Fractures of the pelvis in children: a review of the literature

Axel Gänsslen, Nima Heidari & Annelie M. Weinberg
Fractures of the pelvis in children: a review of the literature

Axel Gänsslen · Nima Heidari · Annelie M. Weinberg

Abstract Trauma is the leading cause of death in children. Pelvic ring injuries account for 0.3–4 % of all paediatric injuries. The pattern of fractures differs to that seen in adults as it is more ductile. Pelvic ring injuries tend to be more stable as the relatively thick periosteum restricts bony displacement. Intrapelvic viscera are not well protected and can sustain injury in the absence of pelvic fractures. These injuries have traditionally been treated non-operatively. In this paper, we comprehensively review the literature and propose a protocol for treatment taking into consideration associated organ injuries, hemodynamic status of the patient, patient’s age, type of fracture and the stability of the pelvic ring.

Keywords Children’s pelvic fracture · Children’s trauma · Pelvis fracture

Introduction

Trauma is the leading cause of death in children [53, 139]. Despite a substantial reduction in mortality rates over the past few decades, in 1996, more than 13,000 children died as a result of their injuries [124]. Received wisdom associates morbidity and mortality with concomitant injuries in the majority of cases and not the pelvic fracture itself, but paediatric pelvic injury is of major significance particularly in the severely injured child [67, 161].

Epidemiology

Pelvic ring injuries are rare in children. Engler historically reported the prevalence of pelvic fractures as 0.33 % of all paediatric injuries [36]. Reports in the early 1990s give a higher rate of 3.7 % which then reduced to 2.7 % in the late 1990s [57]. Current literature puts this figure between 0.3 and 4 % [11, 41, 51, 54, 62, 96, 112, 140]. An annual incidence of 1.1–8.8 cases per year during an observation period of 13–60 years has been reported [3, 89, 115, 144]. Sacral fractures are present in 0.16 % of paediatric trauma and 4.76 % of patients with a pelvic fracture [56]. Ten per cent of immature pelvic fractures are unstable [138] and 18.3 % are complex [91].

Age and gender

There is little consensus in the literature regarding the upper age limit for “paediatric pelvic trauma”, ranging from 14 to 20 years [3, 41]. Others define a paediatric patient as one with an “immature pelvis” with an open triradiate cartilage [138].

Overall, there is a male predominance with a male:female ratio of approximately 1.4:1. The mean age depends on the upper age limit of the study. In the classical immature group of patients (<14 years of age), the mean age is 8.2 years.
whereas in patients up to the age of 16, the mean age is 9.4 years [3, 21, 51, 122, 140]. Taking both sets of data together shows a mean age of 9 years.

### Anatomical considerations

The growing pelvis differs from the adult pelvis. It is more ductile as it contains more cartilage [18, 28] and deforms with loading rather than fracture [144]. The ligaments are relatively strong and the physes are open, which together with the sacroiliac joint and the pubic symphysis account for the significant absorption of energy at the time of injury. Pelvic radiographs may show asymmetry without a fracture, indicating plastic deformation. Injuries of the pelvic ring tend to be more stable as the relatively thick periosteum restricts bony displacement.

Intrapelvic viscera are not well protected and can sustain injury in the absence of pelvic fractures [97]. Consequently, even simple or minimally displaced fractures carry a significant risk of additional intrapelvic and intraabdominal injuries [97]. These biomechanical properties of the immature pelvis account for the relatively high incidence of isolated pubic rami fractures or fractures of the iliac wing [9, 21, 51, 65, 81, 122, 129, 135].

### Mechanism of injury

The majority of paediatric pelvic injuries (83.3 %) are due to high energy trauma [3, 21, 51, 81, 95, 96, 118, 122, 135, 141, 144, 150, 156] (Table 1) and are associated with shock in 62.8 % of cases [67].

In 15,725 children under the age of 16 who were involved in side impact collisions, only 0.1 % suffered a pelvic fracture. Children aged 8–11 experienced isolated pubic ramus fractures, whereas children aged 12–15 experienced multiple fractures of the pelvic ring [2]. While lateral compression forces tend to lead to instability of the hemipelvis in adults, in children acetabular injuries and fractures through the triradiate cartilage are seen [88].

### Associated injuries

Children with pelvic injuries have on average 5.2 concomitant injuries [41].

A wide range of injury severity scores (10–30.5) have reported with an average value calculated from pooled data of 15.7 points [21, 96, 122, 135, 156, 160].

Life-threatening bleeding is rarely seen and is reported to occur in only 0–2 % of cases [11, 64, 65, 95, 118]. There are no clear data on transfusion requirement, but rates of 17–40 % have been reported [15, 64, 118, 150]. Of these patients, 10–31 % were in shock on admission [95, 118]. The source of potentially fatal haemorrhage is commonly secondary to intra-abdominal and thoracic injuries [3, 15, 21, 48, 51, 62, 111, 118, 135, 140, 150].

The prevalence of additional retroperitoneal and pelvic vascular bleeding may be significant. Retroperitoneal haematoma formation is reported in 9–46 % [21, 118, 122] and intrapelvic haematoma 9–39 % of cases. Pelvic

