a malpositioned bicortical screw |
| Grimshaw 2012 [5]              | Cadaver Biomechanical | Partially stable open book injury (AO/Orthopaedic Trauma Association 61-B3.1)<br><br>Suggestion to extend results to fixation of all partially stable open-book fractures (OTA 61-B1 and 61-B3.1) since most unstable pattern was tested. | 12 (7:5) osteopenic embalmed cadaver pelvic specimens                        | 87 years (82-93 years) /<br>6 osteopenic, 6 osteoporotic<br><br>DXA scans were obtained to ensure uniformity of bone density | 6 hole 3.5mm symphysis plate (Synthes) used with locking screws or standard unlocked bicortical screws                                                                                                                                                                                                                                                                                                      | 1. Collection failure data with two specimens<br>2. Bilateral stance model, 1 Mio cycles at 440N, 2Hz  | 1. Both specimens failed at 1985 N, nonlocking screws: failed anteriorly, fracturing through right pubic rami locked screws: failed posteriorly with disruption through sacroiliac joint<br>2. Minor diastasis of initial pubic symphysis reduction in all specimens (mean 2.45mm; range 1.5 - 4.0mm) | No statistically significant difference in diastasis: nonlocking: 2.4 ± 0.8mm locked: 2.5 ± 1.0mm                                                                                                                                                                                                                               | 1. Load to failure test<br>2. All pelvic specimens in both fixation groups completed 1 mio cycles without demonstrating any visible evidence of plate or screw failure.                                                                          |

# Locked vs. Non-Locked Plating in Pelvis and Acetabulum

| 1 <sup>st</sup> author Year | Type of Study                                     | Injury                                          | # of Patients (Female : Male) or # and type of specimens              | Mean Age (range) / Mean bone density                                                                                                   | Plating system(s) Group I, II, III...                                                                                                                                                                                                                                                                                                                              | Test method                                                                                                                                                                                                            | Failure modes / Results                                                                                                                                                                                                                                                                                                     | Differences between locked and non-locked plating                                                                                                                                                                                                                                                                                                                                                                               | Interesting points                                                                                                                                                                                                               |
|-----------------------------|---------------------------------------------------|-------------------------------------------------|-----------------------------------------------------------------------|----------------------------------------------------------------------------------------------------------------------------------------|--------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------|------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------|-----------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------|---------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------|----------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------|
| Moed 2014 [6]               | Cadaver Biomechanical                             | Vertically unstable Type-C (OTA 61-C1.2) injury | 8 (7:1) embalmed pelvic specimens                                     | 77 years (59-98 years) /<br>4 osteopenic, 3 osteoporotic, 1 normal<br><br>DXA scans were obtained to ensure uniformity of bone density | SI joint reduced and fixed using two 6.5mm cannulated screws (Synthes)<br><br>Six-hole 3.5mm plate specifically designed for the symphysis pubis (Synthes) having both locked and unlocked capability; four pelvises fixed with locked screws; four pelvises fixed with standard unlocked bicortical screws                                                        | Two-legged stance setup, Stressing at 440N with 2Hz, for a total of one million cycles or until fixation failure<br><br>On three levels measurements of symphyseal gap before and after cyclic loading                 | Five specimens (3 locked and 2 unlocked) experienced failure at the interface between mounting jig and the S1 vertebral body, between 360'000 and 715'000 cycles.<br><br>In all pelvises: slight diastasis of the initial pubic symphysis reduction, regardless of fixation method, overall mean of 1.0mm (range 0.2-1.7mm) | No statistically significant difference in the number of completed loading cycles before failure between locked (average: 701'000 cycles) and unlocked (average: 692'000 cycles) plating of the pubis symphysis.<br><br>No significant difference in symphyseal widening                                                                                                                                                        | Because of their relatively low bone density, as demonstrated by the DXA measurements, the specimens in this study should be considered appropriate to determine any advantage of locked plating over standard unlocked plating. |
| Pizanis 2013 [7]            | Biomechanical                                     | OTA classification type 61-B1.1                 | 5 x 6 Synthetic composite pelvises (Model 4061, Synbone, Switzerland) | n/a                                                                                                                                    | Plate types for symphysis fixation (all Synthes):<br>a) Regular narrow 4-hole DC Plate 4.5 (DCP)<br>b) Anatomical symphysis 6-hole "combi-hole" Plate 3.5 (SCP and SL-CP)<br>c) Anatomical symphysis 6-hole interlocking Plate 3.5 (SLP).<br><br>Teste groups (plate type and prebending):<br>I: DCP 0° / II: DCP 10°<br>III: SCP 10° / IV: SLP 0°<br>V: SL-CP 10° | Assessment of compressive force and contact area in the symphyseal gap after tightening the central or DC screws, after tightening the peripheral screws and after removal of the reducing tong with final tightening. | SLP 0° reached a high contact area and a homogeneous distribution of the contact area throughout the symphysis but it failed to maintain the compression force until the end of the experiment.<br>SL-CP 10° showed highest compression force of all five tested groups.                                                    | In contrast to group SCP 10° no initial loss of the compression force in the groups with peripheral interlocking screws (SL-CP 10° and SLP 0°) was observed.<br>The contact area in group with locking screws only (SLP 0°) was significantly lower than in the groups with central dynamic compression screws (SCP 10° and SL-CP 10°).<br>The distribution of the contact area was independent from the locking screw effects. | The experimental results suggest a biomechanical advantage in using prebended plates for symphysis fixation compared to non-bended plates.                                                                                       |
| Moed 2012 [8]               | Retrospective analysis of multicenter case series | Disruption of pubic symphysis                   | 6 male patients                                                       | 48 years (40-64 years)                                                                                                                 | Stainless steel locked symphyseal plates and screws (Synthes), specifically designed for the pubic symphysis:<br>5x four-hole plate with all screws locked,<br>1x six-hole plate with 4 out of 6 screws locked                                                                                                                                                     | Radiographic appearance of implant failure                                                                                                                                                                             | Divers failure modes: bone resorption at screw-bone interface, gapping of the pubic symphyseal reduction, complete unilateral screw pullout from bone, breakage of screws at screw-plate interface, unscrewing of the locked screws and pullout from bone, see also Table 1                                                 | n/a                                                                                                                                                                                                                                                                                                                                                                                                                             | Failure mechanisms of locked design-specific plate fixation of the pubic symphysis include those seen with conventional uniplanar fixation as well as those common to locked plate technology.                                   |

