Initial stability of circumferential meshes with impacted bone allografts for massive femoral defects

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Abstract When the proximal femur is absent due to a failed femoral stem in total hip arthroplasty, impacted bone grafts contained within circumferential meshes could be an alternative reconstructive method. The purpose of this study was to analyse the initial resistance to axial and rotational forces in a fresh frozen bovine model with complete loss of the proximal femur reconstructed with a circumferential metal mesh, impacted bone allografts and a long cemented stem. Four bovine femurs with a complete proximal bone defect were reconstructed with a circumferential mesh, impacted bone grafts and a cemented stem. The results were compared with four intact femurs using the same implant. Under axial load, subsidence was observed at an average of 617 kg in the experimental group, and a cortical fracture occurred at 1335 kg in the control group. Under rotational load, experimental femurs failed at an average of 79 kg and the control femurs fractured at 260 kg. This model provided 50% of the resistance to axial load and 30% of the resistance to rotational load compared to an intact femur, which is enough to resist physiological load. This stability encourages the use of circumferential meshes, impacted bone allografts and cemented stems in revision hip surgery with massive bone loss.

Résumé Dans l'arthroplastie totale de hanche les pertes de substances fémorales secondaires à un descellement de la pièce fémorale peuvent être traitées par des greffes impactées. Il s'agit d'une méthode de reconstruction

alternative et satisfaisante. Le propos de cette étude est d'analyser la résistance axiale et en rotation d'allogreffes fraîches impactées d'origine bovine et servant de lit à une pièce fémorale longue. 4 fémurs bovins ont été reconstruits de la sorte, les résultats ont été comparés à 4 fémurs intacts avec le même implant en charge axiale, la migration de la prothèse est observée avec une charge de 617 kg dans le groupe des fémurs greffés et une fracture corticale est survenue à 1335 kg dans le groupe contrôle. En rotation, la pièce fémorale présente une mobilité en moyenne à 79 kg alors que dans le groupe contrôle ceci ne survient qu'à 260 kg. Ce modèle présente donc une résistance de 50% en charge axiale et de 30% en rotation, si on le compare à un modèle fémoral sur fémur intact. Cette stabilité nous encourage à utiliser une telle technique d'allogreffes impactées avec une pièce fémorale cimentée dans les révisions de prothèses totales de hanches avec pertes osseuses massives.

Introduction

Progressive bone stock loss caused by a failed femoral stem after total hip arthroplasty (THA) is a major problem in revision hip surgery. When the proximal femur is deficient or absent there are only a few options for reconstruction, including long distal fixation uncemented implants, proximal femur replacement cemented stems and allograft-prosthesis composite [11, 14].

The use of impacted bone allograft technique in revision surgery on the femoral side has been reported with good to excellent results over the mid- and long-term [3, 7, 8, 20, 23, 24]. A prerequisite for its use is containment of the grafts. When segmental defects are present, metal meshes are used to contain the allograft [8, 22]. Good clinical and

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experimental outcomes have been reported with the use of impaction bone grafting and metal meshes in segmental defects [1, 2, 22].

Reconstruction of the proximal femur can be achieved with the use of circumferential metal mesh, impacted bone grafts and a long cemented femoral stem. However, the initial stability of this reconstruction has not been studied to date despite it representing an important factor in the long-term survival of an implant. The purpose of this study was to analyse the initial resistance in vitro to axial and rotational forces of a fresh frozen bovine model with a complete loss of the proximal femur reconstructed with a circumferential metal mesh containing impacted bone allografts and a long polished triple-tapered cemented stem.

Material and methods

A protocol of impaction bone grafting technique previously published by Schreurs and Bolder [1, 21] was adapted to eight bovine femurs with a minimum endosteal diameter of 14 mm, similar weight (1979 g; SD: 122 g) and length (34.4 cm; SD: 0.66 cm). A pool of morcellised bone graft was made from bovine femoral heads. No defatting of the grafts was performed, and all reconstructions were made with the same pool of grafts for better reproductibility.

All experiments involving the bone grafting technique were performed by a experienced surgeon.

We tested two groups with four femurs each under axial and rotational load.

Experimental group

An osteotomy was performed 8 cm distally to the tip of the greater trochanter to create a complete segmental femoral defect type IV, following the methodology of Pak and Paprosky [17]. The complete proximal bone defect was reconstructed with a 15×15-cm stainless steel mesh (thickness: 0.15 inches; diameter of holes: 2 mm; Fico, Buenos Aires, Argentina). The mesh was fixed to the remaining diaphyseal bone with three double cerclage wires (Ortron 90; diameter: 1 mm; De Puy, Warsaw, Ind.). Following cleaning of the canal impaction bone, grafting was performed according to the technique described by Gie [8] using specific instruments (Primary Impaction Grafting Instruments; De Puy Int., Leeds, UK). An additional three double cerclage wires were placed in the proximal mesh to contain the impaction force that was applied uniformly until rotational stability of the impactor was achieved (Fig. 1). Bone cement CMW1 (De Puy) was injected retrogradely, followed by the insertion of a 200-mm long polished tri-tapered stem (C-Stem; De Puy) with a distal end cup (Fig. 2).