### Table 1 Prevalence of mechanisms of injury reported in the literature

<table>
<thead>
<tr>
<th>Author</th>
<th>Year of publication</th>
<th>MVA</th>
<th>Pedestrian</th>
<th>Passenger</th>
<th>Bicycle</th>
<th>Motorcycle</th>
<th>Fall</th>
<th>Sport</th>
<th>Farm</th>
<th>Crush</th>
<th>Other</th>
</tr>
</thead>
<tbody>
<tr>
<td>Banerjee [3]</td>
<td>2009</td>
<td>36</td>
<td>29</td>
<td>6</td>
<td>1</td>
<td>0</td>
<td>7</td>
<td>0</td>
<td>0</td>
<td>0</td>
<td>1</td>
</tr>
<tr>
<td>Nabaweesi [96]</td>
<td>2008</td>
<td>185</td>
<td>114</td>
<td>71</td>
<td>0</td>
<td>0</td>
<td>18</td>
<td>0</td>
<td>0</td>
<td>0</td>
<td>16</td>
</tr>
<tr>
<td>Chia [21]</td>
<td>2004</td>
<td>101</td>
<td>77</td>
<td>16</td>
<td>7</td>
<td>1</td>
<td>10</td>
<td>4</td>
<td>0</td>
<td>0</td>
<td>10</td>
</tr>
<tr>
<td>Grisoni [51]</td>
<td>2002</td>
<td>33</td>
<td>22</td>
<td>3</td>
<td>4</td>
<td>0</td>
<td>9</td>
<td>0</td>
<td>0</td>
<td>4</td>
<td>5</td>
</tr>
<tr>
<td>Silber [135]</td>
<td>2001</td>
<td>137</td>
<td>100</td>
<td>37</td>
<td>0</td>
<td>0</td>
<td>22</td>
<td>0</td>
<td>0</td>
<td>0</td>
<td>7</td>
</tr>
<tr>
<td>Upperman [156]</td>
<td>2000</td>
<td>75</td>
<td>45</td>
<td>25</td>
<td>5</td>
<td>0</td>
<td>3</td>
<td>2</td>
<td>0</td>
<td>0</td>
<td>15</td>
</tr>
<tr>
<td>Rieger [122]</td>
<td>1997</td>
<td>40</td>
<td>17</td>
<td>10</td>
<td>10</td>
<td>2</td>
<td>1</td>
<td>8</td>
<td>3</td>
<td>1</td>
<td>0</td>
</tr>
<tr>
<td>Lane-O’Kelly [81]</td>
<td>1995</td>
<td>59</td>
<td>49</td>
<td>4</td>
<td>4</td>
<td>0</td>
<td>7</td>
<td>0</td>
<td>2</td>
<td>2</td>
<td>0</td>
</tr>
<tr>
<td>Musemeche [95]</td>
<td>1987</td>
<td>56</td>
<td>35</td>
<td>18</td>
<td>0</td>
<td>3</td>
<td>1</td>
<td>0</td>
<td>0</td>
<td>0</td>
<td>0</td>
</tr>
<tr>
<td>Stachler [141]</td>
<td>1987</td>
<td>84</td>
<td>50</td>
<td>0</td>
<td>18</td>
<td>0</td>
<td>16</td>
<td>8</td>
<td>0</td>
<td>16</td>
<td>0</td>
</tr>
<tr>
<td>Torode [150]</td>
<td>1985</td>
<td>123</td>
<td>103</td>
<td>14</td>
<td>6</td>
<td>0</td>
<td>11</td>
<td>5</td>
<td>2</td>
<td>0</td>
<td>0</td>
</tr>
<tr>
<td>Reichard [118]</td>
<td>1980</td>
<td>110</td>
<td>80</td>
<td>20</td>
<td>8</td>
<td>2</td>
<td>6</td>
<td>0</td>
<td>0</td>
<td>0</td>
<td>4</td>
</tr>
<tr>
<td>Stuhler [144]</td>
<td>1977</td>
<td>42</td>
<td>29</td>
<td>7</td>
<td>0</td>
<td>0</td>
<td>9</td>
<td>0</td>
<td>0</td>
<td>6</td>
<td>5</td>
</tr>
<tr>
<td>Total number of patients from all studies</td>
<td>1081</td>
<td>750</td>
<td>231</td>
<td>63</td>
<td>8</td>
<td>120</td>
<td>27</td>
<td>7</td>
<td>29</td>
<td>63</td>
<td></td>
</tr>
<tr>
<td>%</td>
<td></td>
<td>83.3</td>
<td>57.8</td>
<td>17.8</td>
<td>4.9</td>
<td>0.6</td>
<td>9.2</td>
<td>2.1</td>
<td>0.5</td>
<td>2.2</td>
<td>4.9</td>
</tr>
</tbody>
</table>
vascular lesions are present in 2–8 % [91, 118, 146], and this increases up to 43 % of cases in complex pelvic trauma [118]. The presence of a posterior pelvic injury is associated with a higher risk of pelvic bleeding [89].

Open pelvic fractures are characterized by the presence of wounds in the peripelvic and perineal regions, any associated perforations of hollow intra-pelvic viscera and vaginal or rectal injuries [91, 93]. These injuries are rare with reported rates of 1.9–12.9 % [33, 81, 91, 93, 95]. They are accompanied with a high ISS of 40 [93] or Polytrauma Score of 31 points [91]. Mortality rate of up to 20 % has been reported [93].

Concomitant truncal (Table 2), extremity (Table 3) and genitourinary (Table 4) injuries are seen in a high proportion of children with pelvic injuries.

**Differences between paediatric and adult pelvic fractures**

The incidence of pelvic [29, 62, 119] and acetabular fractures [57] fractures is lower in children. But low energy injuries such as falls, bicycle injuries and motor vehicle accidents are implicated more often [139] (Table 5).

Associated chest, spinal [139], abdominal and upper extremity injuries [29, 120] are less prevalent when compared to adults. Head injuries, however, tend to be more severe and increase mortality from 3 to 30 % [139]. The overall injury severity is comparable to that in adults [29, 57, 62], but complex pelvic injuries are more common [57, 91].

The frequency of pelvic fracture-associated haemorrhage is lower in children [62, 89, 118, 122], but there is a much higher risk of bleeding [64, 118, 122], abdominal injuries and greater transfusion requirements [62, 89, 118, 122] in communicating pelvic fractures.

The mortality rate in children is thought to be lower than that of adults [29, 62], but a recent multicenter analysis reported a higher mortality rate in children [57].

