Positron emission tomography–computed tomography in the assessment of viability of femoral head in acetabular fractures

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Abstract

Purpose The aim of this study was to use positron emission tomography–computed tomography (PET-CT) imaging as a tool for assessment of viability of femoral head in acetabular fractures and help in early detection of complications like avascular necrosis (AVN) of the femoral head.

Methods In our study PET-CT was done pre-operatively and six weeks postoperatively in 31 patients who underwent open reduction and internal fixation (ORIF) of acetabular fractures and fracture–dislocations. There were 26 male and five female patients who were treated in our institute between January 2009 and July 2010. Patients were subsequently followed up with plain radiographs for a mean period of 3.8 years and minimum of two years.

Results Although seven out of 31 patients showed avascularity of the femoral head on PET-CT in the pre-operative period, only two patients progressed to AVN at final follow up, whereas the other five patients regained the vascularity at the end of six weeks. There was no statistically significant correlation between vascular status on pre-operative scan and the presence of AVN on final follow-up radiograph. There was a significant correlation between avascularity of the femoral head on the sixth week PET-CT and AVN in the final radiograph.

Conclusion PET-CT seems to be useful as a prognostic investigation in the assessment of the vascular status of the femoral head following injuries around the hip. Both pre-operative and postoperative imaging are necessary to understand the time-dependent changes in blood flow following injury.

Keywords Fracture of acetabulum · Hip fracture · Avascular necrosis of femoral head · PET-CT · Complications of acetabular fractures

Introduction

Acetabular fractures are often associated with subluxation or dislocation of the femoral head. Associated fractures of the femoral head are also not uncommon. Due to the extensive disruption of the soft tissues including the capsule of the hip joint, blood supply to the femoral head may be compromised in these injuries. The reported incidence of avascular necrosis (AVN) of femoral head following surgically managed acetabular fractures varies between 5.7 % and 30 % during follow-up periods that have ranged from six to 11.3 years [1–5]. AVN has been reported (two out of 35 patients) even following conservative management of displaced acetabular fractures using skeletal traction [6]. Delayed reduction of the fracture–dislocations and severe osteochondral injuries to the acetabulum have been found to be associated with very high (30 %) incidence of AVN [4]. Diagnostic tests that have been used in the quantification of blood flow to the femoral head in acetabular fractures include SPECT scan and intra-operative core biopsy of the femoral head. MRI scan has not been used extensively till now for this purpose, perhaps due to the artifacts from the metallic implants around the hip joint. The aim of this study was to use PET-CT for imaging the blood flow in the femoral head following acetabular fractures in pre-operative and postoperative periods. Knowledge of the vascular behaviour of the femoral head following injury is useful in pre-operative counselling of patients and in determining the optimal time for imaging of the femoral head for predicting future probability of avascular necrosis.

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Patients and methods

This was a prospective study conducted in our institute between January 2009 and July 2010. Thirty-one patients were included in this study. There were 26 male and five female patients (male-to-female ratio, 5.2:1). The average age of the patients was 46.1 years (range, 27–57 years). All patients with acetabular fractures and fracture–dislocations of the hip were included in this study. All the injuries were the result of road traffic accidents. The following patients were excluded from the study: patients with ipsilateral fracture of the neck of femur along with an acetabular fracture, critically ill poly-trauma patients (these patients were too unstable to be shifted for advanced imaging), peri-prosthetic acetabular fractures following total hip replacement, and patients who had previous operations on the proximal femur. Thirty-five patients were treated in our institute for acetabular fracture and fracture–dislocations during the above mentioned period and four patients declined to participate in the study. Permission of the institutional review board was obtained prior to the commencement of the study. Written consent was obtained from the patients who participated in the study.

