

Modified pedicle screw-rod versus anterior subcutaneous internal pelvic fixation for unstable pelvic anterior ring fracture: A retrospective study and finite element analysis

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Abstract

Objectives: This study compared the stability and clinical outcomes of modified pedicle screw-rod fixation (MPSRF) and anterior subcutaneous internal pelvic fixation (INFIX) for the treatment of anterior pelvic ring fractures.

Methods: In a retrospective review of a consecutive patient series conducted in a level 1 trauma university hospital, 63 patients with Orthopaedic Trauma Association (OTA)/Arbeitsgemeinschaft für Osteosynthesefragen (AO) type B or C pelvic ring fractures were treated by MPSRF (n=30) or INFIX (n=33). The mean follow-up was 20 months. The main outcome measure was the incidence of complications and adverse outcomes, and fixation stability was evaluated by finite element analysis (FEA).

Results: The 2 groups did not differ in terms of injury severity score, OTA classification, cause of injury, and time to pelvic surgery ($P>0.05$). However, the MPSRF group had a higher satisfactory rate according to the Tornetta and Matta grading system than the INFIX group (73.33% vs 63.63%) as well as a higher Majeed score (81.5 ± 10.4 vs 76.3 ± 11.2), which was statistically significant at 6 months' post-surgery ($P<0.001$). FEA showed that MPSRF was stiffer and more stable than INFIX and had a lower risk of implant failure.

Conclusions: Both MPSRF and INFIX have acceptable biomechanical stability for the treatment of unstable pelvic anterior ring fractures. However, MPSRF has better fixation stability and lower risk of implant failure, which can lead to better clinical outcomes.

Introduction

Anterior pelvic structures are more fragile and prone to fracture than dorsal parts as they bear higher loads [1]. Clinically, high-energy pelvic ring fractures leading to decreased functionality account for approximately 1.5–3.9% of all fractures [2]. The high rates of morbidity and mortality are of concern to orthopedists and an economic burden to patients and society.

Anterior pelvic external fixation is a rapid and temporary corrective measure for unstable pelvic fractures in cases where there is hemodynamic instability [3]. However, it is associated with complications such as pin tract infection (in 2–50%), fixator loosening (in 0–20%), loss of reduction (0–30%), and restriction of daily activities, particularly in obese patients [4, 5]. Moreover, open reduction has the potential disadvantage of extensive exposure including muscle stripping, as well as risk of damage to neurovascular structures. Therefore, minimally invasive fixation is increasingly being used as an alternative to external fixators [6, 7]. Insertion of supra-acetabular pedicle screws connected via a subcutaneous contoured rod tunnelled just below the belly crease (so-called bikini area) [8], which is known as the subcutaneous anterior pelvic fixation (INFIX) technique, has the advantages of convenience, minimal invasiveness and blood loss, and less discomfort for patients with anterior pelvic ring injury [9, 10]. However, there is limited evidence for the efficacy of INFIX and many aspects require

improvement such as the persistence of pubic pain, soft tissue irritation, loss of reduction, and especially fixator loosening [5, 11].

We previously showed that modified pedicle screw-rod fixation (MPSRF) can lead to more rapid recovery from anterior pelvic ring fractures [12]. However, it is unclear how it compares to INFIX in terms of strength and stability. To address this question, in the present study we compared the two methods by assessing radiologic reduction, functional outcomes, and associated complications. We also examined the postoperative biomechanical characteristics of the implants when patients assumed single-/dual-leg standing and sitting postures by finite element analysis (FEA), a computational method for assessing and predicting the outcome of surgery that eliminates variations in bone quality, fracture pattern, bone anatomy, and fixation location upon application of physiological loads [13] that has been used in various pelvic fracture models [14, 15].

Methods

Patients and methods

This retrospective study was reviewed and approved by the Ethics Committee of Zhongshan Hospital. All procedures were performed in accordance with the Declaration of Helsinki and strictly adhered to institutional guidelines. A total of 63 patients with anterior pelvic ring injury admitted to Zhongshan Hospital or its Qingpu branch were enrolled from January 2014 to January 2017, with a minimum follow-up of 13 months. Inclusion criteria were unstable anterior pelvic ring fracture with a stable posterior ring (either intact or recovered after fixation) diagnosed by the senior trauma surgeon, hemodynamic stability, and full consciousness. Patients with an open contaminated wound, who were lost to follow-up before 3 months, had a pathologic fracture, or were < 16 years of age were excluded (Fig. 1).

The pelvis of each patient was examined by preoperative radiography (including anterior-posterior [AP], inlet, and outlet views) and computed tomography (CT) in order to fully evaluate fracture-dislocation. Imaging data were analysed by 2 senior orthopedists according to the Arbeitsgemeinschaft für Osteosynthesefragen (AO) and Orthopaedic Trauma Association (OTA) modified tile type classification. Post-surgery clinical outcome was assessed based on Tornetta and Matta grade, Majeed score, and complications.

