Research Article

Mapping of the Stable Articular Surface and Available Bone Corridors for Cup Fixation in Geriatric Acetabular Fractures

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Abstract

Background: The optimal treatment of acetabular fractures in the senior cohort is undetermined. Total hip arthroplasty in the setting of an acetabular fracture is increasing in popularity. However, there is concern regarding the fixation of a prosthetic cup in a fractured acetabulum. The purpose of this study is to map the area of stable articular surface and bone corridors available for cup fixation in this fracture cohort.

Methods: CT scans of acetabular fractures in 131 consecutive geriatric patients older than 65 years from two level 1 academic trauma centers were analyzed. Acetabular fractures were classified using the Letournel classification, the available stable articular surface, and the bone corridors available for fixation.

Results: Fractures involving the anterior column were the most common fracture type seen. The dome only pattern was the most common stable articular surface pattern. The sciatic corridor was available for fixation in all fracture types, followed by the gluteal pillar corridor. Most fractures had at least two corridors (93%) available for screw fixation.

Conclusions: The findings of this study may aid in the development and evaluation of fixation strategies for acetabular cups allowing geriatric acetabular fracture patients earlier weight bearing after primary hip arthroplasty.

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Primary total hip arthroplasty (pTHA) for the treatment of elderly patients with acetabular fractures is an emerging treatment modality and subject to much debate in recent years.[1–3] The need for a stable socket to allow early weight bearing after pTHA is critical and is potentially associated with decreased revision rates.[1,3] Elderly patients with fractures of the acetabulum may benefit from primary total hip arthroplasty and immediate postoperative weight bearing to theoretically alleviate the risks of thrombotic events, decubitus ulcers, and deconditioning, and there are some studies supporting this protocol.[1,4] However, there is concern regarding the fixation of a prosthetic cup in a fractured acetabulum, and many surgeons are hesitant to allow immediate weight bearing in arthroplasty patients in the setting of a fracture.[4,5] Several studies have shown safety of primary total hip arthroplasty for geriatric acetabular fractures.[1,3–5] However, these are generally case series or are performed in select patients, and there remains a theoretical concern with respect to fixation of the prosthetic cup in a fractured acetabulum. There is scant evidence or guidelines directing surgeons on when it is possible to implant an acetabular implant into a fractured acetabulum.

The Letournel classification is the most widely used classification system used to describe acetabular fractures,[6] and recently, it has been incorporated into the AO/OTA fracture classification.[7] Additional classification systems have also been proposed, all of which focus on surgical fixation of the hip socket and not arthroplasty.[8]

A classification system geared toward pTHA of acetabular fracture would focus on the available bone articular surface and bone stock for acetabular cup fixation. Classification systems discussed in the arthroplasty literature in regard to acetabular bone loss and pelvic discontinuity[9] could potentially assist in guiding treatment. However, these classifications were not constructed with acetabular fractures in mind and may not represent the exact clinical scenario that surgeons face in the setting of a fracture.

Insights into the recurrent patterns of available stable articular surface and bone stock for cup fixation in the setting of acetabular fractures in the elderly may contribute to our understanding and help in the development of clear recommendations regarding the use of pTHA in the treatment of geriatric acetabular fractures. To the best of our knowledge, this type of fracture mapping for acetabular fractures has not previously been performed.

The purpose of this study is to survey acetabular fracture patterns in the geriatric cohort and map the remaining stable articular surface and bone stock available for cup fixation. We hypothesized that this survey would reveal recurrent patterns of stable articular surface and available bone corridors for cup fixation. These findings could lay the foundation for preoperative planning, surgical treatment, and the possibility of designing implants that use the intact articular surface.

