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Effectiveness of surgical fixation for lateral compression type one (LC-1) fragility fractures of the pelvis: a systematic review

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Abstract *(297 words)*

Objectives: To undertake a systematic review of the evidence base for the effectiveness of surgical fixation of lateral compression (LC-1) fragility fractures of the pelvis compared to non-surgical approaches.

Searches: MEDLINE, EMBASE, the Cochrane Central Register of Controlled Trials (CENTRAL), and two international trials registers were searched up to January 2017 (Medline to July 2017) for studies of internal or external fixation of fragility fractures of the pelvis.

Participants: Patients with lateral compression pelvic fractures (LC-1 fractures), otherwise known as 'pubic ramus fractures' or 'sacral insufficiency fractures' or 'pelvic insufficiency fractures'.

Interventions: Surgery using either external or internal fixation devices. Conservative non-surgical treatment was the defined comparator.

Outcome measures: Outcomes of interest were patient mobility and function, pain, quality of life, fracture union, mortality, hospital length of stay and complications (additional operative procedures, number and type of adverse events and serious adverse events).

Quality assessment and synthesis: The Joanna Briggs Institute Checklist for Case Series was used to assess the included studies. Results were presented in a narrative synthesis.

Results: Of 3421 records identified, four retrospective case series met the inclusion criteria. Fixation types were not consistent between studies or within studies and most patients had more than one type of pelvic fixation. Where reported, mobility and function improved post-surgery, and a reduction in pain was recorded. Length of hospital stay ranged from four days to 54 days for surgical fixation of any type. Reported complications and adverse outcomes included: infections, implant loosening, pneumonia and thrombosis. Use of analgesia was not reported,

Conclusions: Surgical fixation of LC-1 fragility fractures in the elderly has the potential to reduce pain and promote early mobilisation. However, there is insufficient evidence to support guidance on the most effective treatment for patients who fail to mobilise after sustaining an LC-1 fragility fracture.

Registration: PROSPERO registration number: CRD42017055872

Strengths and limitations of this study

- This review systematically examines the available evidence, searching multiple databases, assessing the risk of bias in included studies and using methods to reduce error and bias in study selection, data extraction and assessment of risk of bias.
- This is a rapidly evolving area for surgery, with ever increasing incidence, so the searches of electronic databases were supplemented by searches for on-going trials.
- Key health databases were searched and efforts were made to find unpublished studies via trial registers, however we did not have the resources to search more widely and retrieval was restricted to studies published in English.
- The review found many narratives on surgery for fragility fractures of the pelvis, but no randomised controlled trials, and only four retrospective case series that met all the inclusion criteria.

Key words: surgery; internal fixation; external fixation; fragility fracture; pelvis; systematic review

Effectiveness of surgical fixation for lateral compression type one (LC-1) fragility fractures of the pelvis: a systematic review

Introduction

Fragility fractures of the pelvis (FFP) can result in significant long term disability,[1] have a significant impact on patients and put a strain on health care provision. A common fragility fracture pattern in older adults is the lateral compression type-1 (LC-1) pelvic fracture. This typically results from a low-energy fall from standing height, and increases in likelihood with age.[2-4] LC-1 fractures are projected to have the largest incidence increase (by 56% over 20 years) of all osteoporotic fractures and the associated treatment costs are predicted to rise by 60% between 2005 and 2025. [5 6]

The effects of LC-1 fractures can be devastating for patients. The pain and associated immobility leads to secondary complications, including respiratory and urinary tract infections, pressure sores and venous thromboembolic events.[7 8]

Many patients with LC-1 fractures report that they do not return to their pre-injury function and they have reduced independence with activities of daily living.[2 4] This can result in the need for intermediate care or residential facilities in addition to anxiety, emotional stress and reduced confidence.[9 10] Mortality for FFP at one year is 27%, [11] which is comparable to hip fractures at 33%. [12] Furthermore, hospital stay for FFP has been shown to be similar to hip fractures in the elderly.[10 13]

The standard treatment for hip fractures (so-called fractured neck of femur) is rapid surgical fixation or joint replacement, within 36-hours of injury, aimed at early weight-bearing and minimising immobility-related complications.[14] Paradoxically, despite the similarities in patient cohorts and their vulnerability to pain-induced immobility, the standard of care for elderly LC-1 fragility fractures of the pelvis (LC-1 FFP) is non-operative treatment and to 'mobilise as pain allows'.[15-17] Many patients with stable fractures are able to mobilise within a few days of injury, typically with a walking aid. However, patients with unstable fractures (those that are unable to withstand physiologic loads without displacement [18]) typically have disabling pain with almost all movements, even moving around the bed. This unstable group are at greater risk of the immobility-related complications discussed above.[10-13 15]

There are various classifications of pelvic ring fractures based on the mechanism of injury, ligamentous involvement, and anatomical location. For the purpose of this review, LC-1 FFPs were defined by respective anatomical classifications in patients with a low energy mechanism.

1. Young and Burgess: an oblique or transverse ramus fracture with or without ipsilateral anterior sacral alar compression fracture (LC-1). [19 20]

2. Tile classification: rotationally unstable, vertically stable. Ipsilateral, the rami commonly fractured anteriorly and the posterior complex is crushed (Tile B2).[21]
3. AO classification: unilateral, partial disruption of posterior arch, internal rotation (AO 61- B2.1). [22]
4. The Rommens classification is designed specifically to encompass the different fracture patterns seen in fragility fractures of the pelvis. The LC-1 FFP injury corresponds with Rommens type II b and II c injuries allowing further stratification of the severity of this injury. This describes an ipsilateral anterior disruption with either a sacral crush fracture (type IIb) or undisplaced sacral, iliosacral or ilium fracture (type IIc). [18]

Until recently, surgical fixation options for these fractures were limited. External fixators, a combination of pins, bars and clamps outside of the skin, are cumbersome, poorly tolerated and carry a high risk of pin- site infections and pressure sores.[23] An alternate surgical option is fixation of the back of the pelvis with sacroiliac screws, a well-established technique in younger patients.[4] However, these procedures require significant technical expertise to implant and, crucially, the screws carry very poor 'purchase' in osteoporotic bone,[8] leading to ineffective fracture stabilisation. What works in younger patients with good bone quality is less effective in the older patients.[24] In 2010 a new technique of anterior subcutaneous internal fixation (INFIX) was developed, combining the principles of internal and external fixation. It involves placing screws in the supra-acetabular corridors and developing a subcutaneous tunnel in which a rod is connected to the screws to stabilise the pelvis. Adoption of the INFIX device has been growing as it has the potential for significant advantages over external fixation including lack of pin site infection, cumbersome implants and a second procedure for removal. However, its use for the management of the FFP population who sustain an LC-1 fracture remains controversial. The use of the INFIX device has been described across other age groups and pelvic fracture types;[23 25 26] however, there has been no systematic review on its utility in LC-1 FFP. Given the uncertainty around the management of LC-1 fractures in the elderly and the potential of INFIX to change the management of these injuries, we sought to identify and synthesise the evidence on the effectiveness of surgical fixation in fragility fractures of the pelvis. We included both internal and external surgical fixation, in order to provide a broad overview of the evidence on surgical fixation.

Objective

To undertake a systematic review of the evidence base for the effectiveness of surgical fixation of LC-1 fragility fractures when compared to non-surgical approaches.

Materials and Methods

The protocol was prospectively registered in PROSPERO: CRD42017055872. The Centre for Reviews and Dissemination (CRD) guidance for undertaking reviews in healthcare was

followed and reporting is in line with PRISMA guidelines.[27 28] There was no patient involvement in this review.

Data sources

An experienced information specialist undertook searches of MEDLINE (including Epub Ahead of Print, In-Process & Other Non-Indexed Citations, Ovid MEDLINE Daily and Ovid MEDLINE), EMBASE and the Cochrane Central Register of Controlled Trials (CENTRAL). ClinicalTrials.gov and the WHO International Clinical Trials Registry Portal were also searched for any information on studies that were in progress. The search terms included: ('Ilium' or 'Ischium' or 'Pubis' or 'Pelvic Bones') AND ('Bone Fractures' or 'Osteoporotic Fractures' or 'Compression Fractures) AND ('Fracture fixation' or 'Fracture fixation, Internal' or 'External fixators' or 'Splints' or 'Orthopedic fixation devices' or 'Bone plates' or 'Bone screws' or 'Bone wires' or 'Internal fixators'). The search strategy developed in Ovid MEDLINE (Supplementary file 1) was adapted for use in the other databases searched. The searches were limited to studies published in the English language from 1980 to date. All searches were initially run on 19 January 2017. As this is an area of rapid development, the search in MEDLINE was updated on 06 July 2017.

Study Selection

Studies of patients with LC-1 FFP (defined above) undergoing surgery using either external or internal fixation devices were eligible for inclusion. Conservative non-surgical treatment was the defined comparator. If studies included other types of pelvic fractures, the study was included if the data on LC-1 FFP patients were reported separately and/or if 80% or more of participants had a LC-1 fragility fracture. Studies were excluded if LC-1 fractures were the result of a high-energy mechanism, defined as a fall from greater than standing height or if fractures arose secondary to pathology other than reduced bone density. Randomised controlled trials (RCTs), non-randomised trials and other comparative designs, observational studies (e.g. cohort), and case series of 10 or more cases were included. Study designs other than RCTs are at high risk of bias when assessing treatment effectiveness; however, as the review was potentially to inform a future RCT, an inclusive approach was taken. Biomechanical and cadaver studies were excluded.

Titles and abstracts were independently reviewed by two reviewers for potentially relevant studies. Full text articles of potentially relevant studies were obtained and also reviewed independently by two reviewers (AB, HI) against the inclusion criteria, with discrepancies resolved by a third reviewer (MN).

Data Extraction and Quality Assessment

Data were extracted by one researcher using a piloted form and. checked by a second reviewer with discrepancies resolved by discussion (HI, AB). Data extracted were: publication year, study design, number of cases, total sample size, population type, mean

age, percentage of male/female patients, fracture details, follow-up period, outcome measures and outcome data, details of the interventions and comparators, and complications. Defined outcomes of interest were: patient mobility and function (using standardised outcome measures), pain (Visual Analogue Scale (VAS) scores, analgesic or opiate requirements), quality of life (using standardised patient reported outcome measures (PROMS)), fracture union rate, mortality, hospital length of stay, complications (additional operative procedures, number and type of adverse events and serious adverse events) and radiographic alignment.

Quality assessment using the Joanna Briggs Institute Checklist for Case Series was undertaken by one researcher and checked by a second; disagreements were adjudicated by a third.

Data Synthesis

The aim of the synthesis was to identify gaps in the evidence and identify implications for future research. A narrative and tabular summary of the key study characteristics, study risk of bias and clinical outcomes was undertaken. Where possible, data were reported separately for internal and external fixation. The planned quantitative synthesis as outlined in the protocol was not possible due to the lack of randomised controlled trials.

Results

Study selection

The electronic searches identified 3421 records after deduplication and four records were found through other sources. Following screening of titles and abstracts, 83 full papers were assessed for eligibility, 79 were excluded (supplementary file 2) and four studies met the inclusion criteria (Figure 1).[29-32]

We identified two relevant, on-going trials that are likely to include some patients with LC-1 fractures, though they are not specifically the target population in either trial. One is comparing surgeon choice of surgical technique with non-operative care [33] and the other an experimental surgical intervention with conservative care.[34] Final data collection for these trials will take place in December 2018; [33] and October 2019.[34]

[Figure 1. Study flow chart to be inserted here]

Characteristics of included studies

No RCTs comparing the effectiveness of external or internal fixation to non-operative management were identified. All the included studies were case series: three retrospective [30-32] and in the fourth, patients were identified post operatively with data collected prospectively.[29] Sample sizes ranged from 14 to 127 and the total duration of follow up ranged from the day of removal of external fixator to 31 months. The procedures were

undertaken from 2004 onwards to 2014 in Germany (n=3) and Italy (n=1). One study did not report when the procedures were undertaken[29] and another reported seven years after the last patient was included.[32] Study characteristics are given in Table 1.

Fixation types were not consistent between studies or within studies and most patients had more than one type of pelvic fixation. All internal fixations were posterior or a combination of anterior and posterior. Three studies reported effectiveness data on sacroiliac screws,[30-32] and one on supra-acetabular external fixation,[29] or a combination of these fixations. Hoch et al also included patients who had additional sacroplasty (n=13) in combination with the internal fixation techniques.[32]

The average age of participants across the studies ranged from 69.6 to 81 years old and the percentage of female participants ranging from 64% to 92%. Comorbidities were reported within all the studies and included osteoporosis, hypertension, chronic heart disease and physical status. Where reported, between 20% and 57% of participants had osteoporosis.[29-31] Two studies included a few patients with high-energy injuries; however, the majority of patients sustained their injuries following low energy falls.[29 32]

The fracture classifications used were AO/Tile and Rommens, along with a narrative description of the injury.

Mean time from injury to surgery ranged from 3.6 days [29] to 6 months.[30] The duration of surgery was reported in two studies: the duration for internal fixation ranged between 70 and 220 minutes [30] and for external fixation was between 9 minutes and 35 minutes.[29]

All four studies allowed most patients to fully or partially weight bear following surgery. Arduini et al (2015) dictated 4-6 weeks strict bedrest followed by partial weight bearing for a further 6-8 weeks.[30] The patients in this study differ from the other case series in that participants had chronic lower limb or back pain after six months of non-operative treatment. These patients were operated on at 6 months for chronic rather than acute pain, making it inappropriate to compare the outcomes and post-operative regime for acute fractures between this and the other studies.

Table 1. Study characteristics

Author (Year) Study Site	Inclusion /Exclusion criteria	Patient Descriptors	Injuries documented and accounted for	Fracture classification	Cause of fracture and frequencies (e.g. fall)	Fixation type	Time to surgery (days) Operation time (minutes) Post op Regime	Follow up Time points
Arduini et al (2015) Italy Retrospecti ve case series	Surgery for fragility fracture of the pelvis. Indications for surgery include: chronic lower limb pain or lower back pain with no other diagnosis following FANS treatment **Exclusion** Not reported	**Screened** Not reported **Sample Size** 14 **Mean Age (SD)** 69.6 **Gender** 9F:5M **Comorbidities** Osteoporosis = 5 taking bis-phosphonates	**Concurrent** None reported **Previous** Undisplaced anterior ring pelvic fracture in the previous 2 years =4 Other pelvic ring fracture =2	**Rommens** Type II = 3, Type III = 9, Type IV =2	**Low Energy** =6 **Spontaneous pain** =8	SI Screws and symphysis plate or pubic rami screw =8 Trans sacral bridge plate and SI Screws =3 Lumbar-pelvic fixation and symphysis plate =3	**Time to surgery** 6 Months **Operation time** Range 70 – 220 mins **Post op Regime** Bed rest for 4-6 weeks and partially weight bearing for a further 6-8 weeks	Primary 6 months Secondary 1 and 3 months
Gansslen et al (2013) Germany Case series: data collected prospectivel y patients identified from database post operatively	Patients ≥ 65 years with type B injuries stabilized by a supra-acetabular external fixator in a standardized technique were selected from the hospital pelvic database of all patients with pelvic ring and acetabular injuries. **Exclusion** Not reported	**Screened** Not reported **Sample Size** 25 **Mean Age (SD)** 79.3 (9.9) (range 66-99) **Gender** F23:M2 **Comorbidities** At least one significant co-morbidity =19 (76%), most had two including hypertension, chronic heart disease or osteoporosis	**Concurrent** isolated pelvic trauma = 21 distal radius fracture and/or minor head injury =4 **Previous** None reported	**AO** B 2.1 =24 B 3.3 =1 A 3.3 =1	**Low energy** =22 **High energy** =3	Supra-acetabular external fixation	**Time to surgery** Mean(SD) 3.6 (3.3) (range 0–13) **Operation time** Mean(SD) = 19 (7.4) (range 9–35) **Post op Regime** Fully weight bearing =14 Partial weight bearing on the affected sacral side =4 Partial weight bearing =7	**Primary:** Post-operative discharge **Secondary:** Removal of external fixator
Hoch et al (2017)	Over 65 years, with a lateral compression	**Screened** Not reported	**Concurrent** **Overall** ISS 10.1 (SD4.6),	**AO** B2.1 =115 (90%)	**Overall** Low energy =103 High energy =13	Unilateral iliosacral screw fixation = 28	**Time to surgery** Mean(SD) 6.4 (4.1)	**Primary:** Two Years

