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Original Article

Combined anterior and posterior ring fixation versus posterior ring fixation alone in the management of unstable Tile B and C pelvic ring injuries: A randomized controlled trial

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ABSTRACT

Purpose: Combined anterior and posterior ring (APR) fixation is classically performed in Tile B2 and C1 injuries to achieve superior biomechanical stability. However, the posterior ring (PR) is the main weight bearing portion that is responsible for weight transmission from the upper parts of the body to the lower limbs through the sacrum and the linea terminalis. It is hypothesized that isolated PR fixation can achieve comparable radiological and clinical outcomes to APR fixation. Therefore, we conducted this study to compare the two fixation principles in managing Tile B2 and C1 injuries.

Methods: Our study included 20 patients with Tile B2 injuries and 20 patients with Tile C1 injuries. This study was a randomized control single-blinded study via computerized random numbers with a 1:1 allocation by using random block method. The study was performed at a level one trauma center. A total of 40 patients with Tile B2 and C1 injuries underwent combined APR or isolated PR fixation (Group A and B, respectively). Matta & Tornetta radiological principles and Majeed pelvic scoring system were used for the assessment of primary outcomes and postoperative complications. Secondary outcomes included operative time, amount of blood loss, intraoperative assessment of reduction, need of another operation, length of hospital stay, ability to weight bear postoperatively and pain control metrics. We used student *t*-test to compare the difference in means between two groups, and Chi-square test to compare proportions between two qualitative parameters. We set the confidence interval to 95% and the margin of error accepted to 5%. So, $p \leq 0.05$ was considered statistically significant.

Results: The mean follow-up duration was 18 months. The operative time (mean difference 0.575 h) and the intraoperative blood loss (mean difference 97.5 mL) were lower in Group B. Also, despite the higher frequency of rami displacement before union in the same group, there were no significant differences in terms of radiological outcome (excellent outcome with $OR = 2.357$), clinical outcome (excellent outcome with $OR = 2.852$) and postoperative complications assessment ($OR = 1.556$) at last follow-up.

Conclusion: The authors concluded that isolated PR fixation could favorably manage Tile B2 and C1 pelvic ring injuries with Nakatani zone II pubic rami fractures and intact inguinal ligament. Its final radiological and clinical outcomes and postoperative complications were comparable to combined APR fixation, but with less morbidity (shorter operation time, lower amount of blood, and no records of postoperative wound infection).

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Introduction

Marvin Tile[1] classified pelvic ring injuries according to rotational and vertical stability into three types A, B and C. Among them, Tile B2 injuries are lateral compression injuries that are rotationally unstable but vertically stable. In contrast, Tile C1 injuries are completely unstable injuries: iliac fractures, sacro-iliac (SI) fracture-dislocations, or sacral fractures (Fig. 1). Tile B and C pelvic ring injuries are mainly caused by high-energy trauma (the exception is fragility fractures in the elderly population). Therefore, they are associated with multiple injuries and extensive soft tissue morbidity.[2] In such injury patterns, anterior pelvic ring disruption takes one of the following two forms: a symphysis ligamentous disruption in anteroposterior compression types II and III injuries that require stabilization[3], or in the form of rami fractures without an element of ligamentous disruption that are much more stable by the support of the surrounding soft tissue.[4]

The development of percutaneous technique for the superior pubic rami fixation has led to a topographic classification for these fractures called Nakatani classification.[5] He classified the pubic rami into three zones: type I fractures occur in medial to the obturator foramen, type II fractures occur at the middle one-third of the superior pubic rami, and type III fractures occur in lateral to the obturator foramen.

The aim for surgical treatment of unstable Tile B2 and C1 pelvic ring injuries is anatomical reduction to allow early weight-bearing and pain relief, as well as to prevent future pelvic asymmetry. So, we usually used combined anterior and posterior ring (APR) fixation[6], relying on the fact that adequate reduction and fixation of anterior pelvic ring enhance better fixation of posterior ring (PR) and stability overall pelvic.[7] However, anterior ring fixation requires a second incision with a longer operation time and more blood loss.[8,9] The main disadvantage of the second incision is the higher risk of wound infection either superficial or deep, which questions its necessity and raises concerns about the possibility of isolated PR fixation in managing Tile B2 and C1 pelvic ring injuries with good outcomes.[9]

The fundamental algorithm was the questionable need for additional anterior ring fixation in managing Tile B2 and C1 pelvic ring injuries combined with PR fixation, whether the incidence of postoperative complications, radiological and clinical outcomes differed between these two groups. After reviewing the literature, we found a lack of knowledge in the prospective assessment of such outcomes between the two fixation groups. So, this randomized controlled trial aims at proving or denying the need for anterior ring fixation in managing Tile B2 and C1 pelvic ring injuries.

Methods

After obtaining the Hospital Research/Ethics Committee approval (Federal Wide Assurance: FWA 000017585 approval FMASU MD 272/2019) and written informed consent from the patients, we carried this study prospectively on 46 patients with Tile B2 and C1 injuries between March 2019 and July 2020, but only 40 patients were included because follow-up data of 6 patients were lost. We screened all patients for enrollment by detailed clinical assessment of their history, physical examination and radiological investigations: plain X-rays pelvis (both hips including anteroposterior, inlet and outlet views) and CT pelvis. Inclusion criteria in the study were: patients with Tile B2 and C1 pelvic ring injuries, Nakatani zone II pubic rami fractures with intact inguinal ligament (more stable injuries), recent pelvic ring injuries less than three weeks (amenable to closed reduction techniques in isolated PR fixation group), and age group between 16 – 60 years old. Exclusion criteria in the study were: patients with Tile A pelvic ring injuries, Nakatani zone I and III pubic rami fractures (more unstable injuries with a higher risk of malunion or delayed union), neglected pelvic ring injuries exceeding three weeks, aged less than 16 and over 60 years old, and associated urogenital or abdominal injuries. We enrolled in our study those who met the inclusion criteria.

We considered the randomized controlled trial with an important research question: whether we needed anterior ring fixation in managing Tile B2 and C1 pelvic ring injuries combined with PR fixation or not. The hypothesis was that PR fixation is at least as good as APR fixation. An independent doctor created the randomization sequence using Excel 2016 (computerized random numbers) with a 1:1 allocation via random block sizes of two, four and six. He assigned the sample numbers equally to each group and assigned the block. Patients and physicians allocated to each intervention group were aware of the allocation, but the data analysts and the outcome assessors were kept blinded to the allocation.

We prospectively carried out this study on 46 patients with Tile B2 and C1 injuries between March 2019 and July 2020 that met our inclusion criteria. The independent doctor allocated the 46 cases to 2 groups: Group A (23 cases) managed by APR fixation, Group B (23 cases) managed by PR fixation. However, records were complete in 40 patients (87%) in the prospective analysis, of which six were lost at follow-up (Fig. 2). Each group included 10 cases with Tile B2 (lateral compression type II injuries) and 10 cases with Tile C1 injuries (vertical shear injuries). The mean age of the patients was 30 years old, and the mean injury severity score in Group A was 24.9 and 22.5 in Group B (Table 1). We used SI screws or Iliac wing plating for PR fixation and anterior ring plating for anterior ring

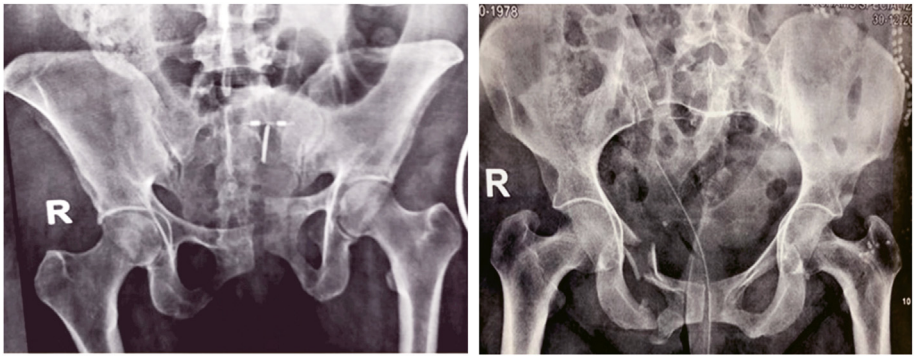

Fig. 1. Preoperative X-rays show Tile B2 and C1 injuries, respectively.

