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Treatment of unstable pelvic fractures in children with an external fixator: Retrospective study of 56 patients

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Abstract

Purpose: We retrospectively analyzed the data of patients who underwent external fixation treatment for unstable pelvic fractures and evaluated the clinical effects of this treatment and factors influencing pelvic function recovery.

Methods: The data of patients with unstable pelvic fractures treated with an external fixator between January 2006 and December 2018 were retrospectively analyzed. The analyzed parameters included demographic data, fracture healing, pelvic asymmetry, deformity index, and complications. Fractures were categorized using the Tiles classification. Pelvic function was evaluated using the Cole score. Pelvic risk factors were identified using univariate and multivariate logistic regression analyses.

Results: Fifty-six patients (29 and 27 with type B and C fractures, respectively) were included. All fractures were healed at the time of the final follow-up. Nine and three patients had pin tract infections and loosened external fixators postoperatively, respectively. Pelvic asymmetry was reduced from 1.34 ± 0.15 cm to 0.70 ± 0.19 cm ($p < 0.01$), and the deformity index decreased from 0.13 ± 0.03 to 0.07 ± 0.02 ($p < 0.01$). The Cole score was excellent and good in 41 and 15 patients, respectively. Risk factors for pelvic function recovery included injury severity score > 25.5, age > 11.3 years, and lower-extremity fractures.

Conclusions: External fixation is an effective method for treating unstable pelvic fractures in children, with the advantages of a simple operation, short surgical time, no interference with treatments for associated injuries, and avoidance of re-trauma caused by open reduction. An ISS > 25.5, patient age > 11.3 years, and associated lower-extremity fractures are predictors of pelvic function recovery.

Level of evidence: Level IV.

Keywords: Children, external fixation, pelvic fracture, surgical treatment

Introduction

The incidence of pelvic fractures in children is 2.4%–7.5%[1–4] and is significantly lower than that in adults.[5] Fractures are often secondary to high-energy trauma, such as motor vehicle accidents and falls from heights, because of the particularity of pediatric pelvic anatomy.[6] The incidence of pelvic fractures combined with other injuries can be as high as 86% because of high-energy injury mechanisms.[5] Therefore, associated injuries that render treatment more complex must be considered when managing pelvic fractures. The optimal therapeutic method for pediatric pelvic fractures, which should be considered based on the fracture type, patient age, associated injuries, and local medical conditions, remains unclear.

Conservative treatment can achieve satisfactory outcomes in children with stable pelvic fractures. However, the treatment of unstable pelvic fractures in children remains controversial. Traditionally, children were believed to have a strong reshaping potential and high healing rate; therefore, they were mostly treated conservatively. However, recent studies have shown that the remodeling

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ability of the pelvis is limited, and conservative treatment leads to residual lumbosacral pain, scoliosis, and other complications. Therefore, surgical treatment is currently recommended.[7–9]

Open reduction internal fixation and closed reduction external fixation are the main surgical methods for treating children with unstable pelvic fractures. Few studies have analyzed the factors influencing the postoperative recovery of pelvic function. Therefore, we retrospectively analyzed the data of patients who underwent external fixation treatment for unstable pelvic fractures and evaluated the clinical effects of this treatment and factors influencing pelvic function recovery.

Material and methods

The data of patients with pelvic fractures who were treated between January 2006 and June 2018 were reviewed. Patients aged $<$18 years with unstable pelvic fractures according to the Tile classification who were treated via external fixation and followed up for $\geq$48 months were included. Patients with pathological fractures, lower-limb deformities, a history of pelvic or lower-limb surgery, or incomplete clinical data, including those who were lost to follow-up, were excluded.

Surgery was required in patients with type B1 open-book injuries with $>$2 cm diastasis of the pubic symphysis; type B1 and B2 injuries combined with craniocerebral trauma, urinary system injuries, and hemodynamic instability; type B2 fractures with no associated injury but closed reduction failure (pelvic asymmetry $>$ 1.1 cm); and type B3 and C fractures.

