Acute management of high-energy pelvic ring injuries

PhD thesis

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Introduction

High-energy pelvic ring injuries (HE-PRI) are associated with mortality and morbidity. They represent great challenge to the managing team even in the well prepared, high volume trauma centres. The John Hunter Hospital is a state designated peer-verified level 1 trauma centre in NSW, Australia, a primary referral centre for a population of 1.100.000 and area of 130.000km ^{2}. All severely injured patients, including all high-energy pelvic fractures, are brought to this centre either directly from the accident scene or through referring hospitals. This is the busiest trauma centre in the state of NSW with 4500 trauma admissions per year including >400 patients with ISS>15. Earlier prospective clinical study from the same institute described the population based epidemiology of pelvic ring fractures, and identified areas with potential for improvement. Despite all great efforts, these severe injuries still can cause exsanguination, which is the main cause of early mortality associated. Pelvic ring injury associated mortality is primarily due to bleeding and to lesser extent due to septic complications. Bleeding control is achieved with combination of procedures. Different management strategies exist, but all include haemostatic resuscitation with blood and clotting factors, detection and control or exclusion of extra-pelvic bleeding, and mechanical pelvic ring stabilization (either non-invasively or invasively). There are several studies showing benefits of emergency non-invasive pelvic ring stabilization, but very little data is available so far on the efficacy and safety of the method.

Bleeding associated with pelvic fractures comes from the broken bone, the pelvic venous plexus and from named arteries and their branches. Pelvic fracture related arterial bleeding (PFRAB) is usually not self limiting like some of the low-pressure venous bleeders. Using angiography for diagnosis and treatment of PFRAB is widely used. There is general agreement that it is the best option to control PFRAB however timing of the procedure is less uniform. Early identification of best candidates for therapeutic angiogram is much needed.

The pelvic ring injury is managed in stages (acute temporary fixation followed by definitive surgery) usually, but selected patients may benefit from acute definitive pelvic fixation. The role of acute definitive pelvic ring fixation needs to be determined and best candidates need to be identified.

Survivors of shock may have significant associated injuries responsible for later septic complications and sometimes suboptimal outcomes. Rectum injuries have known association with pelvic ring injuries. A late diagnosis carries risks of morbidity and mortality. The first step to recognize these associated injuries is to understand the injury patterns they occur.

Based on clinical needs described above, we set up our primary aims for our clinical research projects on the acute management of HE-PRI:

1. Determine the safety and efficacy of non-invasive emergency pelvic ring stabilisation.
2. Determine predictors of PFRAB from measures available early in the ED.
3. Determine the role of acute definitive pelvic ring fixation.
4. Identify patterns of pelvic ring injuries with associated rectum tears.

Four clinical studies were carried out to achieve our goals. During the investigation of these complex injuries, new patterns of pelvic ring injuries were recognized and findings are reported here.

1. Safety and efficacy of non-invasive emergency pelvic ring stabilization

Background

Emergency evaluation of patients with high-energy pelvic ring injuries (HE-PRI) focuses on quick evaluation of the physiology with measures of vital signs and acid/base status. If signs of shock are present, always major bleeding is expected to be the cause. All possible bleeding extrapelvic sources are determined or excluded. Pelvic bleeding may be self limiting in some cases, but most of the time requires a well organized effort to achieve haemostasis. There is no single effective method, but multiple steps required to succeed. There is no general agreement in the way and sequence these haemostatic efforts are carried out. Local resources and team training play important role in the development of institutional guidelines to manage these challenging situations. All guidelines include some sort of pelvic ring stabilization: either non-invasively with application of sheet wrapping or custom made orthesis or invasively with an external fixator or the pelvic C-clamp.

Emergency non-invasive pelvic ring immobilization is recommended by Advanced Trauma Life Support (American College of Surgeons Committee on Trauma) and also by Institute of Trauma and Injury Management (ITIM, NSW) evidence-based guidelines. Since the introduction of our institutional guidelines, application of pelvic binding became routine. There is little known about the efficacy of the method. Anecdotal reports recorded potential adverse events related, such as skin necrosis due to pressure, pierced bladder by bone fragments and neurologic deficit due to compressed nerve roots. We aimed to test adherence to our guidelines and to test safety and efficacy of emergency non-invasive pelvic ring stabilization in a clinical study. We hypothesized that the adherence to the guidelines in our institution is good and the Pelvic Binding (PB) improves the position of the pelvic ring without major complications.

Patients and methods

All patients admitted to the John Hunter Hospital with HE-PRI, were entered into our prospective electronic data base after March 2005. Data collection included demographic data (age, gender), mechanisms of injury, associated injuries, physiological parameters (blood pressure, heart rate, temperature, Ph, Base Deficit, lactate), trauma scores (Injury Severity Score, Abbreviated Injury Scale score for pelvis), fracture types (according to AO/OTA and Young-Burgess classification systems), resuscitation fluids (blood products), procedures (application of PB, angiography/embolization, definitive pelvic ring fixation, laparotomy findings), complications and outcomes (mortality and stay in hospital and on the intensive care unit).