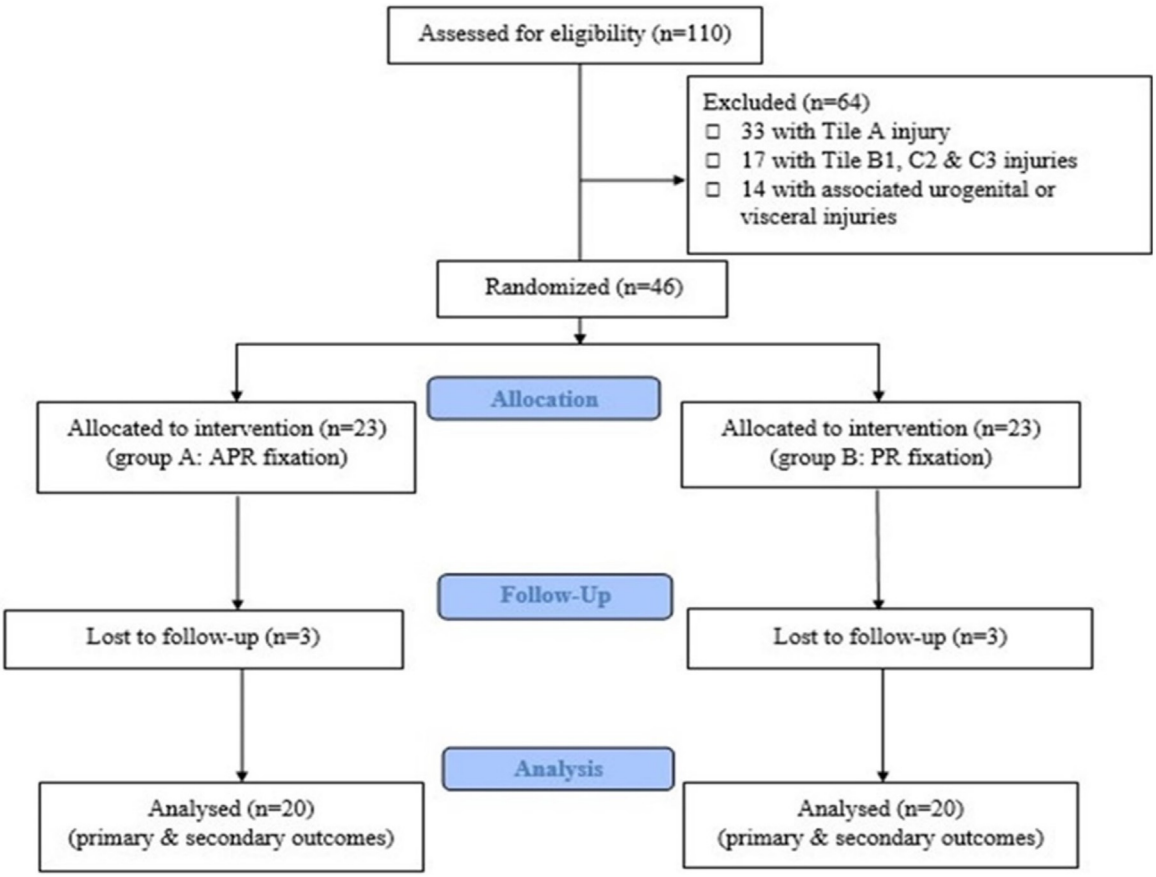

Fig. 2. Consort flow diagram of the study group.

Table 1
Preoperative data of the study group ($n = 20$, each group)

Variables	Mean or value		SD or percentage	
	Group A	Group B	Group A	Group B
Age (year)	28.20	31.45	10.11	13.62
Sex, *n* (male/female)	11/9	12/8	27.5%/22.5%	30.0%/20.0%
Young Burgess classification, *n*	LC II, 10	LC II, 10	25.0%	25.0%
	Vertical shear, 10	Vertical shear, 10	25.0%	25.0%
Tile classification, *n*	Tile B2, 10	Tile B2, 10	25.0%	25.0%
	Tile C1, 10	Tile C1, 10	25.0%	25.0%
Fixation technique, *n*	SI screw + pubic rami plating, 14	SI screw, 12	35.0%	30.0%
	Iliac wing plating + pubic rami plating, 6	Iliac wing plating, 8	15.0%	20.0%

ISS: injury severity score, SI: sacro-iliac, LC: lateral compression, SD: standard deviation.

fixation. A single SI screw was used in the APR fixation group, while we used two SI screws through the body of the first and second sacral vertebrae in the PR fixation group. In addition, we used a single para-symphyseal plate in Tile B2 injuries, while we used double superior and anterior symphyseal plates in Tile C1 injuries.

Reduction of PR was either closed reduction of SI joint dislocations, fracture-dislocations and sacral fractures or open reduction in iliac wing fractures through the lateral window of the ilioinguinal approach. In Tile B2 injuries, we performed the closed reduction with the anterior pelvic ring to help correct the posterior pelvic rotational deformities through pelvic sheets or binders, which allows the use of percutaneous SI screws through working portal cutting the circumferential wrap. While Tile C1 injuries showed vertical and posterior translation, vertical displacement was corrected by applying longitudinal axial skeletal traction through the distal femur. Meanwhile, we corrected the posterior displacement by applying a supraacetabular pin connected to a T-handle with a vector of pull anteriorly towards the ceiling (push-pull technique). We performed anterior pelvic ring reduction and fixation in Group A via the classic Pfannenstiel approach, or extended more lateral and completed the anterior intrapelvic approach. Fixation was done via pubic rami plating.

We noted the quality of reduction intraoperatively and graded the results as anatomical reduction, acceptable reduction or non-anatomical reduction.[9] Twenty-eight cases (70%) have anatomical reduction of symmetrical pelvis with no residual vertical or rotational displacements in previous fracture or dislocation gap. Ten cases (25%) have acceptable reduction when the vertical and

Table 2
The mean difference of the outcomes of the two fixation groups.

Variables	Group A (mean ± SD)	Group B (mean ± SD)	*t*-test	*p* value
Operation time (h)	1.98 ± 0.44	1.40 ± 0.35	4.56	< 0.001
Blood loss (mL)	335.00 ± 138.70	237.50 ± 150.33	2.13	0.045
Length of stay (day)	2.05 ± 0.22	2.00 ± 0.32	0.57	0.574

SD: standard deviation.

rotational displacements were measured between 1–2 cm, and non-anatomical reduction happened in two cases (5%) when residual displacement exceeded 2 cm in any direction.

Postoperative management and evaluation

We followed a partially assisted weight-bearing protocol for six weeks for both groups (use axillary or forearm crutches to carry about 50% of the body weight through the injured lower extremity). In addition, X-ray films and neurovascular examination were done postoperatively.