Germany Retrospective case series	fracture of the pelvis **Exclusion** Not reported	**Sample Size** 128 **Mean Age (SD)** Overall 81 (8.3) Non-Operative 82.7 (7.9) Operative 78.3 (7.6) Died before treatment 92 P<0.002 **Gender** Overall F109:M19 Non-operative F66:M11 Operative F42:M8 Died before treatment F1:M0 **Comorbidities** Overall ASA 2.7 (SD 0.5) Non-operative ASA 2.8 (SD 0.6) Operative ASA 2.6 (SD 0.5)	isolated 89, Additional injury ISS <16 = 31, ISS>16 = 8 **Non-Operative** ISS 10.0 (SD3.9), isolated 56, Additional injury ISS <16 = 15, ISS>16 = 6 **Operative** ISS 9.4 (SD2.1), isolated 33, Additional injury ISS <16 = 16, ISS>16 = 1 **Died before treatment** ISS 48, ISS>16 = 1 **Previous** Not reported	B3.3 =13 (10%) Unilateral pubic rami =117 (91%) Bilateral =11 (9%) Complex pelvic fractures =2	Unknown =12 **Non-Op** Low energy =63 High energy =7 Unknown =7 **Operative** Low energy =40 High energy =5 Unknown =5 **Died before treatment** High energy =1	S1 Screws x2 = 4 S1 + S2 screw = 2 Bilateral iliosacral screws = 14. Additional percutaneously sacroplasty = 13 Triangular fixation =2 Additional anterior fixation plate =3 Navigation=7	**Operation time** Not reported **Post op Regime** Full weight bearing Plus 3 weeks community physio	**Secondary:** 6 weeks 3, 6, and 12 months included a clinical examination + radiographs
Hopf et al (2015) Germany Retrospective case series	Posterior pelvic ring fractures. Over 55 years, low energy trauma. Persistent lower back pain or unacceptable mobility **Exclusion** Patients under 55 years with a high energy trauma. If pain improved within 6 days and mobility was acceptable:	**Screened** "In the 'recruitment period' 87 patients with posterior ring fractures of the pelvis could be treated without surgery" **Sample Size** 30 **Mean Age (SD)** Mean 78.4, Range 56-96 **Gender** 27F:3M **Comorbidities** Osteoporosis =17	**Concurrent** Not reported **Previous** Not reported	Anterior + Posterior = 18 Bilateral Posterior = 11 Unilateral Posterior =1	**Low energy** = 30	iliosacral screws per side 1 screw unilateral = 6 2 screws unilateral = 18 3 screws unilateral =2 Bilateral 1 screw = 2 patients. 2 screws one side, 1 screw on other side = 2	**Time to surgery** Mean 9.2 (range 1-24) **Operation time** Not reported **Post op Regime** Mobilised day 1 post op	Primary: Mean 31 months Secondary: None
ASA = American Society of Anesthesiologists physical status classification; SD = standard deviation; SI = Sacroiliac								

Quality assessment

Hoch et al (2017) was the only study to include a non-operative group for comparison and a third group of those who died before treatment.[32] This was the highest quality study included and had the largest sample size of 128 patients (50 operative patients, 77 non-operative and 1 died before treatment and as such was excluded from investigation within the paper), however, the patients were recruited retrospectively (method not defined) and approached at two years following injury.[32] Patients in this study were selected for surgery if they were not able to mobilise three days after injury, after appropriate physical therapy and pain relief. The inclusion criteria or methods for selecting patients for inclusion were not clear in two studies [29 30] and it is uncertain in three studies whether there was complete and/or consecutive inclusion of eligible patients in the case series (Table 2).[29-31]

Table 2. Quality Assessment

Question	Arduini et al (2015)	Gansslen et al (2013)	Hoch et al (2017)	Hopf et al (2015)
1. Were there clear criteria for inclusion in the case series?	Unclear	Unclear	Yes	Yes
2. Was the condition measured in a standard, reliable way for all participants included in the case series?	Yes	Yes	Yes	Yes
3. Were valid methods used for identification of the condition for all participants included in the case series?	Unclear	Yes	Unclear	Unclear
4. Did the case series have consecutive inclusion of participants?	Unclear	Yes	Yes	Unclear
5. Did the case series have complete inclusion of participants?	Unclear	Unclear	Yes	Unclear
6. Was there clear reporting of the demographics of the participants in the study?	Yes	Yes	Yes	Yes
7. Was there clear reporting of clinical information of the participants?	Yes	Yes	Yes	Yes
8. Were the outcomes or follow up results of cases clearly reported?	Yes	Yes	Yes	Yes
9. Was there clear reporting of the presenting site(s)/clinic(s) demographic information?	Yes	Yes	Yes	Yes
10. Was statistical analysis appropriate?	Yes	Unclear	Yes	Yes

The inclusion criteria varied across the studies; three had age-related criteria; over 65 [32] [29] and over 55 years;[31] and one had criteria relating to type of fixation.[29] The injuries were identified in a standard way using radiographs and computerised tomography in all four studies.

Exclusion criteria and details of the number and characteristics of patients screened to identify eligible participants were poorly reported or not reported at all.

Clinical outcomes

The outcomes reported across the studies were mobility and function, pain, fracture union, hospital length of stay, quality of life, additional procedures and complications (Table 3).

Quality of life

Only one study used PROMs, the EQ-5D and SF-12, to assess quality of life.[32] Hoch et al [32] (n=127), the only study with a non-operative arm for comparison, reported no statistically significant difference in quality of life, as measured via the EQ-5D, between the surgical fixation (mean 74.6, standard deviation (SD) 15.5), surgical fixation after failed non-operative management (mean 76.3, SD 14.4), and non-operative management (mean 75.1, SD 13.4) groups ($p>0.3$) . The analysis of the SF-12 questionnaire for physical and mental scores also showed no statistically significant difference between groups ($p>0.2$), but summary scores for the groups are not presented.

Mobility and function

Post-operative mobility was reported in two case series. This was assessed by the ability to stand and walk without crutches at 6 month follow up;[30] and proportion mobilised with or without aids, and under full or partial weight bearing at the time of external fixation removal, which was on average 4 weeks post operation.[29] The reporting of mobilisation is not standardised between the two studies, making comparisons difficult. In Arduini et al, at 6-month follow-up, 11 (78%) patients were asymptomatic with restored ability to stand and walk without crutches; and two patients were able to walk with one crutch. A patient with a history of previous acetabular fracture walked with two crutches and was still waiting for a total hip arthroplasty.[30] In the Gansslen et al, at the time of discharge, 14 patients (56%) were mobilised under full weight bearing. Four patients (16%) were mobilised with crutches with partial weight bearing on the affected sacral injury side.[29] The remaining patients were mobilised partial weight bearing (n = 7). At the time of external fixation removal, 88% of patients had the same mobility as before the accident. Only three were still mobilised partial weight bearing.

Post-operatively, 88% of those who received external fixation [29] returned to their premorbid function.

Pain

Two studies reported a pain outcome. In one pain, measured by a 11 point VAS), significantly reduced following posterior internal fixation (mean pain score: on admission 6.8 and day two post-operative 3.6; $P<0.001$)[31] and supra-acetabular external fixation (mean score (SD): pre-operative 7.7 (1.4) and post-operative 2.3 (1.7); $P<0.0001$). [29] Following removal of the external fixator, 84% of patients were pain free, 12% had mild residual pain and 4% had worse pain. [29] In a second study there was no statistically

significant difference in pain two years after discharge between the non-operative (mean 3.1, SD 2.3), failed non-operative (mean 2.3, SD 2.8) and operative (mean 2.6, SD 2.8) groups ($p>0.5$) based on an 11 point VAS.[32]

Length of hospital stay

All four studies reported length of hospital stay: ranging from four days [29] to 54 days [31] for surgical fixation of any type. Gansslen et al reported that seven (28%) patients were discharged to a geriatric rehabilitation centre and one (4%) transferred to a different hospital. The mean length of hospital stay in Hoch et al was statistically significantly ($p<0.001$) longer in the surgical fixation group (mean 18.1 days, SD 10.0) than in the non-operative group (mean 9.2 days, SD 6.2).[32] Indications for surgery were not fully reported, making it difficult to distinguish why one patient had a primary surgical intervention and another did not. Over all the studies, of the 119 patients who received surgery, 14 patients had already undergone a period of conservative treatment before delayed surgery (6 months post injury), which may partly account for the increased length of stay for operative patients.

Table 3. Outcomes: measures used and main findings

Study ID	Patient mobility and function	Pain	Fracture union	Hospital length of stay	Additional operative procedures (for complication or as part of routine treatment) received: number of patients	Complications: AE and SAE Details of event: number of patients (Overall/per group)
Arduini et al (2015)	Mobility description Independent = 11 1 crutch =2 2 crutches =1	Not measured	% healed at 6 months 100%	Mean 5.8 days	One intra-pelvic iliac screw removed but no vascular, neurological or internal organ lesion was seen: 1	No neurological palsy or vascular lesions were observed and no patients needed ICU. No major complications
Gansslen et al (2013)	Not stated but degree of weight bearing reported Pre-op: FWB =24 Frame =1 At discharge: FWB =14 (56%) Crutches with PWB on affected side = 4 PWB = 7 At ExFix removal: Return to pre-injury mobility = 88% PWB = 3	VAS Preoperative: 7.7 ± 1.4 (4 –10) Postoperative: 2.3 ± 1.7 (p < 0.0001) Reduction pre to post op: 5.3 ± 2 (2–9) At fixator removal: 0.6 (0–5) (p <0.0003) Reduction post-op and at implant removal: 1.8 ± 2.1. Pain free: 21 (84%) Mild pain (VAS 1–2): 3 Worse pain(VAS 5): 1 No change/1 point change: 10 Remaining patients showed improvement: 3.1 points	Not measured	Total LOS 11 ± 5.2 days (4-24 days) Post-op LOS 7 ± 5.4 (1-18 days)	ExFix removed after an average 4 ± 1.6 weeks (3-8 weeks): 25 56% were removed after 3 weeks	Pin-infections treated with antibiotics: 2 No cases of post-operative nerve lesions or pin perforations seen
Hoch et al (2017)	Not measured	VAS Non-operative: 3.1 (SD 2.3) Failed non-operative: 2.3 (SD 2.8) Operative: 2.6 SD (2.8) P > 0.5	Not measured	Non-Operative 9.2 (SD 6.2) days Operative group 18.1 (SD 10.0 days) (P < .001)	Mal-positioning of iliosacral screw with neurological complaints: 3 (6%) Wound infection with salvaging of the osteosynthesis: 1 (2%)	**Non-Op 6 (8%)** Severe complications: 2 Pneumonia: 2 Thrombosis: 2 Mesenteric infarction: 1 ARDS: 1 **Surgery 9 (18%)** Severe complications: 1

						Pneumonia: 1 Thrombosis: 1 Diarrhoea: 1 Blood transfusions: 2 Implant loosening: 1 Delayed union: 1 Delayed surgery sub-group: 2 (14%) complications recorded
Hopf et al (2017)2015	Not measured	VAS 0-10 pre op, 2nd day post-operative, pain at discharge Admission = 6.8 2nd day mean = 3.6 p<0.001 Discharge mean = 1.8 p<0.001 long term pain = 6 in two patients	Not measured	Mean = 23.7 days, range 8-54 days	Complications: 3 Intra-op blood loss: 1 Nerve irritation/screw malposition: 1 Gluteal haematoma: 2	3 patients Pneumonia: 2 UTI: 2

AE= Adverse Event, SAE= Serious Adverse Event VAS = Visual analogue scale, FWB = Full weight bearing, PWB = Partial weight bearing, LOS = Length of stay, ExFix = External fixator, ARDS= Acute Respiratory Distress Syndrome, LFCN= Lateral Femoral Cutaneous Nerve, SD = standard deviation

Complications

All studies reported on whether patients experienced complications: the percentage of participants who suffered from complications ranged from no major complications (0%) to 14% across studies. Reported complications and adverse outcomes included: infections,[29] implant loosening,[32] pneumonia,[31 32] and thrombosis [32] (Table 3). Hoch et al. observed no statistically significant difference in the number of complications between the combination of screw and plate fixations and non-operative groups (18% v 8%, p=0.8).

In the study by Gansslen et al, removal of the external fixation was performed after an average of four weeks requiring a second procedure (SD 1.6, range 3-8) (2013). [29] There were two (8%) pin site infections in this series.

Posterior fixations also required further procedures; three patients (6%) had SI screws removed due to malposition and neurological complications in one study.[32] Another study had one patient (7%) with an intra-pelvic iliac screw removed with no residual complaint.[30] Other infrequent surgical complications with posterior fixation included two gluteal haematomas, one wound infection and one intra-operative bleed.[31]

Gansslen et al (2013) was the only study to report radiographic alignment; post-operatively reduction was near anatomic with an average residual sacral displacement of 0.3 mm (0–1 mm) and anterior displacement of 1.4 mm (0–12 mm).

Mortality

Mortality was reported in one study:[32] during hospital stay three patients died due to respiratory insufficiency (two following from pneumonia, and one from a pulmonary embolism) in the non-operative group; and one patient died of a pulmonary embolism and one of a suspected myocardial infarction in the operative group. By two year follow-up, 30% (n=38) of the patients had died; 41% in the non-operative group, 21% in the failed non-operative group, and 18% of the operative group.[32]

Discussion

This systematic review searched for evidence on the effectiveness of surgical fixation compared to non-operative management in the treatment of LC-1 FFP with no age restriction. No robust evidence from RCTs was identified. The evidence-base was restricted to four case series, three of which were retrospective. Poor reporting of the inclusion criteria, how patients were selected and the completeness of inclusion of potential patients raise concerns of study results being affected by selection bias. The limitations of this study design in providing robust evidence of effectiveness is well recognised.[35]

The focus of this review was on surgical fixation. Surgical interventions used in the included studies were unilateral and bilateral percutaneous iliac screws, with or without plating or supra-acetabular external fixation. One study included adjunctive sacroplasty. The

effectiveness of sacroplasty is yet to be established with contradictory results in the literature, however it is thought that the injection of cement into the fracture site can hinder fracture healing.[18] Therefore, studies of sacroplasty as the primary technique were excluded from this review.

Four studies reported on pain pre- and post-operatively using Visual Analogue Scores. The majority of patients recorded reduced levels of pain post-operatively. The other commonly reported outcome measure was length of hospital stay, which ranged from four days to 54 days. In one study the mean length of hospital stay was statistically significantly longer in the surgical fixation group than in the non-operative group. The proportion of patients across the five studies who had complications ranged from 0% to 14%. In the absence of details of the severity of the reported complications it is difficult to draw inferences. In addition, the level of experience of the surgeons and their familiarity with the techniques used in the studies are not reported.

Not all the studies reported on all the outcomes of interest in this review. Only one study assessed quality of life. Pelvic fractures are painful injuries and can significantly affect patients' mobility and their ability to carry out activities of daily living independently.[9] Immobility from prolonged bedrest can lead to potentially serious complications. Hence the role of surgery in improving mobility and quality of life in this frail, at risk population needs to be better defined. Although three studies reported return to pre-injury walking status or independent mobility, none of the studies used a standardised measure, so varied in how they reported patient mobility, ability to perform pre-injury walking status or ability to stand and walk without crutches. The time point for assessment also varied, ranging from an average of 4 weeks to 7.2 months after surgery. This makes the ability to compare the results limited and suggests there is a need for standardisation of a mobility measurement. In 2014, a survey of 111 surgeons from the Orthopaedic Trauma Association (OTA) in the United States showed a large discrepancy in practice decisions and operative agreement of LC-1 pelvic fractures.[36] Future studies should use standardised PROMS to assess important outcomes such as quality of life and ability of patients to undertake activities of daily living.