In this study 41 months of data were assessed. All patients with HE-PRI were included. Patients with stable pelvic rings (A type injuries according to the AO/OTA classification system and acetabulum fractures with intact pelvic ring) were not considered. Patients who were dead on arrival were also excluded. Haemorrhagic shock on presentation was defined as a need for transfusion in the ED or presence of significant acidosis with BD<6

mmol/L. According to the institutional guidelines all patients in haemorrhagic shock with a pelvic fracture (regardless the fracture pattern) should have PB applied immediately. The technique of PB consists of application of a bed sheet around the pelvis at the level of the greater trochanters followed by crossing the sheet and clamping it at four points. In some cases a custom made orthesis was used at the scene by ambulance personnel. In all cases knees were also bound together with a sheet or bandage, according to the guidelines. As a standard procedure in all cases of vertical displacement, manual traction was applied on the shortened lower limb to reduce the cranial displacement before the binding was tightened. PB was removed in the operating theatre at the time of pelvic ring fixation or was removed/ loosened on the ward after 24h, whichever happened earlier.

Pelvic radiographs (AP pelvic radiograph and/or CT scans) before and after the application of PB was reviewed. Pre- and post-binding images were compared when possible. The effect of PB was categorized as `Perfect` if near anatomic alignment of the pelvic ring was achieved, `Improved` if the alignment had improved, but still significant displacement was present, `Not changed` if the alignment had not changed and `Worse` if the deformity or displacement had increased.

All patients identified with local complications, such as associated femoral vessel, rectum and bladder injuries, were assessed individually by independent experts to find out if there was any possible relationship between the injury and PB.

Results

There were 115 patients included in this study with AO/OTA B and C type unstable HE-PRI. Patients had age 43.5±19.7 years, 70% were male, with a mean ISS of 26±14. The utilization of PB was 37% of the unstable HE-PRI. Regarding the specific fracture types utilization was: B1 81%, B2 14%, B3 42%, C1 53%, C2 75%, C3 33%.

There were 36 (31%) patients who had significant blood loss resulting in haemorrhagic shock. The utilization of PB in shocked patients, giving the adherence to the guidelines, was 50%. There was good adherence to the guidelines in cases of B1 type 80% and C type 68% fractures. Adherence was poor in cases of B2 and B3 type fractures, both 20%.

Application of PB was performed in the ED after AP pelvic radiographs in 53% and before imaging in 7%, at the accident scene in 28% and at the referring hospital ED in 12% of the cases. Binding was removed in the ED in 12% of the cases, in the operating room at the time of acute pelvic stabilization (<24h) in 53%, and at the time of planned operative pelvic fixation (>24h) in 23%. In all cases when PB was left on longer than 24h, it was loosened to prevent pressure area development. In one case PB was changed for a pelvic orthesis that was used for non-operative management.

The efficacy of PB was checked on post binding imaging: “Perfect” alignment was achieved in 42%; “Improved” in 26%, had not changed in 21% and was “Worse” in 11% of the cases. Analysing fracture types, good effect was demonstrated (“Perfect” or “Improved” alignment) with all the B1, and most of the C type fractures (82%). In 5 cases we noticed increased deformity after PB application in B2 and B3 type fractures.

The mortality of the cohort was 7.8%. Four patients died within a few hours after arrival due to uncontrolled major bleeding, with the pelvis identified as the main source of blood loss. Two of them had PB applied in the ED in a timely fashion. Two cases were

identified as cases with potential for improvement, as they had either no PB applied or not in a timely fashion (>1 hour of arrival).
Safety analysis was performed in each case with associated femoral vessel, bladder and rectum injury. There was one patient with common femoral artery injury diagnosed by angiography with no clinical sign of limb ischaemia. The patient had combination of a both column acetabulum fracture and a type B3.1 HE-PRI with locked symphysis. During definitive pelvic fixation a sharp bone fragment was found close to the femoral vessels, but penetrating injury was excluded.
There were three patients with rectum tears associated with pelvic ring injuries. All patients had PB applied. All pelvic ring injuries were pure ligamentous disruptions (AO/OTA B1.1 type) and penetration of a bone fragment could be excluded.
There were 10 patients with bladder injuries, all extraperitoneal; four of them had PB applied. In one case there was no bone fragment nearby (B3.2 type injury with locked pubic symphysis). In the other 3 cases there was at least one sharp bone fragment close to the bladder very likely to cause the injury. Application of the binding as a cause of the bladder injury in these cases was not likely, but could not be excluded.
There was no case of neurologic deficit as a result of sacral nerve root damage or nerve compression and no skin pressure area or necrosis developed around the pelvis in any of the patients.

Discussion
Our study showed that application of PB is safe by the first care providers, who are usually not experts on pelvic fractures and may have limited resources for imaging. We had surprisingly low adherence to the guidelines, particularly in type B2 and B3 fractures (both 20%), which is concerning. Too early removal of PB risks re-displacement of the pelvis, dislodging of clots resulting in increased bleeding. Too late removal risks skin integrity as pressure areas may develop. Although we have not recognized any problems with leaving the binding on for up to 24 hours, we cannot recommend leaving it on any longer than that. In high risk cases when PB is applied in presence of local soft tissue compromise, removal should be as soon as possible. If the fracture pattern is not likely to benefit from further lateral compression (B2 and some of the B3 types) we consider loosening or removal of the binding. We could not find any evidence of complications associated with PB application on these fractures; however we have found PB to offer less potential benefit for them. We think inclusion of any fracture classification system in the guidelines would create confusion.
We had some cases with associated internal organ damage. The relationship between the PB and the associated organ damage could be excluded in all cases of rectum and femoral vessel injuries. Bladder injuries were also most likely the result of the accident, but exclusion of a possible iatrogenic injury is more difficult in these cases. There are other possible complications reported in the literature such as skin breakdown or necrosis and peroneal nerve palsy as a result of a second sheet applied around the knees. We did not find any of these complications.
Another potential `disadvantage` of PB is the restoration of the anatomy of the pelvic ring, resulting in underestimation of the severity of the injury. If near anatomic or anatomic alignment appears on static imaging but there are concerns about a possible unstable