**Clinical examination**

In awake and orientated patients, pelvic fractures can be diagnosed or ruled out by clinical examination alone [22, 32, 50, 52, 74, 127, 162] (sensitivity: 69 %, specificity: 95 %, positive predictive value: 65 %, negative predictive value: 91 % [64]).

Inspection of the undressed patient should focus on pelvic asymmetry, leg length discrepancies, colour differences of the feet, and the peripelvic soft tissues (anteriorly, posteriorly, perineum). The urethral meatus and vagina must be checked for any sign of bleeding.

The value of a proposed routine digital rectal examination in the secondary survey to identify occult injuries is still unclear in paediatric patients [78, 133]. Beside localization of pain, the clinical examination must establish the degree of pelvic stability. Lateral compression injuries tend to be more stable than open-book injuries. Repeated manoeuvres to assess stability should be avoided as these can increase the danger of bleeding. Stability of the pelvis is graded as clinically stable or unstable. Instability is rare in paediatric pelvic fractures (1/33 patients, 3 %) [112].

A capillary refill of greater than 3 s warrants further assessment of pedal pulses with Doppler ultrasound.

<table>
<thead>
<tr>
<th>Author</th>
<th>Year of publication</th>
<th>No. of patients</th>
<th>Head</th>
<th>Chest</th>
<th>Abdominal</th>
<th>Liver</th>
<th>Spleen</th>
<th>Spine</th>
</tr>
</thead>
<tbody>
<tr>
<td>Spiguel [140]</td>
<td>2006</td>
<td>13</td>
<td>4</td>
<td>4</td>
<td>2</td>
<td>?</td>
<td>?</td>
<td>0</td>
</tr>
<tr>
<td>Silber [135]</td>
<td>2001</td>
<td>166</td>
<td>64</td>
<td>33</td>
<td>32</td>
<td>?</td>
<td>?</td>
<td>2</td>
</tr>
<tr>
<td>Rieger [122]</td>
<td>1997</td>
<td>54</td>
<td>26</td>
<td>10</td>
<td>?</td>
<td>7</td>
<td>7</td>
<td>3</td>
</tr>
<tr>
<td>Lane O’Kelly [81]</td>
<td>1995</td>
<td>68</td>
<td>25</td>
<td>5</td>
<td>1</td>
<td>0</td>
<td>0</td>
<td>3</td>
</tr>
<tr>
<td>Sy [146]</td>
<td>1995</td>
<td>43</td>
<td>8</td>
<td>1</td>
<td>2</td>
<td>?</td>
<td>?</td>
<td>0</td>
</tr>
<tr>
<td>Rangger [115]</td>
<td>1994</td>
<td>21</td>
<td>4</td>
<td>5</td>
<td>5</td>
<td>0</td>
<td>0</td>
<td>1</td>
</tr>
<tr>
<td>Musemeche [95]</td>
<td>1987</td>
<td>57</td>
<td>13</td>
<td>10</td>
<td>12</td>
<td>3</td>
<td>3</td>
<td>2</td>
</tr>
<tr>
<td>Reichard [118]</td>
<td>1980</td>
<td>120</td>
<td>30</td>
<td>10</td>
<td>5</td>
<td>5</td>
<td>0</td>
<td>6</td>
</tr>
<tr>
<td>Bryan [15]</td>
<td>1979</td>
<td>52</td>
<td>12</td>
<td>3</td>
<td>3</td>
<td>1</td>
<td>1</td>
<td>0</td>
</tr>
<tr>
<td>Stuhler [144]</td>
<td>1977</td>
<td>68</td>
<td>18</td>
<td>1</td>
<td>1</td>
<td>0</td>
<td>0</td>
<td>0</td>
</tr>
</tbody>
</table>

? Data not available
thorough neurological examination of the lower extremities is essential and should be carried out in an awake patient. The early utilization of a patient warming system to avoid hypothermia is recommended [130, 137].

**Imaging**

The gold standard for the radiological examination of pelvic injuries is the antero-posterior pelvic X-ray. Recent data suggest that in an awake and alert patient who is hemodynamic stability, with no peripheral nerve lesions and negative pelvic examination, it is no longer recommended [68, 110]. However in unstable patients, the standard X-ray together with an abdominal-pelvic CT-scan is mandatory [52].

In awake patients (GCS ≥ 14), the presence of pelvic/hip pain, abdominal pain and distension indicates pelvic fractures. The absence of these signs shows a negative predictive value of 87.5 % [112].

Symphyseal width changes from an average of 7.5 mm after birth to 5.5 mm in the adolescent [75, 99]. Acetabular injury is difficult to diagnose on plain X-ray [46, 152]. Indicators are displacement within the triradiate cartilage,
asymmetry of the tear drop, interruption of the iliopectineal line, or signs of an intraarticular effusion [142].

Oblique pelvic X-rays and MRI have no place in the acute assessment of pelvic fractures, but allow further delineation of the more complex aspects of the injury. Conventional cystography is no longer recommended [83, 128]. In suspected urethral lesions, a retrograde urethrogram remains the diagnostic standard but genitourinary injuries can be missed by standard X-rays [150].

CT is increasingly finding a place in the initial evaluation of paediatric trauma patient in 60–80 % of cases [21, 38, 51, 52, 135], especially in doubtful cases [33, 38, 85, 88] with potential advantages in polytrauma patients [33, 38, 85] as it can change fracture classification but rarely the treatment concept [51, 52, 56, 135].

Children tend to sustain isolated pubic ramus and iliac wing fractures, whereas adults sustain significantly more acetabular fractures and SI-joint diastasis [134]. A disrupted SI-joints is typically a fracture dislocation and not a true dislocation [73]. Paediatric sacral fractures are rare, and additional neurological injury is uncommon [56, 103].

Classification (Table 6)

The most commonly used classification systems are those of Key/Conwall [69], Torode/Zieg [150] and the AO/Tile/OTA [87, 94, 148] (Table 6).