Surgical technique

If required, surgical reduction of the posterior pelvic ring injury was performed prior to fixation as previously described [12]. For MPSRF, a 3- to 4-cm oblique incision was made over each anterior inferior iliac spine (AIIS). A bony tunnel from the AIIS to the posterior superior iliac spine was created with a pedicle finder. A polyaxial pedicle screw with a diameter of 7 mm and length of 60 mm was inserted into the tunnel to a depth of about 2 cm from the bone surface to avoid compression of vascular tissue. A subcutaneous tunnel was created from the incisions at bilateral AIIS to the Pfannenstiel incision over the deep fascia. The curved titanium rod was inserted to connect the 3 bilateral pedicle screws via the

subcutaneous tunnel. After confirming that there was sufficient space between the rod and bone by fluoroscopy, the screws were tightened with a torque screwdriver, with those at bilateral AIIIS tightened before the one at the pubic tubercle. A representative case is shown in Supplementary Fig. 1 (S1).

The INFIX was inserted in the same manner. Briefly, 2 polyaxial pedicle screws were placed at bilateral AIIIS. A subcutaneous tunnel was created from 1 side of the AIIIS to the other, and the precontoured titanium rod was connected to the 2 screws via the tunnel. Fracture reduction was performed by the same method as described above. A representative case is shown in Supplementary Fig. 2 (S2).

Postoperative management and follow-up

Functional exercises of the lower limbs and joints were initiated in bed as early as possible after the operation to prevent deep vein thrombosis; regular wound and dressing care was performed in the outpatient clinic until sutures were removed at 2 weeks post-surgery. Crutch-assisted partial weight bearing was permitted at 6 and 10 weeks for AO/OTA type B and C injuries, respectively, as long as the pain was tolerable. Full weight bearing was allowed if osseous union was confirmed by radiography. Physical therapy was prescribed for muscle strengthening and gait training. Hardware removal was performed between 12 and 14 months after the surgery.

Patients were followed up by phone or at the clinic. Routine follow-ups were scheduled for postoperative weeks 4 and 8 and months 6, 12, 18, and 24. Radiographic images included a 3-view (AP, inlet, and outlet) pelvis series and all patients were asked about pain, numbness, and motor ability at each follow-up. Physical and neurologic examinations were performed to evaluate irritation around the implant as well as the condition of the lateral femoral cutaneous nerve (LFCN) and femoral nerves.

Radiographic and functional outcome assessment

The extent of fracture reduction was evaluated by postoperative X-ray examination and graded according to the method of Tornetta and Matta [16] as excellent (displacement ≤ 4 mm), good (5–10 mm), fair (10–20 mm), or poor (displacement > 20 mm). A grade of excellent or good was regarded as a satisfactory outcome.

Clinical outcome measures included operation time, hospital stay, intraoperative blood loss, and postoperative complications. The Majeed rating system was used to assess functional outcome at 6 months, the time of implant removal (10–14 months), and last follow-up; the variables were pain (30 points), standing (36 points), sitting (10 points), sexual intercourse (4 points), and work (20 points). Aggregate scores were classified as excellent (> 85), good (70–84), fair (55–69), or poor (< 55) [17].

FEA

In order to define the solid geometry of the pelvis, we constructed a model of the pelvis of a healthy 32-year-old male (height, 175 cm and weight, 73 kg) based on images from a CT scan. The material properties of the model were obtained from previous studies (Table 3) [1]. A 2-cm gap was created at the

right superior and inferior rami to simulate injury using Geomagic Studio software (3D Systems Inc, Rock Hill, SC, USA). 3-Dimensional models of the rod and screws were constructed using Creo v3.0 software (Parametric Technology Corp, Needham, MA, USA). The materials for the different models and implants were assumed to be elastic, isotropic, and linear. A value of 0.33 was set as Poisson's ratio (ν) for both cortical and cancellous bone.

Table 3
Material properties used in the finite element models.

Material	Elastic Modulus(MPa)	Poisson Ratio(ν)
Sacrum cortical bone	6200	0.33
Ilium cortical bone	17000	0.33
Sacrum cancellous bone	1400	0.30
Ilium Cancellous bone	130	0.20
Screws/rod	110000	0.30
Cartilage	60	0.30

Models of the intact pelvis and injured pelvis with the 2 types of fixation were imported into Workbench v.17.0 software (ANSYS Inc, Canonsburg, PA, USA) to analyse equivalent von Mises (VM) stress and displacement. We performed convergent analysis to balance the accuracy and efficiency of the finite element simulation by adjusting element size. Interaction surfaces including sacrum, sacroiliac cartilage ilium, pubic rami, and bone implant were fully constrained and a vertical load of 600 N was imposed on the superior surface of sacrum to simulate upper body weight. The unilateral (left/right) acetabulum, bilateral acetabulum, and bilateral ischium were fully constrained to simulate single-leg (left/right) and dual-leg standing and sitting postures, respectively (Supplementary Fig. 3).

Statistical analysis

Data were analysed using SPSS v20.0 software (SPSS Inc, Chicago, IL, USA). Data satisfying the conditions of normality are presented as means \pm standard deviation; non-normal data are presented as medians and quartiles. Differences in categorical variables (e.g. postoperative complications) were assessed with the chi-squared test or Fisher's exact test, whereas differences in continuous variables were evaluated with the Student's t test when the assumptions of normality were valid. A P value $<$ 0.05 was considered significant.