injury, stability should be tested under image intensification preferably in the OR by an expert surgeon to decide if the pelvis requires operative stabilization.
Having no control group is a limitation and probably a missed opportunity as pelvic binders are now commonly applied in the prehospital phase following the introduction of a new protocol for the ambulance service of NSW in 2009. This has limited our ability to demonstrate cause and effect with the use of pelvic binders.

2. Early prediction of pelvic fracture related arterial bleeding

Background
Major bleeding associated with HE-PRI is the main cause of early mortality associated. Pelvic bleeding is a combination of bleeding from the broken bones, pelvic venous plexus, and vessels large enough to have anatomic names; with the proportions impossible to determine, most likely variable in each case. Bleeding from the bones can be controlled with emergency stabilization either non-invasively or invasively with application of external fixator or pelvic clamp. Acute definitive pelvic ring fixation plays important role as well. Venous bleeding might be self-limiting with haemostatic resuscitation and stabilization of the pelvis. The role of pelvic packing was investigated and reported in a number of studies. Some arterial bleeders in younger individuals might be self limiting; however there is no hard evidence to support it. Elderly people have sclerotic changes in their arteries making them more vulnerable for injuries and less able to limit bleeding with spasm. Angiography and embolization for control of PFRAB is reported to be effective in many studies, however using it as a screening tool is not feasible due to logistics. Performing pelvic angiography requires patient transfer to a fully equipped angiography suite with an experienced interventional radiologist available. A non-therapeutic study takes valuable time while other potentially life saving efforts are delayed, so it is crucial to identify those candidates who have best chances for a therapeutic intervention. Making the decision for angiography early, in the ED would be preferred. We aimed to identify those predictors of PFRAB that are available within 30-60 minutes after patient arrival to ED. We hypothesized that PFRAB is predictable from information available within 30-60 minutes of arrival.

Patients and methods
Consecutive trauma patients admitted to the level-1 trauma centre with HE-PRI were included in this study for 46 months period. Patients younger than 18 years, dead on arrival (demonstrating no vital functions) and transfers from another hospital with more than 4 hours of delay after the injury were excluded.
Initial management in ED was based on ATLS and New South Wales trauma guidelines. Resuscitation bay diagnostics included AP chest and pelvis radiographs, serial observations of vital parameters including blood pressure, heart rate, respiratory rate measurements, pulse-oxymetry, repeated arterial blood gas analysis and FAST and/or DPL/DPA. External bleeding was immediately controlled by direct pressure or sutures. Emergency non-invasive pelvic ring stabilization (PB) was performed either in the prehospital phase or in the ED within a few minutes of arrival. Decision for blood transfusion in ED was made by the trauma team leader individually in each case considering vital parameters, response to initial fluid resuscitation and estimated blood

loss. The initial FAST (and/or DPL/DPA) exam was used to triage shocked patients; those with positive results were taken to the operating theatre for laparotomy immediately. Patients with negative initial FAST results or positive results but no signs of shock were further assessed with CT scans and/or pelvic angiogram. Pelvic angiogram was indicated based on the discretion of the attending surgeon. The time to angiography was 30-240 minutes after arrival in all cases. PFRAB was defined if identified on (1) pelvic angiography (extravasation of contrast), (2) on CT angiogram (contrast blush into the pelvic haematoma) or (3) during laparotomy (rapidly expanding pelvic haematoma). Those patients who were identified as candidates for angiography (either on pelvic CT angiogram or laparotomy finding) but died before it could be carried out (4 cases) were categorized as having PFRAB.

For details on collected data please see methods of study 1. Univariate analysis (student's t test and Fisher's exact test) was performed for each variable. After testing normality of categorical variables (one-sample Kolmogorov-Smirnov test) the association between PFRAB and all variables were measured by Pearson correlation. Receiver-operator characteristics (ROC) were analysed for all continuous variables. Area under the curve was assessed and cut-off value was determined. Decision tree analysis was also performed for all variables and cut-off values were determined. Data is presented as mean±SD or percentages, $p<0.05$ was considered significant.

Results

There were 143 patients with HE-PRI included in this study. There were 15 (10%) patients identified as having PFRAB: 11 on pelvic angiography, one on CT angiogram and 3 on laparotomy findings. There were no complications or adverse events associated with angiography/embolization. Univariate analysis showed that patients with PFRAB were significantly older; more severely injured (both ISS and AIS pelvis), had lower blood pressures (SBP 1st, SBP worst and MAP), were more acidotic (pH and BD worst), required more often transfusions in ED and required more units of transfusions in the first day than non-PFRAB patients. They also had a higher mortality rate.