Methods

Patient Selection

After institutional review board approval, 153 CT scans of consecutively treated elderly patients (aged ≥65 years) with acetabular fractures were collected from the two level-1 trauma center registries over a 10-year period (2005 to 2014). Acetabular fractures were identified by *International Classification of Diseases, ninth edition* (*ICD-9*) code 808.0 and confirmed by the radiology service. The initial patient cohort consisted of 97 men and 56 women and a mean age of 75 years. CT images of insufficient quality or an image thickness of >3.0 mm were excluded, leaving 131 images. Two fellowship-trained orthopaedic surgeons reviewed all CT scans and excluded acetabular fractures with a concomitant surgical pelvic ring injury and nonsurgical acetabular fractures (ie, stable posterior wall acetabular fractures and low transverse fractures with roof-arc angle >45°). Following screening of the CT data, 97 deidentified CT scans remained and were procured for further analysis.

Fracture Mapping and Analysis

CT data were downloaded as Digital Imaging and Communication in Medicine (DICOM) format and used to segment the pelvis and generate a three-dimensional (3D) model using Mimics software (v.15; Materialise). The involved hemipelvis was cropped, and the femoral head was removed to allow clear visualization of all fracture lines. An image of a left side acetabulum model (Sawbones) was used as a background for fracture mapping. Right side fractures were mirrored to conform to the left side template. Images of the fractured acetabulum were then sized appropriately and overlaid on the template image using image manipulation software (GIMP 2.8.4; Free Software Foundation, 2013). The GIMP pencil tool was then used to outline the stable portion of each fracture. Each stable articular surface was given equal opacity, and all similarly classified maps for each fracture type were superimposed, creating final "heat maps" of the stable articular surface. The 3D images of the fractures were also used to identify the available bone corridors for acetabular cup fixation. The fracture tracings were performed initially by the junior authors and then verified by the senior author.

Fracture Classification

All fractures were classified according to the Letournel classification for acetabular fractures. They were then further classified based on the region of stable articular surface and available bone corridors for acetabular cup screw fixation. Classification by stable articular surface was done according to the zone of articular surface that was fully or partially connected to stable bone: dome zone only (D), posterior zone only (P), anterior zone only (A), dome and posterior (DP), dome and anterior (DA), and all zones (DAP) (Figure 1). Classification by available bone corridors for screw fixation was done according to the available pelvic corridor for screw fixation: superior ramus pubis corridor (R), anterior corridor (A), gluteal pillar corridor (G), sciatic buttress corridor (S), and ischium corridor (I) (Figure 2). The classifications were done by the senior authors in unison.

Data Analysis

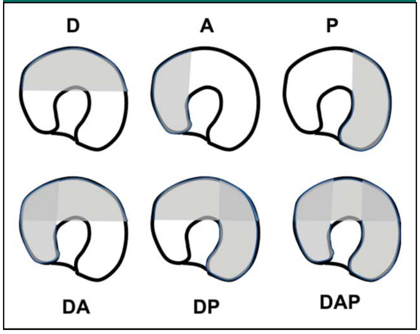
The analysis of the fracture maps was descriptive in accordance with previously published mapping studies.[10,11] Fracture patterns, stable articular surface zones, and available bone corridors were qualitatively analyzed.

Results

CT scans of 131 acetabular fractures were available for this study. After exclusion criteria were applied, 97 fractures (55 left sided and 42 right sided) remained for final analysis. When classified according to the Letournel classification, 57 fractures were of the elementary type, and 40 were of the associated type. Elementary fracture patterns included 17 anterior column fractures (18%), 9 anterior wall fractures (9%), 5 posterior column fractures (5%), 18 posterior wall fractures (19%), and 8 transverse fractures (8%). Associated types included 6 T-type fractures (6%), 5 transverse posterior wall fractures (5%), 12 anterior column posterior hemitransverse fractures (12%), and 17 associated both column fractures (18%). There were no posterior column posterior wall fractures. Fractures involving the anterior column and wall were the most common. Posterior wall fractures, anterior column, and associated both column fractures were the most common individual fracture patterns.

Breakdown of the fractures according to the simplified classification of the available stable articular surface is described in Table 1. The dome only (D) pattern was the most common fracture type (35%, left—35%, right—36%), followed by dome and posterior articular surface (DP—23%, left—25%, right—19%). Most fracture types (77%, left—80%, right—74%) had the stable articular surface at the dome.