Patient age, sex, cause of injury, fracture type, injury severity score (ISS), triradiate cartilage status, surgery time, intraoperative blood loss, fracture healing, pelvic asymmetry, and pelvic deformity index data were reviewed. Preoperative and postoperative pelvic asymmetry and deformity indices were analyzed according to the method proposed by Keshishyan et al.[10] (Figure 1). Pelvic function was evaluated at the last follow-up using the Cole scoring criteria that incorporate activity status, subjective complaints, radiographic information, and physical examination.[11] By incorporating all these data, it is believed that a patient's outcome can be more accurately assessed as the scale is specific to pelvic injuries. Factors influencing pelvic function recovery were analyzed.

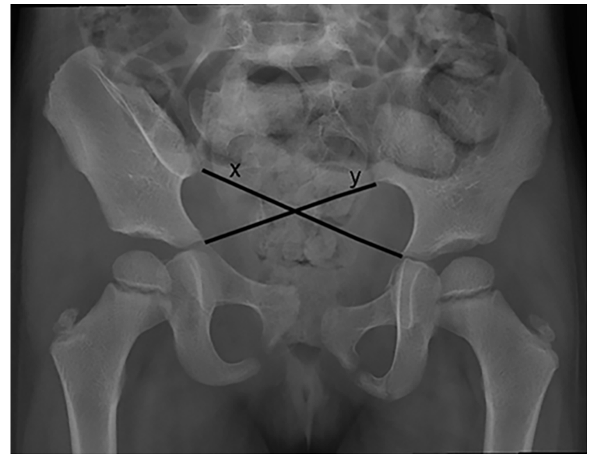

Figure 1. The pelvic asymmetry measurement method.
The lower edge of the ilium of the sacroiliac joint and the medial center of the contralateral acetabulum are represented by x and y, respectively. The difference between x and y is the asymmetry of the pelvis. The deformity index of the pelvis is calculated as: $(x-y)/(x+y)$.

Surgical procedure

The patient was anesthetized and placed supine on a traction table. The C-arm position was adjusted to perform the operation quickly in the pelvic anteroposterior, outlet, and inlet positions. After the entry point and direction of the needle were determined, the skin was incised, the subcutaneous layer was separated, and a 2.0-mm Kirschner wire was inserted into the anterior superior iliac spine using an electric drill. After satisfactory reduction, the Kirschner wire was removed, and a Schanz pin was slowly screwed along the path of the Kirschner wire. The diameter of the Schanz pin was based on preoperative measurements. The Schanz pin was placed in the middle of the inner and outer cortices of the iliac crest and inserted deeper than half the depth of the iliac crest, although not beyond the sacroiliac joint (SIJ). Then, an external fixation clip was used to control the Schanz screw for reduction. The pelvic position was reevaluated using fluoroscopy in the anteroposterior, inlet, and outlet positions. Pelvic asymmetry $<$1.1 cm or $<$0.4 cm indicated acceptable or good reduction, respectively. After reduction, a metal connecting rod was placed, and the external fixation frame was locked.

Postoperative management

The patient was completely bedridden, and the wound was regularly disinfected postoperatively. Patients without ankle joint fixation or traction were encouraged to undergo early ankle pump training. Lower-limb skin traction was applied to patients with vertical instability preoperatively. The traction weight was 10%–12% of the body weight, and the same weight was used for opposing limb traction. The traction was used for 8–12 weeks.

The patients were followed up regularly. Fracture healing and complications were recorded. Radiographs of the pelvis in the anteroposterior, inlet, and outlet positions were obtained at 1, 2, 6, 12, 24, and 48 months postoperatively. Pelvic function was evaluated at 4 years postoperatively using the Cole scoring criteria.

Statistical analysis

Statistical analyses were performed using SPSS software (version 23.0; IBM Corp., Armonk, NY). The Shapiro–Wilk test was used to verify the normality of the data. Normally distributed variables are expressed as mean and standard deviation, whereas non-normally distributed variables are expressed as median (interquartile range [25th quartile to 75th quartile]). Data were analyzed using the *t*-test and Wilcoxon test. Enumeration data are expressed as frequency, rate, or composition ratio and were analyzed using the χ^2 test. Logistic regression analysis was used to identify the risk factors for pelvic function recovery. We first used *t*-tests, rank sum tests, and χ^2 tests to screen out variables with $p < 0.05$ and those considered clinically likely to have an effect. The aforementioned variables were then included in a binary logistic regression (excellent=0, good=1), and a "Forward: LR" approach was used to construct the model. A receiver operating characteristic curve was drawn to determine the cutoff value of the influencing factors and effectiveness of predicting prognosis. Statistical significance was set at $p < 0.05$.