All variables were tested for correlation with arterial bleeding using the Pearson correlation test. Correlation with PFRAB ($r>0.3$) was found with the need for transfusion in ED, ISS, AIS pelvis, AO/OTA class, positive FAST in ED, pH worst, BD worst , dBD (difference between BD first and BD worst) and SBP worst.

Trauma scores (ISS, AIS pelvis) have prediction value, but are difficult or impossible to determine early, therefore are less useful for clinical decision making and were not assessed further.

Regarding the fracture pattern the Young-Burgess classification system had poor correlation ($r=0.08$). The AO/OTA classification system had better correlation ($r=0.34$).

Those potential predictors that are easy to determine early within a few minutes after arrival in ED such as physiological (SBP 1st, SBP worst, MAP), and resuscitation parameters (transfusion needed in ED (yes/no)) and acid/base status (pH 1st, pH worst, BD 1st, BD worst and dBD) were further focused. For continuous variables ROC curves were determined. BD worst had the most favourable ROC curve pattern: the area under the curve was 0.77. Cut off value was determined by expert opinion. At BD=6mmol/L there was sensitivity=0.73 and 1-specificity=0.33. Patients with BD>=6mmol/L had

significantly larger proportion of arterial bleeders than those with BD<6mmol/L as demonstrated on the Chi-square test.
Decision tree analysis showed worst SBP to be the only useful predictor with cut-off value at 104mmHg. For other predictors no such value could be determined with this test.

Discussion
Previous studies reported on the role of pelvic angiography and embolization in the management of PFRAB. The incidence of PFRAB varies with the patient group assessed and with the timing when angiography was performed in wide range of 10-92%. We have found the presence of PFRAB was 10% of HE-PRI.
There are two fundamentally different approaches to the use of angiography in the management of pelvic fractures. Proponents of early use, including us, advocate it immediately after non-invasive pelvis fixation and exclusion of extra-pelvic bleeding. Only associated major intra-abdominal or intrathoracic bleeding has higher priority. The aim is to interrupt the pathologic cascade of shock, acidosis and coagulopathy with early haemorrhage control. Acute management continues with acute invasive (temporary or definitive) pelvic fixation if required. Other authors recommend immediate pelvic ring reduction and fixation with an external fixator or a pelvic clamp and extra-peritoneal pelvic packing performed in the OR. They reserve angiography for those who remain haemodynamically unstable after these procedures. In both approaches there is much emphasis on organized team work, avoidance of delays and implementation of institutional guidelines based on local resources and expertise.
Predictors of PFRAB were identified in a number of previous studies, but most of them have limited clinical value due to poor/no availability in the early phase of the management. We believe that, the decision for angiography should be made early, before severe shock, acidosis and coagulopathy develops. We identified those predictors that are easily available early, shortly after arrival of the patient. We have focused on physiologic parameters and acid/base status determinants. We found that the presence of significant acidosis with BD<6mmol/L, worsening of the acidosis with dBD>2mmol/L, systolic blood pressure of 104mmHg or less and the need for transfusion in ED at any time within 4 hours of arrival can predict PFRAB. Our data clearly demonstrates that the more severe the acidosis was, the more likely the angiography was positive for PFRAB.
Several previous studies reported on unstable pelvic fracture patterns, such as Young-Burgess APC II, III, LC II, III, VS and CM, are potential predictors of PFRAB. We found some correlation only of the AO/OTA system with PFRAB (r=0.34). Accurate fracture classification warrants a CT scan and is time consuming making it less valuable in an acute clinical setting. Other authors evaluated features on the initial AP pelvis radiographs taken in ED such as SIJ disruption with displacement, displaced obturator ring fractures and pubic symphysis diastasis. The relevance of these radiographic features is limited due to the recent protocols of application of PB prior to any imaging.
Contrast blush into a pelvic haematoma on the pelvis CT angiogram is accepted to be evidence of PFRAB. Sensitivity, specificity and accuracy (90%, 98% and 98% respectively) of the CT pelvic angiogram to detect PFRAB were determined by other studies. Two previous studies gave warnings, that absence of contrast blush on the CT scan does not reliably exclude PFRAB. We did not use CT angiogram as a routine

screening tool for PFRAB. In our study only 9 out of 22 patients indicated for angiography had CT scans of their pelvises prior.
Increasing age was found to predict PFRAB in several studies with cut-off values between 55 and 65 years. This can be due to the older patients' sclerotic vessels poor ability to arrest bleeding with vasospasm or the increased chance of antithrombotic or platelet aggregation inhibitor medication. We found age to be a weak predictor (r=0.19).
Female gender predicted PFRAB in a previous study. We did not find it to have any prediction value.
The small number of patients in the PFRAB group (N=15) is a limitation of the study, making statistic analysis and interpretation of results more difficult. Running the study for longer period would not be feasible in a single centre environment since changes in resuscitation strategies would potentially influence the results. A multicentre study with pooling of data may cause paucity due to different treatment protocols and local logistics.

3. Acute definitive fixation of high-energy pelvic ring injuries

Background
Management of HE-PRI patients with multiple associated injuries is a major challenge. Timing of procedures requires careful planning when competing priorities are present. For unstable HE-PRI that requires stabilization, the safe and standard approach is staged management: early fixation with external fixator or pelvic clamp or traction followed by definitive surgery. Some pelvic fracture patterns are suitable for less invasive definitive fixation such as plate fixation of pubic symphysis disruption and lag screw fixation of dislocated sacro-iliac joint (SIJ) or sacrum fracture. Performing these less invasive techniques acutely offers potential benefit for some severely injured patients. If staged approach is used, these patients may sustain longer delays in their pelvic fracture treatment due to associated injuries. Our aim was to determine the feasibility of acute definitive pelvis fixation of selected HE-PRI patients. We assumed that acute definitive pelvic fixation of selected HE-PRI patients is safe and short term outcomes are comparable to staged management.