Results

Clinical outcome

A consecutive series of 63 patients with type B (type B1, n = 11; type B2, n = 32; type B3, n = 9) and type C (type C1, n = 6; type C2, n = 5; and 0 type C3) fractures were enrolled. The causes of injury were traffic accident (n = 25), fall (n = 21), and other (n = 14). Average age and sex ratio did not differ between the 2 groups (P > 0.05). The mean injury severity score of patients who underwent INFIX was 25 points (range, 19–29 points); that of patients who underwent MPSRF was 22 points (range, 19–29 points). The 2 groups were similar with respect to OTA classification and causes of injury as well as time to pelvic surgery (P > 0.05). However, the INFIX group had longer operation time and greater blood loss than the MPSRF group. There was also a statistically significant difference between the 2 groups in terms of hospital stay (Table 1).

Table 1
The demographics of two groups (ISS, injury severity score).

Parameter	MPSRF group(n = 30)	INFIX group(n = 33)	P value
Age(years)	34.4 ± 17.5	36.2 ± 16.9	0.856 ^a
Gender (male/female)	16/14	20/13	0.560 ^{b1}
ISS	22(19, 29)	25(21, 32)	0.283 ^a
AO/OTA/modified Tile type	4/15/6	7/17/3	0.136 ^{b2}
B1/B2/B3	2/3/0	4/2/0	N/A
C1/C2/C3	13	15	N/A
Injury mechanism	11	10	
Traffic injury	6	8	0.846 ^{b1}
Falling injury	5(0, 14)	6(0,16)	N/A
Other	77.3 ± 11.2	52.6 ± 12.9	N/A
Time to surgery(d)	103.6 ± 10.2	87.7 ± 9.3	N/A
Operation time(min)	11(7, 18)	14(8, 21)	0.782 ^d
Intraoperative blood loss (ml)			0.015 ^a
Hospital stays (days)			0.036 ^a
			0.028 ^a
a: Two-sample t-test. b1: Pearson Chi-squared Test. b2: Cochran-Mantel-Haenszel Test.			
c: Fisher's Exact Test d: Log Rank Test N/A: Not applicable			

The median follow-up was 20 months (range, 13–27 months) in the INFIX group and 22 months (range, 17–30) in the MPSRF group. All patients' fractures healed without incident after the operation. For Tornetta and Matta grade, the MPSRF group had a higher satisfactory rate ([“Excellent” + “Good”] / total number of patients) compared to the INFIX group (73.33% vs 63.63%), but the difference was not statistically significant (P = 0.409). The MPSRF group had a higher Majeed score than the INFIX group at 6 months post-surgery (P < 0.001) and at the time of implant removal (P = 0.012). However, there was no difference in the scores of the two groups at 22 months (Table 2).

Table 2
Postoperative functional outcome grading and complications.

	Modified group (n = 30)	Conventional group (n = 33)	P value
Tornetta and Matta grading			0.037 ^{b2}
Excellent	12	6	N/A
Good	13	15	N/A
Fair	4	9	N/A
Poor	1	3	N/A
Satisfactory rate	22/30, (73.33%)	21/33, (63.63%)	0.409 ^{b1}
The Majeed score			N/A
Postoperatively 6 months	81.5 ± 10.4	76.3 ± 11.2	< 0.001 ^a
The time of implant removal	84.8 ± 8.63	80.7 ± 7.37	0.012 ^a
The last follow up(22 months)	88.4 ± 7.12	87.6 ± 6.45	0.065 ^a
Postoperative complications (n)	12	14	0.307 ^c
LFCN irritation (n)	10	8	N/A
Femoral nerve palsy (n)	1	0	N/A
Tardive impingement pain (n)	0	1	N/A
Infection	1	2	N/A
Implant loosening	0	3	N/A
a: Student t-test. b1: Pearson Chi-squared test. b2: Cochran-Mantel-Haenszel Test.			
c: Fisher's Exact Test. N/A: Not applicable			

Complications

LFCN irritation was observed in 10 patients (33.3%) in the MPSRF group and 8 patients (24.2%) in the INFIX group. The symptoms mainly manifested as anterolateral skin numbness of the affected thigh. In most cases this was alleviated by physical therapy at postoperative month 6, and nearly two-thirds of the 26 patients recovered after implant removal. There was 1 case of unilateral femoral nerve palsy immediately after the operation in the MPSRF group, and 1 patient complained of tardive impingement pain without motor dysfunction at 3 months post-surgery in the INFIX group. Additionally, 3 patients who underwent INFIX experienced implant loosening (Table 2).

Biomechanical characteristics of intact model

We constructed, meshed, and solved models of an intact pelvis and injured pelvises with 2 types of fixation in single- (right/left) and dual-leg standing and sitting postures. Displacement distribution and VM stress of the intact pelvis were bilaterally symmetric and centered on the sacrum in the dual-leg standing and sitting postures. The maximum stress was 28, 30, 21, and 18, MPa on the right face of the sacrum in the single-leg (left/right) and dual-leg standing and sitting postures, respectively (S1 B).