# Locked vs. Non-Locked Plating in Pelvis and Acetabulum

| 1 <sup>st</sup> author Year | Type of Study                                         | Injury                                                                                                                                             | # of Patients (Female : Male) or # and type of specimens                                                                    | Mean Age (range) / Mean bone density                                 | Plating system(s) Group I, II, III...                                                                                                                                                                                                                                                                                                                                                                   | Test method                                                                                                                                                                                             | Failure modes / Results                                                                                                                                                                                                                                                                                                                                | Differences between locked and non-locked plating                                                                                                                                                                                                                                                                                                                                                        | Interesting points                                                                                                                                                                                                                                              |
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| Hamad 2013 [9]              | retrospective analysis of a single centre case series | Symphyseal diastasis<br><br>highly unstable fracture configurations caused by anterior-posterior compression, vertical shear or combined mechanism | 11 patients (2:9)                                                                                                           | 42 years (14-68 years)                                               | Locking symphyseal plates, Synthes (4-hole or 6-hole)<br><br>Sacroiliac injury was reduced closed or open and stabilized with either a percutaneous 7.3mm cannulated screw and/or plate                                                                                                                                                                                                                 | Radiographic appearance of implant failure                                                                                                                                                              | Divers failure modes: 2x loosening at screw-bone interface with resultant minor loss of post-operative reduction (gapping of <10mm), 2x breakage of metalware or unscrewing of locked screws but without any significant loss of fixation, 1x pull out of SI screw and fracture of symphyseal locking screws with loss of reduction, see also Table 1. | n/a                                                                                                                                                                                                                                                                                                                                                                                                      | Post-operative rehabilitation protocol focuses on early mobilization                                                                                                                                                                                            |
| Zhang 2013 [10]             | Cadaver Biomechanical                                 | Simulated posterior wall fracture of the acetabulum                                                                                                | 6 male formalin-preserved cadaveric pelvises.                                                                               | 62 years (45-76 years) / Bone abnormalities were ruled out by x-ray. | I: 2 Cancellous screws on all specimens<br>IIa: 3 specimens addition of a 7-hole 3.5mm conventional reconstruction plate with 4 cortical screws<br>IIb: 3 specimens addition of a 7-hole 3.5mm locking reconstruction plate with 4 locking cortical screws<br>All implants from Weigao.                                                                                                                 | All 6 pelvises 6x axially loaded in double-limb stance up to 1500N (10mm per minute).                                                                                                                   | Fracture dislocation, but all vector displacements smaller than clinically tolerable max value of 2mm.                                                                                                                                                                                                                                                 | No statistically significant difference in fracture dislocation                                                                                                                                                                                                                                                                                                                                          | Independent of the fixation construct (screw only or with plates), the motion pattern in the superior and inferior fracture lines was similar.<br><br>In each group, the displacement of superior fracture line was significantly larger than the inferior one. |
| Marin-tschew 2012 [11]      | Biomechanical                                         | High anterior column fracture                                                                                                                      | 3 x 6 Synthetic pelvises (Model 4060, Synbone, Switzerland)<br><br>Cord bands to simulate the relevant hip abductor muscles | n/a                                                                  | I: MPS, nonlocking curved plate (Stryker)<br>II: LPPS non-locking left J-shaped (Synthes)<br>III: LPPS locking left J-shaped (Synthes)<br><br>All pelvises tested with and without additionally placed infra-acetabular lag screw<br>Pelvic ring additionally stabilized.                                                                                                                               | static loading with 6 cycles up to 800N in up right position in single leg stance                                                                                                                       | Fracture displacement, all vector displacements smaller than clinically tolerable max value of 2mm                                                                                                                                                                                                                                                     | Locking screw technology did not increase fracture fixation strength (not reduce max fracture displacement)                                                                                                                                                                                                                                                                                              | Motion pattern were similar for all groups in the three translation axes.<br><br>Additional placement of the infra-acetabular screw reduced the fracture displacement by half in all groups                                                                     |
| Khajavi 2010 [12]           | Biomechanical                                         | Transverse acetabular fracture                                                                                                                     | 4 x 10 Urethan foam hemipelvises, cortical outer shell, cancellous inner matrix (Pacific Research Laboratories, Washington) | n/a                                                                  | I: 10 -hole 3.5mm anterior column reconstruction plate with bicortical screws<br>II: 10 -hole 3.5mm anterior column locking plate with unicortical screws,<br>III: 10-hole 3.5mm anterior column reconstruction plate with bicortical screws and 4.5mm posterior column lag screw,<br>IV: 6-hole 3.5mm posterior column reconstruction plate with bicortical screws and 4.5mm anterior column lag screw | Femoral head loading at 0.2mm/s to 2000N (oriented 45 degrees superomedially (coronal plane) and 25 degrees posteriorly (sagittal plane) through a bipolar hemiarthroplasty attached to testing machine | n/a                                                                                                                                                                                                                                                                                                                                                    | Constructs with two column fixation were statistically stiffer than an anterior column plate alone.<br><br>Non significant trend towards more stiffness for the anterior locking plate compared to the anterior non-locking plate.<br><br>No significant difference between fixation with an anterior column locking plate with unicortical screws and an anterior plate with posterior column lag screw | Most of the displacement measured for all fixation schemes was in the shear direction.                                                                                                                                                                          |