Figure 1

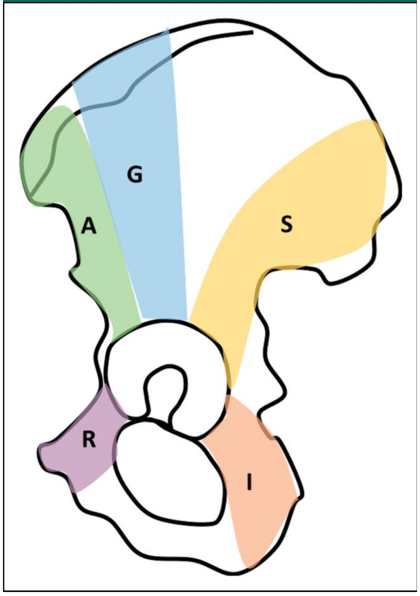


Schematic showing classification of the stable articular surface in elderly (aged ≥65 years) patients with acetabular fractures. A = anterior zone is stable, D = dome zone is stable, DA = dome and anterior zones are stable, DP = dome and posterior zones are stable, DAP = dome, anterior, and posterior zones are stable, P = posterior zone is stable

Only 40% (left—40%, right—40%) had stable posterior articular surface, and only 22% (left—22%, right—21%) had stable anterior articular surface. Figure 3 shows the tracings and heatmap of the stable articular surface of all fractures according to the simplified stable articular surface classification.

Breakdown of the fractures according to the bone corridors available for screw fixation through an acetabular cup is described in Table 2. All (100%) fractures had the sciatic corridor available for cup fixation, followed by the gluteal pillar (90%, left—87%, right—93%) and anterior corridor (76%, left—76%, right—76%). A ramus screw was possible about one third of the time (36%, left—38%, right—33%) and an ischium screw about half of the time (47%, left—49%, right—45%). Table 3 shows the frequency of the different combinations of these corridors. The most common combinations were to have all corridors available (RAGSI—33%, left—35%, right—31%) or all of the dome corridors available (AGS—33%, left—33%, right—33%). At least two corridors were available for fixation 93% (left—91%, right—95%) of time and at least three corridors 81% (left—82%, right—79%) of the time. All three dome corridors were available 76% (left—77%, right—76%) of the time.

Figure 2



Schematic showing classification of the bone stock available for screw fixation through an acetabular cup in elderly (aged ≥65 years) patients with acetabular fractures. A = anterior corridor, G = gluteal pillar corridor, I = ischium corridor, R = superior ramus pubis corridor, S = sciatic buttress corridor

Discussion

In this study, we have mapped acetabular fractures in the elderly and classified the fractures based on available stable articular surface and intact bone corridors for acetabular cup fixation options. Our main findings are twofold: that the acetabular dome is the most common available stable articular surface followed by the posterior articular surface, and that the sciatic buttress corridor was

Table 1

Simplified Classification According to the Stable Articular Surface

Fracture Type	Number	Percentage
D	34	35
P	3	3
A	2	2
DP	22	23
DA	5	5
DAP	14	14
No stable articular surface (ABC fracture type)	17	18
Total classifiable	97	100
Total dome	75	77
Total posterior	39	40
Total anterior	21	22

A = anterior zone is stable, ABC = associated both column, D = dome zone is stable, DA = dome and anterior zones are stable, DP = dome and posterior zones are stable, DAP = dome, anterior, and posterior zones are stable, P = posterior zone is stable

available in all acetabular fracture patterns, followed by the gluteal pillar corridor that was available in nearly all fractures. This study is intended to be an initial step toward development of fixation strategy guidelines for management of geriatric acetabular fracture by means of pTHA.