Results

Fifty-six patients (39 boys and 17 girls; mean age: 7.4 years, range: 2.0–15.2 years) with pelvic fractures were followed up for an average of 60 months (range: 48–108 months), including 29 patients with type B and 27 patients with type C fractures. The causes of injury included traffic accidents (n=48; 85.7%) and falling from a height (n=8; 14.3%). All patients had combined injuries, including head (37.5%), chest (39.3%), abdominal (64.3%), urogenital system (21.4%), and other fractures (42.9%). Seven patients had upper-limb fractures, and 17 had lower-limb fractures. Fifty-two patients had open triradiate cartilage. Further demographic data are summarized in Table 1.

The mean operative time was 58 min (range: 30–120 min), and the mean intraoperative bleeding volume was 4 ml (range: 1–10 ml). Thirty patients underwent lower-limb traction for an average of 8.8 weeks (range: 8–12 weeks). Thirty-eight patients with associated injuries were treated with operation at the same time. Further specific data are summarized in Table 2.

Surgery-related complications occurred in 12 (21.4%) patients. Nine patients experienced infection around the pin tract that gradually improved after disinfection and the administration of oral antibiotics. The wounds healed well after removing the Schanz pin. In three patients, the external fixator loosened postoperatively, which was adjusted promptly with no fracture displacement. At the last follow-up, the Cole score was excellent in 41 patients and good in 15 patients, with excellent and good rates of 100% and 100%, respectively. No fracture nonunion, lower-limb nerve injury, sciatica, scoliosis, myositis ossificans, or other complications were observed (Figure 2).

Table 1. Population demographics.

Population factor	Total population (n=56)
Age (years)	7.4 ± 3.9
Male gender	39 (69.6%)
Mechanism of injury	
Motor vehicle accident	48 (85.7%)
Fall	8 (14.3%)
Associated injury	
Head	21 (37.5%)
Chest	22 (39.3%)
Abdominal	36 (64.3%)
Urogenital	12 (21.4%)
Upper-limb fractures	7 (12.5%)
Lower-limb fractures	17 (30.4%)
Injury severity score	21.8 ± 11.2
Fracture type	
Tile B	29 (51.8%)
Tile C	27 (48.2%)
Triradiate cartilage (open)	52 (92.9%)

Table 2. Operative data.

Variable	n (%), 56
Treatment	
EF	26 (46.4%)
EF and LLT	30 (53.6%)
Operative time (min)	58 ± 21
Complications	
Pin infection	9 (16.1%)
Fixator loosened	3 (5.4%)
Treatment (associated injury)	
Other fractures (ESIN/K-wire/EF)	22 (39.3%)
Head (IHR)	7 (12.5%)
Abdominal (EL)	10 (17.8%)
Angiography	3 (5.3%)
Duration of EF (m)	3.9 ± 1.0
Cole scores	
Excellent	41 (73.2%)
Good	15 (26.8%)

EF: external fixation; LLT: lower-limb traction; ESIN: elastic stable intramedullary nail; IHR: intracranial hematoma removed; EL: exploratory laparotomy.

The pelvic asymmetry was reduced from 1.34 ± 0.15 cm to 0.70 ± 0.19 cm ($p < 0.01$). The deformity index decreased from 0.13 ± 0.03 to 0.07 ± 0.02 ($p < 0.01$) (Table 3).