Two out of 26 male patients had history of chronic cigarette smoking. Comorbidities such as diabetes mellitus, hypertension and ischemic heart disease were present in four of the 31 patients who were above the age of 50 years. The mean follow-up period was 3.8 years and the shortest follow-up period was 2.3 years. Plain radiographs (antero-posterior, internal and external oblique ‘Judet’ views of the hip) and CT scan images of the hip with 3-D reconstruction were obtained prior to operation. Acetabular fractures without dislocation were present in 11 patients and fracture–dislocations were present in 20 patients. Fractures were classified according to the Judet and Letournel classification of acetabular fractures [7]. The types of fractures are shown in Table 1. Posterior dislocations of the hip were associated with posterior wall fractures, posterior column fractures, combined posterior wall and column fractures and combined transverse fracture

with posterior wall fracture. Anterior dislocations were associated with anterior column fractures and central dislocations were associated with bicolumnar fractures, transverse fractures and T-type fractures.

Four patients (13 %) underwent closed reduction of the dislocation as a separate procedure prior to open reduction and internal fixation of the acetabulum. In those patients who underwent initial closed reduction of the hip dislocation, the closed reduction was done within a mean duration of eight hours (five to ten hours) from the time of injury. The posterior (Kocher-Langenbeck) approach was used for ORIF in 22 patients, anterior (ilio-inguinal approach) was used in five patients and combined posterior and anterior approaches were used in four patients. The posterior approach was used in patients with fractures of the posterior wall and posterior column and certain transverse fractures. The anterior approach was used when anterior column fractures and combined approaches were employed in bicolumnar fractures and T-type fractures.

Patients underwent PET-CT pre-operatively. PET-CT was done within a mean of eight hours of admission (range, six to 18 hours). The patient was hydrated well and a bolus dose of 370 MBQ of F18 was administered intravenously. Whole body PET-CT was performed 60 minutes following the injection (Siemens Biograph MCF PET-CT, Germany). A second PET-CT was performed six weeks after the first scan. Patients were followed up with plain radiographs (A-P and Judet views of the hip) at monthly intervals till fracture union and thereafter at six-monthly intervals for a minimum period exceeding two years. Twenty-three patients attended the out-patient department till time of final follow-up. The remaining eight patients, who could not present themselves for follow-up after 12–16 months, mailed their plain radiographs of the hip to our hospital. The radiographic outcomes were assessed according to the scoring system described by Matta [8]. Clinical outcomes were graded at the time of final follow-up according to the Merle d’Aubigne and Postel scoring system [9]. Chi-square and Fisher’s exact tests were used in the statistical analysis which was performed using the SPSS software (version 17; SPSS, Inc., Chicago, IL 2008).

Table 1 Acetabular fracture patterns

Type of fracture	Patients	Surgical approach used
Posterior wall	6	Kocher-Langenbeck
Posterior wall and column	7	Kocher-Langenbeck
Anterior wall and column	4	Ilio-inguinal
Transverse fracture	5	Kocher-Langenbeck (3 patients); Ilio-femoral (2 patients)
Posterior wall and transverse fracture	3	Kocher-Langenbeck
T-shaped fracture	2	Anterior and posterior approaches
Both column fractures	4	Anterior and posterior approaches

Results

The mean time interval between the injury and the performance of open reduction and internal fixation (ORIF) was 50.8 hours (range, 23–216 hours). In nine patients (29.1 %) the injury–treatment interval was between 24 and 48 hours. In 13 out of 31 patients (41.9 %) the injury–treatment interval was more than 48 hours. In those patients in whom ORIF was delayed, the reasons for the delay included late presentation of the patients to our centre following injury and presence of associated injuries that required higher priority in management. Patients who presented late had undergone conservative

management in other hospitals prior to being shifted to our centre. Clinical outcomes according to the Merle d'Aubigne and Postel score at the time of final follow-up were as follows—excellent in 12 patients, good in 12 patients, fair in five patients and poor in two patients. Radiographic grading at final follow-up according to Matta's criteria were as follows—excellent in 12, good in 13, fair in five and poor in two patients. Complications included wound dehiscence in two patients, transient foot-drop in two patients, heterotopic ossification (grade 2) in two patients and Morel-Lavallee lesion in one patient.