The strength of this systematic review is in the rigorous methods used, including searching of multiple databases, duplicate study selection and checking of data extraction and quality assessment as well as protocol registration prior to commencing the review. Although key health databases were searched and efforts were made to search for unpublished studies via trial registers, we did not have the resources to search more widely and retrieval was limited to English language studies. We set out to include internal and external surgical fixation as two separate interventions due to differences in the technique which may lead to differences in effectiveness and complications. The included studies were mostly of internal fixation and reported the methods of surgical fixation as a single group but the impact of

specific methods of internal fixation (in the form of SI screws or plates/screws) cannot be determined from the four case series analysed.

The lack of robust evidence makes it inappropriate to draw any definitive conclusions about effectiveness of internal or external surgical fixation compared to non-surgical management of LC-1 fragility fractures. It is clear from this review that the disparity in management between hip fractures (treated with early surgery) and LC-1 FFS (treated non-operatively) is primarily due the fact that, to-date, there has been no effective surgical solution for the latter group, despite them being at very high risk of immobility-related illness. None of the studies examined here provided evidence supporting surgical fixation of FFS; indeed, there is a suggestion that internal fixation might paradoxically contribute to an increased length of hospital stay. The included studies all used traditional pelvic implants (iliosacral screws and external fixators) that may be less suitable for LC-1 FFS populations. Other studies suggest that iliosacral screws anchored in very soft, deficient bone have poor purchase and become loose and ineffective very quickly.[24] External fixators are poorly tolerated and are prone to pin-site infections.[23]

However, it is clear from the epidemiological data that LC-1 fractures in the elderly are catastrophically disabling for many patients, who either do not survive or never return to their pre-injury baseline function.[7 8] The surgical approach taken to hip fractures is therefore conceptually appealing, provided an effective technique can be identified to provide pain-relieving stability to the pelvis and allow patients to mobilise rapidly.

The introduction of the INFIX technique in 2010 means there is now a device which has the potential to effectively stabilise LC-1 fractures in older adults. The intervention is already in everyday use in specialist pelvic fracture units for the younger population, meaning that pelvic surgeons have experience of the technique.

There is a potential that the enthusiasm of surgeons using INFIX in the younger population may apply the same principles to the older population (as with hip fractures), so the surgery could potentially become the new ‘standard of care’ for these patients. However, although there are a number of papers reporting on the use of INFIX, we were unable to identify any studies that met our inclusion criteria.[37-40] More robust evidence in the form of high quality RCTs is needed to support surgical intervention and the use of devices such as INFIX in the elderly population with fragility fractures of the pelvis. Although a multi-centre RCT within this patient group would be challenging, it would help avoid a situation where patients either do not receive surgical fixation because of lack of evidence, or where they are exposed to a treatment that might be neither beneficial nor cost effective.

Conclusion

Surgical fixation of LC-1 fragility fractures in the elderly has the potential to reduce pain and promote early mobilisation in a large and rapidly expanding group of patients, thereby

reducing the risk of the problems associated with immobility. However, there is currently insufficient robust evidence to support guidance on the most effective treatment for elderly patients who fail to mobilise after sustaining an LC-1 fragility fracture. Given the growing interest of specialist pelvic surgeons in the use of surgical interventions such as INFIX in this population, there is an urgent need for more robust evidence of effectiveness.

Author contributions:

Alison Booth – protocol development, search strategy, study selection, critical appraisal, analysis, writing, approval of final submission

Helen Ingoe – protocol development, search strategy, study selection, critical appraisal, analysis, writing, critique of drafts, approval of final submission

Matthew Northgraves – protocol development, search strategy, study selection, critical appraisal, analysis, writing, critique of drafts, approval of final submission

Elizabeth Coleman – protocol development, analysis, writing, critique of drafts, approval of final submission

Melissa Harden – search strategy, literature searches, writing search methods for protocol and final report, approval of final submission.

Jamila Kassam – concept for review, protocol development, search strategy, study selection, analysis, writing, critique of drafts, approval of final submission

Iris Kwok – protocol development, search strategy, study selection, writing, critique of drafts, approval of final submission

Catherine Hilton – protocol development, search strategy, study selection, writing, critique of drafts, approval of final submission

Peter Bates – concept for review, protocol development, search strategy, analysis, writing, critique of drafts, approval of final submission

Catriona McDaid – concept for review, protocol development, search strategy, analysis, writing of paper, critique of draft papers, approval of final submission

Competing interests

HI, MN, EC, MH, IK, CH, declare they have no conflicts of interest. Since starting this review, AB, JK, PB and CM have received funding for a trial of surgical fixation compared to non-surgical treatment in a LC1 FFP population.

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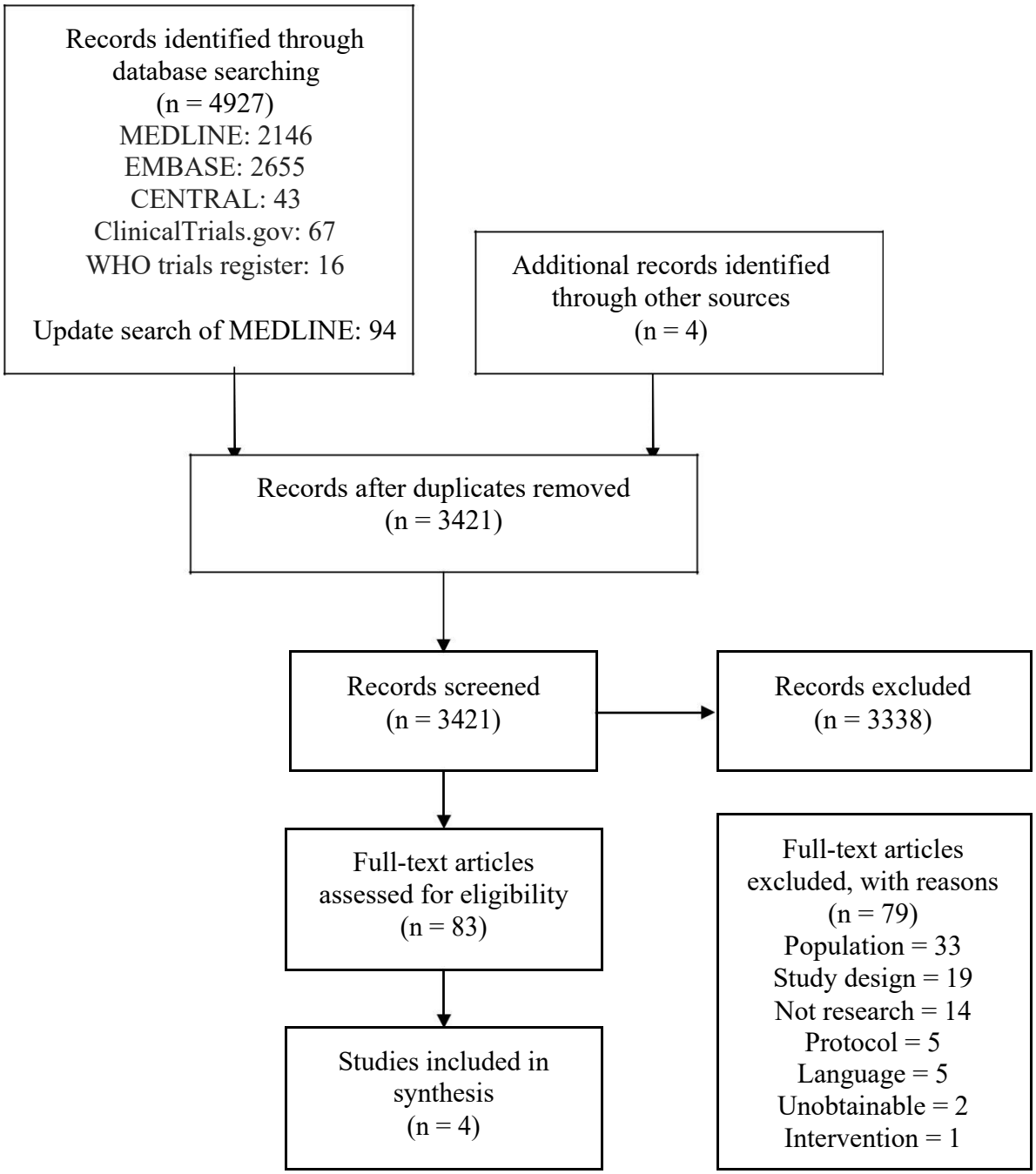
Figure 1 Study Flow Chart



Supplementary file 1: Search Strategy for MEDLINE

Database: Epub Ahead of Print, In-Process & Other Non-Indexed Citations, Ovid MEDLINE(R) Daily and Ovid MEDLINE(R) <1946 to Present>
Search Strategy:
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1 exp Pelvic Bones/ (31120)
2 (pelvis or pelvic).ti,ab. (129440)
3 (ilium$ or ilia or iliac).ti,ab. (39144)
4 (ischium$ or ischial or ischia or ischii).ti,ab. (2353)
5 (pubis or (pubic adj2 (bone$ or ramus or rami))).ti,ab. (3895)
6 1 or 2 or 3 or 4 or 5 (183312)
7 Fractures, Bone/ (69982)
8 Osteoporotic Fractures/ (3912)
9 Fractures, Compression/ (1736)
10 7 or 8 or 9 (75036)
11 6 and 10 (7124)
12 (fractur$ adj3 (pelvis or pelvic)).ti,ab. (4793)
13 (fractur$ adj3 (ilium$ or ilia or iliac)).ti,ab. (280)
14 (fractur$ adj3 (ischium$ or ischial or ischia or ischii)).ti,ab. (87)
15 (fractur$ adj3 pubis).ti,ab. (52)
16 (fractur$ adj3 pubic).ti,ab. (329)
17 (fractur$ adj3 lateral compression).ti,ab. (55)
18 (fractur$ adj3 (LC-1 or LC1)).ti,ab. (6)
19 (fractur$ adj3 sacral insufficiency).ti,ab. (205)
20 or/12-19 (5458)
21 (fractur$ adj3 low-energy).ti,ab. (627)
22 (fractur$ adj3 (fragility or osteoporo$ or osteopeni$ or insufficiency)).ti,ab. (16528)
23 21 or 22 (16963)
24 23 and 6 (845)
25 11 or 20 or 24 (9865)
26 (pelvic adj2 ring adj2 injur$).ti,ab. (446)
27 (pelvic adj2 ring adj2 disrupt$).ti,ab. (192)
28 (lateral compression adj3 injur$).ti,ab. (58)
29 ((LC-1 or LC1) adj3 injur$).ti,ab. (8)
30 or/26-29 (625)
31 25 or 30 (10009)
32 exp Fracture Fixation/ (61190)
33 exp Fracture Fixation, Internal/ (41947)
34 exp Orthopedic Fixation Devices/ (76567)
35 Infix.ti,ab. (23)
36 (fractur$ adj3 (fixation$ or fixator$ or stabilis$ or stabiliz$)).ti,ab. (11748)
37 ((internal or external) adj3 (fixation$ or fixator$ or stabilis$ or stabiliz$)).ti,ab. (25648)
38 ((anterior$ or posterior$) adj3 (fixation$ or fixator$ or stabilis$ or stabiliz$)).ti,ab. (6848)
39 ((surgical or surgery or operati$ or orthop?edic) adj3 (fixation$ or fixator$ or stabilis$ or stabiliz$)).ti,ab. (7737)
40 ((pelvic or pelvis) adj3 (fixation$ or fixator$ or stabilis$ or stabiliz$)).ti,ab. (1210)
41 ((plate$ or plating$ or screw$ or nail$ or pin or pins or rod or rods) adj6 (fixation$ or fixator$ or stabilis$ or stabiliz$)).ti,ab. (25375)
42 (bone$ adj6 (plate$ or plating$ or screw$ or nail$ or pin or pins or rod or rods)).ti,ab. (14857)
43 ((pedicle or pedicular or polyaxial) adj2 screw$).ti,ab. (5448)

44 ((iliosacral or ilio-sacral or sacroiliac or sacro-iliac) adj2 screw$).ti,ab. (422)
45 ((trans-sacral or transsacral) adj2 screw$).ti,ab. (38)
46 pelvic bridg$.ti,ab. (5)
47 ASIF.ti,ab. (675)
48 (posterior adj2 (plate$ or plating)).ti,ab. (551)
49 (anterior adj2 (plate$ or plating)).ti,ab. (1555)
50 (symphyseal adj2 (plate$ or plating)).ti,ab. (40)
51 ((transiliac or trans-iliac or sacral or connect$) adj2 rod$).ti,ab. (431)
52 ((open or closed) adj2 reduction$).ti,ab. (14389)
53 osteosynthesis.ti,ab. (10872)
54 (compression adj2 (plate$ or plating)).ti,ab. (2027)
55 (compression adj2 fixation$).ti,ab. (465)
56 ((fractur$ or orthop?edic) adj2 (immobiliz$ or immobilis$)).ti,ab. (503)
57 or/32-56 (147341)
58 31 and 57 (3165)
59 exp animals/ not humans/ (4856249)
60 58 not 59 (3094)
61 limit 60 to yr="1980 - Current" (2769)
62 limit 61 to english language (2146)

Supplementary file 2: Studies excluded at second screening with reason for exclusion

Reference	Reason for exclusion
[No authors listed]. Managing pelvic fractures. Nursing. 2003;33(12):43.	Not research
[No authors listed]. SESAP critiques / critiques SESAP. Canadian Journal of Surgery. 1997;40(6):420.	Not research
Baird R. Open reduction of pelvic fractures. Western Journal of Medicine. 1991;155(2):171.	Not research
Barei DP, Shafer BL, Beingessner DM, Gardner MJ, Nork SE, Routt ML. The impact of open reduction internal fixation on acute pain management in unstable pelvic ring injuries. Journal of Trauma-Injury Infection & Critical Care. 2010;68(4):949-53.	Population
Bastian JD, Ansorge A, Tomagra S, Benneker LM, Buchler L, Siebenrock KA, et al. Mid-term outcome following fixation of anterior pelvic ring injuries using the modified Stoppa approach. Swiss Medical Weekly. 2013;143:29S.	Population
Bauer J, Holzl A, Verheyden A. The operative treatment of sacral insufficiency fracture with percutaneous iliosacral compression osteosynthesis with a pelvine internal fixator and cannulated iliosacral screws. European Spine Journal. 2013;22:2619.	Not research
Beall DP, Datir A, D'Souza SL, D'Souza LS, Gunda D, Morelli J, et al. Percutaneous treatment of insufficiency fractures : principles, technique and review of literature. Skeletal Radiology. 2010;39(2):117-30.	Study design
Beckmann JT, Presson AP, Curtis SH, Haller JM, Stuart AR, Higgins TF, et al. Operative agreement on lateral compression-1 pelvis fractures. a survey of 111 OTA members. Journal of Orthopaedic Trauma. 2014;28(12):681 -5.	Study design
Blasier DR, McAtee J, White R, Mitchell DT. Disruption of the pelvic ring in pediatric patients. Clinical Orthopaedics and Related Research. 2000;0(376):87-95.	Population
Bohme J, Hoch A, Josten C. Osteoporotic fractures of the pelvis Osteoporotische Frakturen des Beckens. Chirurg. 2012;83(10):875-81.	Language
Boobbyer GN. External fixation with the coat hanger method in treatment of unstable fractures of the pelvis. Injury. 1980;11(3):254-6.	Not research
Browner BD, Cole JD. Initial management of pelvic ring disruptions. Instructional Course Lectures. 1988;37:129-37.	Not research
Caban A. External fixation in the treatment of pelvic fractures. Ortopedia Traumatologia Rehabilitacja. 1999;1(1):49-59.	Language
Chen LH, Shih CH, Hsu WW, Chen WJ, Wu CC, Su JY, et al. Anterior internal fixation of the disrupted sacroiliac joint: A preliminary report. Journal of Surgical Association Republic of China. 1993;26(3):1796-804.	Language
Chen PH, Hsu WH, Li YY, Huang TW, Huang TJ, Peng KT. Outcome analysis of unstable posterior ring injury of the pelvis: comparison between percutaneous iliosacral screw fixation and conservative treatment. Biomedical Journal. 2013;36(6):289-94.	Population
Clamp JA, King RJ, O'Hara JT, Hahn DM. Osteoporotic pelvic insufficiency fracture with gross instability. Journal of Trauma-Injury Infection & Critical Care. 2008;64(5):1380-2.	Study design
Dahners LE, Jacobs RR, Jayaraman G, Mathys Jr R. An external skeletal fixation system for unstable pelvic fractures. Surgical Forum. 1983;0:554-6.	Unobtainable
De Bastiani G, Aldegheri R, Renzi Brivio L. Dynamic axial fixation. A rational alternative for the external fixation of fractures. International Orthopaedics. 1986;10(2):95-9.	Study design
Dechert TA, Duane TM, Frykberg BP, Aboutanos MB, Malhotra AK, Ivatury RR. Elderly patients with pelvic fracture: interventions and outcomes. American Surgeon. 2009;75(4):291-5.	Study design
Dienstknecht T, Berner A, Lenich A, Nerlich M, Fuechtmeier B. A minimally invasive	Population