# Locked vs. Non-Locked Plating in Pelvis and Acetabulum

| 1 <sup>st</sup> author Year | Type of Study                      | Injury                                                                                               | # of Patients (Female : Male) or # and type of specimens                                                                                     | Mean Age (range) / Mean bone density                                       | Plating system(s) Group I, II, III...                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                           | Test method                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                  | Failure modes / Results                                                                                                                                                     | Differences between locked and non-locked plating                                                                                                                                                                                                                                                                                                         | Interesting points                                                                                                                                                                                                                              |
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| Mehin 2009 [13]             | Biomechanical                      | Standardized transverse acetabular fracture                                                          | 5 fresh-frozen pelvic specimen (3:2) all soft tissue removed pelvis sagittally sectioned through the midline of the sacrum and the symphysis | 63 years (49–79 years) / Abnormalities of pelvis examined radiographically | I: Conventional plate-lag screw construct:<br>4.5mm interfragmentary lag screw and 8-hole 3.5mm reconstruction plate (Synthes) contoured to posterior column of acetabulum fixed with 6 screws.<br>II: Locking plate construct:<br>8-hole 3.5mm locking plate (Synthes) approximately contoured to posterior column of acetabulum, without interfragmentary lag screw.<br>Because the directions of the locking screws are dictated by the plate, some of the screws were directed toward the acetabulum (measured 2mm short of the articular surface, otherwise locking screws attained bicortical purchase.). | Simulated femoral head compressive cyclic loading between 50N and 250N up to 500 cycles at a rate of 0.25Hz. Then compression in load control (150N/s) until failure                                                                                                                                                                                                                                                                                                                                                                                                                                                                                         | Failure was defined as increase of 2mm fracture gap (clinical failure) or until end of linear part on the compressive force versus fracture gap curve (mechanical failure). | No statistically significant difference in the fracture gap at 50N compressive force after 500 loading cycles:<br>- fracture gap<br>- in stiffness<br>- in compressive force necessary to cause clinical failure<br>- in compressive force necessary to cause mechanical failure<br>- in amount of rotation at fracture site at point of clinical failure | Technical considerations particular to locking plates:<br>Screws directed into acetabulum because trajectory of locked screw dictated by screw holes and some screws could not be inserted because of overlying soft tissue                     |
| Tadros 2010 [14]            | Presentation of surgical technique | Marginal posterior acetabular wall fractures, posterior hip dislocation reduced by closed maneuvers. | 3 patients (1:2)                                                                                                                             | 35, 65 and 22 years                                                        | Single 3.5mm locking reconstruction plate (Synthes) in two patients. One patient received an additional plate.                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                  | Surgical technique:<br>- Because of hip joint instability, open reduction and internal fixation were indicated in all three patients.<br>- Adequate exposure obtained through a Kocher-Langenbeck approach.<br>- Marginal impaction fragments reduced followed by correction of any displaced cortical fragments, and temporary fixation preformed using K-wires.<br>- Plate contoured to the posterior column.<br>- Plate fixed distally then proximally using nonlocking screws to bring the plate down to the posterior acetabular wall allowing fracture buttressing. The marginal fracture fragment fixed using short monocortical locking-head screws. |                                                                                                                                                                             |                                                                                                                                                                                                                                                                                                                                                           | Weight bearing was restricted for 10- to 12-week postoperatively. The postoperative period was uneventful for the three patients.<br><br>The 6-month follow up X-ray films showed healed fractures with maintained fracture fragment alignment. |

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