Evaluation of fixation stability in the injury model

A lower maximum displacement of the pelvis in the model indicates higher stability or fixation stability. For the finite element models in the 4 postures, the injury model treated by MPSRF had lower maximum pelvis displacement than that treated by INFIX, especially in the sitting posture (0.37 vs 0.21 mm) and single-leg standing posture (left, 0.51 vs 0.38 mm and right, 0.56 vs 0.42 mm), indicating that MPSRF had greater stability (Supplementary Fig. 4). Moreover, maximum pelvis displacement in the injury model treated by MPSRF was comparable to that of the intact pelvis. Maximum VM stress was slightly higher in the injury model treated by INFIX on the face of the sacrum compared to the MPSRF-treated and intact models, with a maximum VM stress in the single-leg (left) posture of 57.3 MPa vs 21 and 28 MPa, respectively (Figs. 2 and 3), which was consistent with the observed trend in maximum pelvis displacement. Thus, the injured pelvis showed greater stiffness when treated by MPSRF compared to INFIX.

Risk of implant failure and micromotion in the injury model

A lower maximum implant displacement indicates a lower risk of implant failure and micromotion and higher fixation stability. For the finite element models in the 4 postures, the injury model treated by MPSRF had 30% and 36% lower maximum displacement compared to the INFIX-treated model in the standing posture (0.40 vs 0.28 mm) and sitting posture (0.30 vs 0.19 mm), respectively, indicating a lower risk of implant failure and micromotion (Supplementary Fig. 4).

A lower maximum VM stress represents a lower risk of pelvic breakage. Maximum implant stress was slightly higher in the injury model treated by MPSRF compared to INFIX in all 4 postures (Supplementary Fig. S4). However, maximum VM stress occurred at the central region of the third pedicle screw of the pubis in the model treated by MPSRF in the standing and sitting postures (Figs. 2D and 3D), implying a lower risk of micromotion. In the single-leg (left/right) posture, the maximum VM stress was on the side opposite to the implant in the INFIX model but on the same side in the MPSRF model (Figs. 2D and 3D). Taken together, the FEA results indicate that anterior pelvic ring fractures treated by MPSRF are stiffer, have greater fixation stability, and lower risk of implant failure than those treated by INFIX.

Discussion

Unstable pelvic ring injuries typically result from high-energy trauma and are considered by orthopaedic surgeons as one of the most clinically challenging lesions. Minimally invasive fixation of pelvic fractures as an adjunct to posterior fixation is becoming more common and can effectively improve anterior pelvic

stability and restore function in the pelvis, while being associated with minimal traumatic invasion and fewer complications [18]. INFIX is a technique in which pedicle screws are placed on the supra-acetabular corridor with a crossrod in the bikini area [19]. INFIX has recently emerged as an alternative to traditional surgical methods with the advantages of few soft tissue complications, improved biomechanical construction, and no disruption of sitting posture or screwdriver function. MPRSF combines the advantages of INFIX and pelvic bridging. The safety and effectiveness of minimally invasive fixation of pelvic fractures have been demonstrated by several anatomic and clinical studies, although fixation stability remains a concern [20, 21]. Additionally, few studies have investigated whether these 2 fixation techniques lead to sufficiently strong implants and adequate biomechanical reduction.

The FEA results showed that displacement distribution and VM stress were similar in the injured pelvis models treated by MPRSF and INFIX compared to the intact pelvis, indicating that both fixation techniques can effectively treat anterior pelvic ring fractures. However, maximum displacements of the pelvis and implant were lower in the MPRSF group than in the INFIX group in the single- (left/right) and dual-leg standing and sitting postures, indicating greater stability. On the other hand, the injury model treated by MPRSF showed slightly higher maximum implant stress compared to the INFIX group in all 4 postures, which may be attributable to part of the stress being concentrated on the third screw and obstructing implant micromovement.

Although the MPRSF group had a longer operation time and greater intraoperative blood loss, there were no significant differences in hospital stay and postoperative complications between the 2 groups. Thus, MPRSF only expanded the local skin incision without causing permanent neurovascular injury and did not increase the risk of postoperative complications. However, radiographic (Tornetta and Matta grade) and functional (Majeed score) outcomes of the MPRSF group were improved compared to the INFIX group, especially at 6 months after surgery. Thus, while both fixation methods can restore stability to the anterior pelvic ring and pelvic function, MPRSF promotes the latter at an earlier time point following operation.