stabilizing system for dorsal pelvic ring injuries. Clinical Orthopaedics & Related Research. 2011;469(11):3209-17.	
Dolati B, Spiss R, Ennemoser O, Colleselli K. The fixation of pelvic ring fractures. World Journal of Urology. 1990;7(4):192-6.	Population
Dong J, Hao W, Wang B, Wang L, Li L, Mu W, et al. Management and outcome of pelvic fractures in elderly patients: a retrospective study of 40 cases. Chinese Medical Journal. 2014;127(15):2802-7.	Population
Draijer F, Egbers HJ, Havemann D. Quality of life after pelvic ring injuries: follow-up results of a prospective study. Archives of Orthopaedic & Trauma Surgery. 1997;116(1):22-6.	Study design
Fang C, Alabdulrahman H and Pape HC. Complications after percutaneous internal fixator for anterior pelvic ring injuries. Int Orthop 2017; 24:24. DOI:10.1007/s00264-017-3415-4.	Population
Firoozabadi R, Oldenburg FP, Krieg JC, Routt MLC. Prevention of iliosacral screw intrusion through the lateral iliac cortex. Techniques in Orthopaedics. 2015;30(1):57-60.	Study design
Gansslen A, Lindahl J. Evaluation tools and outcomes after osteosynthesis of unstable type B and C pelvic ring injuries. Acta Chirurgiae Orthopaedicae et Traumatologiae Cechoslovaca. 2013;80(5):305 -20.	Study design
Gerbershagen HJ, Dagtekin O, Mertens N, Isenberg J, Sabatowski R, Petzke F. Prevalence and severity of chronic pain after pelvic ring fracture. European Journal of Pain. 2009;13:S157.	Study design
Gvozdenovic R, Dahl B, Gehrchen M, Blyme P, Kioer T, Tondevold E. Fixation of unstable posterior pelvic ring fractures - a comparative study [Abstract]. Acta orthopaedica Scandinavica. 1998;69:17.	Population
Hagen J, Castillo R, Dubina A, Gaski G, Manson TT, O'Toole RV. Does Surgical Stabilization of Lateral Compression-type Pelvic Ring Fractures Decrease Patients' Pain, Reduce Narcotic Use, and Improve Mobilization? Clinical Orthopaedics & Related Research. 2016;474(6):1422-9.	Population
Hasler R. Surgical Treatment of Low Energy Pelvic Fractures in the Elderly. ClinicalTrials.Gov	Protocol
Hausler SM, Strobl FF, Paprottka P, Pieske O, Rubenbauer B, Jakobs TF, et al. Technical outcome, complications and effective patient dose of percutaneous CT- fluoroscopy guided screw placement for the fixation of unstable pelvic fractures. CardioVascular and Interventional Radiology. 2013;36:S391.	Study design
Hoch A, Schneider I, Todd J, Josten C, Bohme J. Lateral compression type B 2-1 pelvic ring fractures in young patients do not require surgery. European Journal of Trauma & Emergency Surgery. 2016;2:2.	Population
Hong HX, Hong ZH, Chen HX, Lin L, Zhu Z. Iliosacral screw fixation of transforaminal sacral fractures using local anesthesia and CT. Journal of the American College of Surgeons. 2010;211(2):e7-12.	Population
Jakob M. Treatment of Pelvic Ring Fractures in the Elderly. ClinicalTrials.Gov	Protocol
Lansinger O, Karlsson J, Berg U, Mare K. Unstable fractures of the pelvis treated with a trapezoid compression frame. Acta Orthopaedica Scandinavica. 1984;55(3):325-9.	Population
Latenser BA, Gentilello LM, Tarver AA, Thalgott JS, Batdorf JW. Improved outcome with early fixation of skeletally unstable pelvic fractures. Journal of Trauma-Injury Infection & Critical Care. 1991;31(1):28-31.	Population
Lau TW, Leung F. Occult posterior pelvic ring fractures in elderly patients with osteoporotic pubic rami fractures. Journal of Orthopaedic Surgery. 2010;18(2):153-7.	Intervention (no LC1's had fixation)
Leberte M, Dabezies E. Pelvic fractures. Orthopedics. 1985;8(1):120-3.	Study design
Leslie MP, Baumgaertner MR. Osteoporotic pelvic ring injuries. Orthopedic Clinics of North America. 2013;44(2):217-24.	Not research

Lindahl J, Hirvensalo E, Bostman O, Santavirta S. Failure of reduction with an external fixator in the management of injuries of the pelvic ring. Long-term evaluation of 110 patients. Journal of Bone & Joint Surgery - British Volume. 1999;81(6):955-62.	Population
Matta JM, Saucedo T. Internal fixation of pelvic ring fractures. Clinical Orthopaedics & Related Research. 1989;0(242):83-97.	Population
Minarro JC, Quevedo-Reinoso R, Lopez-Pulido MJ, Gonzalez-Fernandez A. Osteoporotic fractures of the pelvis. Osteoporosis International. 2016;1:S139.	Study design
Moed BR, Whiting DR. Locked transsacral screw fixation of bilateral injuries of the posterior pelvic ring: initial clinical series. Journal of Orthopaedic Trauma. 2010;24(10):616-21.	Population
Nieves JW. PTH (1-34) and Pelvic Fracture Healing - a Randomized Controlled Trial. ClinicalTrials.Gov	Protocol
O'Toole R. Pelvis RCT: Impact of Surgery on Pain in Lateral Compression Type Pelvic Fractures. ClinicalTrials.Gov	Protocol
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Youngman JR, Day AC. Pelvic fractures. Hospital Medicine (London). 2002;63(12):750-2.	Not research
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Zlowodzki M. Comparison of Subcutaneous INFIX and EXFIX for Anterior Pelvic Ring Fractures Requiring Stabilization. ClinicalTrials.Gov	Protocol

PRISMA 2009 Checklist

Section/Topic	#	Checklist Item	Reported on Page #
TITLE			
Title	1	Identify the report as a systematic review, meta-analysis, or both.	1
ABSTRACT			
Structured summary	2	Provide a structured summary including, as applicable: background; objectives; data sources; study eligibility criteria, participants, and interventions; study appraisal and synthesis methods; results; limitations; conclusions and implications of key findings; systematic review registration number.	2
INTRODUCTION			
Rationale	3	Describe the rationale for the review in the context of what is already known.	4-5
Objectives	4	Provide an explicit statement of questions being addressed with reference to participants, interventions, comparisons, outcomes, and study design (PICOS).	5
METHODS			
Protocol and registration	5	Indicate if a review protocol exists, if and where it can be accessed (e.g., Web address), and, if available, provide registration information including registration number.	6
Eligibility criteria	6	Specify study characteristics (e.g., PICOS, length of follow-up) and report characteristics (e.g., years considered, language, publication status) used as criteria for eligibility, giving rationale.	6
Information sources	7	Describe all information sources (e.g., databases with dates of coverage, contact with study authors to identify additional studies) in the search and date last searched.	6
Search	8	Present full electronic search strategy for at least one database, including any limits used, such that it could be repeated.	Sup 1
Study selection	9	State the process for selecting studies (i.e., screening, eligibility, included in systematic review, and, if applicable, included in the meta-analysis).	6
Data collection process	10	Describe method of data extraction from reports (e.g., piloted forms, independently, in duplicate) and any processes for obtaining and confirming data from investigators.	7
Data items	11	List and define all variables for which data were sought (e.g., PICOS, funding sources) and any assumptions and simplifications made.	7
Risk of bias in individual studies	12	Describe methods used for assessing risk of bias of individual studies (including specification of whether this was done at the study or outcome level), and how this information is to be used in any data synthesis.	7
Summary measures	13	State the principal summary measures (e.g., risk ratio, difference in means).	N/A
Synthesis of results	14	Describe the methods of handling data and combining results of studies, if done, including measures of consistency (e.g., I^2) for each meta-analysis.	7

PRISMA 2009 CHECKLIST

Section/Topic	#	Checklist Item	Reported on Page #
Risk of bias across studies	15	Specify any assessment of risk of bias that may affect the cumulative evidence (e.g., publication bias, selective reporting within studies).	N/A
Additional analyses	16	Describe methods of additional analyses (e.g., sensitivity or subgroup analyses, meta-regression), if done, indicating which were pre-specified.	N/A
RESULTS			
Study selection	17	Give numbers of studies screened, assessed for eligibility, and included in the review, with reasons for exclusions at each stage, ideally with a flow diagram.	7
Study characteristics	18	For each study, present characteristics for which data were extracted (e.g., study size, PICOS, follow-up period) and provide the citations.	8
Risk of bias within studies	19	Present data on risk of bias of each study and, if available, any outcome level assessment (see item 12).	11
Results of individual studies	20	For all outcomes considered (benefits or harms), present, for each study: (a) simple summary data for each intervention group (b) effect estimates and confidence intervals, ideally with a forest plot.	12-16
Synthesis of results	21	Present the main results of the review. If meta-analyses done, include for each, confidence intervals and measures of consistency.	16
Risk of bias across studies	22	Present results of any assessment of risk of bias across studies (see Item 15).	N/A
Additional analysis	23	Give results of additional analyses, if done (e.g., sensitivity or subgroup analyses, meta-regression [see Item 16]).	N/A
DISCUSSION			
Summary of evidence	24	Summarize the main findings including the strength of evidence for each main outcome; consider their relevance to key groups (e.g., healthcare providers, users, and policy makers).	16-17
Limitations	25	Discuss limitations at study and outcome level (e.g., risk of bias), and at review-level (e.g., incomplete retrieval of identified research, reporting bias).	18
Conclusions	26	Provide a general interpretation of the results in the context of other evidence, and implications for future research.	19
FUNDING			
Funding	27	Describe sources of funding for the systematic review and other support (e.g., supply of data); role of funders for the systematic review.	20

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PRISMA 2009 CHECKLIST

BMJ Open

Effectiveness of surgical fixation for lateral compression type one (LC-1) fragility fractures of the pelvis: a systematic review

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Effectiveness of surgical fixation for lateral compression type one (LC-1) fragility fractures of the pelvis: a systematic review

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Word count: 4304

Abstract *(286 words)*

Objectives: To undertake a systematic review of the evidence base for the effectiveness of surgical fixation of lateral compression (LC-1) fragility fractures of the pelvis compared to non-surgical approaches.

Searches: MEDLINE, EMBASE, the Cochrane Central Register of Controlled Trials (CENTRAL), and two international trials registers were searched up to January 2017 (Medline to February 2019) for studies of internal or external fixation of fragility fractures of the pelvis.

Participants: Patients with lateral compression pelvic fractures (LC-1 fractures), sustained as the result of a low energy mechanism, defined as a fall from standing height or less.

Interventions: Surgery using either external or internal fixation devices. Conservative non-surgical treatment was the defined comparator.

Outcome measures: Outcomes of interest were patient mobility and function, pain, quality of life, fracture union, mortality, hospital length of stay and complications (additional operative procedures, number and type of adverse events and serious adverse events).

Quality assessment and synthesis: The Joanna Briggs Institute Checklist for Case Series was used to assess the included studies. Results were presented in a narrative synthesis.

Results: Of 3421 records identified, four retrospective case series met the inclusion criteria. Fixation types were not consistent between studies or within studies and most patients had more than one type of pelvic fixation. Where reported, mobility and function improved post-surgery, and a reduction in pain was recorded. Length of hospital stay ranged from four days to 54 days for surgical fixation of any type. Reported complications and adverse outcomes included: infections, implant loosening, pneumonia and thrombosis. Use of analgesia was not reported,

Conclusions: There is insufficient evidence to support guidance on the most effective treatment for patients who fail to mobilise after sustaining an LC-1 fragility fracture.

Registration: PROSPERO registration number: CRD42017055872

Strengths and limitations of this study

- This review systematically examines the available evidence, searching multiple databases, assessing the risk of bias in included studies and using methods to reduce error and bias in study selection, data extraction and assessment of risk of bias.
- This is a rapidly evolving area for surgery, with ever increasing incidence, so the searches of electronic databases were supplemented by searches for on-going trials.
- Key health databases were searched and efforts were made to find unpublished studies via trial registers, however we did not have the resources to search more widely and retrieval was restricted to studies published in English.
- The review found many narratives on surgery for fragility fractures of the pelvis, but no randomised controlled trials, and only four retrospective case series that met all the inclusion criteria.

Key words: surgery; internal fixation; external fixation; fragility fracture; pelvis; systematic review

Effectiveness of surgical fixation for lateral compression type one (LC-1) fragility fractures of the pelvis: a systematic review

Introduction

Fragility fractures of the pelvis (FFP) can result in significant long term disability,[1] have a significant impact on patients and put a strain on health care provision. A common fragility fracture pattern in older adults is the lateral compression type-1 (LC-1) pelvic fracture. This typically results from a low-energy fall from standing height, and increases in likelihood with age.[2-4] LC-1 fractures are projected to have the largest incidence increase (by 56% over 20 years) of all osteoporotic fractures and the associated treatment costs are predicted to rise by 60% between 2005 and 2025. [5 6]

The effects of LC-1 fractures can be devastating for patients. The pain and associated immobility leads to secondary complications, including respiratory and urinary tract infections, pressure sores and venous thromboembolic events.[7 8]

Many patients with LC-1 fractures report that they do not return to their pre-injury function and they have reduced independence with activities of daily living.[2 4] This can result in the need for intermediate care or residential facilities in addition to anxiety, emotional stress and reduced confidence. [9 10] Mortality for FFP at one year is 27%, [11] which is comparable to hip fractures at 33%. [12] Furthermore, hospital stay for FFP has been shown to be similar to hip fractures in the elderly.[9 13] The standard treatment for hip fractures (so-called fractured neck of femur) is rapid surgical fixation or joint replacement, within 36-hours of injury, aimed at early weight-bearing and minimising immobility-related complications.[14] Paradoxically, despite the similarities in patient cohorts and their vulnerability to pain-induced immobility, the standard of care for elderly LC-1 fragility fractures of the pelvis (LC-1 FFP) is non-operative treatment and to 'mobilise as pain allows'.[15-17] Many patients with stable fractures are able to mobilise within a few days of injury, typically with a walking aid. However, patients with unstable fractures (those that are unable to withstand physiologic loads without displacement [18]) typically have disabling pain with almost all movements, even moving around the bed. This unstable group are at greater risk of the immobility-related complications discussed above.[9 11-13 15]

There are various classifications of pelvic ring fractures based on the mechanism of injury, ligamentous involvement, and anatomical location. For the purpose of this review, LC-1 FFPs were defined by respective anatomical classifications in patients with a low energy mechanism.