Patients and methods
Review of our prospective data base on HE-PRI was performed for 43 months period. For details of collected data please see methods of study 1. Consecutive HE-PRI patients with suitable fractures for less invasive internal fixation (percutaneous iliosacral screw fixation and symphyseal plating via limited suprapubic incision) were included in this study. Patients requiring extensive surgery for fixation of unstable pelvises were excluded. Patients were categorized based on timing of pelvic fixation as acute, AC (<24h of presentation) or staged, ST (>24h). Decision for management and timing was made by the attending orthopaedic trauma surgeon based on fracture pattern and availability of the pelvic specialist surgeon. Acute definitive pelvic fixation (AC) or temporary external fixation followed by later definitive surgery (ST) was performed. All procedures of definitive pelvic stabilization were performed or supervised by the same surgeon. Initial pelvic radiographs and CT scans and postoperative imaging were reviewed to measure displacements. Univariate analysis (chi^2 and t tests) was performed at $p<0.05$ and results are presented as mean±SD or percentages.

Results

Forty five patients with HE-PRI met inclusion criteria: 18 patients in the AC (with timing of surgery 5.5±8 h from injury) and 27 patients in the ST (5±3 days) group. AC and ST groups had comparable demographics with age 48±22 years vs. 40±13 and male gender 82% vs. 79% and injury severity with ISS 30±18 vs. 24.5±13 and AIS pelvis 3.7±1 vs. 3.4±1.1. Initial shock parameters were significantly worse for the AC group with systolic BP 69.7±17mmHg vs. 108±21, BD 7.14±mmol/L vs. 4.9±2, lactate 6.67±7mmol/L vs. 2.51±1.3. Angiography was performed in AC 18% vs. ST 21% groups.

The distribution of surgical procedures was comparable in both groups: symphysis plating alone (AC 28%, ST 30%), iliosacral scew fixation alone (AC 22%, ST 11%) and both procedures (AC 39%, ST 59%).

None of the outcome measures showed statistically significant difference. All patients in the AC group survived and one patient died in the ST group (3%). There was a trend for shorter hospital stay for AC patients (25±24 days vs. 37±32) and decreased need for PRBC transfusions in the first 24h (4.7±5U vs. 6.6±4). Fewer cases of pneumonia (0% v. 14%) and deep vein thrombosis (6% vs. 8%) were recognized in the AC group. AC patients had shorter stay on the intensive care unit (2.9±2.5 days vs. 3.7±3.6) with admission rate comparable (AC 67% vs. ST 56%). Initial displacement tended towards more severe in AC group: symphyseal area 24±19.2mm vs. 14±10.1, SIJ area 11.2±8.6mm vs. 6.1±4.9. The quality of reduction demonstrated on postoperative imaging was comparable: pubis area AC 7.5±4.0mm, ST 5.4±4.1, SIJ area AC 3.1±1.7mm, ST 2±1.8.

Discussion

There are many potential benefits of acute definitive pelvic stabilization including easier direct fracture reduction without extensive open surgery, less blood loss, better positioning and respiratory care on ICU, and shorter length of stay. There is little evidence available on timing of pelvic fracture fixation in patients with multiple injuries. Our results show that acute definitive fixation of selected HE-PRI can be performed safely and effectively, even in the multiply injured blunt trauma victim. We compared selected HE-PRI patients with those with similar fracture patterns based on timing of definitive pelvic fixation. AC and ST patients had comparable age, gender and injury severity. In most outcome measures there was a trend to favour acute definitive fixation, however no statistically significant difference was found. If staged management is followed longer delays are experienced in definitive pelvic fixation due to suboptimal soft tissue conditions, expected poor visibility on intraoperative imaging (intestinal gases due to bowel paralysis) and presence of associated injuries with other priorities.

Limitations of the study are the retrospective nature of analysis and the lack of randomization of patients into management arms. Main determinant of management was availability of the pelvic specialist surgeon. In the absence of the subspecialty surgeon staged surgery is a safe alternative. Switching to damage control mode during the acute management may be needed at any time based on the physiologic condition of the patient, even if acute definitive surgery was aimed originally.