LFCN irritation is the most common postoperative iatrogenic complication [22]. In a multicentre review, 30% (21/91) of patients had LFCN irritation although in most cases it was self-limiting and improved once the implant was removed [5]. In line with this study, in our investigation the rate of LFCN injury was 33.3% (10/30) in the MPRSF group and 24.2% (4/33) in the INFIX group. A case series of LFCN irritation suggested that screws that are too deeply or insufficiently embedded in the bone and inadequate pre-bending of the rod can lead to irritation of the LFCN and sartorius muscle. To prevent this, a rod-to-bone distance of 20–25 mm (30–40 mm for obese patients) but < 40 mm is recommended [23]. We first locked the screws at bilateral AIIS so that the pullout strength of the screw was mainly concentrated in the supra-acetabular region, where bone density is high. The screw at the pubic tubercle—which has relatively sparse bone—was then locked, thus providing auxiliary support. Furthermore, additional screws should not be placed too close to the lateral pubis to avoid damaging the spermatic cord or round ligament. For unilateral pubic rami fractures, the screw was fixed into the fracture side if the fracture line was far away

from the pubic symphysis; otherwise, it was inserted on the uninjured side. For bilateral pubic rami fractures, the screw was fixed into the side with less injury.

Recent studies using the INFIX or MPRSF technique have reported potentially devastating complications, especially femoral nerve palsy. There was one such case in the MPRSF group, but symptoms gradually disappeared once emergency screw adjustment was performed, and there was no permanent nerve damage after implant removal. In a case series of iatrogenic femoral nerve palsy, it was suggested that femoral nerve compression occurs as a result of impingement of the implant on the psoas sheath; meanwhile, delayed palsy may be caused by engorgement of the psoas with blood and/or a change in pressure [24]. The authors noted that this could be avoided by placing the interconnecting rod in such a way that it does not limit the space for the psoas and femoral nerve. Our solution for reducing neurovascular compression was to bend the connecting rod outward in the horizontal direction (Fig. 4). Although follow-up is ongoing, the patient's neurovascular compression symptoms have been significantly alleviated.

Despite the positive clinical outcomes and FEA results, our study had several limitations. Firstly, this was a single-centre retrospective study with a relatively small sample size; more cases should be examined in a multicentre investigation, with long-term functional assessment. Secondly, the characteristics of the implant materials are not consistently reported; as such, our results depend on input parameters. Additionally, the FEA model was patient-specific and ignored the effects of ligaments and muscles on the stability of the pelvis and implant devices. Finally, the angle of applied force was constant although variations in the angle may have influenced VM stress and displacement, as reported in a previous study [25].

Conclusion

In conclusion, our study demonstrates that both MPRSF and INFIX used as a minimally invasive procedure in the treatment of unstable pelvic anterior ring fracture provides adequate biomechanical stability. However, fixation stability was greater with MPRSF than with INFIX, which was associated with a lower risk of implant failure according to the results of FEA. Combined with the superior clinical and radiologic outcomes associated with external fixation, MPRSF is the preferred option for the treatment of unstable pelvic anterior ring fractures.

Abbreviations

AIS, anterior inferior iliac spine; AO, Arbeitsgemeinschaft für Osteosynthesefragen; AP, anterior-posterior; CT, computed tomography; FEA, finite element analysis; INFIX, anterior subcutaneous internal pelvic fixation; LFCN, lateral femoral cutaneous nerve; MPRSF, modified pedicle screw-rod fixation; OTA, Orthopaedic Trauma Association; VM, von Mises.

Declarations

All procedures were performed in accordance with the Declaration of Helsinki and strictly adhered to institutional guidelines.

Availability of data and materials

The datasets used and/or analysed during the current study are available from the corresponding author on reasonable request.

Competing interests

The authors declare that they have no competing interests.

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Authors' contributions

ZR, SD, and FC conceived and devised the study. SD, FC, and JH performed the study. JH, MG, FW, and JL analyzed the data. SD, ZR and FC wrote the paper. ZR and XW revised the manuscript. ZR obtained the funding and supervised the whole project. All authors have contributed to the final version and approved the publication of the final manuscript.