The classification of sacral fractures by Denis et al. [31] is integrated into the AO/Tile/OTA system. These are very rare with only 8 cases reported in a 7-year period, with the majority type I (n = 6), and only one fracture of each type II and III [56]. In contrast to adults, there is far fewer associated neurological injuries [103].

These systems describe the patterns of bony injuries seen, but there are other variables that help to facilitate the identification of life-threatening pelvic injuries in the emergency situation. The following definitions have been shown to be useful in children as well as adults and have proven to be useful in the prediction of mortality [102, 154]:

- **simple pelvic fractures** with little soft tissue injury, and pure osteoligamentous instability (90 % of pelvic fractures) [45, 103]
- **complex pelvic trauma** as a pelvic fracture combined with a serious soft tissue lesion in the pelvic region [12]
- fractures with *pelvic and hemodynamic instability*: type B- or C-injuries combined with hemodynamic instability related to the pelvic injury with a systolic blood pressure of <70 mmHg and/or a haemoglobin concentration of <8 g/dl on admission [42, 104].
- **traumatic hemipelvectomy**: a total or subtotal dislocation of one or both hemipelves with complete disruption of the vascular and neural structures of the pelvis [107, 123].

Patients that sustain more unstable fractures also have a higher ISS with associated complex pelvic trauma [91, 122].
Emergency treatment follows the same protocols established in adults and focuses on the presence of hemodynamic and pelvic fracture stability. Emergency measures are required more often in children (17.9%) compared to adults (11.1%) [57].

Children are at a higher risk of injury to the pelvic viscera. The presence of pelvic and extremity fractures predicts concomitant abdominal and head injuries [11, 15, 135, 158] and therefore the overall risk of bleeding complications [11, 62, 89, 150, 158]. Bleeding is commonly associated with solid-organ injuries [15, 48, 62, 86, 111, 116, 118, 135, 150].

Pelvic bleeding control

The main challenge is to accurately evaluate the patient’s hemodynamic status. The initial base deficit is a strong prognostic indicator of shock, high injury severity, shock-related complications and mortality. A threshold of −5 to −8 mmol/l is reported in the literature [63, 71, 100, 113].

Pelvic self-tamponade and ligation of the hypogastric artery are insufficient in controlling haemorrhage [42]. Aortic clamping is only a temporary measure and helps in regaining access to the bleeding site intra-operatively [17].

The currently accepted measures in controlling pelvic haemorrhage are angiography/embolization and pelvic packing. The incidence of angiographic interventions is reported to be approximately 5% [29], and several case reports have communicated its success in achieving hemodynamic stability [6, 79, 109]. This, however, is a time-consuming procedure with reported lag times of 12 and 15 h between admission and the embolization procedure [6, 109]. We believe embolization is indicated only in patients with moderate hemodynamic instability.

Direct control of arterial bleeding can be achieved by ligation of small vessels but reconstruction in larger calibre vessels [42, 154]. The more common source of bleeding from the ruptured large venous plexus is much more difficult and time-consuming to control directly and such attempts risk additional blood loss. Uncontrolled and blind vessel ligation or clip application, especially near the sacral plexus, may lead to iatrogenic nerve injuries. Therefore, in severe and uncontrolled diffuse pelvic bleeding, especially major venous bleeding, pelvic packing is proposed with concurrent, emergent posterior pelvic ring stabilization [26, 27, 37, 39, 101, 105, 151, 155] especially in patients in extremis [42, 98].

### Table 6 Classification of paediatric pelvic ring injuries

<table>
<thead>
<tr>
<th>Classification</th>
<th>Relative frequency of injury (%)</th>
</tr>
</thead>
<tbody>
<tr>
<td>Key and Conwall classification [69]</td>
<td></td>
</tr>
<tr>
<td>I: No break in the pelvic ring (avulsion, iliac wing, superior or inferior pubic rami fracture)</td>
<td>37.5–55.8</td>
</tr>
<tr>
<td>II: Single break in the pelvic ring</td>
<td>27.5–42.8</td>
</tr>
<tr>
<td>III: Double break in the pelvic ring (anterior posterior, straddle fracture)</td>
<td>10.7–11.7</td>
</tr>
<tr>
<td>IV: Isolated acetabular fracture</td>
<td>5–8.9</td>
</tr>
<tr>
<td>Torode classification [150]</td>
<td></td>
</tr>
<tr>
<td>I: Avulsion fractures</td>
<td>3.1</td>
</tr>
<tr>
<td>II: Iliac wing fractures</td>
<td>14.8</td>
</tr>
<tr>
<td>III: Simple pelvic ring fractures (pubic rami fractures, stable symphyseal disruptions)</td>
<td>54.5</td>
</tr>
<tr>
<td>IV: Ring disruption fractures (unstable pelvic segment, straddle fractures, additional acetabular fractures, anterior + posterior ring fractures)</td>
<td>27.6</td>
</tr>
<tr>
<td>AO/OTA classification [87, 94, 148]</td>
<td></td>
</tr>
<tr>
<td>Sacral fractures according to Denis [31]</td>
<td></td>
</tr>
<tr>
<td>Type A: These fractures are stable, the mechanical ring structure of the pelvic ring remains intact</td>
<td>60–80</td>
</tr>
<tr>
<td>Type B: Partially unstable injuries with partial posterior, rotational instability after antero-posterior or lateral compression</td>
<td>10–35</td>
</tr>
<tr>
<td>Type C: Unstable injuries with combined anterior and posterior, vertical instability</td>
<td>10–16</td>
</tr>
</tbody>
</table>
Pelvic emergency fixation

Historically it was thought that operative pelvic stabilization to control bleeding is rarely necessary [95, 118]. Antishock trousers have fallen out of favour in adults due to their high rate of complications [157], whereas in children hemodynamic stabilization without complications has been reported [14]. We do not recommend their use as they restrict access to the patient.