Seven out of 31 patients showed avascularity of the femoral head on PET-CT in the pre-operative period (Fig. 1). Five of these seven patients had posterior dislocation of the hip with fractures of the posterior wall or column. Two patients had central fracture dislocation with bicolumnar fractures. Those with posterior wall and column fractures underwent internal fixation through the Kocher-Langenbeck approach and patients with bicolumnar fractures underwent internal fixation using combined anterior and posterior approaches. The mean age of patients with AVN of the head of femur was 37.3 years (range, 30–42 years). Anatomic reduction of the fracture had been achieved in all (Fig. 2a) but one patient with bicolumnar fracture with marked comminution of the fracture. There was no history of smoking in any of these seven patients. Out of these seven patients, five had regained vascularity on PET-CT performed six weeks after the internal fixation (Fig. 3). Two patients showed persistent loss of isotope uptake in the PET-CT performed six weeks postoperatively (Fig. 4). These two patients progressed to AVN (6.5 %) at the final follow up (Fig. 2b, c). In both these patients the posterior Kocher-Langenbeck approach had been employed for internal fixation.

Statistically, there was no significant association between avascularity in pre-operative PET-CT and AVN at final follow-up ($p=0.05$). However, the correlation between the PET-CT done six weeks postoperatively and AVN at final follow-up was significant ($p<0.002$). There was no statistically significant difference in the AVN rates at final follow up between those patients who had ORIF within 24 hours and those who had ORIF beyond 24 hours from the time of injury ($p=0.67$). In our study, AVN occurred in patients with fracture-dislocations and no AVN was noted in patients with fractures without dislocation of the hip. However, this association was not statistically significant ($p=0.53$).

Discussion

Several techniques have been described earlier for assessment of blood supply of the femoral head following fractures and dislocations. Scintigraphy using ^{99m}Tc -SN-pyrophosphate and SPECT scanning were not reliable in prediction of later AVN in the postoperative period following dislocations of the hip and acetabular fractures [10, 11]. However, in these studies, imaging was performed only pre-operatively and was not repeated in the postoperative period. Single-point imaging is likely to miss the time-dependent fluctuations in the blood supply to the femoral head following acetabular trauma. Our results show that avascularity seen in the pre-operative period often improves in the postoperative period in many patients. Five out of seven patients who had shown avascularity of the femoral head in the initial imaging had recovered blood flow after a period of six weeks. If the vascular status has not improved by six weeks following injury, it is likely to remain 'status quo' and eventually result in AVN.

Contrast enhanced MRI and dynamic contrast enhanced MRI (DCE-MRI) have been reported to be more reliable than MRI without contrast enhancement in the assessment of femoral head vascularity [12–19]. The disadvantage of MRI is the metal artifact interference with image quality following internal fixation of acetabular fractures using stainless steel implants. Titanium implants are associated with less image distortion than stainless steel but they are still susceptible to magnetic susceptibility artifacts [20–22].

PET-CT has several advantages compared to the other modalities of testing avascularity of the femoral head. PET-CT imaging is not affected by the presence of either stainless steel or titanium implants and it is a dynamic, multi-planar imaging modality. The changes of both devascularization as well as restoration of blood supply are detected well on PET-CT. The cost of the imaging using F-18 isotope is comparable to that of contrast enhanced MRI. Out of the 31 patients who were followed up in our study, seven (22.6 %) patients showed changes of AVN in the initial PET scan. Out of these seven patients, five patients regained blood flow and only two patients progressed to AVN at the end of two years. The probable reason for this might be the time-dependent variations in the blood flow to the proximal femur immediately after trauma and six weeks after it. Blood flow to the femoral head is often interrupted immediately following trauma and it is restored in

Fig. 1 Pre-op PET-CT showing right acetabular fracture with no tracer uptake in the right femoral head and intact tracer uptake in the left side

Fig. 2 **a** Post-op radiograph of right acetabular fracture showing congruent reduction. **b** Final follow-up radiographs of the same patient (AP view) showing AVN changes in the femoral head. **c** Final follow-up

radiographs of the same patient (lateral view) showing AVN changes in the femoral head

many cases within a few weeks subsequently. We performed the second PET-CT at six weeks postoperatively since the patients are ambulant, soft tissue healing is likely to be complete and fractures are likely to be stable around this time.