1. Young and Burgess: an oblique or transverse ramus fracture with or without ipsilateral anterior sacral alar compression fracture (LC-1).[19 20]
2. Tile classification: rotationally unstable, vertically stable. Ipsilateral, the rami commonly fractured anteriorly and the posterior complex is crushed (Tile B2).[21]

3. AO classification: unilateral, partial disruption of posterior arch, internal rotation (AO 61 - B2.1).[22]
4. The Rommens classification is designed specifically to encompass the different fracture patterns seen in fragility fractures of the pelvis. The LC-1 FFP injury corresponds with Rommens type II b and II c injuries allowing further stratification of the severity of this injury. This describes an ipsilateral anterior disruption with either a sacral crush fracture (type IIb) or undisplaced sacral ala fracture (type IIc).[18]

Until recently, surgical fixation options for these fractures were limited. External fixators, a combination of pins, bars and clamps outside of the skin, are cumbersome, poorly tolerated and carry a high risk of pin-site infections and pressure sores.[23 24] An alternate surgical option is fixation of the back of the pelvis with sacroiliac screws, a well-established technique in younger patients.[4] Augmented screws, transiliac-transsacral screws, and sacral bars are additional methods used to stabilise pelvic fractures. However, these procedures require significant technical expertise to implant and, crucially, the screws carry very poor 'purchase' in osteoporotic bone,[8] leading to ineffective fracture stabilisation.

What works in younger patients with good bone quality is less effective in older patients.[25] In 2010 a new technique of anterior subcutaneous internal fixation (INFIX) was developed, combining the principles of internal and external fixation. It involves placing screws in the supra-acetabular corridors and developing a subcutaneous tunnel in which a rod is connected to the screws to stabilise the pelvis.

The use of the INFIX device has been described across younger age groups and pelvic fracture types; alone or in combination with external surgical fixation techniques.[26-29] However, the use of INFIX for the management of the FFP population who sustain an LC-1 fracture remains unclear as there has been no systematic review of the evidence.

Given the uncertainty around the management of LC-1 fractures in the elderly and the potential of INFIX to change the management of these injuries, we sought to identify and synthesise the evidence on the effectiveness of surgical fixation in fragility fractures of the pelvis. We included both internal and external surgical fixation, in order to provide a broad overview of the evidence on surgical fixation.

Objective

To undertake a systematic review of the evidence base for the effectiveness of surgical fixation of LC-1 fragility fractures when compared to non-surgical approaches.

Materials and Methods

The protocol was prospectively registered in PROSPERO: CRD42017055872. The Centre for Reviews and Dissemination (CRD) guidance for undertaking reviews in healthcare was followed and reporting is in line with PRISMA guidelines.[30 31]

Patient and public involvement

There was no patient involvement in this systematic review of existing literature.

Data sources

An experienced information specialist undertook searches of MEDLINE (including Epub Ahead of Print, In-Process & Other Non-Indexed Citations, Ovid MEDLINE Daily and Ovid MEDLINE), EMBASE and the Cochrane Central Register of Controlled Trials (CENTRAL). ClinicalTrials.gov and the WHO International Clinical Trials Registry Portal were also searched for any information on studies that were in progress. Examples of the search terms included: ('Ilium' or 'Ischium' or 'Pubis' or 'Pelvic Bones' or 'Pelvis') AND ('Bone Fractures' or 'Osteoporotic Fractures' or 'Compression Fractures' or 'Fragility Fractures') AND ('Fracture fixation' or 'Fracture fixation, Internal' or 'External fixators' or 'Splints' or 'Orthopedic fixation devices' or 'Bone plates' or 'Bone screws' or 'Bone wires' or 'Internal fixators'). The full search strategy developed in Ovid MEDLINE is provided in Supplementary file 1. This was adapted for use in the other databases searched. The searches were limited to studies published in the English language from 1980 to date. All searches were initially run on 19 January 2017. As this is an area of rapid development, the search in MEDLINE was updated on 06 July 2017 and again 19 February 2019.

Study Selection

Studies of patients with LC-1 FFP (defined above) undergoing surgery using either external or internal fixation devices were eligible for inclusion. Conservative non-surgical treatment was the defined comparator. If studies included other types of pelvic fractures, the study was included if the data on LC-1 FFP patients were reported separately and/or if 80% or more of participants had a LC-1 fragility fracture. Studies were excluded if LC-1 fractures were the result of a high-energy mechanism, defined as a fall from greater than standing height or if fractures arose secondary to pathology other than reduced bone density. Randomised controlled trials (RCTs), non-randomised trials and other comparative designs, observational studies (e.g. cohort), and case series of 10 or more cases were included. Study designs other than RCTs are at high risk of bias when assessing treatment effectiveness; however, as the review was potentially to inform a future RCT, an inclusive approach was taken. Biomechanical and cadaver studies were excluded.

Titles and abstracts were independently reviewed by two reviewers for potentially relevant studies. Full text articles of potentially relevant studies were obtained and also reviewed independently by two reviewers (AB, HI) against the inclusion criteria, with discrepancies resolved by a third reviewer (MN).

Data Extraction and Quality Assessment

Data were extracted by one researcher using a piloted form and checked by a second reviewer with discrepancies resolved by discussion (HI, AB). Data extracted were: publication year, study design, number of cases, total sample size, population type, mean age, percentage of male/female patients, fracture details, follow-up period, outcome measures and outcome data, details of the interventions and comparators, and complications. Defined outcomes of interest were: patient mobility and function (using standardised outcome measures), pain (Visual Analogue Scale (VAS) scores, analgesic or opiate requirements), quality of life (using standardised patient reported outcome measures (PROMS)), fracture union rate, mortality, hospital length of stay, complications (additional operative procedures, number and type of adverse events and serious adverse events) and radiographic alignment.

Quality assessment using the Joanna Briggs Institute Checklist for Case Series was undertaken by one researcher and checked by a second; disagreements were adjudicated by a third. [32]

Data Synthesis

The aim of the synthesis was to identify gaps in the evidence and identify implications for future research. A narrative and tabular summary of the key study characteristics, study risk of bias and clinical outcomes was undertaken. Where possible, data were reported separately for internal and external fixation. The planned quantitative synthesis as outlined in the protocol was not possible due to the lack of randomised controlled trials.

Results

Study selection

The electronic searches identified 3845 records after deduplication and four records were found through other sources. Following screening of titles and abstracts, 98 full papers were assessed for eligibility, 94 were excluded (supplementary file 2) and four studies met the inclusion criteria (Figure 1).[33-36]

We identified two relevant, on-going trials that are likely to include some patients with LC-1 fractures, though they are not specifically the target population in either trial. One is comparing surgeon choice of surgical technique with non-operative care [37] and the other an experimental surgical intervention with conservative care.[38] Final data collection for these trials will take place in December 2018; [37] and October 2019.[38]

[Figure 1. Study flow chart to be inserted

here] ***Characteristics of included studies***

No RCTs comparing the effectiveness of external or internal fixation to non-operative management were identified. All the included studies were case series: three retrospective

[34-36] and in the fourth, patients were identified post operatively with data collected prospectively.[33] Sample sizes ranged from 14 to 127 and the total duration of follow up ranged from the day of removal of external fixator to 31 months. The procedures were undertaken from 2004 onwards to 2014 in Germany (n=3) and Italy (n=1). One study did not report when the procedures were undertaken[33] and another reported seven years after the last patient was included.[36] Study characteristics are given in Table 1.

Fixation types were not consistent between studies or within studies and most patients had more than one type of pelvic fixation. All internal fixations were posterior or a combination of anterior and posterior. Three studies reported effectiveness data on sacroiliac screws,[34-36] and one on supra-acetabular external fixation,[33] or a combination of these fixations. Höch et al also included patients who had additional sacroplasty (n=13) in combination with the internal fixation techniques.[36]

The average age of participants across the studies ranged from 69.6 to 81 years old and the percentage of female participants ranging from 64% to 92%. Comorbidities were reported within all the studies and included osteoporosis, hypertension, chronic heart disease and physical status. Where reported, between 20% and 57% of participants had osteoporosis.[33-35] Two studies included a few patients with high-energy injuries; however, the majority of patients sustained their injuries following low energy falls.[33 36]

The fracture classifications used were AO/Tile and Rommens, along with a narrative description of the injury.

Mean time from injury to surgery ranged from 3.6 days [33] to 6 months.[34] The duration of surgery was reported in two studies: the duration for internal fixation ranged between 70 and 220 minutes [34] and for external fixation was between 9 minutes and 35 minutes.[33]

All four studies allowed most patients to fully or partially weight bear following surgery. Arduini et al (2015) dictated 4-6 weeks strict bedrest followed by partial weight bearing for a further 6-8 weeks.[34] The patients in this study differ from the other case series in that participants had chronic lower limb or back pain after six months of non-operative treatment. These patients were operated on at 6 months for chronic rather than acute pain, making it inappropriate to compare the outcomes and post-operative regime for acute fractures between this and the other studies.

Table 1. Study characteristics

Retrospective case series	surgery include: chronic lower limb pain or lower back pain with no other diagnosis following FANS treatment **Exclusion** Not reported	**Mean Age (SD)** 69.6 **Gender** 9F:5M **Comorbidities** Osteoporosis = 5 taking bis-phosphonates	ring pelvic fracture in the previous 2 years =4 Other pelvic ring fracture =2			Trans sacral bridge plate and SI Screws =3 Lumbar-pelvic fixation and symphysis plate =3	**Post op Regime** Bed rest for 4-6 weeks and partially weight bearing for a further 6-8 weeks	
Gänsslen et al (2013) Germany Case series: data collected prospectively patients identified from database post operatively	Patients ≥ 65 years with type B injuries stabilized by a supra-acetabular external fixator in a standardized technique were selected from the hospital pelvic database of all patients with pelvic ring and acetabular injuries. **Exclusion** Not reported	**Screened** Not reported **Sample Size** 25 **Mean Age (SD)** 79.3 (9.9) (range 66-99) **Gender** F23:M2 **Comorbidities** At least one significant co-morbidity =19 (76%), most had two including hypertension, chronic heart disease or osteoporosis	**Concurrent** isolated pelvic trauma = 21 distal radius fracture and/or minor head injury =4 **Previous** None reported	**AO** B 2.1 =24 B 3.3 =1 A 3.3 =1	**Low energy** =22 **High energy** =3	Supra-acetabular external fixation	**Time to surgery** Mean(SD) 3.6 (3.3) (range 0–13) **Operation time** Mean(SD) = 19 (7.4) (range 9–35) **Post op Regime** Fully weight bearing =14 Partial weight bearing on the affected sacral side =4 Partial weight bearing =7	**Primary:** Post-operative discharge **Secondary:** Removal of external fixator
Höch et al (2017)	Over 65 years, with a lateral compression	**Screened** Not reported	**Concurrent** **Overall**	**AO** B2.1 =115 (90%)	**Overall** Low energy =103 High energy =13	Unilateral iliosacral screw fixation = 28	**Time to surgery** Mean(SD) 6.4 (4.1)	**Primary:** Two Years

Author (Year) Study Site	Inclusion /Exclusion criteria	Patient Descriptors	Injuries documented and accounted for	Fracture classification	Cause of fracture and frequencies (e.g. fall)	Fixation type	Time to surgery (days) Operation time (minutes) Post op Regime	Follow up Time points
Arduini et al (2015) Italy	Surgery for fragility fracture of the pelvis. Indications for	**Screened** Not reported **Sample Size** 14	**Concurrent** None reported **Previous** Undisplaced anterior	**Rommens** Type II = 3, Type III = 9, Type IV =2	**Low Energy** =6 **Spontaneous pain** =8	SI Screws and symphysis plate or pubic rami screw =8	**Time to surgery** 6 Months **Operation time** Range 70 – 220 mins	Primary 6 months Secondary 1 and 3 months

Germany Retrospective case series	fracture of the pelvis **Exclusion** Not reported	**Sample Size** 128 **Mean Age (SD)** Overall 81 (8.3) Non-Operative 82.7 (7.9) Operative 78.3 (7.6) Died before treatment 92 P<0.002 **Gender** Overall F109:M19 Non-operative F66:M11 Operative F42:M8 Died before treatment F1:M0 **Comorbidities** Overall ASA 2.7 (SD 0.5) Non-operative ASA 2.8 (SD 0.6) Operative ASA 2.6 (SD 0.5)	ISS 10.1 (SD4.6), isolated 89, Additional injury ISS <16 = 31, ISS>16 = 8 **Non-Operative** ISS 10.0 (SD3.9), isolated 56, Additional injury ISS <16 = 15, ISS>16 = 6 **Operative** ISS 9.4 (SD2.1), isolated 33, Additional injury ISS <16 = 16, ISS>16 = 1 **Died before treatment** ISS 48, ISS>16 = 1 **Previous** Not reported	B3.3 =13 (10%) Unilateral pubic rami =117 (91%) Bilateral =11 (9%) Complex pelvic fractures =2	Unknown =12 **Non-Op** Low energy =63 High energy =7 Unknown =7 **Operative** Low energy =40 High energy =5 Unknown =5 **Died before treatment** High energy =1	S1 Screws x2 = 4 S1 + S2 screw = 2 Bilateral iliosacral screws = 14. Additional percutaneously sacroplasty = 13 Triangular fixation =2 Additional anterior fixation plate =3 Navigation=7	**Operation time** Not reported **Post op Regime** Full weight bearing Plus 3 weeks community physio	**Secondary:** 6 weeks 3, 6, and 12 months included a clinical examination + radiographs
Hopf et al (2015) Germany Retrospective case series	Posterior pelvic ring fractures. Over 55 years, low energy trauma. Persistent lower back pain or unacceptable mobility **Exclusion** Patients under 55 years with a high energy trauma. If pain improved within 6 days and mobility was acceptable:	**Screened** "In the 'recruitment period' 87 patients with posterior ring fractures of the pelvis could be treated without surgery" **Sample Size** 30 **Mean Age (SD)** Mean 78.4, Range 56-96 **Gender** 27F:3M **Comorbidities** Osteoporosis =17	**Concurrent** Not reported **Previous** Not reported	Anterior + Posterior = 18 Bilateral Posterior = 11 Unilateral Posterior =1	**Low energy** = 30	illiosacral screws per side 1 screw unilateral = 6 2 screws unilateral = 18 3 screws unilateral =2 Bilateral 1 screw = 2 patients. 2 screws one side, 1 screw on other side = 2	**Time to surgery** Mean 9.2 (range 1-24) **Operation time** Not reported **Post op Regime** Mobilised day 1 post op	Primary: Mean 31 months Secondary: None

ASA = American Society of Anesthesiologists physical status classification; SD = standard deviation; SI = Sacroiliac

Quality assessment

Höch et al (2017) was the only study to include a non-operative group for comparison and a third group of those who died before treatment.[36] This was the highest quality study included and had the largest sample size of 128 patients (50 operative patients, 77 non-operative and 1 died before treatment and as such was excluded from investigation within the paper), however, the patients were recruited retrospectively (method not defined) and approached at two years following injury.[36] Patients in this study were selected for surgery if they were not able to mobilise three days after injury, after appropriate physical therapy and pain relief. The inclusion criteria or methods for selecting patients for inclusion were not clear in two studies [33 34] and it is uncertain in three studies whether there was complete and/or consecutive inclusion of eligible patients in the case series (Table 2).[33-35]

Table 2. Quality Assessment

Question	Arduini et al (2015)	Gänsslen et al (2013)	Höch et al (2017)	Hopf et al (2015)
1. Were there clear criteria for inclusion in the case series?	Unclear	Unclear	Yes	Yes
2. Was the condition measured in a standard, reliable way for all participants included in the case series?	Yes	Yes	Yes	Yes
3. Were valid methods used for identification of the condition for all participants included in the case series?	Unclear	Yes	Unclear	Unclear
4. Did the case series have consecutive inclusion of participants?	Unclear	Yes	Yes	Unclear
5. Did the case series have complete inclusion of participants?	Unclear	Unclear	Yes	Unclear
6. Was there clear reporting of the demographics of the participants in the study?	Yes	Yes	Yes	Yes
7. Was there clear reporting of clinical information of the participants?	Yes	Yes	Yes	Yes
8. Were the outcomes or follow up results of cases clearly reported?	Yes	Yes	Yes	Yes
9. Was there clear reporting of the presenting site(s)/clinic(s) demographic information?	Yes	Yes	Yes	Yes
10. Was statistical analysis appropriate?	Yes	Unclear	Yes	Yes

The inclusion criteria varied across the studies; three had age-related criteria; over 65 [33 36] and over 55 years;[35] and one had criteria relating to type of fixation.[33] The injuries were identified in a standard way using radiographs and computerised tomography in all four studies.

Exclusion criteria and details of the number and characteristics of patients screened to identify eligible participants were poorly reported or not reported at all.