Pelvic slings, pelvic bed sheets or pelvic belt stabilize of external rotation injuries [8, 13] and allow pelvic compression without restricting access to the patient [34, 125, 136, 159]. Prophylactic application of this device at the scene or in the emergency department should be considered in paediatric patients with unstable pelvic fractures.

Pelvic external fixation is the commonly used technique [51, 115, 117, 122, 150] and can be applied rapidly with low morbidity, particularly in patients with multi-system injuries. Simple anterior constructs do not provide effective mechanical stability for type C-injuries, but do control blood loss by reducing the pelvic volume and assisting tamponade [35, 45] through fracture stabilization and safe guarding the primary clot. McIntyre reported that in 60 % of cases, bleeding was controlled after an anterior external fixator was applied [89].

The pelvic C-clamp has the biomechanical advantage of direct and improved stabilization of the posterior pelvic ring, allowing for more effective pelvic tamponade [47, 61, 104].

Therefore, emergency stabilization of unstable pelvic ring injuries in children should be carried out by pelvic belts or external fixation. Definitive reduction and internal fixation is only recommended once the patient has become stable. Symphyseal plating, anterior plating of the SI-joint and application of iliosacral screws are all feasible techniques [5, 76, 103, 126].

Treatment of additional pelvic injuries

Extra-peritoneal bladder ruptures may be treated non-operatively [49, 84]. In 90–100 %, they are associated with pelvic fractures, whereas only 5–10 % of all pelvic fractures are combined with bladder ruptures [19, 24, 25, 49]. Conservative treatment consists of catheterization in all hemodynamically unstable patients. In all other patients, surgical reconstruction is performed as early as possible.

Intra-peritoneal rupture (35–40 % of all bladder injuries) requires formal repair, depending on the hemodynamic status of the child.

Combined extra- and intra-peritoneal bladder rupture is present in 5–10 % of cases.

Urethral lacerations are more common than bladder injuries. In suspected injuries (bleeding from the urethral meatus), a retrograde urethrogram should be obtained. A pelvic fractures is present in >90 % of patients with urethral ruptures. Most are associated with posterior bony or ligamentous injuries around the sacroiliac joint. Immediate surgery is suggested if there is a need for debridement of associated open wounds or if open reduction and fixation of fractures are necessary [20, 84, 92].

Patients with concomitant massive lower extremity injuries, often as a result of roll-over or crush, have severely damaged soft tissues. Due to the release of inflammatory mediators, a high risk of multiple organ failure is reported [77]. In uncontrollable bleeding, first the pelvis is temporarily stabilized with the pelvic C-clamp and pelvic packing is performed. The extremity haemorrhage is then controlled by tourniquet. Often, an amputation is necessary in these extreme cases.

Open pelvic fractures carry a high risk of mortality [93], related to massive blood loss and septic complications. Management of these injuries mirrors those of closed complex pelvic injuries. After initial control of blood loss, the patient is thoroughly assessed for the presence of additional rectal, vaginal or urogenital injuries as optimal management of these avoids septic complications. A defunctioning loop colostomy and antegrade washout must be carried out in cases of rectal lacerations and perineal injuries.

Treatment includes adequate and extensive debridement of devitalized and injured soft tissues, a thorough washout of all open wounds and adequate second-look operations to avoid development of muscle necrosis. Delayed vaginal, vulval or rectal reconstruction is carried out dependent on the general status of the patient.

Traumatic hemipelvectomy is defined as total dislocation of the hemipelvis with complete disruption of the vascular and neural structures of the pelvis (e.g. the hypogastric vessels and lumbosacral plexus). These injuries are rare with an incidence reported between 0.19 and 0.6 % [107, 123].

The severity of the soft tissue involvement varies from complete to incomplete. There are frequently associated with internal organ injuries (colon, rectum or genito-urinary system).

Immediate completion of the hemipelvectomy is necessary as attempts at pelvic reconstruction only serve to increase mortality.

The question of wound closure is certainly controversial. Some authors close the wound primarily for better future prosthetic fitting, others recommend delayed closure in order to allow the zone of injury to fully declare itself and prefer frequent and generous debridement followed by flap coverage. In all cases, consideration should be given to the retrieval and preservation of skin from the amputated extremity for future wound coverage.
Pelvic compartment syndrome is a rare complication after severe pelvic injury [12, 59] and early detection is mandatory. The pelvic injury itself rarely causes compartment syndrome as all pelvic fasciae are often disrupted. However, expanding haematomas can lead to severe swelling of the complete pelvic region. Muscular compartments around the pelvis are the iliopsoas, the gluteus medius and minimus and the gluteus maximus compartments.

There is a risk of compression-induced ischaemic damage to nerves (sciatic, femoral, obturator nerve) and secondary organ failure due to crush syndrome of the large muscle mass.

Treatment consists of early fasciotomy with evacuation of the haematoma, identification and control of the sources bleeding and extensive debridement of necrotic muscle. Gluteal compartments are approached via a Kocher-Langenbeck incision, iliopsoas compartments via an anterolateral approach to the pelvis. If primary wound closure causes too much tension on the skin, temporary wound closure with vacuum-assisted wound closure systems is recommended.

Degloving injuries (Morel-Lavallée lesions) of the anterolateral thigh region, the gluteal region and the region of the iliac wings are rare but are often seen in crush and rollover injuries. These injuries result from a combination of load and shear stress on skin which is stripped from the underlying deep fascia and thus detached from its blood supply. The space the created between the tissue planes is filled with a haematoma and lymphatic fluid, leading to seroma formation. Secondary infections have been described even in the absence of skin breaches [72]. Spontaneous healing of these lesions is rare.

There is still controversy whether to perform an open radical debridement or to adopt a more conservative approach by evacuating the haematoma and treating the soft tissues expectantly [30, 55, 80].