4. Rectal injuries in association with pelvic ring disruptions

Background

High-energy pelvic ring injuries (HE-PRI) are part of multisystem blunt trauma, and are commonly associated with significant injuries of intra-pelvic organs and distant body regions. Associated injuries are responsible for significant mortality and morbidity and often for suboptimal outcomes. Common associated injuries include severe head injuries, chest, abdominal organ injuries, long bone fractures and genitourinary injuries. The association with rectum injuries is reported 0.15-2.2% in previous studies. They are described as (1) the rectum injury is a result of a perineal laceration extending to the rectum or (2) a bone fragment directly pierces the rectum. This condition is equivalent to an open pelvic ring injury. If the rectum tear is not associated with any perineal laceration (open only into the rectum) the injury may be more difficult to detect. During the secondary survey of the trauma victim per rectum (PR) digital examination is routinely performed as recommended by the ATLS and integrity of the rectum wall is palpated in all cases of pelvic fractures. Many multisystem blunt trauma victims have CT scans performed of their head, spine, chest, abdomen and pelvis with intravenous contrast as part of their emergency workup. Even with advanced imaging it is possible to miss a rectum injury. Consequences of a late diagnosis might be very severe including generalized sepsis from pelvic origin, potentially leading to death. We aimed to (1) determine the incidence of rectum injuries associated with high-energy pelvic ring disruptions and (2) describe the patterns of this combined injury. We assumed that blunt rectum injuries associated with pelvic fractures occur with lateral compression or combined injury mechanisms as a result of direct bone penetration into the rectum or a perineal laceration extends to the rectum.

Patients and methods

Our prospective electronic data base on HE-PRI was reviewed for the 48 months study period. Find details on data collection described previously at methods of study 1. Retrospective analysis of the data was performed for the period of 48 months. There were no exclusions made. Patients' medical charts were reviewed for Emergency Department notes and for operation reports. Autopsy reports were also reviewed for those who deceased in the hospital or arrived in the ED with no signs of life.

Patients identified with associated rectum injuries were further assessed for details of the injury mechanism, and details of the pelvic and rectum injury, management and outcomes. Radiographs were reviewed including emergency department AP pelvis views, CT scans, intraoperative and postoperative images.

Results

In this study there were 194 consecutive patients included with HE-PRI. Rectum tear was associated in 4 cases (incidence 2%). Patient with rectum tears were all males. They were significantly older with age 56.8±6.5 years versus 40.4±20.3, more severely injured with ISS 53.2±15.9 versus 23±14.2, required more transfusions in the first 24h after injury 7.25±2.2 U PRBC versus 2.2±5.1 and stayed longer in hospital 122.2±79.5 days versus 22.6±24.1, than those with no rectum injury. All patients with rectum tears had severe

associated injuries, including facial fractures (1), intracranial haemorrhages (1), multiple rib fractures with haemo-pneumothorax (2), prostathic urethra rupture (2), extra-peritoneal bladder rupture (1) and severe extremity injuries (3 cases). All patients required multiple surgical procedures for the management of the pelvic, rectum and other associated injuries. The overall mortality was 7.8%, all patients with associated rectum injury survived.

The pelvic ring disruption was classified as AO/OTA 61B1 and Young-Burgess APC II in 3 cases and 61B3/APCIII in one case. All patients had disruption of the pubic symphysis with widening greater than 2.5cm on the initial AP pelvis radiographs. The injury mechanisms were the following: horse riding accident with hitting the pelvis on the saddle, motorbike accident with hitting the pelvis on the fuel tank (2 cases) and bicycle rider hit by a car.

One patient had a large perineal laceraton involving the anus and the anterior wall of the rectum and extending to the scrotum, which was obvious on physical examination. In the other three cases the diagnosis was made by PR physical examination with the finding of blood in the rectum and palpation of the defect. Diagnosis was further clarified by CT scan with contrast enema in one case. Diagnosis was made in a timely fashion in three cases and was delayed until day 7 post injury in one. For those who had no perineal laceration, the rectum injuries were located on the anterior wall of the rectum 3-5 cm distance from the anus and were 2-4 cm in size.

All patients had PB applied in ED as per protocol. Two patients had PFRAB detected on pelvic angiography and successfully managed by embolization. Acute pelvic ring fixation (<24h) was performed by open reduction and internal fixation of the pubic symphysis with a plate in two cases. For the other two patients external fixators were applied emergently and were used as definitive fixation.

The rectum injury was managed with diverting colostomies in all cases. Laparoscopic procedure was performed in two cases and open procedure in the other two cases. The colostomy was performed within a few hours of the diagnosis in three cases, and as a planned procedure on day 4 post injury in one case. Distal rectal washout was performed in one case and presacral drainage was used in another one. The rectum injury was directly repaired in one case. The large perineal laceration was managed in stages with initial debridement followed by sphincter repair and step by step closure of the laceration.

Complications occurred in two cases. One patient developed a bleeding duodenal ulcer requiring multiple transfusions, subtotal and later a total gastric resection. Another patient, in whom the rectum injury was diagnosed late, developed generalized sepsis from pelvic origin, which resolved with treatment.

Regarding long term outcomes only one patient could return to his preinjury activities (competitive bicycle riding) with permanent suprapubic catheter and definitive colostomy. Only one patient had his colostomy reversed. One patient had permanent disability due to severe brain damage requiring 24h nursing care. One patient had below knee amputation for his mangled lower extremity. One patient was not available for long term follow up.

Discussion

Rectum injuries are result of penetrating trauma in >90% of the cases. Open fractures of the pelvis are associated with anorectal trauma in 17-64%. In our study the incidence of rectum injuries associated with HE-PRI was 2%. We described the characteristics of this

injury pattern. All our cases had similar injury mechanisms with having something between the lower limbs at the time of the accident (motorbike, horse or bicycle) acting as a wedge and opening the pelvis from the front. Separation of the pubic symphysis was the result in various degrees. With increase of the force applied, the pubis widening was larger and the posterior pelvic ring injury was either unilateral or bilateral. In our cases the rectum injury could not be the result of a bone fragment piercing through, as all these injuries were pure ligamentous disruptions of the pelvic ring with no bone fragments nearby. Penetration of any object could be also excluded as a possible mechanism in all cases. The same injury pattern was described in a previous paper in 1974, including a theory about the anatomic situation of the pelvic floor, making the rectum vulnerable to avulsion injury, if the pubic symphysis widely separates. The location of the injury on the rectum is at the attachment of the levator ani muscle to the rectal wall with a firm aponeurotic band just at the vesicorectal wall. This theory is supported by our observations.