Patients were followed up at two weeks, six weeks, three months, six months and one year postoperatively. Matta & Tornetta radiological principles[10,11] were used to assess the radiological and clinical outcomes via plain X-ray of pelvis showing both hips through anteroposterior, inlet and outlet views, and CT of pelvis if available. We evaluated five criteria on X-ray films postoperatively: residual posterior displacement, vertical displacement, pubic symphyseal translation, sagittal rotation and gapping of the sacroiliac joint. According to the grading of Matta & Tornetta principles, we classified the results as excellent ($\leq$ 4 mm), good (4–10 mm), fair (10–20 mm), and poor (> 20 mm). In addition, clinical assessment was evaluated and calculated by Majeed pelvic scoring system at each follow-up visit and the mean value was presented.[12] And postoperative complications and additional operation were evaluated.

In the 2nd week, we encouraged passive and active-assisted hip movement. Then we started an unassisted weight-bearing and physiotherapy program to strengthen abductors and quadriceps muscles in the 6th week. While complete full weight-bearing and return to work were after three months. After six months, a full radiological and clinical assessment was done. Return to the pre-injury mobility status and athletic sports were achieved in the majority of patients with excellent and good clinical outcomes. After one year, we did clinical and radiological reevaluation.

Statistical analysis

We analyzed the data using statistical program of social science version 20.0. We expressed the quantitative data as mean ± standard deviation (SD), and the qualitative data as frequency and percentage. We calculated the sample size using Epi Info 7 program for sample size calculation, setting alpha error at 5% and power at 80%. According to a previous study by Tsai et al.[13], the expected incidence of excellent radiological outcomes in the study groups were 43% and 68%. Based on this, the needed resultant sample size was 20 cases per group which was enough to detect this difference.

Our study was considered being parametric owing to the normality of the measured quantitative data, of which the sample size is larger than 30 and SD is small compared to the mean. We used student *t*-test to compare the difference in means between two groups, and Chi-square test of significance to compare proportions between two qualitative parameters. We set the confidence interval (*CI*) to 95% and the margin of error accepted to 5%.

Table 3
The percentage difference of the outcomes of the two fixation groups.

Variables	Group A, *n* (%)	Group B, *n* (%)	X^2 value[a]	*p* value
Intra-operative assessment of reduction				
Anatomical reduction	17 (85.0)	11 (55.0)	4.29	0.043
Non-anatomical/acceptable reduction	3 (15.0)	9 (45.0)		
Radiological assessment				
Excellent	14 (70.0)	10 (50.0)	2.82 FE	0.212
Good	4 (20.0)	6 (30.0)		
Fair	2 (10.0)	2 (10.0)		
Poor	0 (0)	2 (10.0)		
Postoperative complications				
Yes	8 (40.0)	6 (30.0)	0.44	0.511
No	12 (60.0)	14 (70.0)		
Need for another operation				
Yes	3 (15.0)	1 (5.0)	1.11 FE	0.613
No	17 (85.0)	19 (95.0)		
Final clinical assessment				
Excellent	14 (70.0)	9 (45.0)	2.97 FE	0.154
Good	6 (30.0)	10 (50.0)		
Fair	0 (0)	1 (5.0)		
Ability to weight bear postoperatively				
Yes	15 (75.0)	14 (70.0)	0.13 FE	0.724
No	5 (25)	6 (30)		
Pain control metrics				
IV Paracetamol	10 (50.0)	12 (60.0)	0.40 FE	0.531
Need for IV opioids	10 (50.0)	8 (40.0)		

[a] Chi-square test (FE: Fisher Exact test), IV: intravenous.

Table 4
Mean difference and 95% *CI* for differences between the two study groups.

Variables	Mean difference	Std. error difference	95% *CI*	
			Lower	Upper
Operation time	0.57500	0.12605	0.31983	0.83017
Blood loss	97.50000	45.73594	4.91243	190.08757
Length of stay (days)	0.05000	0.08811	−0.12837	0.22837

CI: confidence interval.

Table 5
Odds ratio and 95% *CI* for differences between the two study groups.

Variables	Odds ratio	95% *CI*	
		Lower	Upper
Intraoperative assessment of reduction	4.636	1.023	21.004
Excellent radiological assessment	2.333	0.638	8.538
Postoperative complications	1.556	0.420	5.763
Need for another operation	3.353	0.318	35.364
Excellent final clinical assessment	2.852	0.777	10.467
Using Paracetamol pain control metrics	0.667	0.191	2.333
Ability to weight bear postoperative	1.286	0.319	5.175

CI: confidence interval.

So, p value significance was considered: $p \leq 0.05$ (significant), $p \leq 0.001$ (highly significant) and $p > 0.05$ (insignificant). The trial registration number is: NCT05042297.

Results

We followed up the two study groups for periods ranging from 12 to 24 months, and the mean length of follow-up was (18 ± 4.5) months. Radiological assessment, postoperative complications and final clinical outcome were evaluated and compared as primary outcomes, meanwhile mean operation time, intraoperative blood loss, intraoperative assessment of reduction, need for another operation, length of hospital stay, ability to weight bear postoperative and pain control metrics as secondary outcomes (Tables 2–5).

While an analysis of the secondary outcomes showed that the mean operation time and mean blood loss were significantly lower in the PR fixation group (1.4 h and 237 mL) than that in the APR fixation group (2 h and 335 mL). Intraoperative reduction assessment was better in the APR fixation group, with 85% of cases graded as anatomical and 15% as acceptable or non-anatomic, compared with 55% as anatomical and 45% as acceptable or non-anatomic in the PR fixation group. The need for another operation was slightly higher in the APR fixation group (15% of cases) than in the PR fixation group (5% of cases), with no statistically significant difference observed (Tables 2–5).

The mean operative time was 1.7 h with 286 mL mean blood loss. We graded intraoperative assessment of reduction: anatomical in 28 cases, acceptable in 10 cases and non-anatomical in two cases. Postoperative complications were identified in 14 cases (34% of the study group). According to Matta & Tornetta radiological principles[10,11], we graded the radiological assessment: excellent in 24 cases, good in 10, fair in four and poor in two. In addition, three cases required sacroiliac screw removal from the first sacral vertebrae due to screw cutout and we did debridement for one due to superficial wound infection of the Pfannenstiel incision. We managed the other patient with superficial wound infection conservatively via parenteral antibiotics.

The mean Majeed pelvic score at 1-year follow-up was 77.5, excellent in 23 cases, good in 16 and fair in one. The average time to union of the pubic rami was 8–10 weeks with higher displacement before union in the PR fixation group, especially in Tile C1 injuries (9/40) with no significant differences between the two groups. The average length of hospital stay was two days postoperative in both groups.

Table 6
The Majeed clinical score at each follow-up visit.

Time in weeks	Group A ($n = 20$)		Group B ($n = 20$)	
	Mean ± SD	Range	Mean ± SD	Range
Week 6	54.5 ± 11.2	36–67	53.0 ± 10.11	34–66
Week 12	64.0 ± 8.7	42–74.5	62.5 ± 9.1	44–73
Week 24	77.0 ± 5.2	68–80	75.5 ± 4.7	67–80
Week 48	77.5 ± 3.76	70–80	76.0 ± 3.9	68–80

SD: standard deviation.

Table 7
Postoperative complications distribution of the study groups ($n = 14$).

Postoperative complications	Group A, *n* (%)	Group B, *n* (%)
SI screw cutout + LLD	1 (7.14)	1 (7.14)
Foot drop	1 (7.14)	1 (7.14)
Loss of reduction	1 (7.14)	1 (7.14)
Posterior ring malunion or nonunion	2 (14.30)	2 (14.30)
Anterior ring malunion or nonunion	1 (7.14)	1 (7.14)
Wound infection	2 (14.30)	0 (0)

LLD: limb length discrepancy.

After analysis of the primary outcomes of interest, we observed no statistically significant difference in radiological assessment between the two groups, which were graded in the PR fixation group excellent in 50% of cases, good in 30%, fair in 10% and poor in 10%, while in the APR fixation group excellent in 70% of cases, good in 20% and fair in 10%.