Clinical outcomes

The outcomes reported across the studies were mobility and function, pain, fracture union, hospital length of stay, quality of life, additional procedures and complications (Table 3).

Quality of life

Only one study used PROMs, the EQ-5D and SF-12, to assess quality of life.[36] Höch et al [36] (n=127), the only study with a non-operative arm for comparison, reported no statistically significant difference in quality of life, as measured via the EQ-5D, between the surgical fixation (mean 74.6, standard deviation (SD) 15.5), surgical fixation after failed non-operative management (mean 76.3, SD 14.4), and non-operative management (mean 75.1, SD 13.4) groups ($p>0.3$) . The analysis of the SF-12 questionnaire for physical and mental scores also showed no statistically significant difference between groups ($p>0.2$), but summary scores for the groups are not presented.

Mobility and function

Post-operative mobility was reported in two case series. This was assessed by the ability to stand and walk without crutches at 6 month follow up;[34] and proportion mobilised with or without aids, and under full or partial weight bearing at the time of external fixation removal, which was on average 4 weeks post operation.[33] The reporting of mobilisation is not standardised between the two studies, making comparisons difficult. In Arduini et al, at 6-month follow-up, 11 (78%) patients were asymptomatic with restored ability to stand and walk without crutches; and two patients were able to walk with one crutch. A patient with a history of previous acetabular fracture walked with two crutches and was still waiting for a total hip arthroplasty.[34] In the Gänsslen et al, at the time of discharge, 14 patients (56%) were mobilised under full weight bearing. Four patients (16%) were mobilised with crutches with partial weight bearing on the affected sacral injury side.[33] The remaining patients were mobilised partial weight bearing (n = 7). At the time of external fixation removal, 88% of patients had the same mobility as before the accident. Only three were still mobilised partial weight bearing.

Post-operatively, 88% of those who received external fixation [33] returned to their premorbid function.

Pain

Two studies reported a pain outcome. In one pain, measured by a 11 point VAS), significantly reduced following posterior internal fixation (mean pain score: on admission 6.8 and day two post-operative 3.6; $P<0.001$)[35] and supra-acetabular external fixation (mean score (SD): pre-operative 7.7 (1.4) and post-operative 2.3 (1.7); $P<0.0001$). [33]

Following removal of the external fixator, 84% of patients were pain free, 12% had mild residual pain and 4% had worse pain. [33] In a second study there was no statistically significant difference in pain two years after discharge between the non-operative (mean 3.1, SD 2.3), failed non-operative (mean 2.3, SD 2.8) and operative (mean 2.6, SD 2.8) groups ($p>0.5$) based on an 11 point VAS.[36]

Length of hospital stay

All four studies reported length of hospital stay: ranging from four days [33] to 54 days [35] for surgical fixation of any type. Gänsslen et al reported that seven (28%) patients were discharged to a geriatric rehabilitation centre and one (4%) transferred to a different hospital. The mean length of hospital stay in Höch et al was statistically significantly ($p<0.001$) longer in the surgical fixation group (mean 18.1 days, SD 10.0) than in the non-operative group (mean 9.2 days, SD 6.2).[36] Indications for surgery were not fully reported, making it difficult to distinguish why one patient had a primary surgical intervention and another did not. Over all the studies, of the 119 patients who received surgery, 14 patients had already undergone a period of conservative treatment before delayed surgery (6 months post injury), which may partly account for the increased length of stay for operative patients.

al (2017)		Non-operative: 3.1 (SD 2.3) Failed non-operative: 2.3 (SD 2.8) Operative: 2.6 SD (2.8) P > 0.5	measured	Operative 9.2 (SD 6.2) days Operative group 18.1 (SD 10.0 days) (P < .001)	screw with neurological complaints: 3 (6%) Wound infection with salvaging of the osteosynthesis: 1 (2%)	Severe complications: 2 Pneumonia: 2 Thrombosis: 2 Mesenteric infarction: 1 ARDS: 1 **Surgery 9 (18%)** Severe complications: 1

Table 3. Outcomes: measures used and main findings

Study ID	Patient mobility and function	Pain	Fracture union	Hospital length of stay	Additional operative procedures (for complication or as part of routine treatment) received: number of patients	Complications: AE and SAE Details of event: number of patients (Overall/per group)
Arduini et al (2015)	Mobility description Independent = 11 1 crutch =2 2 crutches =1	Not measured	% healed at 6 months 100%	Mean 5.8 days	One intra-pelvic iliac screw removed but no vascular, neurological or internal organ lesion was seen: 1	No neurological palsy or vascular lesions were observed and no patients needed ICU. No major complications
Gänssle n et al (2013)	Not stated but degree of weight bearing reported Pre-op: FWB =24 Frame =1 At discharge: FWB =14 (56%) Crutches with PWB on affected side = 4 PWB = 7 At ExFix removal: Return to pre-injury mobility = 88% PWB = 3	VAS Preoperative: 7.7 ± 1.4 (4 – 10) Postoperative: 2.3 ± 1.7 (p < 0.0001) Reduction pre to post op: 5.3 ± 2 (2–9) At fixator removal: 0.6 (0–5) (p <0.0003) Reduction post-op and at implant removal: 1.8 ± 2.1. Pain free: 21 (84%) Mild pain (VAS 1–2): 3 Worse pain(VAS 5): 1 No change/1 point change: 10 Remaining patients showed improvement: 3.1 points	Not measured	Total LOS 11 ± 5.2 days (4-24 days) Post-op LOS 7 ± 5.4 (1-18 days)	ExFix removed after an average 4 ± 1.6 weeks (3-8 weeks): 25 56% were removed after 3 weeks	Pin-infections treated with antibiotics: 2 No cases of post-operative nerve lesions or pin perforations seen
Höch et	Not measured	VAS	Not	Non-	Mal-positioning of iliosacral	**Non-Op 6 (8%)**

						Pneumonia: 1 Thrombosis: 1 Diarrhoea: 1 Blood transfusions: 2 Implant loosening: 1 Delayed union: 1 Delayed surgery sub-group: 2 (14%) complications recorded
Hopf et al (2017)2015	Not measured	VAS 0-10 pre op, 2nd day post-operative, pain at discharge Admission = 6.8 2nd day mean = 3.6 p<0.001 Discharge mean = 1.8 p<0.001 long term pain = 6 in two patients	Not measured	Mean = 23.7 days, range 8-54 days	Complications: 3 Intra-op blood loss: 1 Nerve irritation/screw malposition: 1 Gluteal haematoma: 2	3 patients Pneumonia: 2 UTI: 2
AE= Adverse Event, SAE= Serious Adverse Event VAS = Visual analogue scale, FWB = Full weight bearing, PWB = Partial weight bearing, LOS = Length of stay, ExFix = External fixator, ARDS= Acute Respiratory Distress Syndrome, LFCN= Lateral Femoral Cutaneous Nerve, SD = standard deviation						

Complications

All studies reported on whether patients experienced complications: the percentage of participants who suffered from complications ranged from no major complications (0%) to 14% across studies. Reported complications and adverse outcomes included: infections,[33] implant loosening,[36] pneumonia,[35 36] and thrombosis [36] (Table 3). Höch et al. observed no statistically significant difference in the number of complications between the combination of screw and plate fixations and non-operative groups (18% v 8%, p=0.8).

In the study by Gänsslen et al, removal of the external fixation was performed after an average of four weeks requiring a second procedure (SD 1.6, range 3-8) (2013). [33] There were two (8%) pin site infections in this series.

Posterior fixations also required further procedures; three patients (6%) had SI screws removed due to malposition and neurological complications in one study.[36] Another study had one patient (7%) with an intra-pelvic iliac screw removed with no residual complaint.[34] Other infrequent surgical complications with posterior fixation included two gluteal haematomas, one wound infection and one intra-operative bleed.[35]

Gänsslen et al (2013) was the only study to report radiographic alignment; post-operatively reduction was near anatomic with an average residual sacral displacement of 0.3 mm (0–1 mm) and anterior displacement of 1.4 mm (0–12 mm).

Mortality

Mortality was reported in one study:[36] during hospital stay three patients died due to respiratory insufficiency (two following from pneumonia, and one from a pulmonary embolism) in the non-operative group; and one patient died of a pulmonary embolism and one of a suspected myocardial infarction in the operative group. By two year follow-up, 30% (n=38) of the patients had died; 41% in the non-operative group, 21% in the failed non-operative group, and 18% of the operative group.[36]

Discussion

This systematic review searched for evidence on the effectiveness of surgical fixation compared to non-operative management in the treatment of LC-1 FFP with no age restriction. No robust evidence from RCTs was identified. The evidence-base was restricted to four case series, three of which were retrospective. Poor reporting of the inclusion criteria, how patients were selected and the completeness of inclusion of potential patients raise concerns of study results being affected by selection bias. The limitations of this study design in providing robust evidence of effectiveness is well recognised.[39]

The focus of this review was on surgical fixation. Surgical interventions used in the included studies were unilateral and bilateral percutaneous iliac screws, with or without plating or supra-acetabular external fixation. One study included adjunctive sacroplasty. The

effectiveness of sacroplasty is yet to be established with contradictory results in the literature, however it is thought that the injection of cement into the fracture site can hinder fracture healing.[18] Therefore, studies of sacroplasty as the primary technique were excluded from this review.

The four included studies reported on pain pre- and post-operatively using Visual Analogue Scores. The majority of patients recorded reduced levels of pain post-operatively. The other commonly reported outcome measure was length of hospital stay, which ranged from four days to 54 days. In one study the mean length of hospital stay was statistically significantly longer in the surgical fixation group than in the non-operative group. The proportion of patients across the four studies who had complications ranged from 0% to 14%. In the absence of details of the severity of the reported complications it is difficult to draw inferences. In addition, the level of experience of the surgeons and their familiarity with the techniques used in the studies are not reported.

Not all the studies reported on all the outcomes of interest in this review. Only one study assessed quality of life. Pelvic fractures are painful injuries and can significantly affect patients' mobility and their ability to carry out activities of daily living independently.[10] Immobility from prolonged bedrest can lead to potentially serious complications. Hence the role of surgery in improving mobility and quality of life in this frail, at risk population needs to be better defined. Although three studies reported return to pre-injury walking status or independent mobility, none of the studies used a standardised measure, so varied in how they reported patient mobility, ability to perform pre-injury walking status or ability to stand and walk without crutches. The time point for assessment also varied, ranging from an average of 4 weeks to 7.2 months after surgery. This makes the ability to compare the results limited and suggests there is a need for standardisation of a mobility measurement. In 2014, a survey of 111 surgeons from the Orthopaedic Trauma Association (OTA) in the United States showed a large discrepancy in practice decisions and operative agreement of LC-1 pelvic fractures.[40] Future studies should use standardised PROMS to assess important outcomes such as quality of life and ability of patients to undertake activities of daily living.

It is clear that there is also a need for consistency in the language and terminology used for describing low impact fractures of the pelvis.[18-22] The existence and use of a number of different classification systems is concerning in terms of understanding decision making processes and the sharing of good practice.

The strength of this systematic review is in the rigorous methods used, including searching of multiple databases, duplicate study selection and checking of data extraction and quality assessment as well as protocol registration prior to commencing the review. Although key health databases were searched and efforts were made to search for unpublished studies via trial registers, we did not have the resources to search more widely and retrieval was limited to English language studies. We set out to include internal and external surgical

fixation as two separate interventions due to differences in the technique which may lead to differences in effectiveness and complications. The included studies were mostly of internal fixation and reported the methods of surgical fixation as a single group but the impact of specific methods of internal fixation (in the form of SI screws or plates/screws) cannot be determined from the four case series analysed.

The lack of robust evidence makes it inappropriate to draw any definitive conclusions about effectiveness of internal or external surgical fixation compared to non-surgical management of LC-1 fragility fractures. It is clear from this review that the disparity in management between hip fractures (treated with early surgery) and LC-1 FFP (treated non-operatively) is primarily due the fact that, to-date, there has been no effective surgical solution for the latter group, despite them being at very high risk of immobility-related illness. None of the studies examined here provided evidence supporting surgical fixation of FFP; indeed, there is a suggestion that internal fixation might paradoxically contribute to an increased length of hospital stay. The included studies all used traditional pelvic implants (iliosacral screws and external fixators) that may be less suitable for LC-1 FFP populations. Other studies suggest that iliosacral screws anchored in very soft, deficient bone have poor purchase and become loose and ineffective very quickly.[25] External fixators are poorly tolerated and are prone to pin-site infections.[28]

However, it is clear from the epidemiological data that LC-1 fractures in the elderly are catastrophically disabling for many patients, who either do not survive or never return to their pre-injury baseline function.[7 8] The surgical approach taken to hip fractures is therefore conceptually appealing, provided an effective technique can be identified to provide pain-relieving stability to the pelvis and allow patients to mobilise rapidly.

The introduction of the INFIX technique in 2010 means there is now a device which has the potential to effectively stabilise LC-1 fractures in older adults. The intervention is already in everyday use in specialist pelvic fracture units for the younger population, meaning that pelvic surgeons have experience of the technique.

There is a potential that the enthusiasm of surgeons using INFIX in the younger population may apply the same principles to the older population (as with hip fractures), so the surgery could potentially become the new ‘standard of care’ for these patients. However, although there are a number of papers reporting on the use of INFIX, we were unable to identify any studies that met our inclusion criteria.[29 41 42] More robust evidence in the form of high quality RCTs is needed to support surgical intervention and the use of devices such as INFIX in the elderly population with fragility fractures of the pelvis. Although a multi-centre RCT within this patient group would be challenging, it would help avoid a situation where patients either do not receive surgical fixation because of lack of evidence, or where they are exposed to a treatment that might be neither beneficial nor cost effective.

Conclusion

There is currently insufficient robust evidence to support guidance on the most effective treatment for elderly patients who fail to mobilise after sustaining an LC-1 fragility fracture. Given the growing interest of specialist pelvic surgeons in the use of surgical interventions in this population, there is an urgent need for more robust evidence of effectiveness.

Author contributions:

Alison Booth – protocol development, search strategy, study selection, critical appraisal, analysis, writing, approval of final submission

Helen Ingoe – protocol development, search strategy, study selection, critical appraisal, analysis, writing, critique of drafts, approval of final submission

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Elizabeth Coleman – protocol development, analysis, writing, critique of drafts, approval of final submission

Melissa Harden – search strategy, literature searches, writing search methods for protocol and final report, approval of final submission.

Jamila Kassam – concept for review, protocol development, search strategy, study selection, analysis, writing, critique of drafts, approval of final submission

Iris Kwok – protocol development, search strategy, study selection, writing, critique of drafts, approval of final submission

Catherine Hilton – protocol development, search strategy, study selection, writing, critique of drafts, approval of final submission

Peter Bates – concept for review, protocol development, search strategy, analysis, writing, critique of drafts, approval of final submission

Catriona McDaid – concept for review, protocol development, search strategy, analysis, writing of paper, critique of draft papers, approval of final submission

Competing interests

HI, MN, EC, MH, IK, CH, declare they have no conflicts of interest. Since starting this review, AB, JK, PB and CM have received funding for a trial of surgical fixation compared to non-surgical treatment in a LC1 FFP population.

Data sharing statement

The data extraction tables and quality assessment tables are available from the corresponding author upon reasonable request.