In all our cases the rectum injury was either visible or located in a short distance from the anus making it possible to palpate. Performing PR examination in ED is routine for patients with pelvic fractures, but it has some limitations. It might be performed by an inexperienced person, or it might be attenuated by the noisy environment or by a PB applied. Therefore we recommend repeating the examination later in a more controlled environment by an experienced person. The best option might be in the operating room or on the intensive care unit, after bleeding control is achieved and patient is stabilized. For high risk patients, other diagnostic options like CT scan after a contrast enema or rectoscopy/sigmoidoscopy might be also considered. The risk of a missed injury outweighs the risks associated with these additional diagnostic procedures.

There is no consensus in the literature regarding the management of rectum injuries. The evidence available is coming from retrospective studies with limited patients involved, and without control groups making the level of evidence low. Most studies assessed penetrating trauma victims as these injuries are much more frequent then blunt ones to the rectum. Diverting colostomy is still the standard of care for all blunt trauma victims. Technical details of the colostomy should be discussed between surgical and orthopaedic teams to save options for optimal fracture management. Other adjuncts like distal rectal washout, presacral drainage and direct repair of the rectum injury are a matter of debate. Our experience is limited to make suggestions about it. In our institute the choice of treatment was based on the attending trauma or general surgeon’s preference.

Colostomy should be performed as soon as bleeding control is achieved and the patient is in a stable condition. Delays in treatment increase the risks of developing complications. All our colostomies were performed with the aim for temporary diversion, but takeoff was performed in only one of our patients.

All our patients survived, however the perineal/genitourinary trauma and also the associated severe distant injuries influenced long term outcomes and quality of life.

5. Unilateral dislocation of the sacroiliac joint with intact anterior pelvic ring

Background

With high-energy mechanism injuries the ring structure of the pelvis usually brakes at two distinct parts. The weaker anterior part (pubic symphysis and pubic rami) is more

prone to injuries; isolated anterior part fractures (pubis and pubic rami) are common. On the sideways of studying patients with HE-PRI, two cases of unilateral SIJ disruptions, with intact anterior pelvic ring, were identified. Conventional classification systems are poorly applicable to these injuries. After detecting the second case we hypothesized that these injuries are rare, but there are more cases possibly.

Patients and methods

We reviewed our prospective data base on HE-PRI for 48 months. Conventional radiographs and CT scans were reviewed for all patients, regardless the fracture type. Cases identified were thoroughly assessed for injury mechanisms, associated injuries, management and outcomes with the aim of finding similarities to describe this rare injury pattern.

A comprehensive literature review was performed using MedLine database and PubMed search engine (since 1950), using keywords of `unstable pelvis`, `sacroiliac joint disruption/dislocation` and `intact anterior pelvic ring` to find similar cases. Studies on human subjects were searched in English.

Results

There were only two cases of isolated unilateral SIJ disruptions with intact anterior pelvic ring out of 184 HE-PRI, in our prospective data base. They were both classified as AO/OTA 61C1 and Young-Burgess CM. Our detected two cases were similar regarding patient demographics (both male, age 18), high-energy injury mechanisms (passenger in a high speed car crash, and motorbike rider), associated severe soft tissue injuries (both had extensive closed deglovig injuries, Morel-Lavallee lesions) requiring surgical repair. In both cases the pelvic ring was reduced with closed manipulation and was fixed with percutaneous insertion of cannulated screws through the SIJ into the body of S1 and S2 (case 1) and into S1 (case 2) vertebrae in supine position of the patient. Definitive pelvic fixation was performed on day 3 (case 1) and on day 10 (case 2) after the accident. The longer delay in case 2 was due to the severe soft tissue damage in the gluteal region. Both patients had their Morel-Lavelee lesions surgically managed together with the pelvis stabilization, including drainage through separate lateral incisions, washout and suction drainage for 72 hours. Both patients had excellent outcomes with complete return to their pre-injury activities 12 months after the accident.

Our comprehensive literature search identified one more case of unilateral SIJ disruption with intact anterior pelvic ring, which was published 2 years later. We have found bilateral SIJ pure dislocations (2 cases) and bilateral fracture dislocations (4 cases) with intact anterior pelvic ring.