We performed the clinical assessment via the Majeed pelvic score at each follow-up visit (out of 80), of which several factors, such as pain, sitting, sexual intercourse, walking aids, gait unaided and walking distance were evaluated.[12] We calculated the mean score at each follow-up visit, which was compared between the two groups (Table 6). No statistically significant difference showed between the two groups. In the PR fixation group, excellent outcome was in 45% of cases, good in 50% and fair in 5%, while in the APR fixation group, excellent in 70% of cases and good in 30%.

We focused the evaluation of postoperative complications on the local complications related to fixation principles and technique rather than general complications related to the patient status and associated injuries (Table 7). The complications rate was slightly higher in the APR fixation group (40%) than that in the PR fixation group (30%) with no statistically significant difference.

We observed a highly statistically significant relationship between operation time and fixation principles, as well as between blood loss together with intraoperative assessment of reduction and fixation principles (Fig. 3). The APR fixation group showed longer operation time, higher amount of blood loss, and more superior intraoperative assessment of reduction than those in the PR fixation group. However, we found no statistical significance

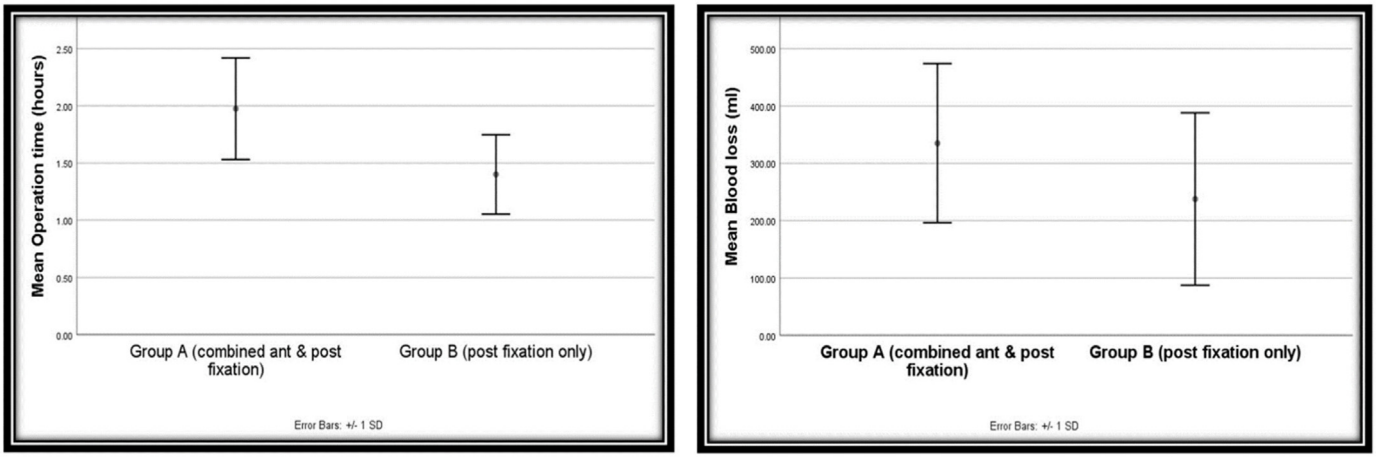

Fig. 3. Error bar relation between mean operation time in hours and fixation principles (highly significant) and between mean blood loss (mL) and fixation principles (significant).

Table 8
Risk analysis for outcome measures with isolated PR fixation (experimental treatment) compared to APR fixation (standard treatment).

Adverse outcome	RR	95% *CI* for RR	Z value	*p* value	ARR†	95% *CI* for ARR‡	NNT§	95% *CI* for NNT¶
Radiological outcome < good	2.00	0.41 to 9.71	0.860	0.390	−0.10	0.12 to - 0.32	−10.00	−3.13 to ∞ to 8.39
Clinical outcome < good	3.00	0.13 to 69.52	0.685	0.493	−0.05	0.05 to −0.15	−21.00	−5.69 to ∞ to 12.44
Postoperative complications	0.75	0.32 to 1.77	0.657	0.511	0.10	0.39 to −0.19	10.00	−5.16 to ∞ to 2.54
Wound infection	0.20	0.01 to 3.92	1.060	0.289	0.10	0.23 to −0.03	10.50	−17.29 to ∞ to 4.03
Operative time > 1.69 h	0.21	0.07 to 0.63	2.790	0.005	0.55	0.80 to 0.30	1.82	1.24 to 3.40
Operative blood loss > 286 mL	0.24	0.10 to 0.58	3.166	0.002	0.65	0.88 to 0.42	1.54	1.13 to 2.41
Intraoperative reduction < anatomical	2.00	0.20 to 20.33	0.586	0.558	−0.05	0.11 to −0.21	−20.0	−4.71 to ∞ to 8.89
Reoperation	0.33	0.04 to 2.94	0.989	0.323	0.10	0.28 to −0.08	10.00	−12.00 to ∞ to 3.53
Inability to weight-bear postoperatively	1.40	0.53 to 3.68	0.683	0.495	−0.10	0.18 to −0.38	−0.00	−2.62 to ∞ to 5.48
Postoperative need for intra-venous opioids	0.80	0.40 to 1.60	0.631	0.528	0.10	0.41 to −0.21	10.00	−4.84 to ∞ to 2.46

RR: relative risk, *CI*: confidence interval, ARR: absolute risk reduction, NNT: number needed to treat, Z: Z statistic.
†: Negatively signed absolute risk reduction (ARR) denotes absolute risk increase (ARI).
‡: 95% CI for ARR that includes the value zero denotes the effect size is not statistically significant at $p < 0.05$ level.
§: Negatively signed number needed to treat (NNT) denotes number needed to harm (NNH).
¶: 95% *CI* for NNT that includes infinity (∞) denotes the effect size is not statistically significant at $p < 0.05$ level.

between radiological outcome, postoperative complications, need for another operation, final clinical outcome, mean clinical score, ability to weight bear postoperative, pain control metrics and fixation principles.

After statistical analysis of the whole study, we analyzed the results using a forest plot analysis (Table 8). The purpose was to show the effect estimates for the primary and secondary outcomes of the two fixation principles (Figs. 4–7). The results showed that only the operative time < 1.69 h and intraoperative blood loss < 286 mL (mean values) are statistically significant favoring isolated PR fixation (experimental treatment) over APR fixation (standard treatment).

Also, we performed a Tile subgroup analysis to compare the two fixation principles in each of Tile B and C injuries separately (Tables 9–12). Tile B injuries showed no statistically significant differences between the two fixation principles regarding the primary and secondary outcomes. Only the mean operation time and the intraoperative mean blood loss were significantly lower in the PR fixation group (1.33 h and 258 mL, respectively) than the APR fixation group (2 h and 375 mL, respectively). However, a more superior intraoperative assessment of reduction was showed in the APR fixation group managing for Tile C injuries. It was graded anatomical in 90% of cases, acceptable or nonanatomic in 10% of cases. In comparison, they were graded in the PR fixation group anatomical in 40% of cases, acceptable or nonanatomic in 60% of cases. Also, the mean operation time was significantly lower in the PR fixation group (1.5 h) than the APR fixation group (1.95 h). However, we observed no statistically significant differences regarding the primary and the remaining secondary outcomes between the two fixation groups.

Discussion

This study aims to compare the effects of APR fixation versus isolated PR fixation in managing Tile B2 and C1 pelvic ring injuries. We observed a higher frequency of superior pubic rami displacement before union in the PR fixation group, especially in Tile C1 injuries (9/20), and a better intraoperative assessment of reduction in the APR fixation group. The results were comparable between the two groups as regards: final radiological and clinical outcomes (Figs. 8 and 9), rate of postoperative complications, need for another operation, length of hospital stay, ability to weight bear postoperatively and pain control metrics. We highlight that postoperative wound infection occurred in two patients in the APR fixation group. In comparison, the PR fixation group showed a shorter operation time, lower amount of blood loss and no records for postoperative wound infection. Such results prove that the potential risks of additional anterior ring fixation overweigh the estimated benefits. The average time to union was 8–10 weeks, with no significant differences in both study groups.

