# Clinical and Biomechanical Assessment of the Treatment of Type B Periprosthetic Fractures of the Femur

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## This dissertation is submitted for the degree of Doctor of Medicine at University College London

## Declaration

I hereby declare that this dissertation is the result of my own work and includes nothing which is the outcome of work done in collaboration except where is specifically indicated in the text and bibliography and that my thesis is not substantially the same as any that I have submitted for a degree of diploma or other qualification at any other University. In addition, this dissertation falls within the word limit of exclusive of tables, footnotes, bibliography, and appendices, as set by the University College London.

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# Abstract

Total hip arthroplasty is a well established treatment modality for the diseased hip. The number implanted rises annually on a global scale which is mirrored by increasing indications. After aseptic loosening and infection, periprosthetic fracture remains one of the commonest complications of this otherwise successful surgery. Management is geared towards restoring function through fixation of the fracture.

The general aim of this thesis is to validate the classification of periprosthetic fractures of the femur around total hip arthroplasty, provide evidence towards the outcomes of methods of fixation of these fractures, and present supplementary biomechanical data regarding fixation and implant stress. It is hypothesised that the Vancouver classification will be a reliable and reproducible system to use, that strut grafts, cables and long-stemmed implants will improve function and outcome when used to manage these injuries, and that biomechanical models will provide evidence on why the use of the implants is successful.

Study I

The purpose of this study was to ensure that the Vancouver Classification of periprosthetic fractures which is most widely used classification system of periprosthetic fractures is repeatable. It was hypothesised that the system would be reliable amongst for all grades of clinician. The inter-rater agreement ranged from 0.61-0.74 and the intra-rater agreement ranged from 0.59-0.67. Validity analysis was scored at 77% ($\kappa = 0.67$). The Vancouver Classification was shown to be reliable and reproducible.

Study II

The purpose of this study was to evaluate the clinical and radiographic outcomes of 40 periprosthetic femoral fractures around stable hip implants treated with cortical onlay strut allografts without revision of the stem. It was hypothesised that this treatment would improve function and result in bony union. At a mean follow-up of 28 months, 98% of patients had radiological evidence of union with all but one of the surviving patients returned to their preoperative functional level within one year.

Study III

The purpose of this biomechanical cadaveric study was to determine the effect of allograft cortical strut length, configuration, cable number, cable tension and the use of wire or cable on the fixation of periprosthetic femoral fractures. It was hypothesised that an increasing number of struts and the use of cable would improve fracture stability. Fracture stability was found to increase with the use of two rather than one strut, and by using cables rather than wires.

Study IV

The purpose of this study was to evaluate the clinical and radiological outcomes of using cementless femoral stems in conjunction with cortical struts, cable plating systems, bone allograft and demineralised bone matrix in 26 patients with Vancouver B2 or B3 fractures. It was hypothesised that this treatment would improve function and lead to radiological union. It was found that all fractures were healed clinically and radiologically, and all patients were reported to be satisfied with the outcome.

Study V

The purpose of this biomechanical study was to determine the strain exerted by an uncemented femoral implant upon a synthetic, composite femur modelling various clinical scenarios. It was hypothesised that strain would be reduced when using a grip, strut or cables. It was found that these devices did reduce the strain exerted upon the femur and may be useful in preventing femoral stem fractures.

Study VI

The purpose of this study was to evaluate the clinical and radiographic outcomes of treating periprosthetic femoral fractures around unstable hip implants treated with revision to an uncoated locked Kent Hip prosthesis. It was hypothesised that this method of treatment would improve clinical and radiological outcome in the 36 patients included in the study group. Harris Hip Scores improved and fracture union was seen in all but one patient; there were three patients in whom the implant was subsequently revised.

Study VII

The purpose of this study was to clinically evaluate interlocking long stem femoral prostheses as either temporary functional spacers or as definitive implants in cases of infected periprosthetic femoral fractures. It was hypothesised that these devices would improve the clinical and radiological outcomes of these patients. The Cannulok uncoated stem was used in twelve cases and the Kent Hip Prosthesis in five cases. Patients were asked post-operatively they were satisfied with the outcome achieved. All patients were satisfied and in eleven cases, revision to a definitive stem was undertaken after successful control of the infection and fracture union.

## Conclusions

The management of periprosthetic fractures is a complex issue. There are numerous ways to manage this injury and treatment must be tailored to the patient and to the specific injury sustained. The results of this work demonstrate that classifying periprosthetic fractures using the Vancouver system is valid. Furthermore cortical struts are an effective adjunct with proven biomechanical advantages in non-infected cases around stable implants, whilst long cementless stems lead to excellent outcomes in the presence of a loose implant irrespective of infection.

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# List of Abbreviations

AG- Periprosthetic fracture of greater trochanter
AL – Periprosthetic fracture of lesser trochanter
AP - Anteroposterior
BMI - Body mass index
CC - Cranial caudal
ETO - Extended trochanteric osteotomy
Fap - Anteroposterior force
Fcc - Craniocaudal force
Fml - Mediolateral force
Fpd - Proximal-distal force
LFA - Low friction arthroplasty
Rx - Anteroposterior bending
Ry - Axial rotation
Rz - Medial-lateral bending
THA - Total hip arthroplasty
TWB - Touch weight bear
Tx - Medial-lateral translation
Ty - Inferior-superior translation
Tz - Anteroposterior translation
UHMWPE - Ultra-high molecular weight polyethylene

# Chapter 1

# An Introduction to Periprosthetic Fractures of the Femur

**Rationale for Chapter -** Periprosthetic fractures of the femur represent a complex and specific issue within orthopaedic hip surgery. It is important to realise the history of primary hip arthroplasty to appreciate its evolution as well as be aware of the various causes of fracture and implications of treatment. This chapter will explore such issues so that the hypotheses outlined in this thesis can be thoroughly evaluated.

## Chapter 1

### 1.1 Introduction

Total hip arthroplasty (THA) is regarded as one of the most successful advances in modern orthopaedic surgery. The clinical success rate is over 90% at 10 years from the time of index procedure[1].In the UK, over 50,000 total hip replacements are carried out annually at a cost to the NHS of more than £140 million per annum. Although the number of procedures has risen by 18% since 1991, it is set to increase further by up to 50% by 2026 [2].This is fuelled by an increasing acceptance by surgeons to implant them in both younger and older patients to restore and maintain quality of life. Furthermore, there are increasing indications for use whilst patients are patients are increasingly comfortable with the thought of prosthetic joint surgery. In spite of the success, complications do occur and although overall complication rates are low, there is potential for severe morbidity and mortality. This is most apparent in periprosthetic fractures or infection.