We first used *t*-tests, rank sum tests, and χ^2 tests to screen out variables with $p < 0.05$. Patient age (t=2.29, p=0.03), ISS (t=6.48, $p < 0.01$), lower-extremity fracture (χ^2=12.78, p=0.01), and postoperative pelvic asymmetry (t=−2.93, p=0.01) were identified as risk factors affecting pelvic function recovery. The aforementioned variables were then included in a binary logistic regression (excellent=0, good=1), and a "Forward: LR" approach was

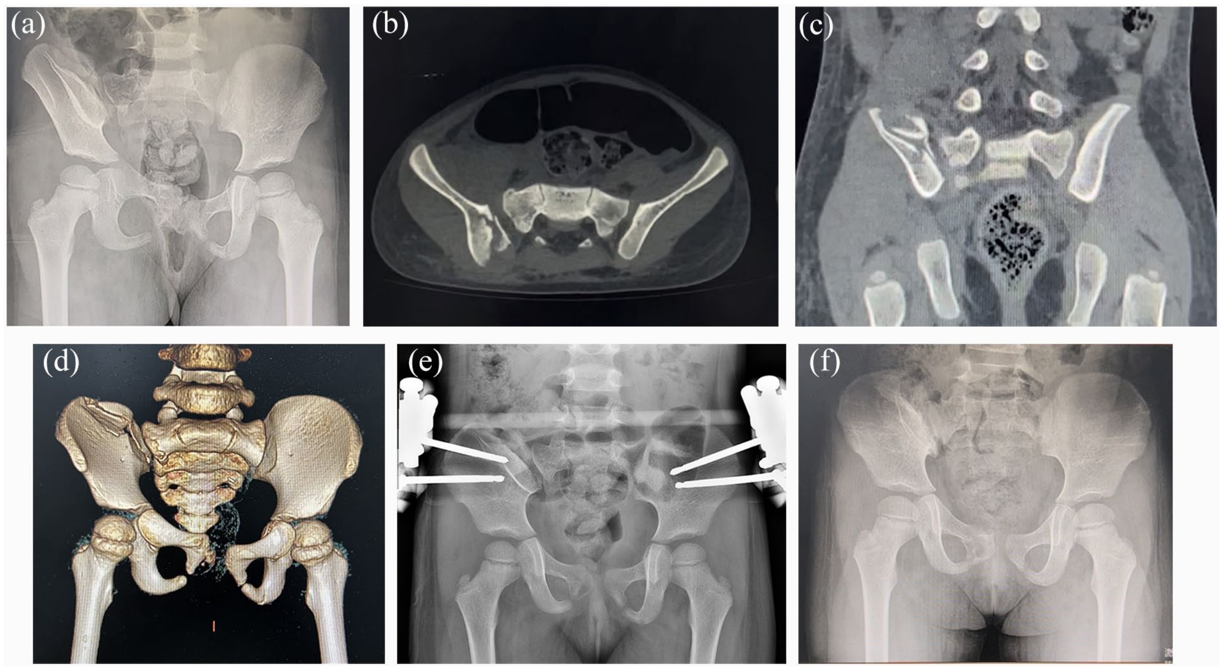

Figure 2. A five-year-old girl with a type C1 pelvis fracture as a result of a motor vehicle accident.
(a) A preoperative anteroposterior pelvic radiograph reveals sacroiliac joint dislocation and pubic symphysis separation. The preoperative pelvic asymmetry is 2.0 cm. (b–d) Pelvic computed tomography image and three-dimensional reconstruction show fracture and dislocation of the sacroiliac joint. (e) Postoperative pelvic anteroposterior radiograph indicates satisfactory reduction. The postoperative pelvic asymmetry is 0.8 cm. (f) An anteroposterior pelvic radiograph obtained 4 years after surgery is shown.

Table 3. Radiographic improvement of the pelvis after surgery.

	Preoperative	Postoperative	t	*P*
Pelvic asymmetry (cm)	1.34 ± 0.15	0.70 ± 0.19	23.01	<0.01
Pelvic deformity index	0.13 ± 0.03	0.07 ± 0.02	17.13	<0.01

used to construct the model. Patient age (p = 0.03, odds ratio [OR] = 1.52), ISS (p = 0.01, OR = 1.36), and lower-extremity fracture (p = 0.02, OR = 39.29) were identified as independent risk factors for pelvic function recovery. In other words, younger patients with less severe injuries tend to have a better recovery (Tables 4 and 5).