Complex pelvic ring injuries require maintenance of the stability of the pelvic ring, primarily dependent on the PR osseoligamentous structures that provide approximately 85% of intrinsic stability.[14] The APR fixation offers higher biomechanical

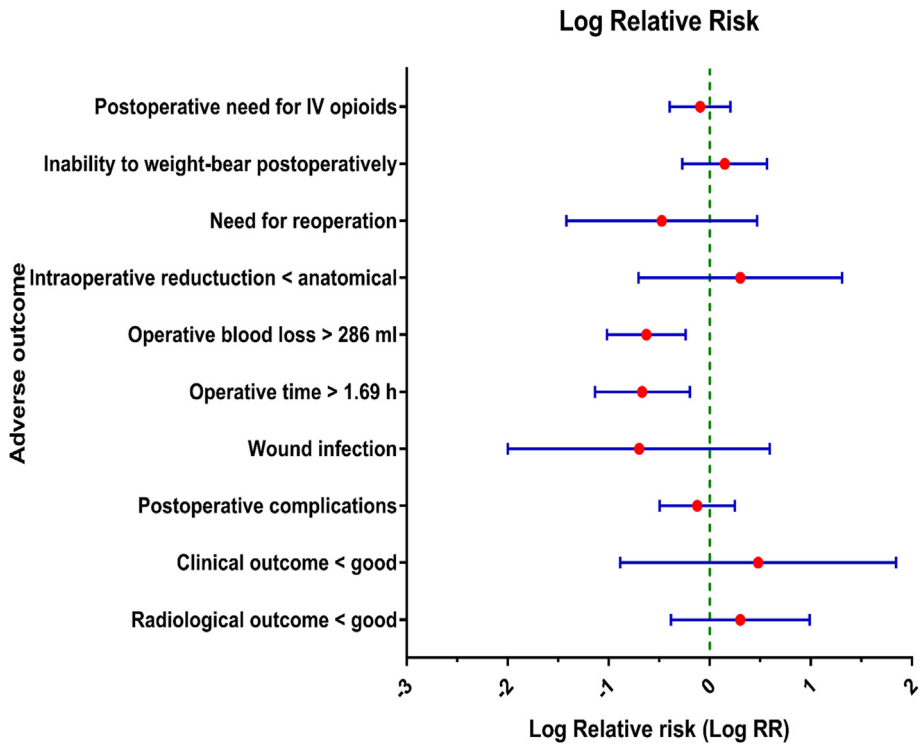

Fig. 4. A forest plot analysis illustrating the Log relative risk for main outcome measures. Rounded markers (red) represent the point estimate. Error bars (blue) represent the 95% *CI* for the point estimate. 95% *CI* including the value 0 (dashed vertical line, green) denotes the effect size is not statistically significant at the $p < 0.05$ level. Only operative time > 1.69 h and operative blood loss > 286 mL are statistically significant favoring isolated PR fixation (experimental treatment) over APR fixation (standard treatment) *CI*: confidence interval.

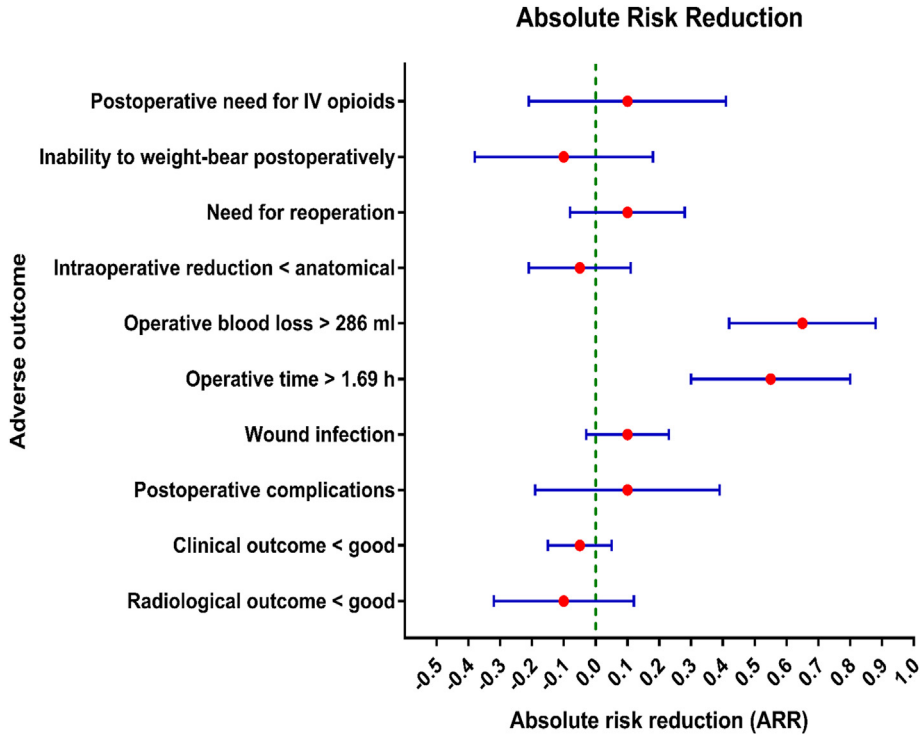

Fig. 5. A forest plot analysis illustrating the absolute risk reduction for main outcome measures. Rounded markers (red) represent the point estimate. Error bars (blue) represent the 95% *CI* for the point estimate. Negatively signed absolute risk reduction denotes absolute risk increase. 95% *CI* including the value 0 (dashed vertical line, green) denotes the effect size is not statistically significant at the $p < 0.05$ level. Only operative time > 1.69 h and operative blood loss > 286 mL are statistically significant favoring isolated PR fixation (experimental treatment) over APR Fixation (standard treatment) *CI*: confidence interval.

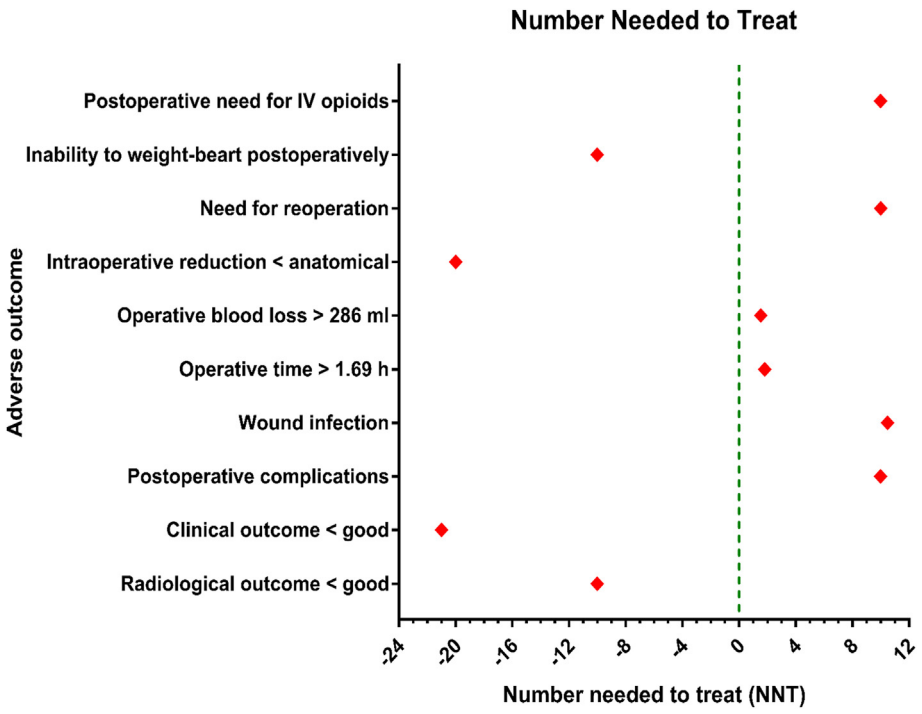

Fig. 6. A forest plot analysis illustrating the number needed to treat for main outcome measures. Markers (red) represent the point estimate. Error bars (blue) represent the 95% *CI* for the point estimate. Negatively signed number needed to treat denotes that the experimental treatment (isolated PR Fixation) has a harmful effect (i.e., number needed to harm) *CI*: confidence interval.