A fracture is defined as a newly formed defect in cortical bone whilst a periprosthetic fracture is specifically one that occurs in proximity to an implant. Femoral fractures occurring around a THA provides an even more complex clinical scenario since the implant is linked to another component; namely the acetabular component and the implant itself can either help or hinder healing by acting as intramedullary splint or as a distracting force and source for potential infection respectively. Furthermore, an evolution in management has been necessitated with newer implant designs and methods of fixation.

This purpose of this thesis will be to identify whether the strategies used to manage periprosthetic fractures after THA improve the clinical and radiological outcomes, and if so, is there biomechanical evidence to support this? Specifically, this thesis investigates the validity and reliability of the Vancouver classification since it will be used to classify this injury throughout this thesis, the outcomes of cortical strut grafts and how effective interlocking implants are in the absence of cement in Type B fractures which are fractures around the stem of a hip replacement.

## 1.2 Components of Hip Replacement Systems

The earliest recorded attempts at replacement of the hip were from Germany in 1891 by Gluck, who used ivory to replace the femoral head [3]. Smith-Petersen from Massachusetts General Hospital subsequently used a glass cup to cover and reshape an arthritic femoral head in 1923.

In 1940 at Johns Hopkins Hospital, USA, Moore was reported to have performed the first metallic hip replacement surgery though this was essentially a proximal femoral replacement. The prosthesis comprised of a large Cobalt-Chrome alloy head proximally that extended in to a shaft that was one foot long. The distal end was bolted to the resected end of the femoral shaft and much like the ivory replacement mentioned before, was essentially a hemi-arthroplasty device with no corresponding acetabular implant. Moore subsequently devised a variant prosthesis in 1952, which could be inserted into the medullary canal of the femur. This became widely known as the Austin Moore prosthesis (see Figure 1.1) and is still used today for the treatment of intra-capsular femoral neck fractures.

Judet and Judet [4] described the used of an acrylic femoral head replacement (see Figure 1.2) in 1950. It was similar in design to the mid-head hip resection prosthesis in use today though again was a hemiarthroplasty device.

*Figure 1.1: Austin-Moore prosthesis - The voids seen in the stem allow for bony in-growth following insertion*

*Figure 1.2: Judet and Judet's acrylic hip replacement*

Baw from Burma [5] pioneered the use of ivory hemiarthroplasty prostheses to replace non-united fractures of the femoral neck. The prosthesis was implanted in patients ranging from the ages of 24 to 87 and the success rate was reported to be88% based upon Judet’s criteria. Although biologically compatible, it was thought that it was used in preference to metal by Baw for reasons including cost and availability.

Despite the apparent merits of ivory, it was not a material that could be produced in large enough quantities to become a viable bearing surface. Furthermore, there was a need to develop joint replacement systems that would not only replace the femoral head but also the acetabular side since arthritis of the hip was a much more common affliction than femoral neck fractures.

Modern total joint arthroplasty of the hip was pioneered by Sir John Charnley from Wrightington Hospital, UK. Although reaming of the acetabulum had previously been described, insertion of an acetabular component with which an artificial femoral head articulates had not. He used a stainless steel monoblock femoral component and a Teflon acetabular cup and called it the Low Friction Arthroplasty (LFA) [6] (see Figure 1.3).

Although this coupling failed due to Teflon’s poor wear properties, the change to ultra-high molecular weight polyethylene brought about a reduced incidence of osteolysis with secondary loosening. Since this time, there has been a trend toward modular components which allow for greater intra-operative freedom in recreating and restoring normal biomechanics.

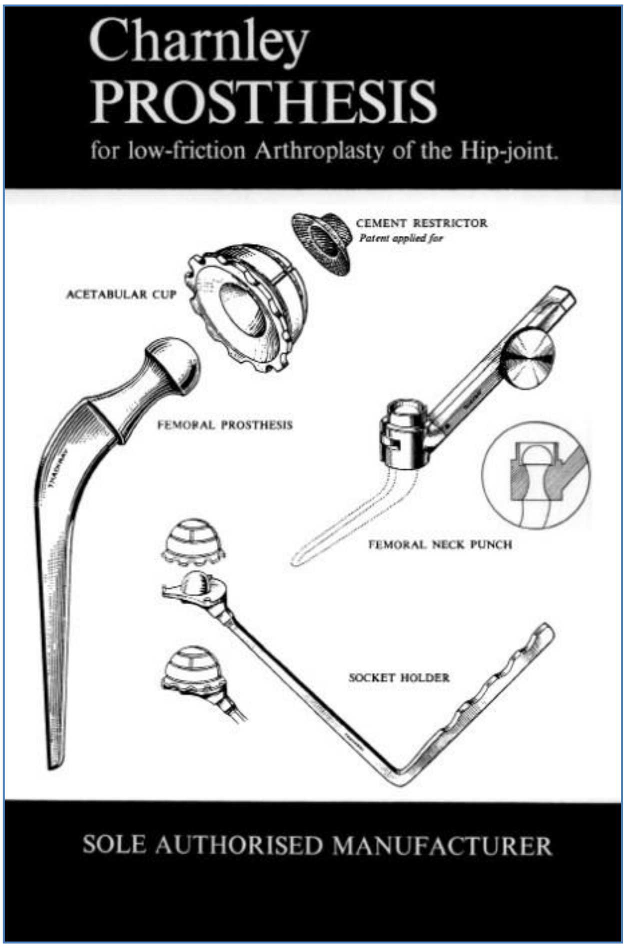

*Figure 1.3: Manufacturer's advert for the Charnley Prosthesis*

(http://www.aaos75th.org/stories/physician_story.htm?id=12 – no copyright)

These modular components consist of:

- Femoral side
    - Stem and head
    - Neck may also be modular is some cases
    - Some stems are bi-bodied and others have a sleeve and a stem that goes through that sleeve
- Acetabular side
    - Shell and liner (uncemented)
    - OR Single cup (cemented)

### 1.3 Early Reports of Periprosthetic Fracture

Periprosthetic fracture of the femur after hip arthroplasty surgery was first described by Horwitz and Lenobel in 1954 [7]. It occurred in a female patient who sustained an intertrochanteric fracture around the stem of a cemented hemiarthroplasty whilst convalescing from the aforementioned operation. A transfixing bolt and wire loop were used to reconstruct and stabilise the femur before reinserting the prosthesis into the reduced femur. Unfortunately, the patient died one month following surgery.

