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Biomechanical analysis using FEA and experiments of a standard plate method versus three cable methods for fixing acetabular fractures with simultaneous THA

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ABSTRACT

Acetabular fractures potentially account for up to half of all pelvic fractures, while pelvic fractures potentially account for over one-tenth of all human bone fractures. This is the first biomechanical study to assess acetabular fracture fixation using plates versus cables in the presence of a total hip arthroplasty, as done for the elderly. In Phase 1, finite element (FE) models compared a standard plate method versus 3 cable methods for repairing an acetabular fracture (type: anterior column plus posterior hemi-transverse) subjected to a physiological-type compressive load of 2207 N representing 3 x body weight for a 75 kg person during walking. FE stress maps were compared to choose the most mechanically stable cable method, i.e. lowest peak bone stress. In Phase 2, mechanical tests were then done in artificial hemipelvises to compare the standard plate method versus the optimal cable method selected from Phase 1. FE analysis results showed peak bone stresses of 255 MPa (Plate method), 205 MPa (Mears cable method), 250 MPa (Kang cable method), and 181 MPa (Mouhsine cable method). Mechanical tests then showed that the Plate method versus the Mouhsine cable method selected from Phase 1 had higher stiffness (662 versus 385 N/mm, $p = 0.001$), strength (3210 versus 2060 N, $p = 0.009$), and failure energy (8.8 versus 6.2 J, $p = 0.002$), whilst they were statistically equivalent for interfragmentary sliding ($p \geq 0.179$) and interfragmentary gapping ($p \geq 0.08$). The Plate method had superior mechanical properties, but the Mouhsine cable method may be a reasonable alternative if osteoporosis prevents good screw thread interdigitation during plating.

1. Introduction

Acetabular fractures are simple (i.e. elementary) or complex (i.e. associated) with 10 distinct injury types [1]. They are intricate, deep, and hard to manage surgically. Depending on the patient demographics, the trauma centre, and the region of the world, acetabular fractures can potentially account for 14%–50% of all types of pelvic fractures, while all types of pelvic fractures can potentially account for 1.5%–11% of all bone trauma [2,3]. Acetabular fractures are increasing in numbers in the general population, and even more in the elderly over 60 years of age due to falls on the greater trochanter [4–10].

For the elderly, there are inherent difficulties for surgical treatment of acetabular fractures, such as preexisting osteoarthritis, osteoporosis, femoral head fracture, femoral neck fracture, or marginal impaction [11–15]. Performing an acute total hip arthroplasty (THA) simultaneously for elderly patients may improve outcomes through a single operation, increase patient activity levels, and avoid the "wait and see" approach for a belated THA due to avascular necrosis of the femoral head or post-traumatic arthritis [10,16].

Biomechanical assessments have been made of widely employed techniques for acetabular fracture repair [3,17–26]. None of these studies, however, biomechanically evaluated the effect of a simultaneous THA procedure or cabling as an alternative to plating [27–29].

Therefore, this study biomechanically compared a "standard" plate method versus 3 cable methods for fixing a complex

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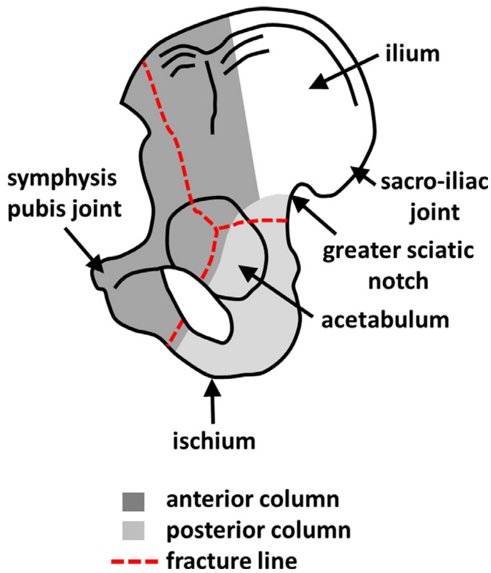

Fig. 1. A hemipelvis specimen showing an anterior column plus posterior hemi-transverse (AHT) acetabular fracture.

acetabular fracture as part of a combined THA procedure, as increasingly done for the elderly.

2. Methods

2.1. General strategy

In Phase 1, finite element (FE) models were developed for a "standard" screw-plate technique versus 3 cabling techniques for surgically fixing an anterior column plus posterior hemi-transverse (AHT) acetabular fracture (Fig. 1) in the presence of a simultaneous THA and subjected to loading. Surface stress maps for the FE models were compared to determine which cabling method was mechanically the most stable and had the least risk of failure, i.e. lowest bone stress. In Phase 2, mechanical testing was done in artificial hemipelvis models to obtain various mechanical properties of the plate method versus the optimal cabling method from Phase 1. These FE models and experiments represent only the immediate post-operative situation when the fracture has not yet healed, which is the "worst case scenario".