ISS and age were identified as predictors of better effectiveness (Figure 3). The optimal cutoff value of the ISS was 25.5, area under the curve (AUC) was 0.91 (95% confidence interval [CI]: 0.84–0.99), sensitivity was 93.3%, and specificity was 80.5%. The optimal cut-off value of patient age was 11.3 years, AUC was 0.68 (95% CI: 0.51–0.84), sensitivity was 46.7%, and specificity was 82.9%.

Discussion

In this study, all the patients had good radiographic and clinical outcomes and achieved excellent or good pelvic function scores at the final follow-up. With the exception of pin tract infection and screw loosening, no complications occurred, indicating that the external fixation of pelvic fractures in children is safe and effective.

The incidence of pediatric pelvic fractures is low, and the majority are closed injuries that are associated with pelvic ring fractures[12,13] caused by high-energy trauma. Traffic accidents occurred in 85.7% (48/56) of the patients in this study, which is higher than the 68% reported by Subasi et al.[14] Only patients who required surgical treatment were included in this study, and pelvic fractures caused by traffic accidents are more likely to be associated with additional injuries and require surgical intervention. All the children in this study had associated injuries, which are a major cause of death in pediatric patients with pelvic fractures, with mortality rates ranging from 3.2% to 18%.[15,16]

The treatment of pediatric pelvic fractures must take into account the patient's age, hemodynamic status, type

Table 4. Univariate analysis of pelvic function.

Categories	Cole score		χ^2/t/z	p
	Excellent	Good		
Gender (male: female)	28:13	6:9	3.69	0.07
Age (years)	6.70 ± 3.60	9.32 ± 4.31	2.29	0.03
ISS	17.32 ± 8.67	33.93 ± 8.00	6.48	<0.01
Injury mechanism (low energy:high energy)	2:39	1:14	0.07	1.00
Combined lower-extremity fracture (yes:no)	7:34	10:5	12.78	0.01
Fracture type (B:C)	21:20	8:7	0.02	1.00
Preoperative asymmetry	1.34 ± 0.15	1.35 ± 0.14	−0.08	0.94
Postoperative asymmetry	0.66 ± 0.17	0.81 ± 0.19	−2.93	0.01

ISS: injury severity score.

Table 5. Multivariate analysis of pelvic function.

Risk factors	Partial regression coefficient	Standard error	The Wald statistic	p Value	OR (95% CI)
Lower-extremity fractures	3.67	1.63	5.07	0.02	39.29 (1.61–960.16)
Age	0.42	0.19	4.97	0.03	1.52 (1.05–2.20)
ISS	0.30	0.12	6.92	0.01	1.36 (1.08–1.70)
Postoperative asymmetry	2.94	3.40	0.75	0.39	18.91 (0.02–14,696.40)

OR: odds ratio; CI: confidence interval; ISS: injury severity score.