Parish and Jones reported seven cases 10 years later in 1964 [8]. Their report was divided into fractures sustained in the trochanteric area, or in proximal, middle and distal areas of the femoral shaft thus giving rise to the earliest classification system of this injury.

Two years later, Sir John Charnley described a periprosthetic femur fracture, again in a female patient [9]. She was treated with a cemented Thompson prosthesis following a cervical hip fracture but fell seven months later. She consequently sustained an oblique fracture in the proximal part of the femur and was treated with balanced traction; the fracture was reported to have healed after 3 months.

The next large series of patients was reported by Whittaker et al. in 1974. It comprised of 20 cases in 19 patients;17 hemiarthroplasties and 3 cemented THAs [10]. Like Parish and Jones' series [8], early mobilisation, traction, long-stem revision or plates were used.

Whilst these surgeons were pioneers of their time, their experience with periprosthetic femoral fractures was limited. Today, the reconstructive orthopaedic surgeon deals with periprosthetic fractures frequently. Periprosthetic femoral fracture is a devastating complication after total hip arthroplasty that often results in poor clinical outcome [11, 12]. They are challenging to treat, as they require both the skills of a revision surgeon and those of a trauma specialist.

### 1.4 Epidemiology and Aetiology

Depending on the source, there is a variation in the reported incidence of periprosthetic fracture. According to the Swedish Hip Registry, one of the commonest reasons for reoperation after THA is periprosthetic femoral fractures. These constitute the third commonest reason (9.5%) after aseptic loosening (60.1%) and recurrent dislocation (13.1%) [13, 14].

The Mayo Clinic Joint Registry has reported a lower cumulative prevalence of periprosthetic femoral fractures at 1% in primary total hip replacements and 4% in revision total hip replacements [15]. They can be classified as occurring intraoperatively or postoperatively. Primary cemented THA was shown to have a lower incidence of intraoperative fracture than uncemented THA - 0.3% vs. 5.4% respectively. This is also evident in revision cases where the incidence is 3.6% in cemented revision THA and 20.9% in uncemented revision THA.

There is an increasing incidence of late postoperative periprosthetic femoral fracture which is attributable to many factors. These appear to be linked to the overall increased usage of THA, whereby, the injury occurs in elderly patients [16] who are at risk of falls and in young patients who are at risk for high-energy trauma events. The consequence of rising primary procedures is a rise in revision procedures and in these instances, fractures [15] can be attributable to cementless press-fit fixation or bone impaction allograft techniques which are used to gain stability of the stem [15, 17-20].

The majority of periprosthetic femoral fractures occur postoperatively with low energy events; -either after falls or spontaneously during activities of daily living [21]. Indeed, Lewallen et al. reported that half of the patients with periprosthetic femoral fractures present with insidious pain, with no history of a fall or of trauma [12]. It should be borne in mind that osteolytic lesions often occur in asymptomatic hips [22, 23] and continuous surveillance of THA patients (especially younger ones with higher activity levels) may help in timely intervention and reduce the incidence of osteolytic related fractures [15, 24].

With regards to intraoperative fractures, they are most likely to occur during femoral canal preparation, during insertion of the prosthesis, dislocation of the existing prosthetic stem and cement removal [25-28].

### 1.5 Rationale for Surgical Management

The conservative treatment of periprosthetic fractures has become obsolete since these methods are fraught with complications. These include:

- Prosthesis loosening: 19–100%
- Pseudoarthrosis: 25 – 42%
- Abnormal varus positioning of the femur: 45% [11, 29, 30]

Subsequent revision meanwhile is fraught with difficulties due to malunion.

Furthermore non-operative methods such as traction or cast immobilization are overall discouraged since they increase the risk of deep vein thrombosis, pulmonary embolism, pneumonia, pressure ulceration and knee joint contractures [11, 29, 31].

The goals of surgical treatment are to achieve:

- Early union
- Anatomical alignment and length
- A stable prosthesis
- Early mobilisation
- Return to pre-morbid function
- Maintenance of bone stock

## 1.6 Classification Systems

Classification of a fracture is a useful tool within orthopaedic surgery since it helps to define the problem using a common language. This allows for surgeons from different continents and who speak different languages to understand the nature of an injury without needing to see physical radiographic evidence. The best classification systems are those that help to guide treatment since they serve more than a simple role in description alone.

The site of the fracture is the simplest way to categorise fractures. Indeed, this was the basis of the initial classification systems used. Parrish and Jones [8] have outlined one of the earliest classifications used for periprosthetic femoral fractures in 1964.They classified their nine-patient case series into four groups based on the site of fracture (Table 1.1).

*Table 1.1: The Classification System of Parrish and Jones*

| Group | Fracture Site |
|---|---|
| **Group 1** | Fractures in trochanteric area |
| **Group 2** | Fractures in the proximal part of the shaft |
| **Group 3** | Fractures in the mid-shaft |
| **Group 4** | Fractures in the distal part of the shaft of the femur |

Classification systems based on site and pattern of fracture were subsequently published by Whittaker et al. [32] in 1974 (Table 1.2), Johansson et al. [30] in 1981(Table 1.3), and Bethea et al. [29] in 1982 (Table 1.4).

*Table 1.2: The Classification System of Whittaker et al.*

| Type | Details of Fracture |
|---|---|
| **Type I** | Intertrochanteric region with the stem always extending across the fracture site in to the distal femur thus providing good stability |
| **Type II** | Oblique or spiral fracture around the tip of the stem, which is located within the intramedullary canal in both fragments, offering some stability to the fracture |
| **Type III** | Fracture located at or below the stem tip and is completely unstable if displaced |

*Table 1.3: The Classification System of Johansson et al.*

| Type | Details of Fracture | Treatment recommendation |
|---|---|---|
| **Type I** | Fracture proximal to the tip of the prosthesis, with the stem of the prosthesis remaining in the medullary canal | Intra-operative: surgical stabilisation<br>Post-operative : Non-operative |
| **Type II** | Fracture line extending from the proximal portion of the femoral shaft to beyond the distal tip of the prosthesis, with the prosthetic stem dislodged from the medullary canal of the distal fragment | Conversion to long stem prosthesis supplemented by internal fixation with plate or cerclage wires |
| **Type III** | Fracture entirely distal to the tip of the prosthesis | Intra-operative: stabilised in order to complete the hip replacement<br>Post-operative: Surgical fixation |