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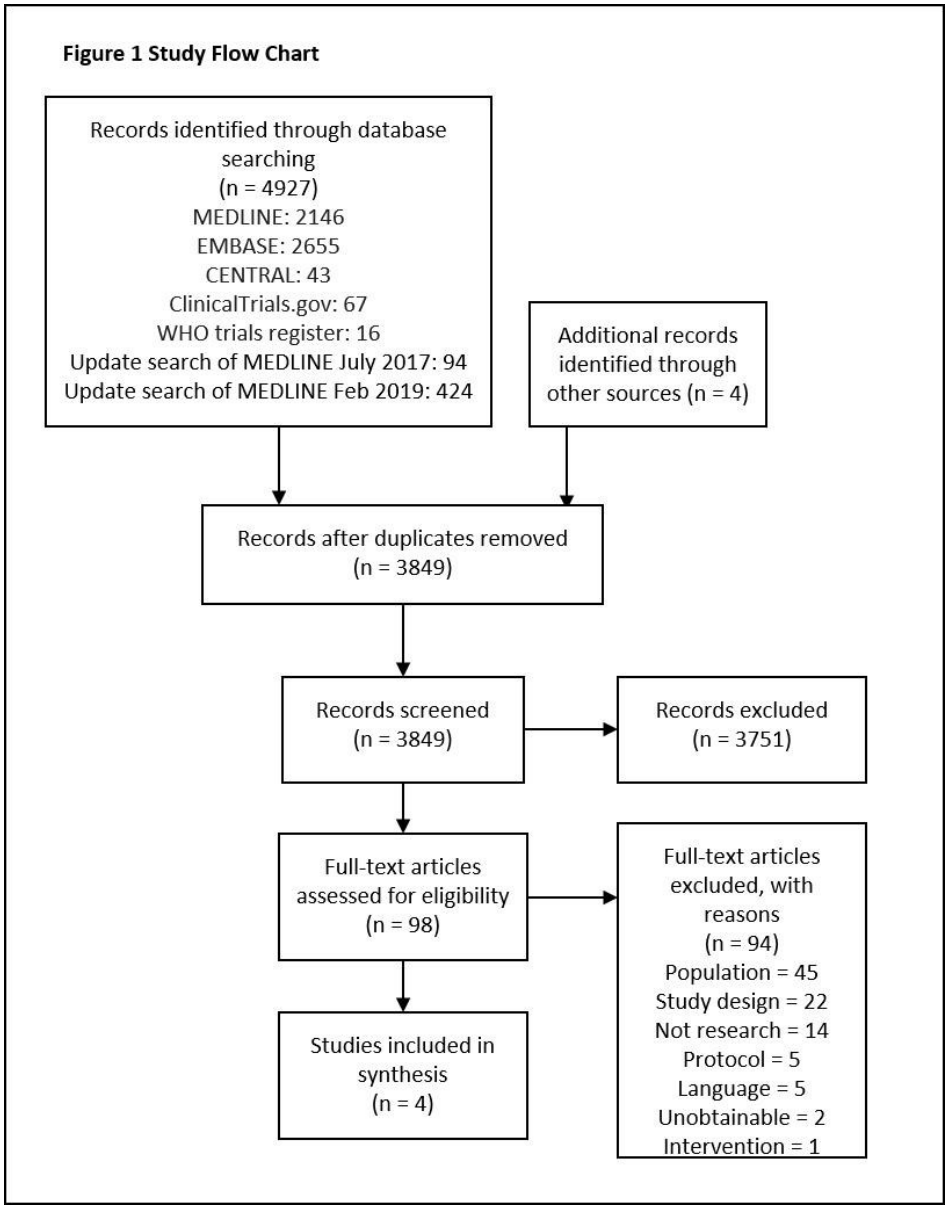

Figure 1 Study flow chart

Supplementary file 1: Search Strategy for MEDLINE

Database: Epub Ahead of Print, In-Process & Other Non-Indexed Citations, Ovid MEDLINE(R) Daily and Ovid MEDLINE(R) <1946 to Present>
Search Strategy:
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1 exp Pelvic Bones/ (31120)
2 (pelvis or pelvic).ti,ab. (129440)
3 (ilium$ or ilia or iliac).ti,ab. (39144)
4 (ischium$ or ischial or ischia or ischii).ti,ab. (2353)
5 (pubis or (pubic adj2 (bone$ or ramus or rami))).ti,ab. (3895)
6 1 or 2 or 3 or 4 or 5 (183312)
7 Fractures, Bone/ (69982)
8 Osteoporotic Fractures/ (3912)
9 Fractures, Compression/ (1736)
10 7 or 8 or 9 (75036)
11 6 and 10 (7124)
12 (fractur$ adj3 (pelvis or pelvic)).ti,ab. (4793)
13 (fractur$ adj3 (ilium$ or ilia or iliac)).ti,ab. (280)
14 (fractur$ adj3 (ischium$ or ischial or ischia or ischii)).ti,ab. (87)
15 (fractur$ adj3 pubis).ti,ab. (52)
16 (fractur$ adj3 pubic).ti,ab. (329)
17 (fractur$ adj3 lateral compression).ti,ab. (55)
18 (fractur$ adj3 (LC-1 or LC1)).ti,ab. (6)
19 (fractur$ adj3 sacral insufficiency).ti,ab. (205)
20 or/12-19 (5458)
21 (fractur$ adj3 low-energy).ti,ab. (627)
22 (fractur$ adj3 (fragility or osteoporo$ or osteopeni$ or insufficiency)).ti,ab. (16528)
23 21 or 22 (16963)
24 23 and 6 (845)
25 11 or 20 or 24 (9865)
26 (pelvic adj2 ring adj2 injur$).ti,ab. (446)
27 (pelvic adj2 ring adj2 disrupt$).ti,ab. (192)
28 (lateral compression adj3 injur$).ti,ab. (58)
29 ((LC-1 or LC1) adj3 injur$).ti,ab. (8)
30 or/26-29 (625)
31 25 or 30 (10009)
32 exp Fracture Fixation/ (61190)
33 exp Fracture Fixation, Internal/ (41947)
34 exp Orthopedic Fixation Devices/ (76567)
35 Infix.ti,ab. (23)
36 (fractur$ adj3 (fixation$ or fixator$ or stabilis$ or stabiliz$)).ti,ab. (11748)
37 ((internal or external) adj3 (fixation$ or fixator$ or stabilis$ or stabiliz$)).ti,ab. (25648)
38 ((anterior$ or posterior$) adj3 (fixation$ or fixator$ or stabilis$ or stabiliz$)).ti,ab. (6848)
39 ((surgical or surgery or operati$ or orthop?edic) adj3 (fixation$ or fixator$ or stabilis$ or stabiliz$)).ti,ab. (7737)
40 ((pelvic or pelvis) adj3 (fixation$ or fixator$ or stabilis$ or stabiliz$)).ti,ab. (1210)
41 ((plate$ or plating$ or screw$ or nail$ or pin or pins or rod or rods) adj6 (fixation$ or fixator$ or stabilis$ or stabiliz$)).ti,ab. (25375)
42 (bone$ adj6 (plate$ or plating$ or screw$ or nail$ or pin or pins or rod or rods)).ti,ab. (14857)
43 ((pedicle or pedicular or polyaxial) adj2 screw$).ti,ab. (5448)
44 ((iliosacral or ilio-sacral or sacroiliac or sacro-iliac) adj2 screw$).ti,ab. (422)

45 ((trans-sacral or transsacral) adj2 screw$).ti,ab. (38)
46 pelvic bridg$.ti,ab. (5)
47 ASIF.ti,ab. (675)
48 (posterior adj2 (plate$ or plating)).ti,ab. (551)
49 (anterior adj2 (plate$ or plating)).ti,ab. (1555)
50 (symphyseal adj2 (plate$ or plating)).ti,ab. (40)
51 ((transiliac or trans-iliac or sacral or connect$) adj2 rod$).ti,ab. (431)
52 ((open or closed) adj2 reduction$).ti,ab. (14389)
53 osteosynthesis.ti,ab. (10872)
54 (compression adj2 (plate$ or plating)).ti,ab. (2027)
55 (compression adj2 fixation$).ti,ab. (465)
56 ((fractur$ or orthop?edic) adj2 (immobiliz$ or immobilis$)).ti,ab. (503)
57 or/32-56 (147341)
58 31 and 57 (3165)
59 exp animals/ not humans/ (4856249)
60 58 not 59 (3094)
61 limit 60 to yr="1980 -Current" (2769)
62 limit 61 to english language (2146)

Supplementary file 2: Studies excluded at second screening with reason for exclusion

Reference	Reason for exclusion
Lau TW, Leung F. Occult posterior pelvic ring fractures in elderly patients with osteoporotic pubic rami fractures. Journal of Orthopaedic Surgery. 2010;18(2):153-7.	Intervention (no LC1's had fixation)
Bohme J, Hoch A, Josten C. Osteoporotic fractures of the pelvis Osteoporotische Frakturen des Beckens. Chirurg. 2012;83(10):875-81.	Language
Caban A. External fixation in the treatment of pelvic fractures. Ortopedia Traumatologia Rehabilitacja. 1999;1(1):49-59.	Language
Chen LH, Shih CH, Hsu WW, Chen WJ, Wu CC, Su JY, et al. Anterior internal fixation of the disrupted sacroiliac joint: A preliminary report. Journal of Surgical Association Republic of China. 1993;26(3):1796-804.	Language
Pavelka T, Salasek M, Weisova D. [Complications associated with surgical treatment of pelvic ring fractures]. Acta Chirurgiae Orthopaedicae et Traumatologiae Cechoslovaca. 2013;80(3):208-15.	Language
Zhang J, Wu K, Zhang W, Wu W, Hou S. [Percutaneous fixation of pelvic fracture by acutrak full thread headless hollow compression screw]. Chinese journal of reparative and reconstructive surgery. 2012;26(1):91 -6.	Language
[No authors listed]. Managing pelvic fractures. Nursing. 2003;33(12):43.	Not research
[No authors listed]. SESAP critiques / critiques SESAP. Canadian Journal of Surgery. 1997;40(6):420.	Not research
Baird R. Open reduction of pelvic fractures. Western Journal of Medicine. 1991;155(2):171.	Not research
Bauer J, Holzl A, Verheyden A. The operative treatment of sacral insufficiency fracture with percutaneous iliosacral compression osteosynthesis with a pelvine internal fixator and cannulated iliosacral screws. European Spine Journal. 2013;22:2619.	Not research
Boobbyer GN. External fixation with the coat hanger method in treatment of unstable fractures of the pelvis. Injury. 1980;11(3):254-6.	Not research
Browner BD, Cole JD. Initial management of pelvic ring disruptions. Instructional Course Lectures. 1988;37:129-37.	Not research
Leslie MP, Baumgaertner MR. Osteoporotic pelvic ring injuries. Orthopedic Clinics of North America. 2013;44(2):217-24.	Not research
Rommens PM, Hofmann A. Comprehensive classification of fragility fractures of the pelvic ring: Recommendations for surgical treatment. Injury. 2013;44(12):1733 -44.	Not research
Smith BL. How to manage that pelvic fracture. Modern Medicine. 2005;68(8):30-4; quiz 5.	Not research
Smith JM. Pelvic fractures. Western Journal of Medicine. 1998;168(2):124-5.	Not research
Stahel PF, Mauffrey C, Smith WR, McKean J, Hao J, Burlew CC, et al. External fixation for acute pelvic ring injuries: decision making and technical options. The Journal of Trauma and Acute Care Surgery. 2013;75(5):882-7.	Not research
Whyte Jt. Stress fractures of the pelvis and lower extremities. Diagnosis and management. Advance for Nurse Practitioners. 2005;13(7):55-6, 8-9.	Not research
Wiss DA. What's new in orthopaedic trauma. Journal of Bone & Joint Surgery - American Volume. 2002;84(11):2111-9.	Not research
Youngman JR, Day AC. Pelvic fractures. Hospital Medicine (London). 2002;63(12):750-2.	Not research
Acker A, Perry ZH, Blum S, et al. Immediate percutaneous sacroiliac screw insertion for unstable pelvic fractures: is it safe enough? European Journal of Trauma & Emergency Surgery 2018;44(2):163-69.	Population
Barei DP, Shafer BL, Beingessner DM, Gardner MJ, Nork SE, Routt ML. The impact of open reduction internal fixation on acute pain management in unstable pelvic ring injuries. Journal of Trauma-Injury Infection & Critical Care. 2010;68(4):949-53.	Population
Bastian JD, Ansorge A, Tomagra S, Benneker LM, Buchler L, Siebenrock KA, et al. Mid-term outcome following fixation of anterior pelvic ring injuries using the modified Stoppa approach. Swiss Medical Weekly. 2013;143:29S.	Population
Blasier DR, McAtee J, White R, Mitchell DT. Disruption of the pelvic ring in pediatric patients. Clinical Orthopaedics and Related Research. 2000;0(376):87-95.	Population
Chen PH, Hsu WH, Li YY, Huang TW, Huang TJ, Peng KT. Outcome analysis of unstable posterior ring injury of the pelvis: comparison between percutaneous iliosacral screw fixation and conservative treatment. Biomedical Journal. 2013;36(6):289-94.	Population

Dienstknecht T, Berner A, Lenich A, Nerlich M, Fuechtmeier B. A minimally invasive stabilizing system for dorsal pelvic ring injuries. Clinical Orthopaedics & Related Research. 2011;469(11):3209-17.	Population
Dolati B, Spiss R, Ennemoser O, Colleselli K. The fixation of pelvic ring fractures. World Journal of Urology. 1990;7(4):192-6.	Population
Dong J, Hao W, Wang B, Wang L, Li L, Mu W, et al. Management and outcome of pelvic fractures in elderly patients: a retrospective study of 40 cases. Chinese Medical Journal. 2014;127(15):2802-7.	Population
Eckardt H, Egger A, Hasler RM, et al. Good functional outcome in patients suffering fragility fractures of the pelvis treated with percutaneous screw stabilisation: Assessment of complications and factors influencing failure. *Injury* 2017;48(12):2717-23.	Population
Elzohairy MM, Salama AM. Open reduction internal fixation versus percutaneous iliosacral screw fixation for unstable posterior pelvic ring disruptions. Orthopaedics & traumatology, surgery & research 2017;103(2):223-27.	Population
Fang C, Alabdulrahman H and Pape HC. Complications after percutaneous internal fixator for anterior pelvic ring injuries. Int Orthop 2017; 24:24. DOI:10.1007/s00264-017-3415-4.	Population
Gu R, Huang W, Yang L, et al. Comparisons of front plate, percutaneous sacroiliac screws, and sacroiliac anterior papilionaceous plate in fixation of unstable pelvic fractures. Medicine 2017;96(36):e7775.	Population
Gvozdenovic R, Dahl B, Gehrchen M, Blyme P, Kioer T, Tondevold E. Fixation of unstable posterior pelvic ring fractures - a comparative study [Abstract]. Acta orthopaedica Scandinavica. 1998;69:17.	Population
Hagen J, Castillo R, Dubina A, Gaski G, Manson TT, O'Toole RV. Does Surgical Stabilization of Lateral Compression-type Pelvic Ring Fractures Decrease Patients' Pain, Reduce Narcotic Use, and Improve Mobilization? Clinical Orthopaedics & Related Research. 2016;474(6):1422-9.	Population
Hoch A, Pieroh P, Henkelmann R, et al. In-screw polymethylmethacrylate-augmented sacroiliac screw for the treatment of fragility fractures of the pelvis: a prospective, observational study with 1-year follow-up. *BMC surgery* 2017;17(1):132.	Population
Hoch A, Schneider I, Todd J, Josten C, Bohme J. Lateral compression type B 2-1 pelvic ring fractures in young patients do not require surgery. European Journal of Trauma & Emergency Surgery. 2016;2:2.	Population
Hong HX, Hong ZH, Chen HX, Lin L, Zhu Z. Iliosacral screw fixation of transforaminal sacral fractures using local anesthesia and CT. Journal of the American College of Surgeons. 2010;211(2):e7-12.	Population
Lansinger O, Karlsson J, Berg U, Mare K. Unstable fractures of the pelvis treated with a trapezoid compression frame. Acta Orthopaedica Scandinavica. 1984;55(3):325-9.	Population
Latenser BA, Gentilello LM, Tarver AA, Thalgott JS, Batdorf JW. Improved outcome with early fixation of skeletally unstable pelvic fractures. Journal of Trauma -Injury Infection & Critical Care. 1991;31(1):28-31.	Population
Lindahl J, Hirvensalo E, Bostman O, Santavirta S. Failure of reduction with an external fixator in the management of injuries of the pelvic ring. Long-term evaluation of 110 patients. Journal of Bone & Joint Surgery - British Volume. 1999;81(6):955-62.	Population
Ma X, Zheng X, Zhao W, et al. Interval versus external fixation for the treatment of pelvic fractures: a comparative study. Clin Invest Med 2017;40(3):E102.	Population
Matta JM, Saucedo T. Internal fixation of pelvic ring fractures. Clinical Orthopaedics & Related Research. 1989;0(242):83-97.	Population
Moed BR, Whiting DR. Locked transsacral screw fixation of bilateral injuries of the posterior pelvic ring: initial clinical series. Journal of Orthopaedic Trauma. 2010;24(10):616-21.	Population
Noser J, Dietrich M, Tiziani S, et al. Mid-term follow-up after surgical treatment of fragility fractures of the pelvis. *Injury* 2018;49(11):2032-35.	Population
Noser J, Dietrich M, Tiziani S, et al. Mid-term follow-up after surgical treatment of fragility fractures of the pelvis. Injury 2018;49(11):2032-35. doi: 10.1016/j.injury.2018.09.017	Population
Routt ML, Jr., Simonian PT, Grujic L. The retrograde medullary superior pubic ramus screw for the treatment of anterior pelvic ring disruptions: a new technique. Journal of Orthopaedic Trauma. 1995;9(1):35-44.	Population
Salari P, Cannada LK, Moed BR. Do asymptomatic patients have normal function after percutaneous fixation of the posterior pelvic ring? A case-control pilot study. Journal of Orthopaedic Surgery. 2015;10:68.	Population
Scherer J, Tiziani S, Sprengel K, et al. Subcutaneous internal anterior fixation of pelvis fractures-which configuration of the InFix is clinically optimal?-a retrospective study. Int	Population