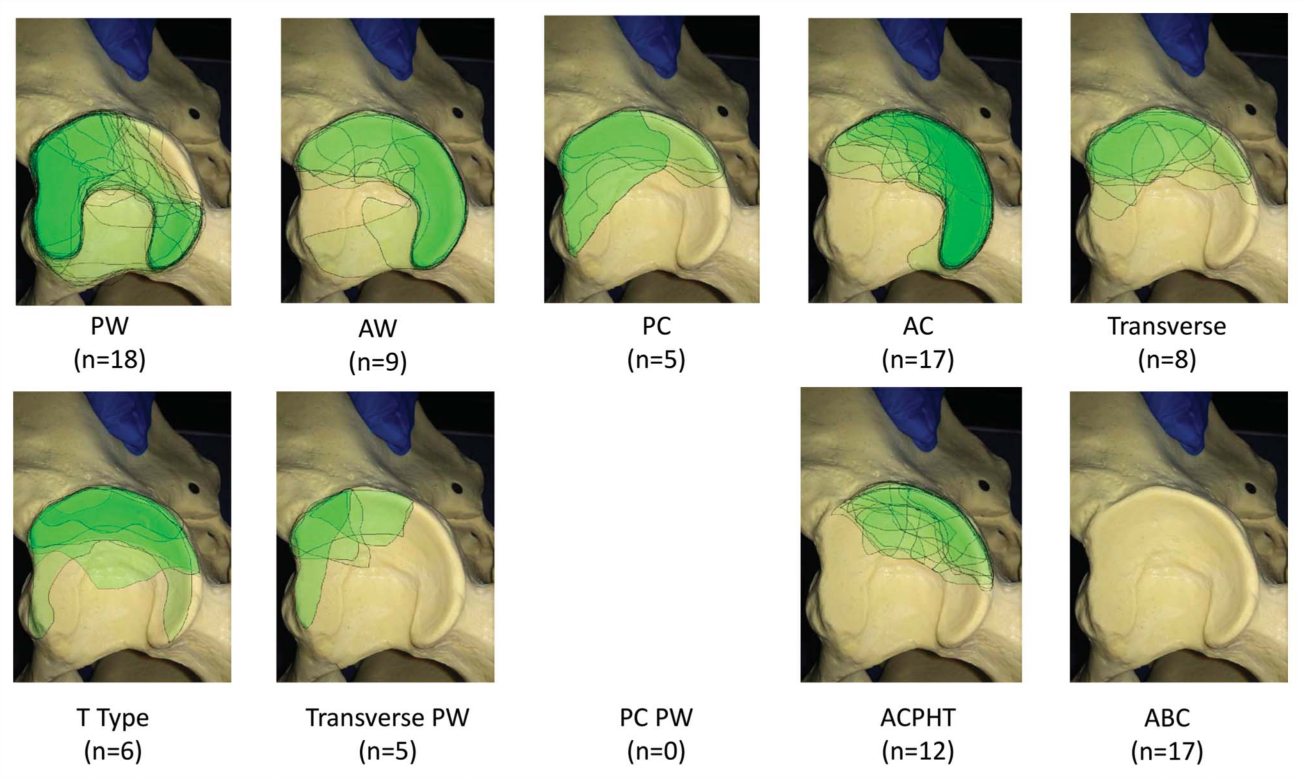
With the increasing incidence of acetabular fractures in the geriatric cohort and elevated morbidity and mortality rate,[12,13] it is important to create reliable and reproducible treatment algorithms that allow early mobilization. Treating these injuries with primary total hip arthroplasty may have the added advantages of early weight bearing and has been shown to potentially have improved outcomes compared with delayed or conversion total hip arthroplasty in select studies.[1,4,5] The main concern for allowing these patients to bear weight immediately after surgery is cup instability. This concern is routinely addressed by limiting the weight bearing after surgery to non–weight bearing or limited weight bearing for 6 or more weeks.[1,4,5,14–17] However, the elderly cohort has been shown to benefit from early weight bearing, especially in the hip fracture cohort[18,19]; therefore, there will be a distinct advantage of finding fixation constructs that will allow stable cup fixation and immediate weight bearing. These constructs will have to rely primarily on the stable portions of the acetabular articular surface, but there is, unfortunately, no literature to describe what constitutes a stable articular surface capable of acutely supporting an acetabular implant in the context of acetabular fractures.