*Table 1.4: The Classification System of Bethea et al.*

| Type | Details of Fracture | Treatment recommendation |
|---|---|---|
| **Type A** | Fractures at tip of the femoral component either transversely or with a distal spiral | No specific recommendation |
| **Type B** | Spiral fractures around the femoral component | Non-operative intervention |
| **Type C** | Fractures proximal to the tip of the stem with comminution around the stem | Surgical fixation |

*Table 1.5: The Classification System of Cooke and Newman*

| Type | Details of Fracture | Treatment Recommendation |
|---|---|---|
| **Type 1** | Comminuted fractures around the stem of the prosthesis. The prosthesis is always loose and the fracture is inherently unstable | Primary operative treatment |
| **Type 2** | Oblique or spiral fractures around the shaft of the prosthesis, in which stability of the fracture is maintained by the presence of the prosthesis | No specific recommendation – either non-operative or operative |
| **Type 3** | Transverse fractures at the tip of the prosthesis and are unstable though the prosthesis may not be loose | Internal fixation with a rigid plate and supplementary bone grafting |
| **Type 4** | Fractures entirely distal to the prosthesis and include spiral fractures of the femoral shaft which extend proximally as far as the tip of the prosthesis | No specific recommendation – either non-operative or operative |

Bethea's classification was modified slightly to include a fourth group by Cooke and Newman [33] when they presented their 75-patient series in 1988 (Table 1.5). Following this, there have been classification systems published by Mont and Maar [34] in 1994 (Table 1.6) and Beals and Tower [11] in 1996 (Table 1.7). Currently, the 'Vancouver Classification' published by Duncan and Masri [35] in 1995 is the most widely used system since it is the only system subjected to validation (Table 1.8). For this reason, it is also the classification system that will be used to describe fracture patterns in the studies that constitute this thesis. It incorporates loosening of the prosthesis and poor bone stock in addition to pattern and site of the fracture and shall be discussed in Section 1.7.

*Table 1.6: The Classification System of Mont and Maar*

| Type | Details of Fracture | Treatment Recommendation |
|---|---|---|
| **Type 1** | Intertrochanteric fracture | Non-operative |
| **Type 2** | Proximal femur | Cerclage treatment with bone grafting |
| **Type 3** | Spanning the prosthesis tip | Cerclage fixation and revision to a cemented long-stem prosthesis |
| **Type 4** | Distal to the prosthesis tip | Long stem revision or traction |
| **Type 5** | Comminuted, blow-out | Long stem revision with supplementary fixation and bone graft |
| **Type 6** | Supracondylar | No specific recommendation |

*Table 1.7: The Classification System of Beals and Tower*

| **Type** | **Details of Fracture** | **Treatment Recommendation** |
|---|---|---|
| **Type I** | Fracture in the trochanteric region | Non-operative |
| **Type II** | Proximal metaphyseal/diaphyseal fractures that do not involve the stem tip | Non-operative with traction or operative with limited cerclage fixation |
| **Type IIIA** | Proximal diaphyseal fractures at stem tip with less than 25% disruption of the prosthetic interface | Revision to a long-stemmed non cemented prosthesis and bone grafting |
| **Type IIIB** | Proximal diaphyseal fractures at stem tip with greater than 25% disruption of the prosthetic interface | Ingrowth revision supplemented by bone graft |
| **Type IIIC** | Supracondylar fracture at the tip of a long femoral stem | Traction followed by a cast or cast brace. Intramedullary devices if the fracture is unstable |
| **Type IV** | Supracondylar fracture distant to the stem tip | Non-operative, intramedullary nails or plates |

*Table 1.8: The 'Vancouver Classification' System of Duncan and Masri*

| **Type** | **Details of Fracture** |
|---|---|
| **Type $A_G$** | Fractures of greater trochanter |
| **Type $A_L$** | Fractures of lesser trochanter |
| **Type B1** | Fracture around the stem or extending just below it in which the femoral component is solidly fixed |
| **Type B2** | Fracture around the stem or extending just below it in which the femoral component is loose |
| **Type B3** | Fracture around the stem or extending just below it in which the femoral component is loose and there is severe bone stock loss |
| **Type C** | Fractures well below the stem tip |

## 1.7The Vancouver Classification

The Vancouver Classification divides periprosthetic fractures in to three types of which Type A fractures are split in to two subtypes and Type B in to three subtypes. There are thus six possible types of fracture that exists according to this system and these shall now be discussed in more detail.

### 1.7.1 Type A Fractures

The Vancouver classification system splits Type A fractures in to either those involving the greater trochanter ($A_G$) or lesser trochanter ($A_L$). Fractures involving the greater trochanter are recognised as a later complication of wear debris induced osteolysis where by the combination of weak bone coupled together with the pull of the tendons attached to the greater trochanter predisposes to an avulsion type injury.

Undisplaced or minimally displaced fractures of the greater trochanter can be managed without surgical intervention since there is an opposition to the forces acting on this bony prominence by the *Glutei* and *Vasti*.

The management of displaced fractures is not yet well defined since it is debatable whether the restoration in abductor function is more important that the risk of surgery. Nonetheless, there are successful reports of fixation using either a claw plate [36] or wire fixation [37].

Fractures of the lesser trochanter are generally managed non-operatively. This is due to its close proximity to the femoral vessels. Furthermore, isolated fractures unrelated to metastatic disease tend to regain excellent function. The exception to this is where the fracture of the lesser trochanter extends into the femoral shaft and the fracture is instead a Type B injury. In this instance, the extension of the fracture is likely to destabilise the medial wall of the femur potentially causing a loose implant.

### 1.7.2 Type B Fractures

The Vancouver classification identifies Type B fractures into three different subtypes. Common to all subtypes is the presence of the fracture at the level of the femoral implant.

Type B1 fractures occur around stable implants - namely one that is well fixed. Loose implants may be observed as changes in position between sequential radiographs or alternatively osteolytic loosening will be observed as lucencies at the interfaces between bone and cement or cement and bone. Irrespective of normal radiographs, the final confirmation of a loose implant will be at surgery whereby a loose implant will toggle in a surgeon’s hands. Exclusion of these three findings will allow a fracture around a femoral implant to be labelled a Type B1 fracture.

Loose implants will automatically lead to a Type B2 or B3 classification and will always require replacement to restore function. Differentiation between these two subtypes is dependent upon bone stock; there is adequate bone stock in Type B2 fractures and inadequate bone stock in Type B3 Fractures. Bone stock is generally lost around implants in patients who have had revision arthroplasty (whether it is secondary to aseptic or infective failure), severe trauma to the proximal femur or excision of malignant lesions.