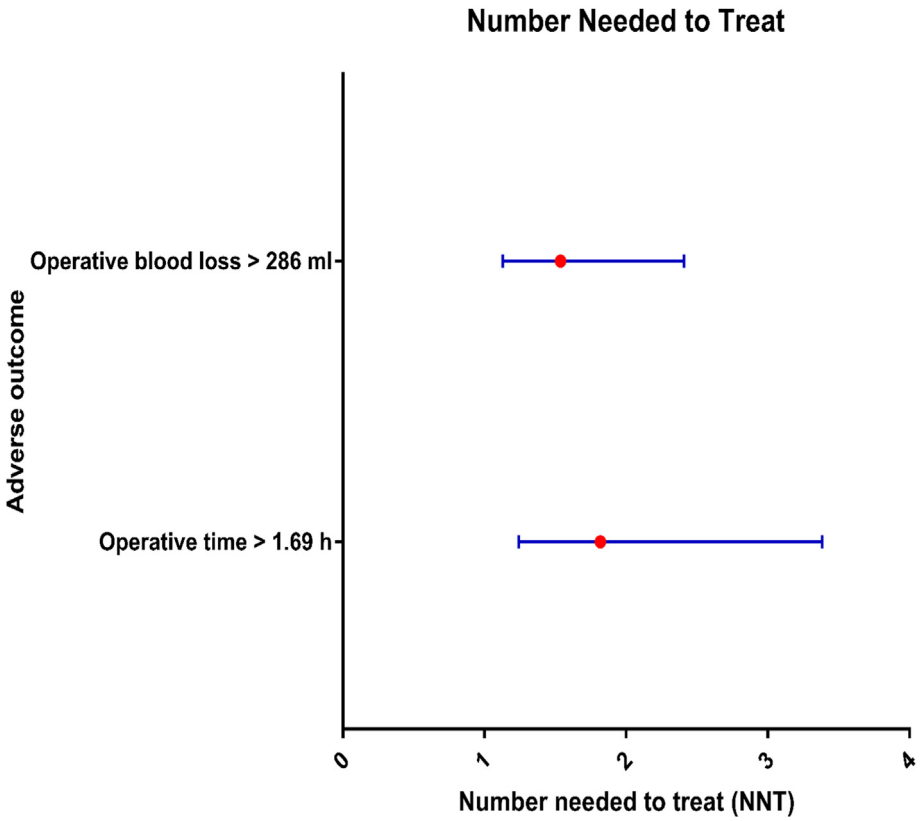

Fig. 7. A forest plot analysis illustrating the number needed to treat for operative blood loss > 286 ml and operative time > 1.69 h. Rounded markers (red) represent the point estimate. Error bars (blue) represent the 95% *CI* for the point estimate. Point estimate and 95% confidence intervals for either outcome measure includes positive values, which favors isolated PR fixation (experimental treatment) over APR fixation (standard treatment) *CI*: confidence interval.

Table 9
Relation between fixation principles and outcome measures of interest (student *t*-test) in Tile B subgroup ($n = 20$).

Variables	Group A (mean ± SD)	Group B (mean ± SD)	*t*-test	*p* value
Operation time (h)	2.00 ± 0.41	1.33 ± 0.33	4.26	< 0.001
Blood loss (mL)	375.00 ± 88.98	258.33 ± 160.73	2.15	0.055
Length of stay (days)	2.00 ± 0.00	2.08 ± 0.29	0.91	0.372

SD: standard deviation

Table 10
Relation between fixation principles and outcome measures of interest (Chi-square test) in Tile B subgroup ($n = 20$).

Variables	Group A, *n* (%)	Group B, *n* (%)	X^{2a} value	*p* value
Intra-operative assessment of reduction				
Anatomical reduction	8 (80.0)	7 (70.0)	0.49 FE	0.652
Non-anatomical/acceptable reduction	2 (20.0)	3 (30.0)		
Radiological assessment				
Excellent	8 (80.0)	7 (70.0)	1.05 FE	0.512
Good	2 (20.0)	2 (20.0)		
Fair	0 (0)	1 (10.0)		
Postoperative complications				
Yes	3 (30.0)	2 (20.0)	0.55 FE	0.624
No	7 (70.0)	8 (80.0)		
Need for another operation				
Yes	1 (10.0)	0 (0)	1.26 FE	0.465
No	9 (90.0)	10 (100)		
Final clinical assessment				
Excellent	7 (70.0)	6 (60.0)	0.32 FE	0.681
Good	3 (30.0)	4 (40.0)		
Ability to weight bear postoperatively				
Yes	8 (80.0)	8 (80.0)	0.08 FE	1.012
No	2 (20.0)	2 (20.0)		
Pain control metrics				
IV Paracetamol	5 (50.0)	6 (60.0)	0.15 FE	0.705
Need for IV opioids	5 (50.0)	4 (40.0)		

[a] Chi-square test (FE: Fisher exact test), IV: intravenous.

Table 11
The primary outcomes of Tile C subgroup between two groups ($n = 20$ cases).

Variables	Group A (mean ± SD)	Group B (mean ± SD)	*t*-test	*p* value
Operation time (h)	1.95 ± 0.50	1.50 ± 0.38	2.11	0.051
Blood loss (mL)	295.00 ± 170.70	206.25 ± 137.42	1.19	0.254
Length of stay (days)	2.10 ± 0.32	1.88 ± 0.35	1.42	0.171

SD: standard deviation

stability with good functional outcomes in Tile B2 and C1 injuries.[15] However, anterior ring fixation has additional risks and it is questionable whether this is necessary after posterior ring fixation.[16] So, we started to study isolated PR fixation in managing unstable Tile B and C injuries and assess the outcomes compared to combined APR fixation. We aimed to restore the anterior pelvic ring integrity in the isolated PR fixation group via closed reduction techniques. Closed reduction of Tile B2 injuries was performed by applying pelvic sheets first to correct the rotational deformity before fixation with SI screws, while Tile C1 injuries was performed by a longitudinal distal femur skeletal traction and the push-pull technique to correct the vertical and posterior translation, respectively.[17]

In our study, assessments of clinical outcomes were nearly equal between the two groups, which were evaluated using the Majeed pelvic score (out of 80) at each follow-up visit. The mean score at 1-year follow-up was 77.5 in Group A and 76 in Group B (Table 5). The clinical study scores were comparable to the study of Petryla et al.[18] They performed a single-center retrospective cohort study that compared one-year clinical outcomes between isolated PR and combined APR fixation in lateral compression II (Tile B2) injuries. However, it showed no significant differences between two groups. And the mean Majeed score at one-year follow-up (out of 100) was 88 in isolated PR fixation (range 74.0–95.5) and 87 in combined APR fixation groups (range 70.0–96.0). Thus, the results of this study were consistent with our hypothesis showing no significant relationship between the clinical outcomes and fixation principles.

