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Periprosthetic fracture fixation of the femur following total hip arthroplasty: A review of biomechanical testing

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A B S T R A C T

Background: Periprosthetic femoral fracture can occur following total hip arthroplasty. Fixation of these fractures are challenging due to the combination of fractured bone with an existing prosthesis. There are several clinical studies reporting the failure of fixation methods used for these fractures, highlighting the importance of further biomechanical studies in this area.
Methods: The current literature on biomechanical models of periprosthetic femoral fracture fixation is reviewed. The methodologies involved in the experimental and computational studies of this fixation are described and compared.
Findings: Areas which require further investigation are highlighted and the potential use of finite element analysis as a computational tool to test the current fixation methods is addressed.
Interpretation: Biomechanical models have huge potential to assess the effectiveness of different fixation methods. Experimental *in vitro* models have been used to mimic periprosthetic femoral fracture fixation however, the numbers of measurements that are possible in these studies are relatively limited due to the cost and data acquisition constraints. Computer modelling and in particular finite element analysis is a complimentary method that could be used to examine existing protocols for the treatment of periprosthetic femoral fracture and, potentially, find optimum fixation methods for specific fracture types.

Contents

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1. Introduction

Periprosthetic femoral fracture (PFF) is a complication associated with total hip arthroplasty (THA). A concerning increase in the incidence of this condition has been predicted, in line with the increasing number of THA operations (Learmonth et al., 2007; Lindahl et al., 2006; Tsiridis et al., 2009) . PFF can occur intra-operatively or post-operatively, creating a variety of fracture configurations and locations. There are various associated risk factors including the age of the patient (Wu et al., 1999), osteoporosis (Lou et al., 2007), the prosthesis design (Garellick et al., 1999; Toni et al., 1994), and whether a cemented or un-cemented prosthesis is used (Berry, 1999; Schwartz et al., 1989), each of which also influences the method of fixation (Franklin and Malchau, 2007; Lindahl et al., 2006).

A large number of clinical studies have investigated fracture following THA (Garcia-Cimbrelo et al., 1992; Kavanagh, 1992; Löwenhielm et al., 1989; Tsiridis et al., 2004). These have led many authors to classify PFF based on fracture configuration, position along the femur and associated bone quality (Duncan and Masri, 1995; Johansson et al., 1981; Mont and Maar, 1994). One of the most commonly used systems is known as the Vancouver classification (Duncan and Masri, 1995). Here, fractures located within the trochanter region are classified as type A. Fractures located within the stem region are classified as type B, with subsets representing those with a stable implant (B1), a loose implant (B2) and a loose implant plus insufficient bone stock (B3). Finally fractures positioned distal to the stem are classified as type C. Among these, type B fractures represent approximately 80% of all cases (Corten et al., 2009; Lindahl et al., 2006), and these have been the focus of several clinical and laboratory studies.

Treatment of PFF is challenging due to the combination of the fractured bone and the existing prosthesis, with the further complication, in some cases, of the cement used for prosthesis fixation. This creates a different biomechanical scenario to the fracture of an intact femur. Traditional treatment methods such as traction and bracing have been replaced by open reduction and internal fixation, along with revision of the prosthesis in some cases (Lindahl et al., 2006). Many authors have reported the clinical outcomes of different fixation methods (Bryant et al., 2009; Buttaro et al., 2007; Haddad et al., 2000; Partridge and Evans, 1982; Serocki et al., 1992; Tsiridis et al., 2003, 2005). Among these, there are several studies that report the failure of the fixation for these fractures (Fig. 1), indicating that the protocol for classifying PFF cases and subsequent selection of the fixation method are perhaps currently insufficient. Several authors have proposed treatment algorithms for different types of fracture (Masri et al., 2004; Parvizi et al., 2004) in light of available fixation techniques. However, these proposals lack any significant biomechanical evidence.

Biomechanical *in vitro* studies and computer *in silico* models have the potential to assess and optimise the performance of different methods of fixation. These techniques allow certain aspects of the *in vivo* conditions to be replicated in a controlled manner so that the biomechanical effects of various parameters can be assessed both individually and in combination. These types of study have been implemented extensively in the area of THA (Crowninshield et al., 1980; Huiskes, 1980; Prendergast and Taylor, 1990) and there is a growing body of work focusing on fracture fixation (Chen et al., 2010; Krishna et al., 2008; Perren, 1991; Stoffel et al., 2003). A number of biomechanical studies have also investigated PFF, although as yet, not all types of these fractures or fixation methods have been comprehensively evaluated.

The aim of this review is to examine the available literature relating to the biomechanical assessment of PFF. Current experimental and computational methodologies are evaluated and the trends in the results, as well as areas of disagreement, are highlighted. Recommendations for future research and areas which require further scientific investigation are discussed.

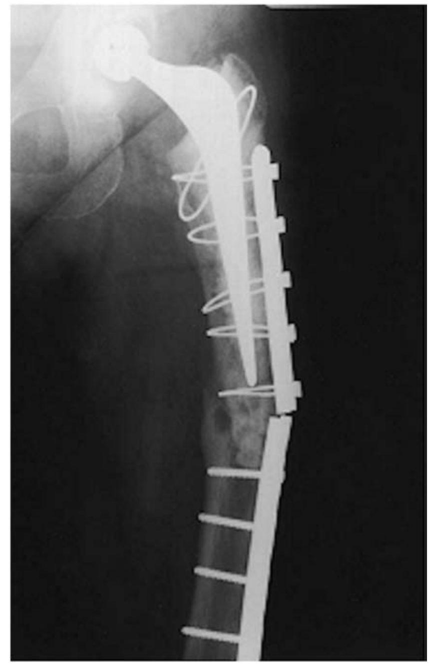

Fig. 1. Anteroposterior radiograph showing the failure of the periprosthetic femoral fracture fixation methods. Dall-Miles plate fracture from Tsiridis et al. (2003) with permission from Elsevier.

2. Methodology

2.1. Experimental methods

2.1.1. Introduction

Experimental *in vitro* studies have been used to assess the biomechanical stability of various methods of PFF fixation. These studies compare the mechanical performance of different fixation methods in the laboratory by stabilising a periprosthetic fracture in a cadaveric or synthetic femur. The following section reviews the methods used and examines their robustness, with a focus on three specific aspects: the type of specimen, the loading protocol and the methods of measurement.

2.1.2. Specimen type and repeatability

Since the majority of studies have made comparisons between different fixation methods, it is necessary for there to be parity between the specimens used so that any differences in outcome can be attributed to the fixation method alone. Both cadaveric and synthetic samples have been used, as is summarised in Table 1.

Cadaveric specimens more closely represent the '*in vivo*' material but there is inherent variability between samples, including, crucially, the bone quality and geometry as well as the potential presence of pre-existing damage in the bone. This variance would likely necessitate large sample sizes to obtain statistically significant results, but this is usually impractical due to the availability of the tissue and, from Table 1, it can be seen that most sample sizes here are small. To overcome this, several authors have adopted an approach of undertaking a number of different procedures sequentially on each specimen, using a randomised ordering method to reduce the effect of any cumulative damage to the specimens. Whilst such an approach is perhaps the best that can be achieved with limited specimens, little work seems to have been undertaken to assess the effect of these repeated tests. Haddad et al. (2003) used a standard fixation method as a control for each specimen, which was retested within each variable group. Whilst this enabled results to be compared to the most recent standard, the variation in the measures of the standard during the tests was not reported.