Loss of bone stock invariably makes reconstruction more difficult since a lack of adequate support compromises the stability of the new implant that will be implanted.

This thesis will focus on this group of fractures (Vancouver Type B) since it this group that remains the most technically challenging and open for debate with respect to treatment.

### 1.7.3Type C Fractures

The Vancouver classification identifies Type C fractures as those occurring within the femoral diaphysis well below the tip of the implant and consequently they have no impact upon implant stability.

Fixation of the fracture is based around sound AO principles; namely reduction of the fracture and stabilisation to facilitate either direct or indirect healing thereby promoting rapid restoration of function. The main additional consideration when managing these fractures is that the presence of a gap between any stem tip and the fixation plate will create a stress riser.

### 1.8 Objectives

The research aims to complete the following tasks:

1. To validate the classification of periprosthetic femoral fractures.
2. To provide clinical and biomechanical evidence towards the use of cortical strut grafts in cemented stems.
3. To provide clinical and biomechanical analysis of the use of revision stems in the treatment of periprosthetic fractures.

It is hypothesised that the Vancouver classification will be a reliable and reproducible system to use, that strut grafts, cables and long-stemmed implants will improve function and outcome when used to manage these injuries, and that biomechanical models will provide evidence on why the use of the implants is successful.

## 1.9 Outline

Chapter 1 of this thesis provides an overview of periprosthetic femoral fractures and need for research.

Chapter 2 validates the Vancouver classification of this injury. This is necessary since different patterns of fracture require different treatments.

Chapter 3 investigates the clinical and radiographic outcomes of fractures around stable hip implants treated with cortical onlay strut allografts without revision of the stem.

Chapter 4 determines the biomechanical effect of cortical strut grafts and cables on fracture stability.

Chapter 5 investigates the clinical and radiographic outcomes of periprosthetic femoral fractures treated with cementless revision of the stem in conjunction with cortical struts, cables, bone allograft and demineralised bone matrix.

Chapter 6 uses a biomechanical model to determine the site of stem fracture in uncemented implants.

Chapter 7 outlines the results in periprosthetic fractures using an uncoated interlocking stem alone; either as a spacer or definitive implant.

Chapter 8 describes the results when using an interlocking stem as either a spacer or definitive implant in infected periprosthetic fractures.

Chapter 9 concludes my thesis by stating the unique contribution of the study to research, policy and practice. It ends with a reflective account of the conduct and findings of the study.

# Chapter 2

## Independent validation of the Vancouver classification

**Rationale for Chapter –** Chapters 3 and onwards will discuss the use of specific medical devices when managing periprosthetic fractures of the femur. To ensure that the study groups include the same fracture types, a classification system that can be used confidently without question is vital. In this chapter, independent validation of the Vancouver Classification will be undertaken to ensure that it is a suitable classification tool in a UK population.

# Chapter 2

## 2.1 Introduction

A classification system for periprosthetic fractures has to be reliable and valid if it is to be a consistent guide to management. Various systems have been described, some of which depend on the site of the fracture, such as that of Parrish and Jones [8] and Johansson et al. [30] and others on the pattern of the fracture or the relationship to the stability of the implant [8, 30, 38-41].

The classification system developed in Vancouver [42] is simple and takes account of the stability of the femoral component and the state of the surrounding bone stock both of which are important in determining treatment. It divides the femur into three zones; A, B and C. Zone A is the proximal metaphysis, and fractures in this zone tend to involve the greater or lesser trochanter and do not extend into the diaphysis. Zone-B fractures involve the diaphyseal region but do not extend into the distal diaphysis. This zone is further subdivided into B1: fractures with a stable implant (see Figure2.1), B2: fractures with a loose implant (see Figure 2.2) and B3: fractures with a loose implant in the presence of severe loss of bone stock. Zone-C fractures occur in the distal diaphysis where the fracture is remote from the implant and can be treated relatively independently of the prosthesis.

The reliability of any classification system is dependent on the consistency between different users (inter-observer), or the same user on different occasions (intra-observer), and the validity which assesses the degree to which the abnormality described in the classification actually represents the true abnormality [43].

*Figure 2.1: Anteroposterior radiograph of the left proximal femur showing a Vancouver B1 fracture around an Austin Moore hemiarthroplasty*

*Figure 2.2: Anteroposterior radiograph of the right proximal femur showing a Vancouver B2 periprosthetic fracture around a cemented total hip replacement*

The Vancouver Classification is the only system which has been subjected to psychometric testing of reliability and validity. An understanding of this system should enable an orthopaedic surgeon to construct a plan of management [21]. The purpose of this study is to ensure that this repeatable i.e. there is minimal test-retest variability. It is hypothesised that the system will be reliable amongst for all grades of clinician with respect to intra-observer and inter-observer assessment. This is relevant since further chapters will investigate outcomes of different types of fracture.

## 2.2. Methods

This study has two parts: (1) independent classification of the fractures according to the Vancouver system [42-44] using plain pre-operative radiographs and (2) verification with intra-operative findings and classification.

A cohort of 30 consecutive patients presenting to University College London Hospital, UK who had sustained a proven periprosthetic femoral fracture were retrospectively analysed. Only patients with a pre-operative radiological diagnosis and complete operative documentation of the type of fracture were included. Two patients had incomplete data and could not be included. This left 28 patients in the study (12 men:16 women; mean age 72.34 years (range: 47.2 - 89.6).

Assessment of the fracture type took on three parts:

*Site of fracture* – this involved either of the trochanters, or occurred at the level or just below the stem, or distal to the stem. This was assessed both radiographically and verified intra-operatively.

*Bone quality* – this was assessed from the radiographs using Paprosky's classification [45] of femoral defects. Definitive decisions about the type of reconstruction based on the stability of the implant and the degree of bone loss were made per-operatively. The bone was considered to be adequate if good diaphyseal fixation could be achieved and poor if it was damaged or considered to be too thin to achieve this.

*Implant stability* – this was assessed pre-operatively from the radiographs to determine whether implants appeared loose or well fixed and was confirmed at operation. If the implant was found to be stable, fixation of the fracture alone was undertaken, but if it was unstable the prosthesis was revised.

Other than plain radiographs, no patient underwent additional imaging before surgery.

In order to evaluate if the Vancouver classification is a valid and reliable tool that could be used by all grades of medical staff, the following test subjects were recruited:

- Six consultant orthopaedic surgeons who undertook joint replacement surgery.
- Six trainee orthopaedic surgeons (Specialist Registrar level).
- Six medical students who had no specialist orthopaedic training.