Fig. 1 Experimental group: segmental defect type IV. Reconstructed with circumferential metal mesh and an impacted bone graft

Control group

An osteotomy at the femoral neck was performed, and the head was resected. The femur was prepared using a femoral broach, the canal was cleaned, a distal plug was placed and retrograde cementation of the femoral stem with a centraliser was done in the same way as in the experimental group (Fig. 3).

Preoperative and postoperative anteroposterior (AP) and lateral total femur radiographs were taken to control femur integrity and stem position. Specimens were stored in a freezer at -20°C for 24 h to allow completely polymerisation of the poly(methyl methacrylate) (PMMA) before mechanical testing.

Mechanical testing

Specimens were defrosted and kept moistened until the mechanical test. Two femurs of each group were tested under axial load and two under rotational load. The testing was performed at the biomechanical laboratory of the National Technological University in Buenos Aires, with the assistance of mechanical engineers. The femurs were fixed with a clamp under the loading device (Universal Testing Machine; Shimadzu Seizakusho, Japan), and the machine was set to travel at a constant displacement rate of 4 mm per minute [19]. For axial testing, the femurs were

Fig. 2 Experimental group: segmental defect type IV. Reconstructed with circumferential metal mesh, an impacted bone graft and a long, polished tri-tapered stem

tilted 15° in a lateral direction in order to obtain physiological load [19]. For rotational testing, the femurs were fixed in the clamp horizontally, and load was applied to the eccentric prosthetic femoral head, resulting in bending and rotational load.

System failure was defined as fracture of the femur, rupture of the mesh or gross (> 5 mm) subsidence at the

Fig. 3 Control group: intact femur with long polished tri-tapered stem

Fig. 4 Experimental group: failure pattern under axial load due to subsidence at the cement–bone interface

stem–cement and cement–bone interface measured with a digital caliper.

Following the experiment, radiographs were obtained to confirm the failure mechanism.

Results

The failure pattern of femurs within each group was the same. There were no mesh fractures or wire ruptures.

Under axial load, the femurs of the experimental group presented minimal (2 and 3 mm) subsidence at 350 and 375 kg, but they were still solid enough to support load until an average load of 617 kg when they failed because a

Fig. 5 Experimental group with rotational load: failure at the cement mantle

subsidence of 10 and 13 mm, respectively, at the cement–graft interface (Fig. 4). The failure mechanism in the control group was a fracture of the medial cortex due to varus angulation at an average of 1335 kg without subsidence (Fig. 4). The experimental group failed under the rotational load as a result of fracture at the cement mantle at an average of 79 kg (Fig. 5). The control femurs developed a spiral fracture at an average of 260 kg.

Discussion

Circumferential metal meshes, impaction bone grafts and long cemented femoral stems presented a favourable initial resistance to axial and rotational load in the bovine femurs evaluated here.

The impaction grafting technique has been reported with good results in revision hip surgery: this technique restores bone stock, and morcellised bone grafts can be used as carriers of antibiotics in cases of previous infections [3, 4, 7, 8, 20, 23]. When segmental defects are present, the combination of morcellised grafts with metal meshes has been associated with a favourable outcome [8, 12, 22]. The main advantages of meshes are their adaptability to the remaining bone and the fact that they allow easier revascularisation of the grafts since the meshes are fenestrated and cancellous bone grafts are in contact with the surrounding soft tissue [2, 15]. The disadvantages include the eclipse of the bone remodelling process, as seen on radiographs, and the implantation of yet another foreign body.

In the absence of the proximal femur, a circumferential mesh with impaction bone grafts and a long stem can be used to reconstruct the proximal metaphysis. Initial stability is necessary for the incorporation of the grafts, and this initial stability represents an important factor in the long-term survival of an implant. [5, 16] However, no published information is available on evaluations of the stability of circumferential defects reconstructed with metal meshes and impacted bone grafts in revision hip surgery.

We used bovine femurs as such a model has been used in previous studies testing the impaction bone grafting technique. Bovine femurs are thought to be relevant to the human situation because they contain trabecular bone only proximally and the endostal surface is hard and smooth, similar to the sclerotic bone found in revision surgery. Endostal diameter is wide enough to allow the grafting technique, a good cement mantle and a long polished stem [13]. However, the values cannot be directly extrapolated to humans.

One of the main complications associated with this technique is early subsidence of the femoral stem [6, 10, 18]. Although some degree of migration is expected as a result of deformation of the grafts and stem subsidence, the magnitude of this subsidence considered safe has not yet been

established. The prosthesis design (tri-tapered stem) should adapt to this deformations to prevent early loosening of the implant [9]. In our study, the experimental group showed some subsidence at the beginning of axial load, but this stabilised until failure at an average of 617 kg, which represents 50% resistance compared to an intact femur and enough resistance to resist physiological load in a normal femur during gait [16]. Rotational resistance of the experimental group was 30% of that of the control group showing a lower torsional strength. These findings were similar to other mechanical tests of the impaction bone grafting technique, but this should be confirmed by clinical data [16].

The initial stability of this reconstruction encourages the use of circumferential meshes to contain impacted bone allografts combined with long cemented stems in complex revision hip surgery with massive bone loss. Immediate postoperative partial weight-bearing would not affect the stability of this reconstruction, but torsional loading such as stair climbing should be restricted in the early postoperative period.

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