We prefer a radical and thorough debridement of all devitalized tissues followed by open wound management. Pelvic stabilization (minimal invasive techniques) should be performed as soon as possible due to potential infection. Drainage should be performed with vacuum-assisted techniques.

Definitive treatment

In the past, the treatment of paediatric pelvic fractures consisted of bed rest, traction, pelvic slings, or hip spica casts [15, 48, 95, 111, 116, 122, 150, 161]. More recently, operative stabilization of pelvic ring plays an increasing role in the management of these injuries with the treatment aims being anatomical reduction and maintenance of a symmetrical pelvis [88, 132, 149]. Most authors prefer external fixation (Table 7) [35, 117, 149, 150].

Even in the 1970s, Blatter recommended open reduction and internal fixation only in severely displaced iliac wing and pelvic ring fractures, sutting of the symphysis in concomitant injuries of the bladder or urethra or supracondylar traction in Malgaigne fractures. The majority of patients were treated non-operatively [10].

In the 1980s, some authors advocated surgical treatment as they thought persistent displacement can lead to leg length discrepancies, ankylosis of the sacro-iliac joint, malunion and pain [33]. External fixation was rarely advocated. Its use was only recommended when pelvic ring displacement is greater than 2 cm to avoid limb-length discrepancies [60], but acceptable results are reported [67].

As non-operative management of displaced pelvic fractures results in pelvic asymmetry and may lead to poor clinical results, several authors have focused on operative stabilization of the pelvic ring [66, 88, 90, 122, 143, 150].

Accepted indications for operative fixation are:

- concomitant soft tissue injuries requiring open wound treatment [18, 114]
- additional haemorrhage control during resuscitation [9]
- optimization of patient mobility [18]
- prevention of deformity in severely displaced fractures [15, 18, 67, 88, 132, 161]
- in special circumstances to improve patient care (e.g. polytrauma) [1, 18]

Displaced fractures require surgical reduction and stabilization, but at the present time, only case series are reported in the literature. The reported techniques include PDS-banding of the pubic symphysis and of the SI-joint [163], symphyseal plating and anterior plating of a disrupted SI-joint [43, 143], posterior iliosacral screw fixation and external fixation [7, 9].

No clear guidance or didactic approach is presented in the current literature. There is a wide range in the rates of operative intervention by various authors ranging from 0.6 up to 30 % with comparable rates of external and internal fixation (Table 7).

Our own protocol was developed with the knowledge gained from treating paediatric patients with complex pelvic trauma and reviewing their long-term outcome [91].

Our proposed a protocol takes into consideration associated organ injuries, the hemodynamic status of the patient, the patient’s age, the type of fracture and the stability of the pelvic ring [106]. A comparable approach has been recently reported by Silber and colleagues [135].

Treatment options in pelvic ring instability

In paediatric patients with an unstable pelvic ring who are hemodynamically stable, reconstruction and anatomical
stabilization of the pelvis is the primary goal. The indication of pelvic ring stabilization depends on the stability of the pelvis.

Type A fractures can sufficiently be treated functionally with no risk of further displacement by a short period of bed-rest and pain-dependent early ambulation. Reduction and stabilization is only performed in severely displaced or open fractures (e.g. iliac crest fractures, pubic ramus fractures, avulsion fractures in young athletes).

In type B-type fractures, stabilization of the anterior pelvic ring provides sufficient stability for early ambulation with partial weight bearing. Symphyseal disruptions normally need an open reduction and plate osteosynthesis, as external fixation alone leads to a high rate of secondary displacement in adults [82], whereas the more “stable” lateral compression injuries can be treated by conservative means in the majority of cases. External fixation of these injuries is rarely necessary.

C-type injuries should be treated by combined posterior and anterior stabilization, as posterior displacement of >5 mm leads to a high rate of malunion.

The type of implant depends on the fracture anatomy and more importantly on the patient’s age.

Adolescent patients (age 14–18 years) can be treated much like adults with the well-described techniques of osteosynthesis [149, 153]. In immature patients with an open triradiate cartilage, we distinguish between patients aged ≤10 years and those between 10 and 14 years.

In patients older than 10 years of age, adult and anatomically preshaped implants can be used in the majority of cases.

In the younger age group (age ≤10 years), special anatomical considerations have to be taken into account when choosing the technique and implants for osteosynthesis:

- **symphyseal disruption** screw/cerclage osteosynthesis, possibly with additional transosseous suturing in toddlers, in older children plate osteosynthesis with a two-hole 1/3 tubular plate or a two-four hole small fragment plate.
- **displaced superior pubic ramus fractures** carries the risk of bladder laceration. Open reduction and stabilization in toddlers with a K-wire, in older children with a 3.5-mm transpubic cortical screw.
- **unstable transpubic fractures as part of a type B- or C-injury** supra-acetabular external fixator [44]
- **iliac wing fracture** in toddlers K-wire stabilization, in older children screw- and/or plate osteosynthesis
- **transiliac fracture dislocation** (“crescent fracture”) posterior screw fixation of the iliac fracture by closed or open reduction
- **sacroiliac dislocation** anterior plate osteosynthesis with “mini-implants” (e.g. small H-plate), in older patients 3-hole small fragment plate(s)
- **sacral fractures** minimal invasive stabilization technique with percutaneous iliosacral K-wire fixation or with a 3.5-mm screw

Mobilization with partial weight bearing is started 3–4 weeks postoperatively. This also depends on associated injuries. It is preferable to allow the patient’s symptoms to guide mobilization. We recommend the removal of implanted metalwork after 3–6 months. An external fixator can be removed 2–3 weeks postoperatively.