All participants in the study were made familiar with the Vancouver classification by means of a short lecture that used both oral and visual aids. Once all test subjects felt suitably comfortable with the Vancouver classification, they were individually shown radiographs of the 28 patients at a single sitting. Each test subject who examined the radiographs then classified the fracture according to its type (A, B1, B2, B3 and C). This exercise was repeated after an interval of two weeks.

The data were analysed using the weighted kappa statistic to measure the level of agreement for two observers, using the Landis and Koch [46] criteria for interpretation (Table 2.1).

*Table 2.1: Interpretation of weighted kappa values*

| **Weighted kappa (κ)** | **Interpretation** |
|---|---|
| **0.00 to 0.20** | Slight agreement |
| **0.21 to 0.40** | Fair agreement |
| **0.41 to 0.60** | Moderate agreement |
| **0.61 to 0.80** | Substantial agreement |
| **0.81 to 1.0** | Near perfect agreement |

Validity was tested on the radiological and operative findings of the B group of fractures by comparing the radiographs with the operative findings. Confirmation of pre-operative radiological classification was made at the operation, by the surgeon and documented in the operative notes. Information about the quality of the bone and the stability of the implant for the B1 subgroup assessment was derived from the pre-operative radiographs.

## 2.3 Results

The inter-observer agreement for each staffing grade for the first and second reading respectively was:

- Consultant orthopaedic surgeons – 0.72 and 0.74
- Trainee orthopaedic surgeons – 0.68 and 0.70
- Medical students – 0.61 and 0.61

The intra-observer agreement for each staffing grade for the first and second reading respectively was:

- Consultant orthopaedic surgeons – 0.64 and 0.67
- Trainee orthopaedic surgeons – 0.61 and 0.64
- Medical students – 0.59 and 0.60

In the validity analysis derived from the surgical findings and the radiological analysis, the observed agreement within the B1, B2 and B3 subgroups was 77% with a kappa value of 0.67 indicating substantial agreement with the operative findings (Table 2.2).

*Table 2.2: Details of diagnoses given for types of periprosthetic fractures*

| | **B1** | **B2** | **B3** |
|---|---|---|---|
| **Radiological diagnosis** | 8 | 12 | 2 |
| **Peri-operative diagnosis** | 6 | 9 | 2 |

### 2.4 Discussion

Periprosthetic fractures are associated with a high rate of major complications including early mortality and considerable morbidity, and are expensive to treat [11, 12]. A standardised classification system and accepted treatment algorithms may minimise these problems, but the classification system adopted should be both reliable and valid thereby enabling selection of the most appropriate treatment for each case [43, 44].

The Vancouver classification has gained worldwide acceptance with its logical analysis of the configuration of the fracture, the stability of the implant and the quality of the bone stock [22]. However, its reliability and validity have previously only been tested by the originating group [44, 47]. They performed a similar assessment comparing using forty radiographs that were evaluated by 6 observers, 3 experts and 3 nonexperts. Each observer read the radiographs on 2 separate occasions and classified each case as to its type whilst validity was assessed within the B group by looking at the agreement between the radiographic classification and the intraoperative findings. Intraobserver agreement ranged from 0.73 to 0.83 with negligible differences between experts and nonexperts whilst interobserver agreement was 0.61 for the first reading and 0.64 for the second reading thus indicating substantial agreement between observers. Validity analysis revealed an observed agreement kappa value of 0.78, indicating substantial agreement between the radiographic classification and the intraoperative findings.

A recent study of the Swedish hip registry demonstrated that the majority (80%) of periprosthetic fractures encountered were type B although difficulty was encountered in establishing pre-operatively between a diagnosis of type-B1 and type-B2 fractures [14]. The high failure rate of treatment was attributed to the under-diagnosis of loose implants [48]. To overcome this limitation, exploration of the joint and testing of the stability of the implant were recommended.

The increasing availability and quality of CT may make it a useful adjunct in the categorising the disease. Pre-operatively, it can be used to assess bone stock and to identify the pattern of the fracture Post-operatively however, the presence of struts and cables can make it difficult to evaluate union of fracture and in these circumstances. CT may be helpful in confirming the degree of union both for the fracture itself and between allograft and the host bone when it has been required [49].

It may be argued that not using CT for more detailed imaging is a limitation. However, the pre-operative diagnosis determined by the classification of the radiographs, rarely changed at the time of surgery. This may be a reflection of the clinical practice of the hospital, since all the periprosthetic femoral fractures are managed by the hip revision unit and consequently, both bone stock and stability are assessed stringently during surgery. If the fracture had differed from that anticipated from the radiological assessment, long-stemmed revision implants and allograft bone were already available. For this reason, CT was not routinely performed.

It can be difficult to determine the stability of prosthesis and the quality of the bone stock based solely upon radiographic means. This is reflected by the kappa value for validity which was 0.67 for consultants within the B subgroup which, although representing substantial agreement, does not achieve the level of near-perfect agreement. For this reason, it may be suggested that all periprosthetic fractures should be managed by surgeons with experience in revision surgery so that expertise in either stabilising the fracture or revising the femoral component is available at the time of surgery.

Although the exact incidence of periprosthetic fractures is unknown, it is thought to be rising and with an increasingly ageing population, this is likely to continue [50]. Spiralling health-care costs may force a decrease in the length of follow-up after a THA with the results that asymptomatic loosening is not identified at an early stage with an increase in risk of subsequent fracture [24].

The results confirm that the Vancouver classification system is reliable and reproducible. In addition, it has been shown that substantial agreement can be found between individuals with no specialist training. This allows management to be planned by less experienced surgeons, who may instigate early referral of appropriate cases to specialist centres. Validation of this classification system has also been proven since there was substantial agreement with the operative findings.

Despite this, there will always be cases in which the establishment of a pre-operative diagnosis may be difficult. The management of periprosthetic fractures should therefore ideally be carried out by experts in the field with the appropriate resources available to them. It is preferable to be able to classify a fracture pre-operatively so that the most appropriate surgical option can be identified. This is because those fractures with a stable pattern tend only to require simple reduction and fixation, whilst those with associated loosening of the components will frequently need more extensive surgery [48, 51, 52].

# Chapter 3

# Use of cortical onlay allografts around Type B1 fractures

**Rationale for Chapter –** The use of the Vancouver Classification system has been shown to be reliable and valid. When an implant is well fixed, it is preferable to retain the original implant. A biological plate such as a cortical strut graft may provide an efficacious adjunct to fixation. This chapter will identify whether using such grafts has been effective.