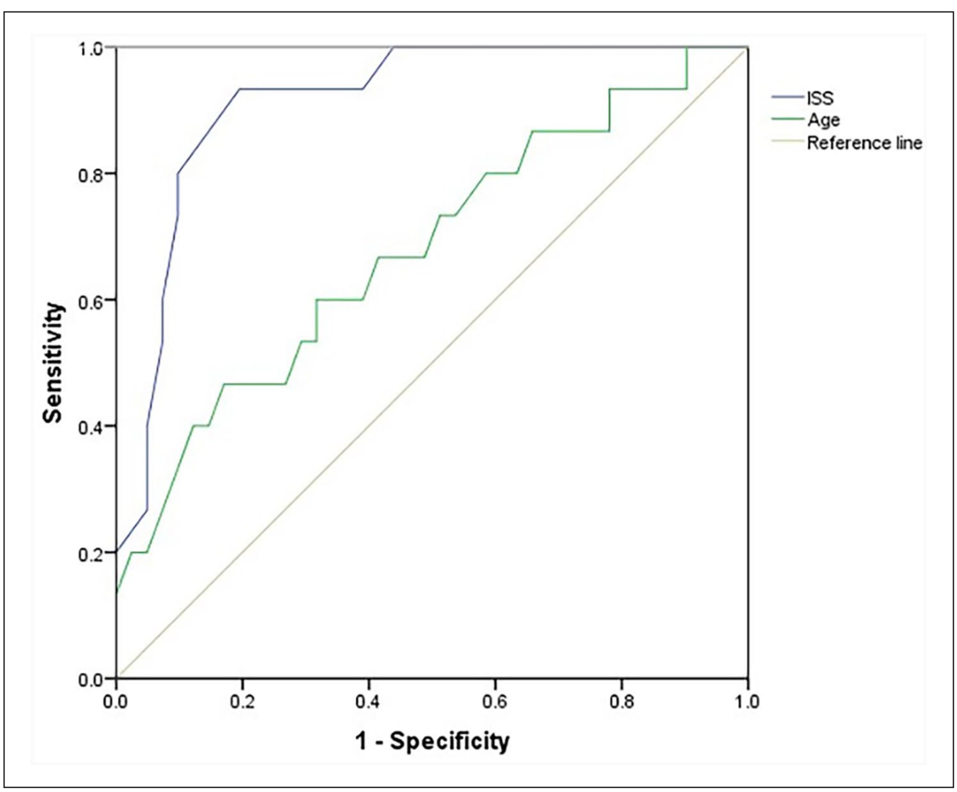

Figure 3. Receiver operative characteristic curves.
The ROC curves for ISS and age have an area under the curve of 0.91 and 0.68, respectively. The cut-off values are 25.5 and 11.3 years, respectively.
ROC: receiver operating characteristic; ISS: injury severity score.

of fracture, and the planned management of associated injuries. The treatment of unstable pelvic fractures remains controversial. However, with the deepening of the understanding of pelvic fractures, patients are now more inclined to surgical treatment. Previous studies have reported that pelvic asymmetry and the deformity index do not improve after fractures.[10] As pelvic asymmetry is the only treatment-related variable that affects outcomes, minimizing pelvic asymmetry is an important treatment goal.[17] Smith et al.[18] suggested that patients should be treated with open reduction and internal or external fixation following closed reduction associated with pelvic asymmetry $\geq$1.1 cm. Amorosa et al.[19] reported that surgical reduction and fixation of unstable or displaced pelvic fractures are worthwhile regardless of the age or skeletal maturity of the patient.

Surgical treatments of pelvic fractures include internal fixation and external fixation. Anatomical reduction and solid fixation can be achieved via open reduction and internal fixation, and the resulting strength is comparable to that of a normal pelvic ring. However, in pediatric patients, the pelvis is small and has inferior resistance to operation, significantly increasing the difficulty of operation. Open reduction separates tissues and extensively peels off the periosteum, resulting in operation-related complications. Pelvic fractures in children have a high incidence of associated injuries, increasing the risk of intraoperative and postoperative complications. Therefore, open reduction with internal fixation is not optimal for the treatment of unstable pelvic fractures in children, especially in patients with craniocerebral injuries, thoracic or abdominal injuries, or hemodynamic instability.

Pelvic fracture from high-energy injury was connected to sacral fractures, and 40%–50% of sacral fractures have a concomitant pelvic fracture. Neurologic injury was rare, representing 15.1% of all sacrum fractures.[20] The rate of neurologic deficits was related more to degree of pelvic instability than to the specific fracture pattern in the sacrum.[20] Percutaneous pelvic fixation with screws in the posterior pelvic ring has gained increasing popularity for treating sacrum fractures. The use of ilio-sacral (IS) screws has been demonstrated to provide biomechanical strength in unstable fractures that is equivalent to IS plate fixation or sacral bars.[21] Previous research has confirmed that IS screws can be safely used to treat sacral fractures in children.[22] In the current study, we did not find any cases of pelvis ring fracture with comminution of the sacrum with neurological spinal root deficits.