2.2. Phase 1: FE modelling

2.2.1. Surgical test groups

There were 6 FE models developed based on commercially available components (Fig. 2). The "Intact" model was a hemipelvis intact control (Model #3405, Sawbones, Vashon, WA, USA) (Fig. 2A). The "Cup" model was an intact hemipelvis equipped with an acetabular metal shell and ultra-high molecular weight polyethylene (UHMWPE) liner (Reflection, Model #7133-5158 and #7133-3336, Smith and Nephew Inc., Memphis, TN, USA) (Fig. 2B).

The "Plate" model was a hemipelvis with an acetabular cup that had an anterior column plus posterior hemitransverse (AHT) acetabular fracture repaired with 1 posterior column plate and 1 anterior column lag screw (Fig. 2C). This is considered the "gold standard" of care applied for complex acetabular fractures and is the most commonly used technique performed by the majority of orthopaedic surgeons specializing in trauma and pelvic fractures [30–33]. Specifically, a 3.5 mm diameter, 6-hole, 70 mm long stainless steel reconstruction plate (Model #71,809,516, Peri-Loc, Smith and Nephew Inc., Canada) was mounted using 4 stainless steel cortical screws (Smith and Nephew Inc., Canada), namely, 2 above

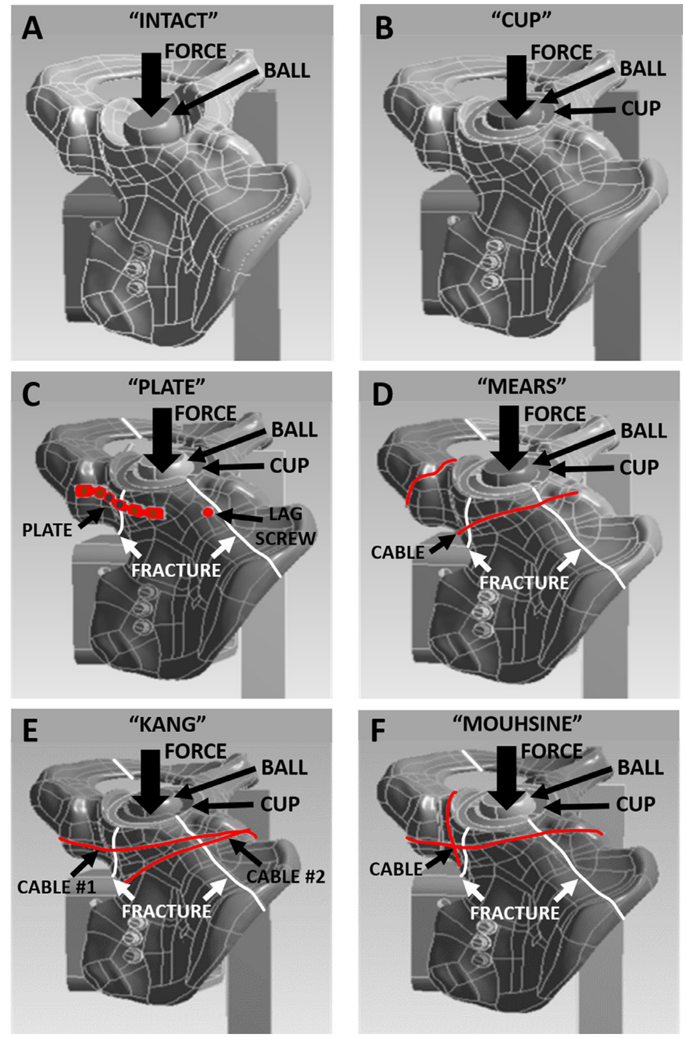

Fig. 2. FE CAD models for AHT acetabular fracture fixation positioned in a test setup simulating physiological loading. (A) Intact, (B) Cup, (C) Plate, (D) Mears, (E) Kang, (F) Mouhsine. Fracture fixation implants like screws, plates, and cables are coloured red.

and 2 below the transverse fracture line. From top to bottom, the first screw was 46 mm long and directed anteriorly and medially into the Ilium, the second screw was modelled as being directed more medially into the Ilium, the third screw was 44 mm long and inserted obliquely into the Ischium, and the bottom screw was 60 mm long placed all the way down into the Ischium. Finally, a 4.0 mm diameter, 100 mm long fully threaded stainless steel cancellous lag screw was inserted into the anterior column of the acetabulum.

The "Mears" model was a hemipelvis with an acetabular cup that had an anterior column plus posterior hemitransverse (AHT) acetabular fracture repaired with 1 cable only (Fig. 2D) [27]. A 2.0 mm braided stainless steel cable (Accord, Model #71,340,008, Smith and Nephew Inc., Memphis, TN, USA) passed through a thru-hole at the base of the anterior inferior iliac spine (AIIS). The cable crossed the point of the meeting of both fractures and the arcuate line of the ilium, and then proceeded along the quadrilateral plate of the acetabulum to the lesser sciatic notch (LSN), where it curved around from medial to lateral. The cable then crossed the lateral surface of the ischium to the postero-superior end of the obturator foramen, where it curved medially again, going up along the quadrilateral plate, where it made a cross sign with the previous path of the cable on the inner side of the hip bone, till it reached