# Chapter 3

## 3.1 Introduction

The majority of periprosthetic fractures occur around loose implants and necessitate revision of the femoral stem. However, when the femoral component is well fixed it often is retained, with open reduction and internal fixation of the fracture. A number of alternatives are available for such treatment [53-61], some of which are associated with high failure rates [34, 62, 63]. Cortical onlay strut allografting, as the primary method of fixation or as adjunctive fixation when a plate is used, has emerged as an attractive option for the treatment of periprosthetic femoral fractures around stable implants [64-66].

Chandler et al. [31] reviewed the outcomes of treatment of nineteen fractures around well-fixed femoral hip or knee implants; they reported that seventeen had united by eighteen weeks and the patients had returned to their pre-morbid level of activity [31]. The allograft struts confer stability to the fracture site, and they can incorporate [67] and ultimately increase the femoral bone stock [68-73].

The primary aim of this study was to determine the clinical and radiographic outcomes of periprosthetic femoral fractures around stable hip implants treated with cortical onlay strut allografts without revision of the stem. It is hypothesised that this treatment would result in bony union and improve function. The primary end point was fracture union, and secondary end points included strut-to-host bone union, the final amount of bone stock, and postoperative function.

## 3.2 Methods

A survey of four centres (Vancouver General Hospital, Vancouver, British Columbia, Canada; Mayo Clinic, Rochester, Minnesota; Mount Sinai Hospital, University of Toronto, Toronto, Ontario, Canada; and Massachusetts General Hospital, Boston, Massachusetts) identified 40 consecutive patients in whom a fracture around a well-fixed femoral stem had been treated with cortical onlay strut allografts without revision of the femoral component. These centres were chosen due to their collaborative links and for their ability to provide full and necessary data on the patients included in this study whilst the author of this thesis was practicing at the principle hospital. Concomitant revision of the stem, whatever the cause, led to exclusion from the study. One patient with concomitant revision of an aseptically loose acetabular socket was included since this was an independent finding of the periprosthetic fracture. All of the patients were followed until fracture union or until a reoperation was performed.

There were 14 men and 26 women, with an average age of 69 years (range: 44 - 93). The average weight of the patients was 81 kg (range: 46 - 112).

The cause of fracture was either:

- Major trauma – 4 patients
- Minor trauma – 32 patients
- No obvious cause – 4patients

No obvious underlying medical condition that would predispose to fracture was noted. 12 patients, including one in whom the fixation failed, smoked tobacco.

Serial radiographs were reviewed with regard to:

- Fracture union
- Union of the allograft to the host
- Femoral alignment
- Amount of bone stocks
- Stem fixation

*Fracture union* was defined as cortical continuity as seen on both the antero-posterior and lateral radiographs. The presence of cortical bridging was required for a diagnosis of union, although this could not always be visualised circumferentially because of the presence of the plate.

*Union of the allograft to the host* was evaluated whenever possible to the criteria for incorporation described by Emerson et al. [70].

*Femoral alignment* was defined as the alignment of the stem relative to the long axis of the femur.

*Amount of bone stock* was evaluated with use of the cortical index, which quantifies the ratio of the cortical thickness to the canal diameter at the femoral isthmus. The cortical index was determined on antero-posterior and lateral radiographs both preoperatively and at the final review for all fractures treated with cortical struts alone. The ratio could not be evaluated reliably in patients who had also been treated with a metal plate, as the overlying metal obscured part of the bone. The ratio of the final value (with the struts) to the initial value was used as an estimate of the change in cortical bone stock. This measurement provides an estimate of the potential bone stock available after fracture union; it does not take into account the fact that the cortical composite may continue to remodel.

*Stem fixation* was evaluated through positional changes and increasing lucencies at the bone-cement and cement-implant interfaces in cemented prostheses, and bone-implant in uncemented prostheses.

Postoperative pain and mobility were compared with the preoperative status. Whenever possible, a Harris hip score [74] was recorded at the time of the clinical review or was estimated from questionnaire data.

In 27 patients, the fracture was around a previously revised femoral stem. 23 stems were cemented. All of the femoral components appeared to be well fixed radiographically. Nine of the fractures were transverse, and the remainder were spiral or oblique. There were more than three fracture fragments in three patients.

The type of fracture fixation, the source of the allograft struts, and the use of any additional biological augmentation (particulate bone graft or demineralised bone matrix) were determined by the treating surgeon and differed among centres. 19 patients were treated with cortical onlay strut allografts alone, 12 were treated with a plate and one cortical strut, and nine were treated with a plate and two struts. Fresh-frozen femoral allografts were used as struts in 29 patients; fresh-frozen tibial allografts, in seven; and freeze-dried fibular allografts, in four. Autograft was placed at the fracture site and beneath the cortical strut or struts in eight patients, morselised allograft was used in 29, and demineralised bone matrix was used in 15.

The allograft strut and plate were usually placed on the anterior and lateral femoral cortices, although nine patients in whom two cortical struts were used had them placed on the medial and lateral cortices. When a metal plate was used, it was placed laterally while the strut was placed anteriorly or medially (see Figures 3.1 and 3.2).

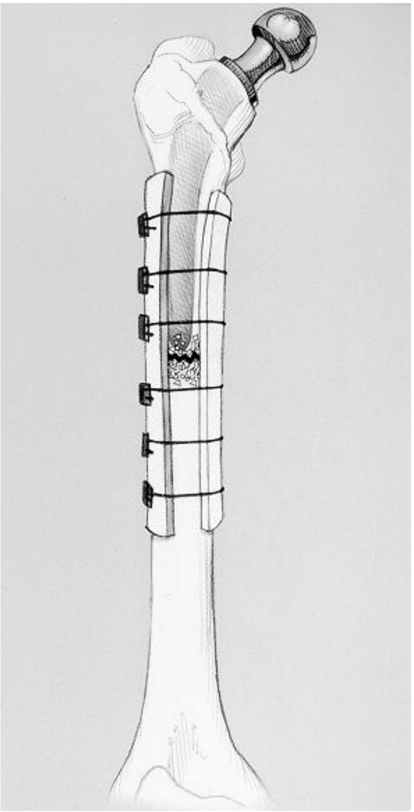

*Figure 3.1: Schematic illustration of the fixation of a fracture at the tip of a femoral stem with two cortical struts and three cables proximal and distal to the fracture. Either autograft or allograft or demineralised bone matrix is used at the fracture site and at the strut-host junction as a form of biological augmentation.*