This study analyzed the fracture morphology of acetabular fractures in the geriatric cohort and identified the stable fragments that may facilitate fixation and mobilization. In terms of fracture morphology as defined by the Letournel classification, the most common fracture patterns involved the anterior column (anterior column and anterior column and posterior hemitransverse), followed by posterior wall fractures and associated both column fractures. Previous studies on geriatric acetabular fractures have also reported a highest percentage of anterior column patterns; however, the percentage of women and ACPHT + ABC fractures were higher than reported in our study.[2,20] This finding may be explained by the fact that one of our study trauma centers was skewed toward high-energy geriatric acetabular fractures. In a previous study that differentiated between low- and high-energy trauma,[13] the percentage of women was 39.3% in 56 patients with low-energy trauma and 24.6% in 130 patients with high-energy trauma (compatible with our study's 36.6%). Similarly, they reported a rate of ABC + ACPHT of 44.6% in low-energy trauma and 23.8% in high-energy trauma (compatible with our study's 30%). Mapping of acetabula via CT scans has been previously performed primarily for the purpose of testing and designing acetabular fracture fixation constructs.[21,22]

In the current study, our aim was to identify stable bone stock that would be available for fixation of an acetabular cup. We first looked at the stable articular surface and found that screw fixation to the acetabular dome was possible in most (77%) of the observed fractured patterns, with additional screws into the posterior surface (40%) or anterior surface (22%) in a large number of cases. This finding by itself would suggest that in most acetabular fracture cases in the elderly, it will be possible to fix the cup with 3 to 4 screws into the stable pelvis bone stock and a higher likelihood that the patient will be allowed early weight bearing.

Acetabular fracture patterns in the elderly are associated with the increased frequency of bone impaction and fracture comminution.[4,14–17] This association would suggest that in some fracture cases, the articular surface may be fractured and impacted into what is still a stable bone corridor for screw fixation. This phenomenon has led us to further classify the available bone

Figure 3



Photographs showing the available stable articular surface for all Letournel fracture types. ABC = associated both column, AC = anterior column, ACPHT = anterior column posterior hemi-transverse, AW = anterior wall, PC = posterior column, PW = posterior wall

corridors for screw fixation judging by their appearance in 3D CT. Using this analysis, we have found that the sciatic buttress was available for screw fixation in all observed fracture patterns, followed closely by the gluteal pillar (90%). Most observed fractures had two (93%) or three (81%) corridors available for fixation. One can imagine that through a multihole cup, 2 to 3 screws can be targeted in each corridor, making it possible to fix the cup using four or more screws in almost every elderly acetabular fracture, in multiple planes. For example, ABC and ACPHT fractures (30% of our study cohort) typically have little to no intact articular surface and would be considered by most surgeons to be the least likely to have bone stock available for stable cup fixation.

Table 2

Bone Corridors Available for Screw Fixation Through an Acetabular Cup (n = 97 Acetabular Fractures)

Fracture Type	Number	Percentage
R	35	36
A	74	76
G	87	90
S	97	100
I	46	47

A = anterior corridor, G = gluteal pillar corridor, I = ischium corridor, R = superior ramus pubis corridor, S = sciatic buttress corridor

According to our analysis, 100% of these fractures had an available sciatic buttress corridor, 78% had an available gluteal pillar corridor, and 65% had at least three corridors available for fixation. Further research is needed to determine the true size and bone quality if these corridors, as well as, if screw fixation into these corridors, with or without augmentation, can allow early weight bearing in these patients. Maximizing the number of holes in a cup can limit the cup surface that is available for bone ingrowth. However, cup ingrowth is highly dependent on cup stability, and fixation should take precedence over ingrowth.