For the anterior fixation, surgical operation using an external fixator is easy and flexible and quickly provides a reliable fixation with a shorter operation time. The early use of external fixators controls fracture displacement, reduces bleeding, prevents shock, and obtains firm fixation without affecting the treatment of associated injuries. Several studies have reported good surgical outcomes of external fixation in patients with horizontally-unstable tile B pelvic fractures.[18,23] For type C pelvic fractures combined with SIJ dislocation, the use of external fixation and a sacroiliac screw achieved a better reduction effect than external fixation alone.[18,24]

Patients with concomitant SIJ injuries present with severe fracture patterns and associated injury. We believe that there are still limitations in the use of IS in children, most of which have been reported in the literature for children older than 10 years. IS fixation avoided long-term traction; however, it causes extensive destruction and greater blood loss. In our opinion, SIJ injuries in children frequently involve a trans-epiphyseal fracture of the iliac bone, and their muscle strength is weaker than that of adults. Alignment can be maintained by adjusting the position and depth of Schanz pins along with lower-limb traction. Patients with SIJ injuries were treated with an external fixator and lower-limb traction, which avoids complications associated with IS screws. Holt and Mencio[25] used external fixation to treat anterior and posterior compression fractures and bilateral sacral fractures in children, and their functional recovery was good despite unsatisfactory pelvic symmetry. In the current study, the patients with vertical instability (type C fractures) underwent lower-limb skin traction for 8 to 12 weeks postoperatively. All the patients had good radiographic and clinical outcomes. The pelvic asymmetry was significantly reduced postoperatively. No patient developed complications such as non-structural scoliosis, lumbar pain, Trendelenburg sign, or SIJ tenderness and pain although some did not achieve normal pelvic asymmetry.

The clinical outcomes of pediatric pelvic fractures are influenced by the patient's age and pelvic maturity.[26] Previous studies have reported that an ISS $\geq$ 16[27,28] is an independent risk factor for pelvic fractures combined with multiple traumas. Smith et al.[18] reported no correlation between the ISS and final follow-up outcomes. However, the results of the current study confirmed that an ISS $>$ 25.5 is associated with poor pelvic function. Patients with a high ISS have severe trauma, especially those with unsatisfactory recovery of neurological function, which may also lead to lower-limb claudication and abnormal muscle strength, affecting pelvic function. The ISS value may also represent a worse fracture type, indicating posterior ring fractures. However, external fixation alone cannot achieve sufficient stability in patients with posterior pelvic ring fractures, which may lead to unsatisfactory functional recovery. In this study, the effects of anterior and posterior ring fractures on prognosis were not analyzed separately. The current study also found that patient age $>$11.3 years and combined lower-extremity fractures are risk factors for pelvic function. Patients with triradiate cartilage closure have limited remodeling ability, which leads to poor pelvic function. Although the mortality rate of children (aged < 13 years) with pelvic fractures is higher than that of adults, the incidence of serious complications is lower, indicating that young children have better resilience than older individuals.[16] Limb fractures may lead to discrepancies in limb length. Compensation for the pelvis is lost when patients present with pelvic fractures, and the pelvis cannot compensate for deformities caused by lower-limb fractures. Therefore, the indications for surgery can be appropriately widened for patients with lower-limb fractures. Anatomical reduction should be performed as far as possible during surgery to avoid complications.

Limitations

This study was limited by its retrospective design and lack of a control group, preventing the comparison of external fixation with other treatments. The follow-up time was short, limiting the ability to evaluate the sexual or reproductive outcomes of the patients.

Conclusions

External fixation is an effective method for treating unstable pelvic fractures in children, with the advantages of a simple operation, short surgical time, no influence on treatments for associated injuries, and avoidance of re-trauma caused by open reduction. An ISS > 25.5, patient age > 11.3 years, and associated lower-extremity fractures are predictors of pelvic function recovery.

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Author Contributions

Yuwei Wen, Danjiang Zhu, and Qiang Wang conceived and designed the study, acquired the data, and analyzed and interpreted the data. Baojian Song, and Wei Feng drafted the manuscript and revised it critically for important intellectual content. Danjiang Zhu gave final approval of the version to be submitted.

Declaration of conflicting interests

The author(s) declared no potential conflicts of interest with respect to the research, authorship, and/or publication of this article.

Ethics approval and consent to participate

Our study was approved by the ethical committee of Beijing Children's Hospital (approval no. 2021-30). All patients provided written informed consent prior to enrollment in the study.

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