In our study, no significant correlation was found between the duration between the injury and surgery and the AVN. Hougaard and Thompson [23] found significantly high rates of AVN (52.9 %) in patients who underwent reduction of the dislocated hip more than six hours following the injury and this prompted the ‘six hour rule’ for reduction that was widely adopted by numerous trauma centres. In a human cadaveric angiographic study in dislocated hip joints, Yue et al. [24] found that the angiographic changes were due to stretching and twisting of the arteries, and early reduction of the hip joint may reverse these changes. Delay in reduction may lead to thrombosis and fibrosis leading to permanent occlusion of the vessels [25]. Our study did not show increased rate of AVN in delayed reductions. While it is possible that delay in reduction may be detrimental to the circulation of the femoral head, the duration of time for reduction is debatable. We found no statistically significant difference in the AVN rates at final follow-up between those patients who had ORIF within 24 hours and those who had ORIF beyond 24 hours from the time of injury

($p=0.67$). Factors other than time interval for reduction may also play a role in the final development of AVN and these include quality of reduction, degree of initial injury and duration of follow-up. It is note-worthy that partial AVN was detected in two out of 50 hips that had undergone closed reduction of the dislocation within three hours of injury [26].

In the study by Yue et al. [24] a significantly higher rate of AVN was noted in fracture–dislocations in contrast to acetabular fractures without hip dislocations. This is perhaps due to the higher degree of damage to the soft tissue envelope around the hip in fracture–dislocations. In our study we noted no AVN in fractures without dislocations. Both the patients with AVN had fracture dislocation, but this association was not statistically significant ($p=0.53$). Trials including larger cohorts of patients are necessary for further analysis.

The relationship between the surgical approach and avascular necrosis of the femoral head has been studied by numerous authors and a recent systematic review of the existing evidence has shown a higher incidence of avascular necrosis following posterior approach (16.9 %) compared to the anterior approach (7.9 %) to the hip [27]. Ganz et al. [28] demonstrated that traditional posterior approaches pose a risk of damage to the anastomoses between the inferior gluteal artery

Fig. 3 Six week PET-CT showing restoration of tracer uptake in the right femoral head following open reduction and fixation of right acetabular fracture

Fig. 4 Six week PET-CT showing persistent loss of tracer uptake in left acetabular fracture

and the deep branch of the medial circumflex femoral artery. Studies that have measured the oxygenation of the femoral head intra-operatively have reported significant reduction in the oxygenation during the posterior approach compared to the anterior approach [29]. However, it would not be practical to uniformly adopt anterior approaches alone for fixation of acetabular fractures. Certain fracture configurations mandate the posterior approach for accurate reduction and stable fixation. In our study, the posterior approach had been employed in both the patients who had AVN at final follow-up, but statistical significance could not be established due to smaller numbers of anterior approaches. Larger cohorts with sufficient statistical power would be useful in this regard. The type of fracture itself may have a bearing on the vascular insult to the femoral head. Incidence of AVN has been found to be higher in posterior fracture dislocations compared to other types of acetabular fractures [30]. This factor is outside the control of the surgeon.

Conclusions

The dynamic and multi-planar nature of the PET-CT imaging is useful in documenting the variations in blood flow following trauma. An important observation of this study is that imaging needs to be repeated after an interval of six weeks to understand whether blood flow has re-established itself following the initial absence. When the vascular flow is reestablished, it is likely to occur within an average of six weeks. Lack of return of vascular flow even by six weeks following trauma is probably a good indicator of avascular necrosis in the future. We do not recommend the routine use of PET-CT till further data is available from other studies. PET-CT is a promising tool for the investigation of vascular changes in the femoral head following trauma and is not affected by the presence of metallic implants.

Clinical relevance It is useful to know the perfusion status of the femoral head in the early postoperative period for the purpose of prediction and counselling of the patient regarding the possibility of requirement of further surgical procedures in the case of development of AVN. Our study shows that postoperative vascular flow to the femoral head is subject to fluctuations, and reliable prognostic data can only be obtained by scans performed six weeks or later following injury.

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