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Figures

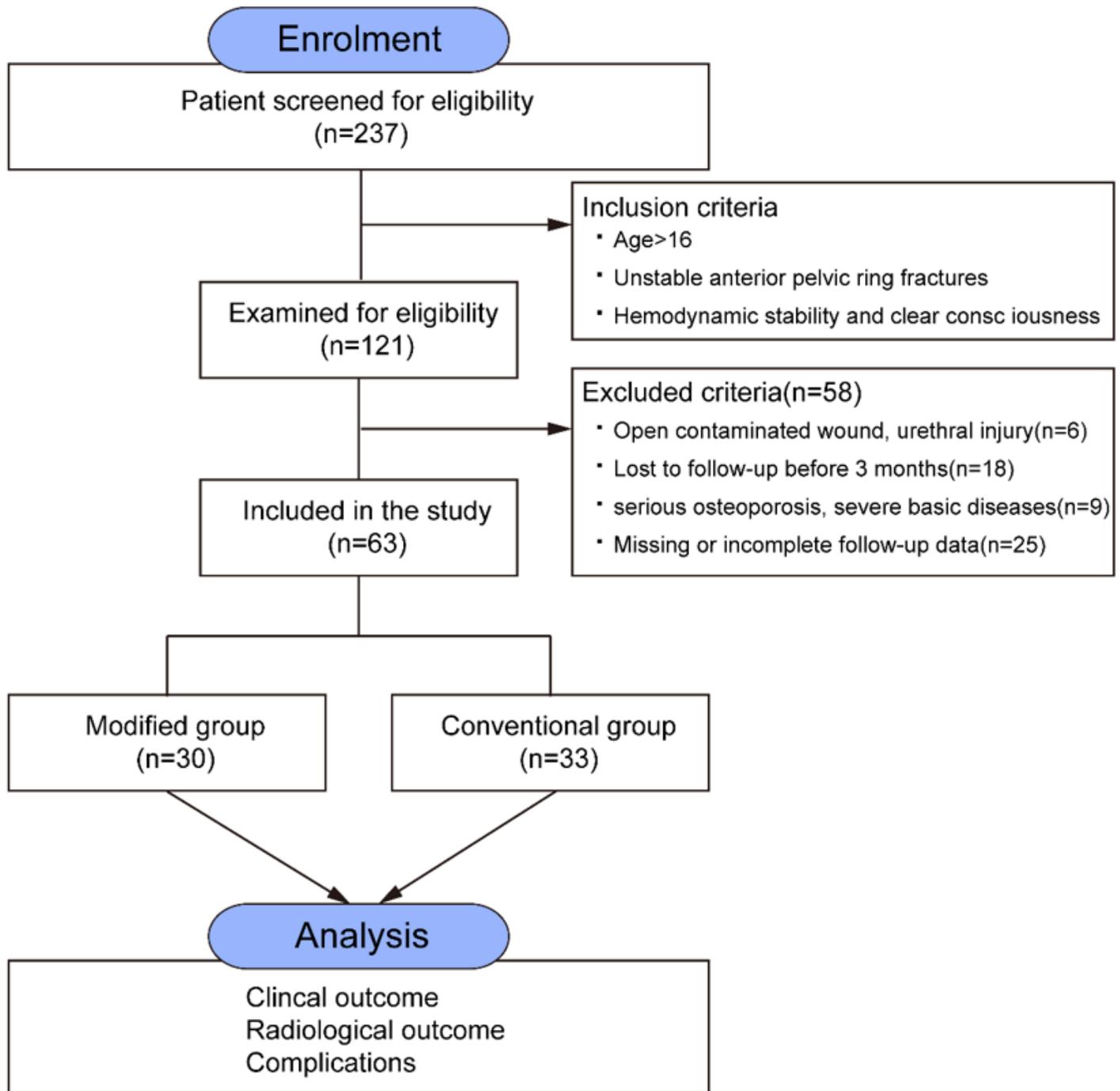


Figure 1

Flow diagram of patient's exclusion. 63 patients with anterior pelvic ring injuries were enrolled from January 2014 to January 2017 in our institution.