---

**Table 7 Treatment methods in pelvic fractures**

<table>
<thead>
<tr>
<th>Author</th>
<th>Year of publication</th>
<th>Conservative</th>
<th>EF</th>
<th>ORIF</th>
<th>CRIF</th>
<th>ORIF + EF</th>
<th>Osteosynthesis (%)</th>
<th>Operative</th>
<th>Total no. of patients</th>
</tr>
</thead>
<tbody>
<tr>
<td>Banerjee [3]</td>
<td>2009</td>
<td>43</td>
<td>1</td>
<td>0</td>
<td>0</td>
<td>0</td>
<td>2.2</td>
<td>1</td>
<td>44</td>
</tr>
<tr>
<td>Spiguel [140]</td>
<td>2006</td>
<td>11</td>
<td>2</td>
<td>0</td>
<td>0</td>
<td>0</td>
<td>15.4</td>
<td>2</td>
<td>13</td>
</tr>
<tr>
<td>Karunakar [66]</td>
<td>2005</td>
<td>134</td>
<td>0</td>
<td>12</td>
<td>2</td>
<td>0</td>
<td>9.5</td>
<td>14</td>
<td>148</td>
</tr>
<tr>
<td>Chia [21]</td>
<td>2004</td>
<td>118</td>
<td>2</td>
<td>5</td>
<td>0</td>
<td>0</td>
<td>5.6</td>
<td>7</td>
<td>125</td>
</tr>
<tr>
<td>Grisoni [51]</td>
<td>2002</td>
<td>52</td>
<td>0</td>
<td>0</td>
<td>0</td>
<td>1</td>
<td>1.8</td>
<td>1</td>
<td>57</td>
</tr>
<tr>
<td>Silber [135]</td>
<td>2001</td>
<td>165</td>
<td>0</td>
<td>1</td>
<td>0</td>
<td>0</td>
<td>0.6</td>
<td>1</td>
<td>166</td>
</tr>
<tr>
<td>Upperman [156]</td>
<td>2000</td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
<td>9.5</td>
<td>9</td>
<td>95</td>
</tr>
<tr>
<td>Rieger [122]</td>
<td>1997</td>
<td>38</td>
<td>6</td>
<td>6</td>
<td>1</td>
<td>0</td>
<td>29.6</td>
<td>16</td>
<td>54</td>
</tr>
<tr>
<td>Keshishyan [67]</td>
<td>1995</td>
<td>31</td>
<td>12</td>
<td>0</td>
<td>0</td>
<td>0</td>
<td>27.9</td>
<td>12</td>
<td>43</td>
</tr>
<tr>
<td>Rangger [115]</td>
<td>1994</td>
<td>18</td>
<td>1</td>
<td>1</td>
<td>0</td>
<td>0</td>
<td>14.3</td>
<td>3</td>
<td>21</td>
</tr>
<tr>
<td>Barabas [4]</td>
<td>1991</td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
<td>5.5</td>
<td>3</td>
<td>55</td>
</tr>
<tr>
<td>Stachel [141]</td>
<td>1987</td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
<td>2.8</td>
<td>3</td>
<td>108</td>
</tr>
<tr>
<td>Musemeche [95]</td>
<td>1987</td>
<td>51</td>
<td>2</td>
<td>4</td>
<td>0</td>
<td>0</td>
<td>10.5</td>
<td>6</td>
<td>57</td>
</tr>
</tbody>
</table>

*EF* external fixation, *ORIF* open reduction and internal fixation, *CRIF* closed reduction and internal fixation
Hospital stay

Hospital stay for pelvic injury is reported being the second most expensive cause of hospitalization costing on average $15,011.61 per patient [41].

The typical duration of stay is 6–22 days with a median of 8–9 days [3, 21, 64, 140, 160], and the majority of patients can be discharged home (approximately 70 %) [3, 140]. On average 5 days of this period is spent in ICU [3, 21, 135].

Mortality

Mortality is reported to between 0 and 25 % with an average of 6.4 % (Table 8). There has been no significant change in mortality during the last 30 years (5.6–6.4 %). Some authors assert that death from pelvic fractures is rare in children [11, 95, 116] and is associated with concomitant severe head injury and overall injury severity [160]. Further factors which significantly influence mortality are the presence of complex pelvic trauma (19 % mortality) [91], the type of pelvic fracture [89, 150] and the presence of an open crush injury, a subgroup of complex pelvic trauma (20 % mortality) [93]. Subasi et al. [145] did not observe a difference in overall mortality between unstable type B- and C-injuries.

Long-term results

Several long-term complications have been presented in the literature.

Fracture-related sequelae include: persistent nerve deficits [21, 35, 56], a recto-vaginal fistula and pelvic infection [95], dyspareunia or altered vaginal sensation [23, 70] and vaginal obstructive complications [40, 95].

Complex pelvic injuries are associated with a high rate of local complications. Mosheiff et al. [93] had 11 wound and septic complications in 15 patients with open crush injuries (73 %), two cases of recurrent bowel obstructions and one case of vascular graft failure. Meyer-Junghänel et al. [91] reported a 38 % complication rate. Two patients had wound and three had severe bleeding complications.

The majority of reported complications are due to problems of bone healing including leg length discrepancies [21, 35, 88], delayed union of pubis [35, 88], fracture non-union [21, 35, 46, 122, 150], subluxation of an SI-joint