Discussion

HE-PRI are likely to involve both the weaker anterior (pubis and pubic rami) and the stronger posterior part (iliac wings, SIJ and sacrum) of the pelvis. In case of posterior lesions, associated anterior injuries are the rule. Bilateral posterior lesions reflect even greater amount of energy transfer. Isolated unilateral SIJ disruptions with the anterior pelvic ring intact are extremely rare with only three cases reported so far. Bilateral SIJ disruptions (either pure dislocations or fracture dislocations) are also rare with only a few cases reported. These cases were similar in the mechanism of injury being a severe direct

hit to the sacral area from behind (possibly with some variations in the direction of the force) or an upwardly directed force applied on the ischial tuberosities. Associated soft tissue injuries of the lower back and gluteal area were reported. Our cases reiterate this injury mechanism with a unique previously not described pelvic dislocation.
Detection of these injuries might be difficult on conventional radiographs. High index of suspicion is needed in young patients with initially unremarkable pelvis radiographs especially when the thorough physical examination detects soft tissue injuries in the area. Additional inlet/outlet views and a CT scan are essential to visualize the damaged skeleton.
For optimal outcome the dislocation should be reduced and stabilized. We prefer closed reduction with aid of manual traction and manipulation with Schantz pins inserted into the iliac crest and percutaneous fixation with cannulated screws. Less invasive technique is required with respect to the damaged soft tissues around. Loss of skin integrity and extensive soft tissue damage can influence timing and method of bony fixation. Minimally invasive drainage of the Morel-Lavallee lesion is performed through separate small incisions in a safe and efficient way. Using separate incisions for bone fixation and for the closed degloving injury is preferred, but may not be always possible. In those cases alternative techniques such as plate fixation of the SIJ through anterior approach may be considered.

Summary of conclusions and possible future directions

1. Emergency non-invasive pelvic ring fixation is safe and effective, even in hands of the first care provider. The adherence to the guidelines should be improved with further education. Fracture alignment could be improved in all B1 and most C type fractures. Although in some fracture patterns (B2 and B3) the deformity had increased, there was no evidence found of any significant hazards associated with the use of PB.
2. Physiologic parameters such as BD<6mmol/L, decrease of BD>2mmol/L between two measures, SBP<104mmHg and the need for transfusion in ED can all predict PFRAB in ED. After exclusion of abdominal, chest, extremity and external bleeding, these predictors can be valuable to triage blunt trauma victims for pelvic haemorrhage control with angiography.
3. Acute definitive pelvic ring stabilization in selected HE-PRI can be performed safely and effectively even in the multiply injured blunt trauma victim.
4. Rectum injuries associated with pelvic fractures are present in 2% of all HE-PRI. They are result of AP directed force on the pelvis. Rectum injuries are possible to detect by physical examination as they are either visible or palpable on the anterior wall in 2-4cm distance from the anus. The conventional teaching about rectum injuries associated with pelvic ring disruptions should be revised with the addition of this injury pattern as a separate entity.
5. Unilateral SIJ disruptions with intact anterior pelvic ring are unique injuries after high energy impact. They are associated with severe soft tissue damage. Posterior ring fractures/dislocations can occur in young patients without anterior ring fractures or dislocations.
6. The future of early management of HE pelvic injuries might be development of operating rooms in the trauma centres, equipped with options to perform all

possible interventions at one place, including advanced imaging, bone fixation, pelvic packing and angiography/embolization if needed. In this setting delays and decision making errors can be minimised.

List of abbreviations

AIS	Abbreviated Injury Scale
AO	Arbeitgemeinschaft fur Osteosynthesefragen
ATLS	Advanced Trauma Life Support
BD	Base Deficit
BP	Blood Pressure
CT	Computed Tomography
DPA/DPL	Diagnostic Peritoneal Aspiration/ Lavage
ED	Emergency Department
FAST	Focused Abdominal Sonography on Trauma
HE-PRI	High-Energy Pelvic Ring Injury
ICU	Intensive Care Unit
ITIM	Institute of Trauma and Injury Management
NSW	New South Wales
OTA	Orthopedic Trauma Association
PFRAB	Pelvic Fracture Related Arterial Bleeding
PB	Pelvic Binding
PR	Per Rectum
PRBC	Packed Red Blood Cells
ROC	Receiver Operator Characteristics
SIJ	Sacro-Iliac Joint

Peer reviewed scientific publications related to this thesis

Papers

1. Toth L, McGrath B, King K, Balogh ZJ. Safety and efficacy of emergency non-invasive stabilization of the pelvic ring, *Injury*, 2012 (43) 1330-1334

2. Toth L, Balogh ZJ. Unilateral dislocation of sacroiliac joint with intact anterior pelvic ring: report of 2 cases. *J of Trauma*, March 2010 (68) E83-E86

3. Enninghorst N, Toth L, King KL, McDougall D, Mackenzie S, Balogh ZJ. Acute definitive internal fixation of pelvic ring fractures in polytrauma patients: a feasible option. *J of Trauma*. 2010 (68) 935-941

4. Toth L, King KL, McGrath B, Balogh ZJ. Early prediction of pelvic fracture related arterial bleeding during trauma resuscitation: a prospective clinical study. Submitted for publication to *J Orthop Trauma.*

Abstracts

1. Toth L, Mackay P, Smith S, Deane S, Balogh Zs. Rectal injuries in association with pelvic ring disruptions. 9th European Congress of Trauma and Emergency Surgery, Budapest, 2008. (oral presentation)

2. Toth L, King K, McGrath B, Balogh ZJ: Safety and efficacy of emergency non-invasive pelvic ring stabilization. 10th European Congress of Trauma and Emergency Surgery, Antalya, Turkey, 2009. (oral presentation)

3. Toth L, McGrath B, King K, Balogh Z. Prediction of pelvic fracture related arterial bleeding: a prospective clinical study. 11th European Congress of Trauma and Emergency Surgery 2010. (oral presentation)