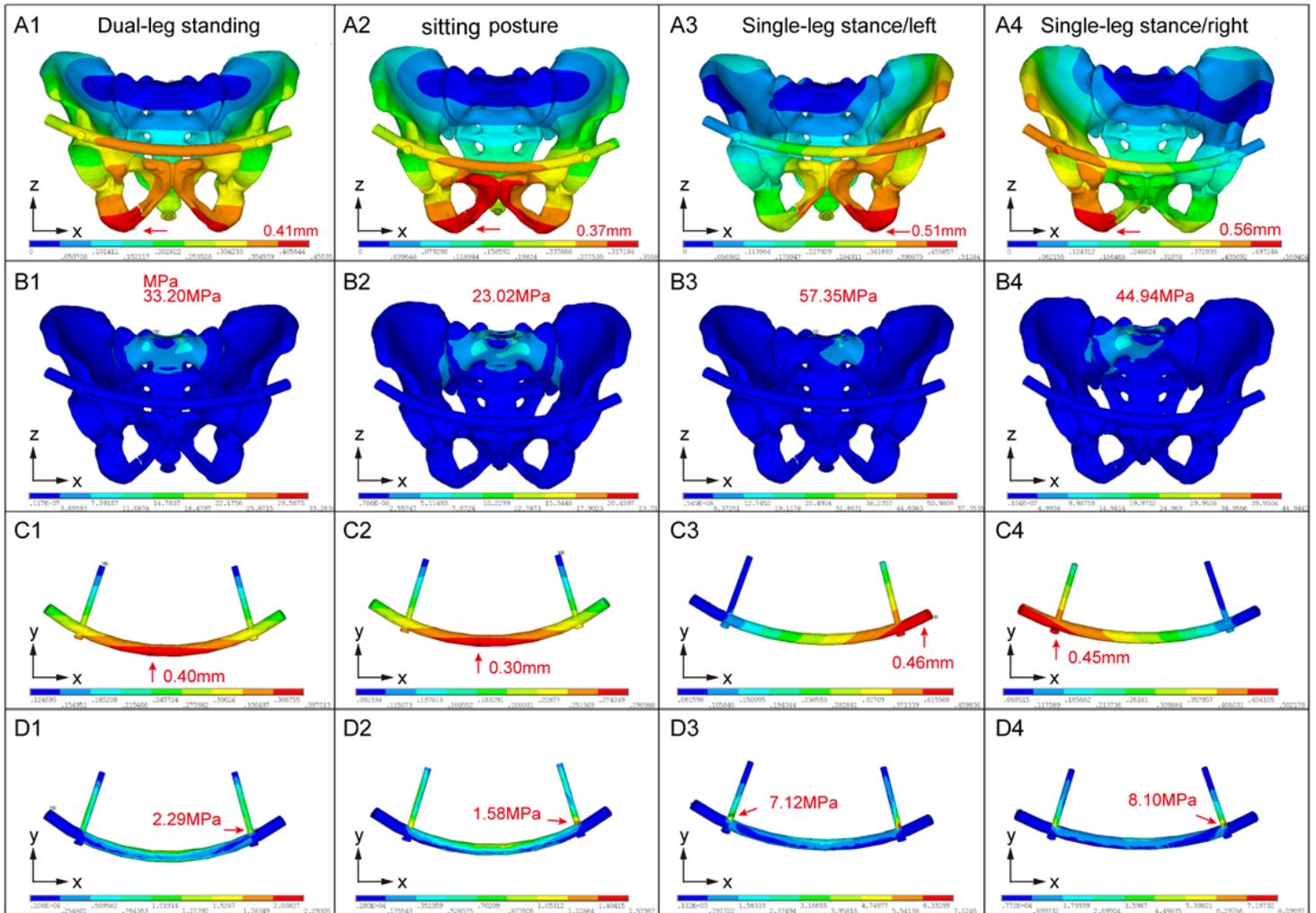


Figure 2

FE injured model using INFIX under four posture. including the dual-leg standing, sitting posture and single-leg stance(left/right). A: The displacement of the injured pelvis with INFIX. B: The Von Mises stresses applied to the injured pelvis with INFIX. C: The displacement of the implant device. D: The Von Mises stresses applied to the implant device.