Table 3

Bone Corridor Available for Screw Fixation Through an Acetabular Cup

Observed Corridor Combinations	Number	Percentage
R	0	0
RA	0	0
RAG	0	0
RAGS	2	2
RAGSI	32	33
RAGI	0	0
RSI	1	1
I	0	0
SI	2	2
GSI	3	3
AGSI	8	8
AGS	32	33
AG	0	0
GS	10	10
S	7	7
G	0	0
A	0	0
Total classifiable	97	100
2 or more corridors	90	93
3 or more corridors	78	80
4 or more corridors	42	43
5 corridors	32	33

A = anterior corridor, G = gluteal pillar corridor, I = ischium corridor, R = superior ramus pubis corridor, S = sciatic buttress corridor

The concept of arthroplasty in the setting of bone loss in not new and has been studied extensively in the arthroplasty literature. Several arthroplasty-based classifications exist, the two most broadly used being the American Academy of Orthopaedic Surgeons classification system first published by D'Antonio et al[23] and the Paprosky classification system.[9] Like the classification system proposed in this article, the Paprosky and American Academy of Orthopaedic Surgeons systems describe the location of bone loss that may lead to cup instability. Treatment of bone loss depends on the location and amount of bone loss with various treatment options available, including revision total hip with or without bone grafting, augments, cup-cage, or custom triflange constructs.[24] According to the Paprosky classification system, having more than 50% coverage of the acetabular implant provides initial stability to the acetabular cup. However, it is not self-evident that the bone loss encountered in the revision arthroplasty setting will result in similar cup instability patterns that occur in geriatric acetabular fractures. This phenomenon should be the subject of future biomechanical and clinical research.

Screw fixation into the broken osteoporotic acetabulum may raise the concern for screw stability and early screw loosening. It was beyond the scope of the current study to assess the quality of the remaining stable bone stoke available for cup fixation. This could have been done by CT methods of bone mineral density estimation together with volumetric assessment of the bone corridors. This would have required phantom-calibrated CT images, which we did not have available. Regardless, one should appreciate that failures of open reduction and internal fixation in geriatric acetabular fractures are not typically due to screw loosening and are usually the result of early posttraumatic arthritis or acceleration of preexisting low-grade degenerative joint disease.[15,20,25,26] Furthermore, early loosening of cup screw fixation was not observed in case series of primary total hip arthroplasty done for geriatric acetabular fractures, albeit in the presence of concomitant acetabular open reduction and internal fixation.[14,15,17] Because of the anticipated poor bone quality, small screw diameter (5-mm screws used in arthroplasty compared with the 7-mm or bigger screws used in trauma surgery), and unknown screw length (typically inserted with no image guidance), surgeons should aim for bicortical screw fixation into the available corridors. Future consideration should be given to the role for CT guided/navigated screw insertion to maximize screw purchase and utilization of corridors. There may also be room for designing a fracture cup with clustering of screw holes in the direction of corridors and the use of screw augmentation (eg, polymethyl methacrylate) technology.

This study has some noteworthy limitations. First, fracture pattern mapping by our method resulted from a two-dimensional (2D) rendering of a complex 3D acetabular fracture pattern. However, we were able to assess the fracture in the segmented 3D model before making the 2D rendering. The resultant 2D rendered fractures adequately represented their 3D counterparts; however, future research will be required to better identify the 3D patterns of these fractures and test appropriate fixation constructs. Furthermore, the cohort analyzed in this study may not accurately represent fracture pattern frequencies seen in other facilities, the methods and results were descriptive in nature, and the interpretation of fracture maps is qualitative and subjective. Despite these limitations, this is the first study, to our knowledge, to map acetabular fracture patterns with primary total hip arthroplasty in mind and the first to suggest a classification of these fractures that is geared toward management of these fractures with arthroplasty.

Conclusions

This study reports on the fracture patterns of acetabular fractures in the geriatric cohort. Based on our mapping, we note significant bone stock in the acetabular dome and fixation options being readily available in the sciatic buttress and gluteal pillar. The findings of this study may lead to further research into improved design and fixation strategies of acetabular cups in this patient cohort.

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