Schmitz P, Baumann F, Grechenig S, Gaensslen A, Nerlich M, Muller MB. The cement-augmented transiliacal internal fixator (caTIFI): an innovative surgical technique for stabilization of fragility fractures of the pelvis. Injury. 2015;46:S114-20.	Population
Scolaro JA, Firoozabadi R, Routt ML. Treatment of Pediatric and Adolescent Pelvic Ring Injuries With Percutaneous Screw Placement. Journal of Pediatric Orthopedics. 2016;2:2.	Population
Sen RK, Gopinathan NR, Tamuk T, Kumar R, Krishnan V, Sament R. Predictors of early outcome in unstable pelvic fractures. Chinese Journal of Traumatology. 2013;16(2):94-8.	Population
Shui X, Ying X, Mao C, Feng Y, Chen L, Kong J, et al. Percutaneous Screw Fixation of Crescent Fracture-Dislocation of the Sacroiliac Joint. Orthopedics. 2015;38(11):e976-82.	Population
Studer P, Suhm N, Zappe B, Bless N, Jakob M. Pubic rami fractures in the elderly--a neglected injury? Swiss Medical Weekly. 2013;143:w13859.	Population
Sullivan MP, Scolaro JA, Milby AH, Mehta S. Isolated pelvic ring injuries: functional outcomes following percutaneous, posterior fixation. European journal of orthopaedic surgery & traumatologie. 2015;25(6):1025-30.	Population
Tosounidis T, Kanakaris N, Nikolaou V, Tan B, Giannoudis PV. Assessment of Lateral Compression type 1 pelvic ring injuries by intraoperative manipulation: which fracture pattern is unstable? International Orthopaedics. 2012;36(12):2553-8.	Population
Uchida K, Kokubo Y, Yayama T, Nakajima H, Miyazaki T, Negoro K, et al. Fracture of the pelvic ring: A retrospective review of 224 patients treated at a single institution. European Journal of Orthopaedic Surgery and Traumatology. 2011;21(4):251-7.	Population
Vaidya R, Martin AJ, Roth M, et al. Midterm Radiographic and Functional Outcomes of the Anterior Subcutaneous Internal Pelvic Fixator (INFIX) for Pelvic Ring Injuries. J Orthop Trauma 2017;31(5):252-59.	Population
Vaidya R, Martin AJ, Roth M, Tonnos F, Oliphant B, Carlson J. Midterm radiographic and functional outcomes of the anterior internal pelvic fixator (INFIX). Journal of Orthopaedic Trauma. 2017;5:05.	Population
Vanderschot P, Kuppers M, Sermon A, Lateur L. Trans-iliac-sacral-iliac-bar procedure to treat insufficiency fractures of the sacrum. Indian Journal of Orthopaedics. 2009;43(3):245-52.	Population
Wahnert D, Raschke MJ, Fuchs T. Cement augmentation of the navigated iliosacral screw in the treatment of insufficiency fractures of the sacrum: a new method using modified implants. International Orthopaedics. 2013;37(6):1147-50.	Population
Wang H, Fu YH, Ke C, et al. Minimally invasive stabilisation of posterior pelvic ring instabilities with pedicle screws connected to a transverse rod. Int Orthop 2018;42(3):681-86. doi: https://dx.doi.org/10.1007/s00264-017-3714-9	Population
Webb LX, Caldwell K. Disruption of the posterior pelvic ring caused by vertical shear. Southern Medical Journal. 1988;81(10):1217-21.	Population
Wild JJ, Jr., Hanson GW, Tullos HS. Unstable fractures of the pelvis treated by external fixation. *Journal of Bone & Joint Surgery - American Volume*. 1982;64:1010-1020	Population
Wu X, Liu Z, Fu W, et al. Modified pedicle screw-rod fixation as a minimally invasive treatment for anterior pelvic ring injuries: an initial case series. Journal of Orthopaedic Surgery 2017;12(1):84. doi: https://dx.doi.org/10.1186/s13018-017-0590-3	Population
Yu X, Tang M, Zhou Z, Peng X, Wu T, Sun Y. Minimally invasive treatment for pubic ramus fractures combined with a sacroiliac joint complex injury. International Orthopaedics. 2013;37(8):1547-54.	Population
Hasler R. Surgical Treatment of Low Energy Pelvic Fractures in the Elderly. ClinicalTrials.Gov	Protocol
Jakob M. Treatment of Pelvic Ring Fractures in the Elderly. ClinicalTrials.Gov	Protocol
Nieves JW. PTH (1-34) and Pelvic Fracture Healing - a Randomized Controlled Trial. ClinicalTrials.Gov	Protocol
O'Toole R. Pelvis RCT: Impact of Surgery on Pain in Lateral Compression Type Pelvic Fractures. ClinicalTrials.Gov	Protocol
Zlowodzki M. Comparison of Subcutaneous INFIX and EXFIX for Anterior Pelvic Ring Fractures Requiring Stabilization. ClinicalTrials.Gov	Protocol
Beall DP, Datir A, D'Souza SL, D'Souza LS, Gunda D, Morelli J, et al. Percutaneous treatment of insufficiency fractures : principles, technique and review of literature. Skeletal Radiology. 2010;39(2):117-30.	Study design
Beckmann JT, Presson AP, Curtis SH, Haller JM, Stuart AR, Higgins TF, et al. Operative agreement on lateral compression-1 pelvis fractures. a survey of 111 OTA members. Journal of Orthopaedic Trauma. 2014;28(12):681-5.	Study design
Clamp JA, King RJ, O'Hara JT, Hahn DM. Osteoporotic pelvic insufficiency fracture with	Study design

gross instability. Journal of Trauma-Injury Infection & Critical Care. 2008;64(5):1380-2.

De Bastiani G, Aldegheri R, Renzi Brivio L. Dynamic axial fixation. A rational alternative for the external fixation of fractures. International Orthopaedics. 1986;10(2):95-9.	Study design
Dechert TA, Duane TM, Frykberg BP, Aboutanos MB, Malhotra AK, Ivatury RR. Elderly patients with pelvic fracture: interventions and outcomes. American Surgeon. 2009;75(4):291-5.	Study design
Draijer F, Egbers HJ, Havemann D. Quality of life after pelvic ring injuries: follow-up results of a prospective study. Archives of Orthopaedic & Trauma Surgery. 1997;116(1):22-6.	Study design
Firoozabadi R, Oldenburg FP, Krieg JC, Routt MLC. Prevention of iliosacral screw intrusion through the lateral iliac cortex. Techniques in Orthopaedics. 2015;30(1):57-60.	Study design
Gansslen A, Lindahl J. Evaluation tools and outcomes after osteosynthesis of unstable type B and C pelvic ring injuries. Acta Chirurgiae Orthopaedicae et Traumatologiae Cechoslovaca. 2013;80(5):305-20.	Study design
Gerbershagen HJ, Dagtekin O, Mertens N, Isenberg J, Sabatowski R, Petzke F. Prevalence and severity of chronic pain after pelvic ring fracture. European Journal of Pain. 2009;13:S157.	Study design
Hausler SM, Strobl FF, Paprottka P, Pieske O, Rubenbauer B, Jakobs TF, et al. Technical outcome, complications and effective patient dose of percutaneous CT-fluoroscopy guided screw placement for the fixation of unstable pelvic fractures. CardioVascular and Interventional Radiology. 2013;36:S391.	Study design
Kim WY, Lee SW, Kim KW, et al. Minimally invasive surgical treatment using 'iliac pillar' screw for isolated iliac wing fractures in geriatric patients: a new challenge. *European journal of trauma and emergency surgery : official publication of the European Trauma Society* 2018	Study design
Leberte M, Dabezies E. Pelvic fractures. Orthopedics. 1985;8(1):120-3.	Study design
Lee SW, Kim WY, Koh SJ, et al. Posterior locked lateral compression injury of the pelvis in geriatric patients: an infrequent and specific variant of the fragility fracture of pelvis. Arch Orthop Trauma Surg 2017;137(9):1207-18.	Study design
Minarro JC, Quevedo-Reinoso R, Lopez-Pulido MJ, Gonzalez-Fernandez A. Osteoporotic fractures of the pelvis. Osteoporosis International. 2016;1:S139.	Study design
Pennig D. External and internal fixation in pelvic ring disruption. Journal of the Japanese Orthopaedic Association. 1991;65(3):S557.	Study design
Rommens PM, Ossendorf C, Pairon P, Dietz SO, Wagner D, Hofmann A. Clinical pathways for fragility fractures of the pelvic ring: personal experience and review of the literature. Journal of Orthopaedic Science. 2015;20(1):1-11.	Study design
Routt ML, Jr., Kregor PJ, Simonian PT, Mayo KA. Early results of percutaneous iliosacral screws placed with the patient in the supine position. Journal of Orthopaedic Trauma. 1995;9(3):207-14.	Study design
Rubash HE, Brown TD, Nelson DD, Mears DC. Comparative mechanical performances of some new devices for fixation of unstable pelvic ring fractures. Medical & Biological Engineering & Computing. 1983;21(6):657-63.	Study design
Sanders D, Fox J, Starr A, Sathy A, Chao J. Transsacral-Transiliac Screw Stabilization: Effective for Recalcitrant Pain Due to Sacral Insufficiency Fracture. Journal of Orthopaedic Trauma. 2016;30(9):469-73.	Study design
Schmitz P, Baumann F, Acklin YP, et al. Clinical application of a minimally invasive cement-augmentable Schanz screw rod system to treat pelvic ring fractures. *International orthopaedics* 2018 doi: 10.1007/s00264-018-3988-6	Study design
Suzuki T, Shindo M, Soma K, Minehara H, Nakamura K, Uchino M, et al. Long-term functional outcome after unstable pelvic ring fracture. Journal of Trauma-Injury Infection & Critical Care. 2007;63(4):884-8.	Study design
Ting B, Zurakowski D, Herder L, Wagner K, Appleton P, Rodriguez EK. Preinjury ambulatory status is associated with 1-year mortality following lateral compression Type I fractures in the geriatric population older than 80 years. The Journal of Trauma and Acute Care Surgery. 2014;76(5):1306-9.	Study design
Dahners LE, Jacobs RR, Jayaraman G, Mathys Jr R. An external skeletal fixation system for unstable pelvic fractures. Surgical Forum. 1983;0:554-6.	Unobtainable
Wang S, Zhang P, Du D, Yang S. Anterior internal fixation to treat vertical unstable pelvic fracture. Chinese Journal of Traumatology. 2002;5(1):59-61.	Unobtainable

PRISMA 2009 Checklist

Section/Topic	#	Checklist Item	Reported on Page #
TITLE			
Title	1	Identify the report as a systematic review, meta-analysis, or both.	1
ABSTRACT			
Structured summary	2	Provide a structured summary including, as applicable: background; objectives; data sources; study eligibility criteria, participants, and interventions; study appraisal and synthesis methods; results; limitations; conclusions and implications of key findings; systematic review registration number.	2
INTRODUCTION			
Rationale	3	Describe the rationale for the review in the context of what is already known.	4-5
Objectives	4	Provide an explicit statement of questions being addressed with reference to participants, interventions, comparisons, outcomes, and study design (PICOS).	5
METHODS			
Protocol and registration	5	Indicate if a review protocol exists, if and where it can be accessed (e.g., Web address), and, if available, provide registration information including registration number.	5
Eligibility criteria	6	Specify study characteristics (e.g., PICOS, length of follow-up) and report characteristics (e.g., years considered, language, publication status) used as criteria for eligibility, giving rationale.	6
Information sources	7	Describe all information sources (e.g., databases with dates of coverage, contact with study authors to identify additional studies) in the search and date last searched.	6
Search	8	Present full electronic search strategy for at least one database, including any limits used, such that it could be repeated.	Sup 1
Study selection	9	State the process for selecting studies (i.e., screening, eligibility, included in systematic review, and, if applicable, included in the meta-analysis).	6
Data collection process	10	Describe method of data extraction from reports (e.g., piloted forms, independently, in duplicate) and any processes for obtaining and confirming data from investigators.	7
Data items	11	List and define all variables for which data were sought (e.g., PICOS, funding sources) and any assumptions and simplifications made.	7
Risk of bias in individual studies	12	Describe methods used for assessing risk of bias of individual studies (including specification of whether this was done at the study or outcome level), and how this information is to be used in any data synthesis.	7
Summary measures	13	State the principal summary measures (e.g., risk ratio, difference in means).	N/A
Synthesis of results	14	Describe the methods of handling data and combining results of studies, if done, including measures of consistency (e.g., I^2) for each meta-analysis.	7

PRISMA 2009 Checklist

Section/Topic	#	Checklist Item	Reported on Page #
Risk of bias across studies	15	Specify any assessment of risk of bias that may affect the cumulative evidence (e.g., publication bias, selective reporting within studies).	N/A
Additional analyses	16	Describe methods of additional analyses (e.g., sensitivity or subgroup analyses, meta-regression), if done, indicating which were pre-specified.	N/A
RESULTS			
Study selection	17	Give numbers of studies screened, assessed for eligibility, and included in the review, with reasons for exclusions at each stage, ideally with a flow diagram.	7
Study characteristics	18	For each study, present characteristics for which data were extracted (e.g., study size, PICOS, follow-up period) and provide the citations.	7-8
Risk of bias within studies	19	Present data on risk of bias of each study and, if available, any outcome level assessment (see item 12).	11
Results of individual studies	20	For all outcomes considered (benefits or harms), present, for each study: (a) simple summary data for each intervention group (b) effect estimates and confidence intervals, ideally with a forest plot.	Table 3
Synthesis of results	21	Present the main results of the review. If meta-analyses done, include for each, confidence intervals and measures of consistency.	12-16
Risk of bias across studies	22	Present results of any assessment of risk of bias across studies (see Item 15).	N/A
Additional analysis	23	Give results of additional analyses, if done (e.g., sensitivity or subgroup analyses, meta-regression [see Item 16]).	N/A
DISCUSSION			
Summary of evidence	24	Summarize the main findings including the strength of evidence for each main outcome; consider their relevance to key groups (e.g., healthcare providers, users, and policy makers).	16-18
Limitations	25	Discuss limitations at study and outcome level (e.g., risk of bias), and at review-level (e.g., incomplete retrieval of identified research, reporting bias).	18
Conclusions	26	Provide a general interpretation of the results in the context of other evidence, and implications for future research.	19
FUNDING			
Funding	27	Describe sources of funding for the systematic review and other support (e.g., supply of data); role of funders for the systematic review.	20

From: Moher D, Liberati A, Tetzlaff J, Altman DG, The PRISMA Group (2009). Preferred Reporting Items for Systematic Reviews and Meta-Analyses: The PRISMA Statement. PLoS Med 6(6): e1000097. doi:10.1371/journal.pmed1000097

PRISMA 2009 Checklist