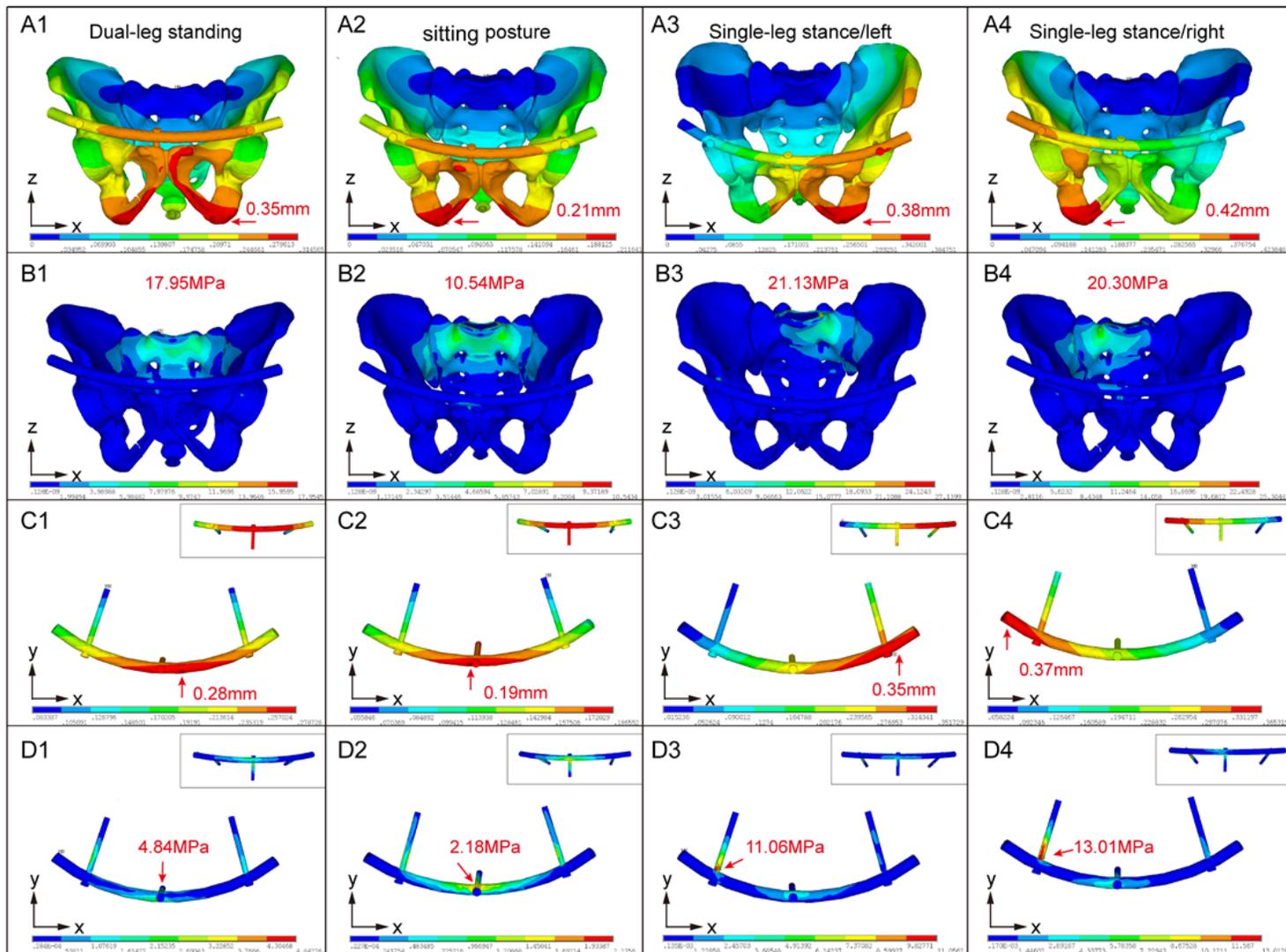


Figure 3

FE injured model with MPSRF under four posture. including the dual-leg standing, siting posture and single-leg stance(left/right). A: The displacement of the injured pelvis with MPSRF. B: The Von Mises stresses applied to the injured pelvis with MPSRF. C: The displacement of the implant device. D: The Von Mises stresses applied to the implant device.

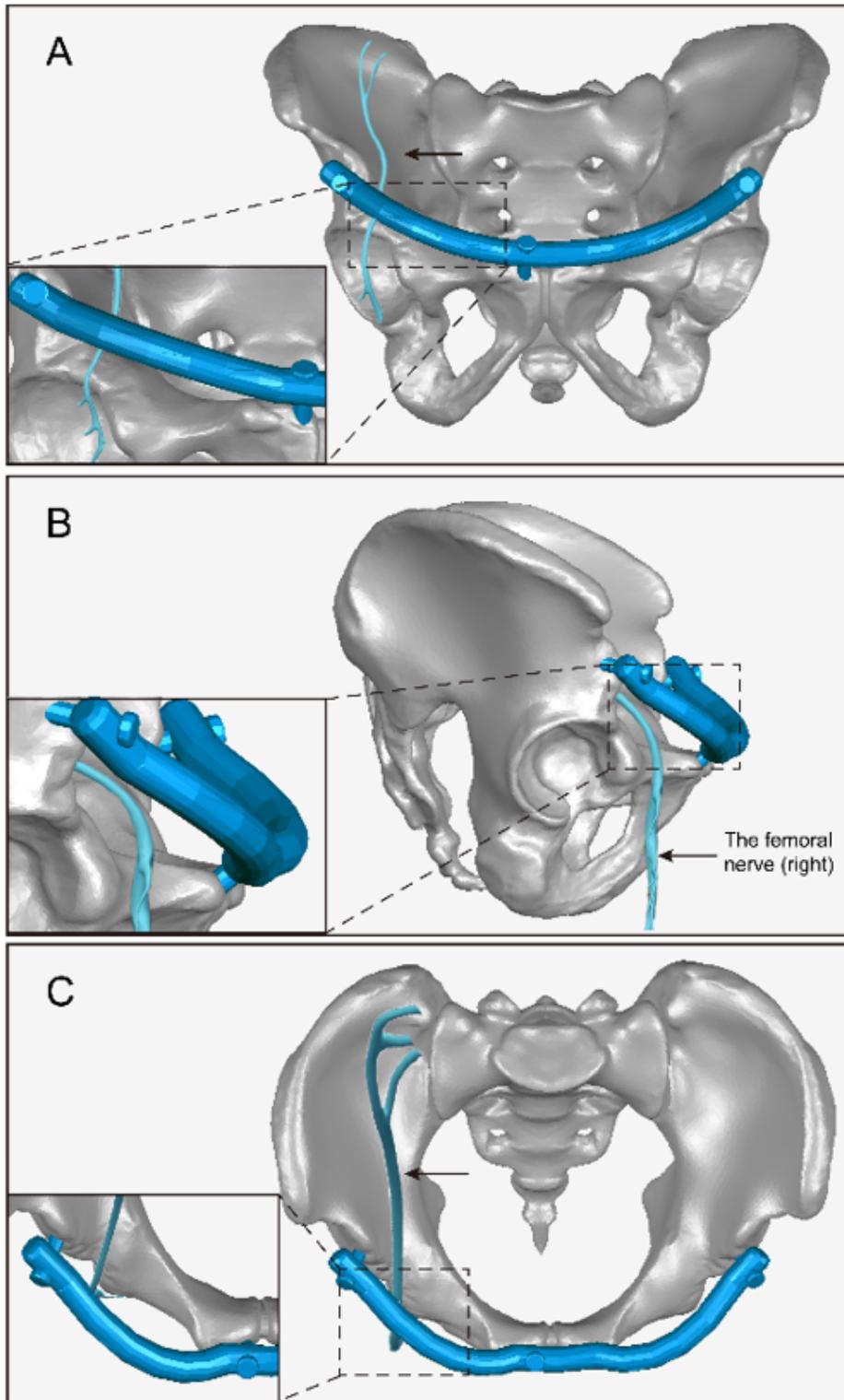


Figure 4

The diagram of the improvement applied to the MPSRF. The diagram of the improvement applied to the MPSRF, bending the connecting rod outward in the horizontal direction.

Supplementary Files

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- [Supplement.docx](#)