In comparison, Khaled et al.[12] claimed after a mean follow-up period of 37.4 months, the Majeed score of isolated PR fixation in Tile B injuries with one or two sacroiliac screws was (90.0 ± 11.3) and (89.2 ± 13.6) (out of 100), respectively showing superior functional results. Their results were consistent with our hypothesis of better clinical outcomes after isolated PR fixation. Meanwhile, the study of Suzuki et al.[19] retrospectively reviewed the clinical outcomes in 57 patients with Tile B and C injuries. They found that the long-term functional outcomes were irrelevant to fracture types or fixation methods, and the mean Majeed pelvic score was 79.9 (range 30–100) after a minimum follow-up of 24 months. The inclusion of Tile C injuries and all of their subtypes in this study was a major cause for poor clinical outcomes, emphasizing the importance of classifying fractures into subgroups to avoid wide disparities in fracture types and outcomes.

Regarding the differences in clinical outcomes related to the fracture types independent of the fixation techniques, Ismail et al.[16] retrospectively compared the Majeed scores in 26 patients with Tile

Table 12
The outcome measures of interest in Tile C subgroup between two groups ($n = 20$ cases).

Variables	Group A, *n* (%)	Group B, *n* (%)	X^2[a] value	*p* value
Intra-operative assessment of reduction				
Anatomical reduction	9 (90.0)	4 (40.0)	5.51 FE	0.041
Non-anatomical/acceptable reduction	1 (10.0)	6 (60.0)		
Radiological assessment				
Excellent	6 (60.0)	3 (30.0)	4.00 FE	0.181
Good	2 (20.0)	4 (40.0)		
Fair	2 (20.0)	1 (10.0)		
Poor	0 (0)	2 (20.0)		
Postoperative complications				
Yes	5 (50.0)	4 (40.0)	0.15 FE	0.702
No	5 (50.0)	6 (60.0)		
Need for another operation				
Yes	2 (20.0)	1 (10.0)	0.18 FE	0.603
No	8 (80.0)	9 (90.0)		
Final clinical assessment				
Excellent	7 (70.0)	3 (30.0)	3.89 FE	0.061
Good	3 (30.0)	6 (60.0)		
Fair	0 (0)	1 (10.0)		
Ability to weight bear postoperatively				
Yes	7 (70.0)	6 (60.0)	0.11 FE	1.012
No	3 (30.0)	4 (40.0)		
Pain control metrics				
IV Paracetamol	5 (50.0)	6 (60.0)	0.28 FE	0.662
Need for IV opioids	5 (50.0)	4 (40.0)		

[a] Chi-square test (FE: Fisher exact test), IV: intravenous.

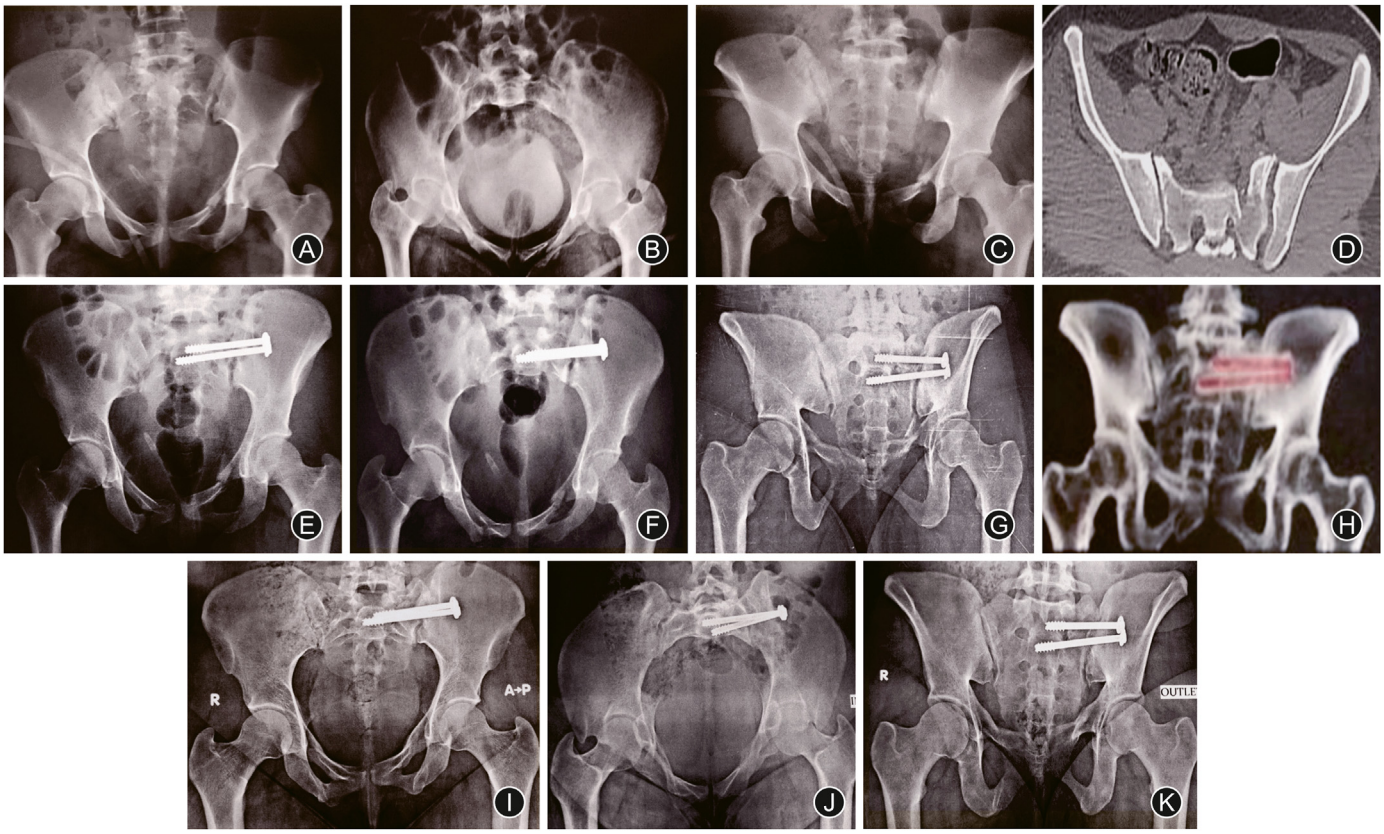

Fig. 8. A 27-year-old female fell from a height. (A–D) preoperative radiographs and CT scan showing Tile B2 injury (LT sacro-iliac dislocation and bilateral fractures of the pubic rami); (E–H) postoperative radiographs and CT scan showing posterior ring fixation with S1 and S2 sacro-iliac screws; and (I–K) Radiographs 14 months postoperatively.