<table>
<thead>
<tr>
<th>Author</th>
<th>Year of publication</th>
<th>No. of patients</th>
<th>No of deaths</th>
<th>Rate of mortality (%)</th>
</tr>
</thead>
<tbody>
<tr>
<td>Banerjee [3]</td>
<td>2009</td>
<td>44</td>
<td>7</td>
<td>15.9</td>
</tr>
<tr>
<td>Spiguel [140]</td>
<td>2006</td>
<td>13</td>
<td>0</td>
<td>0</td>
</tr>
<tr>
<td>Vitale [160]</td>
<td>2005</td>
<td>1,190</td>
<td>86</td>
<td>7.2</td>
</tr>
<tr>
<td>Chia [21]</td>
<td>2004</td>
<td>125</td>
<td>5</td>
<td>4</td>
</tr>
<tr>
<td>Grisoni [51]</td>
<td>2002</td>
<td>57</td>
<td>3</td>
<td>5.3</td>
</tr>
<tr>
<td>Guillamondegui [52]</td>
<td>2002</td>
<td>130</td>
<td>3</td>
<td>2.3</td>
</tr>
<tr>
<td>Junkins [65]</td>
<td>2001</td>
<td>16</td>
<td>2</td>
<td>12.5</td>
</tr>
<tr>
<td>Silber [135]</td>
<td>2001</td>
<td>166</td>
<td>6</td>
<td>3.6</td>
</tr>
<tr>
<td>Upperman [156]</td>
<td>2000</td>
<td>95</td>
<td>4</td>
<td>4.2</td>
</tr>
<tr>
<td>Rieger [122]</td>
<td>1997</td>
<td>54</td>
<td>8</td>
<td>14.8</td>
</tr>
<tr>
<td>Lane O’Kelly [81]</td>
<td>1995</td>
<td>68</td>
<td>0</td>
<td>0</td>
</tr>
<tr>
<td>McIntyre [89]</td>
<td>1993</td>
<td>57</td>
<td>2</td>
<td>3.5</td>
</tr>
<tr>
<td>Vazquez [158]</td>
<td>1993</td>
<td>79</td>
<td>3</td>
<td>3.8</td>
</tr>
<tr>
<td>Garvin [48]</td>
<td>1990</td>
<td>36</td>
<td>1</td>
<td>2.8</td>
</tr>
<tr>
<td>Musemeche [95]</td>
<td>1987</td>
<td>57</td>
<td>8</td>
<td>14.0</td>
</tr>
<tr>
<td>Stuchel [141]</td>
<td>1987</td>
<td>108</td>
<td>3</td>
<td>2.8</td>
</tr>
<tr>
<td>Torode [150]</td>
<td>1985</td>
<td>141</td>
<td>11</td>
<td>7.8</td>
</tr>
<tr>
<td>Reichard [118]</td>
<td>1980</td>
<td>120</td>
<td>2</td>
<td>1.7</td>
</tr>
<tr>
<td>Stuhler [144]</td>
<td>1977</td>
<td>68</td>
<td>6</td>
<td>8.8</td>
</tr>
<tr>
<td>Reed [116]</td>
<td>1976</td>
<td>83</td>
<td>2</td>
<td>2.4</td>
</tr>
<tr>
<td>Quinby [111]</td>
<td>1966</td>
<td>20</td>
<td>5</td>
<td>25</td>
</tr>
</tbody>
</table>
problems and thus do not need specific treatment [35, 46, 122, 150]. Sacroiliac injury can progress to premature sacroiliac fusion with development of hemipelvic undergrowth [35, 48, 58, 88, 150]. Malunion can create leg length discrepancy and may lead to low back pain and spinal deformity [35, 48, 88, 161], but no data on acceptable amount of displacement are available from the literature.

Non-unions of the anterior pelvic ring, including diastasis of the pubic symphysis, usually cause no long-term problems and thus do not need specific treatment [35, 46, 122, 150].

Several reports focus on long-term outcomes. Richter et al. [121] reported on 126 children with a mean follow-up of 4 years (1–28 years). Eleven patients had pain, 16 had difficulty with sporting activities and 14 patients the pelvis showed clinical asymmetry. Bony deformities were present in 29 cases (23 %). Rieger et al. [122] reported on pelvic fractures aged 3-12 years at an average follow-up of 9 years. Three had moderate to severe pain and four patients had urinary incontinence (25 %). The radiological result showed anatomical fracture union in only nine cases (prevalence of radiological abnormalities: 43.7 %). Two patients had a malunion with 10–12 mm displacement. Three patients showed degenerative changes of the SI-joint, and three patients had an ankylosed SI-joint. Two patient developed ankylosis of the pubic symphysis. Re-evaluation of the primary and follow-up X-rays found fractures were missed in 8 patients. In the majority of cases, sacral fractures were not diagnosed at presentation. Blasier et al. found no significant difference in subjective scoring between type B- and C-injuries for pain at rest, pain with activity, limp and leg length discrepancy. Overall, there were 92 % good or excellent results in the patients who were treated operatively and 80 % good or excellent results in the patients who were treated non-operatively [9]. Subasi et al. followed 55 patients with unstable type B- and C-injuries (95 % of their series) after a mean of 7.4 years. Gait abnormalities were seen in 4 patients (7.3 %), leg length discrepancies and lower back pain each in 6 patients (10.9 %), degenerative SI-joint changes and symphysial sclerosis each in two patients (3.6 %) and an ankylosed SI-joint in one patients. Additionally, there were 11 urethral strictures (20 %), 6 patients suffered from urinary incontinence and 6 from erectile dysfunctions (10.9 %), and 56 % of the patients had long-term psychiatric problems [145].

Higher rates of long-term complications were observed following type C-injuries.

Smith et al. reviewed 20 patients who suffered unstable pelvic fractures aged 3-12 years at an average follow-up of 6.5 years. Patients with pelvic asymmetry following the injury had not demonstrated any remodelling at the last follow-up examination [138]. Seventeen of the 20 patients showed pelvic asymmetry. There was a 48 vs. 18 % reduction of asymmetry after operative vs. non-operative treatment. External fixation alone showed more asymmetry than results after anterior + posterior stabilization. After type C-injuries, asymmetry was 3.5 cm initially and 3.3 cm at follow-up after external fixation alone and 3.9 and 0.6 cm with posterior ring internal fixation.
In conclusion, current data on long-term results of pediatric pelvic injuries indicate that complications and poor outcomes are related to instability of pelvic injuries at presentation. There is a good correlation between the clinical and radiological result.

Conflict of interest The authors declare that there are no conflicts of interest.

References

69. Key JA, Conwell HA (1951) Management of fractures, dislocations and sprains. The C. V. Mosby Company, St. Louis