B and C injuries after internal fixation without specifying the fixation principles. The mean follow-up duration was 25 months. The clinical outcomes were superior and reached about 90% with excellent or good scores with no significant differences between Tile B and C injuries. From our view point, the better outcomes in this study were mainly related to the use of minimally invasive fixation methods. Unlike the series case of Mardanpour et al.[20] retrospectively reviewed the clinical and radiological outcomes in 37 patients with

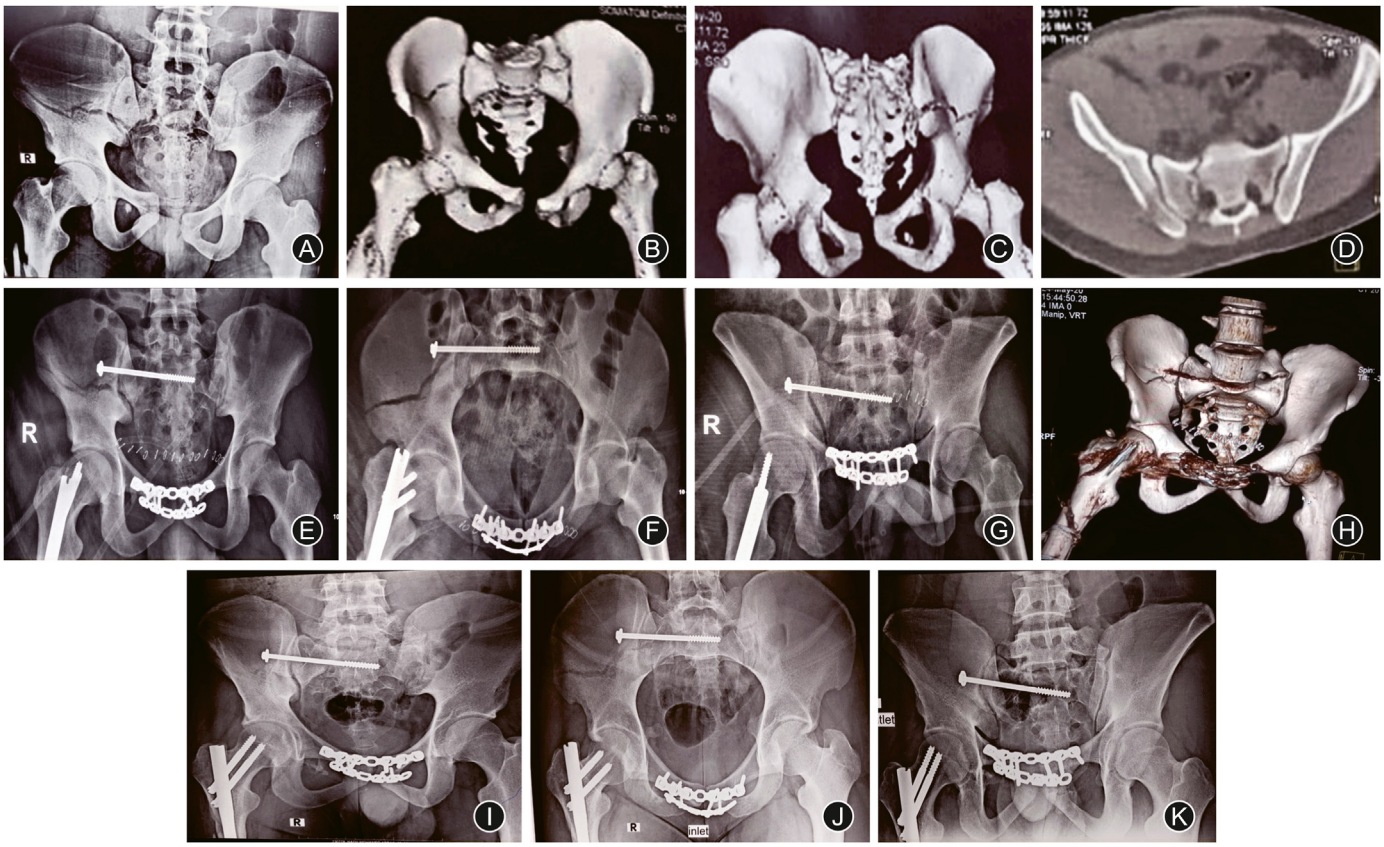

Fig. 9. A 23-year-old male road traffic accident. (A - D) preoperative radiographs and CT scan showing Tile C1 injury (vertical shear fracture of the right sacrum and iliac wing); (E–H) postoperative radiographs and CT scan showing posterior ring fixation with sacro-iliac screw and anterior double symphyseal plates; and (I–K) Radiographs 12 months postoperatively.

Tile B or C injuries. The mean follow-up duration was 45.6 months, and combined APR fixation was done in both types via posterior iliosacral plaques and anterior ring plating. Tile B injuries showed better clinical (excellent in 66% of cases) and radiological outcomes (excellent in 73% of cases) than Tile C injuries (48% and 27% of cases with excellent clinical and radiological outcomes, respectively). As can be seen, the wide inclusion of all Tile B and C fractures using older invasive fixation methods may contribute to the difference in outcomes that we tried to avoid in our study.

In our study, postoperative complications were slightly higher in the APR fixation group (40%) than that in the PR fixation group (30%). The odds ratio (OR) came to be 1.556 with a 95% *CI* ranging from 0.420 to 5.763 (Table 6). Postoperative wound infection was recorded in two patients with the APR fixation, while no records for such complication showed in the PR fixation group. Schmal et al.[8] emphasized this slight difference in his study comparing the two fixation principles in managing Tile B and C injuries. He concluded that combined APR fixation had higher intraoperative and short-term postoperative complications than isolated PR fixation. The OR was 75% higher in the APR fixation group (OR 1.75 with a 95% *CI* ranging from 1.08 to 2.83). However, the study did not compare the radiological and clinical outcomes between the two groups.[8] The comment of this study is that the APR fixation group had a higher rate of intraoperative and short-term postoperative complications, mainly advocating for a more extensive second incision. The potential risk of anterior ring fixation exceeds the estimated benefit, which is consistent with our assumptions.

Regarding the biomechanical outcome of isolated PR fixation, Comstock et al.[21] suggested that isolated rigid PR fixation may exclude the need for additional anterior ring fixation in unstable vertical shear pelvic ring injuries. Furthermore, he claimed to convert such an injury pattern after rigid PR fixation to an isolated pubic ramus, which is considered stable enough for conservative management.[22] Therefore, they performed a biomechanical study using a single posterior fixation method (SI screws, trans-iliac bars or anterior SI plates) that provided about 70%–85% torsional and axial load resistance. Meanwhile, the combined SI screws and trans-iliac bars provided about 90% load resistance compared to the intact pelvis. These results from an earlier series research provide evidence that PR fixation is the key to restoring pelvic ring integrity in vertical shear injuries. Therefore, isolated PR fixation with closed reduction of vertical and posterior translation could be sufficient to manage vertically unstable pelvic ring injuries.

This study is the first randomized controlled trial to highlight the possibility of isolated PR fixation alone in managing unstable Tile B2 and C1 pelvic ring injuries, compared with combined APR fixation. It still showed some limitations. Although one team performs all operations, the surgeon's surgical experience may improve over time. Therefore, operations performed later may show better results, but at the risk of potential performance bias. In addition, the study sample size was small. However, this study is the first to compare these outcomes between the two fixation groups in a prospective randomized study and investigates the possibility of isolated PR fixation for Tile B2 and C1 pelvic ring injuries.

In conclusion, although the intraoperative assessment of reduction was better in the APR fixation group, the isolated PR fixation could favorably manage Tile B2 and C1 pelvic ring injuries

with Nakatani zone II pubic rami fractures and intact inguinal ligament. And the isolated PR fixation achieved comparable final radiological and clinical outcomes and postoperative complications to the APR fixation. So, we found it to be as good as the APR fixation, but with less morbidity (shorter operation time, lower amount of blood loss and no records of postoperative wound infection). Additionally, we plan to optimize the management of unstable Tile B2 and C1 pelvic ring injuries to achieve better radiological and clinical outcomes. Therefore, more prospective studies with longer follow-up and larger number of patients will be carried out in the future.

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Ethical statement

The ethics committee of Ain Shams University has approved the study.

Declaration of competing interest

The authors declare that they have no conflict of interest.

Author contributions

Islam Sayed moussa, Amr Khairy Mahmoud, and Elzaher Hassan Elzaher designed the study, wrote the protocol, analyzed data, reviewed the manuscript critically, and approved the final version to be published; Ahmed Salem Eid and Ahmed Mohamed sallam analyzed the data, and reviewed the manuscript critically; Amr Mohamed Nagy collected data and wrote the manuscript.

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