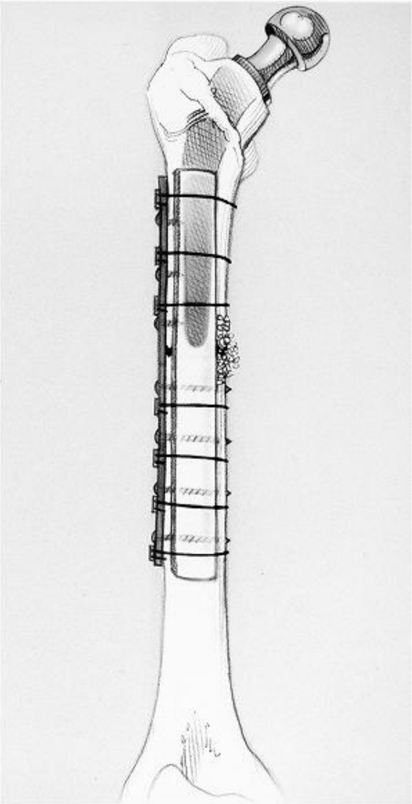

*Figure 3.2: Schematic illustration of the fixation of a fracture at the tip of a femoral stem with a lateral plate and an anterior cortical strut. The cortical strut can also be applied medially. Morselised allograft is shown at the fracture site.*

Cerclage wires were used to stabilise the struts in nine patients, and cerclage cables were used in the rest. A minimum of two and a maximum of six fixation points proximal and distal to the fracture were used. When cortical struts alone were used, a minimum of three fixation points proximal and distal to the fracture site were employed. Two fixation points around the struts were accepted distally when adjunctive plate fixation was used; in such patients, the plate was typically fixed to the distal fracture fragment with four or five bi-cortical screws.

Postoperatively, the patients were instructed to walk without weight-bearing or with toe-touch weight-bearing for three months. Progressive weight-bearing was then encouraged, with all of the patients encouraged to bear weight fully after a maximum of four months from the date of fracture fixation.

## 3.3 Results

### 3.3.1 Follow-up period

Excluding the one patient in whom the repair failed at two months, the patients were followed for a mean of 28 months (range: 6 - 78) after the fracture. Four patients died during the follow-up period, all after union of the fracture and all deaths were unrelated to the surgery or conditions arising thereof.

### 3.3.2 Fracture Union

39 (98%) of the 40 fractures united. The one failure of fixation occurred in a 67 year-old, 88-kg man who tried to return to sporting activity within six weeks of his operation and thus did not comply with treatment recommendations. He presented at two months with a failure of the cortical strut and the plate. The fracture was restabilised with a strut graft and a plate, and ultimately united in good alignment.

19 patients were followed for less than 24 months; nine of them were followed for less than 12 months, but none were followed for less than six months. All had fracture union by the latest follow-up evaluation.

There were four angular malunions, all of which had <10° of malalignment. Two patients had varus malalignment; one, varus and recurvatum malalignment; and one, recurvatum malalignment. One of these patients had had a transverse fracture; two, an oblique fracture; and one, a spiral fracture. Two of these patients had been treated with two cortical onlay allograft struts, and two had been treated with a cortical onlay allograft strut and a plate. All of the patients with malunion were followed for a minimum of two years. All had fracture union within six months after the injury, and none of the deformities progressed after union; the final fracture position and alignment were the same as those seen at six months. Using logistic regression analysis, no relationship between the body-mass index of the patients and malunion or non-union could be established.

Strut union typically was seen within the first year. It was possible to assess incorporation only in the nineteen patients in whom cortical struts alone had been used. In those patients, the ratio of the postoperative to the preoperative cortical index averaged 1.41 (range: 1.03 - 1.67). The ratio was calculated at a mean of 31 months postoperatively and was clearly dependent on the amount of remodelling of the femoral shaft that had taken place. Although the radiographs were not standardised, and error may have been introduced because of difficulties in identifying the same level for measurement on all radiographs, this index nevertheless represents a considerable increase in apparent femoral bone stock. The available serial radiographs did not allow any other quantitative conclusions with regard to the incorporation process. Rounding off one or both ends of the struts and scalloping of <2 mm on the external surface usually were evident within six months and were always seen within a year. Some patients had localised resorption of >2 mm of the onlay allografts at the sites of cables or wires, but no other resorption was seen and measured. Evidence of strut-to-host bridging was seen in all of the patients. So-called cancellisation with the emergence of trabeculae within the cortical struts was seen in six patients who were followed for more than 36 months.

### 3.3.3 Additional Surgery

The one failure of fixation was re-stabilised with a plate and a cortical strut with the addition of demineralised bone matrix at the non-union site. The fracture healed within four months, and the patient regained full function. Seven patients complained of some discomfort in the lateral aspect of the thigh, which was at the site of a metal plate in six patients and related to prominent cables in another. The implants were removed from two patients for this reason. The cortical struts were found to be united to the femur in both patients. Two months after the strut-grafting procedure, a deep wound infection that required débridement and intravenous antibiotic therapy developed in one patient. He was subsequently treated with suppressive oral antibiotics. The fracture united, and there was no clinical evidence of ongoing infection subsequently. One patient required acetabular revision, but there was no clinical or radiographic evidence of femoral loosening in any patient.

### 3.3.4 Functional Outcome

There was a very broad range of Harris hip scores both before the fracture (range: 21 - 96 points; mean: 83 points) and at the final review (range: 16 - 97 points; mean: 81 points) ($p=0.78$). In the group of patients who were followed for more than twelve months, there was no notable difference between the need for walking aids prior to the fracture and that at the final review. All but one of the surviving patients returned to their preoperative functional level within one year. The exception was a man with chronic back and thigh pain that predated the fracture. The symptoms worsened after the fracture, and despite satisfactory union in good alignment and a good range of hip and knee motion, he continued to complain of debilitating pain. The hip and femur were explored, infection was ruled out, and stability of the implants was confirmed. The fixation devices (a plate, cables, and screws) were removed, and the patient was being treated in a pain clinic at the time of the last follow-up.

### 3.4 Discussion

Stable fixation of fractures around well-fixed implants allows for fracture union in satisfactory alignment. Several factors make it more difficult to obtain satisfactory internal fixation. Stresses concentrate at the fracture site near the tip of the implant, and these stresses can be worse in elderly patients, who cannot always comply perfectly with limited weight-bearing protocols. Furthermore, bone quality in these patients often is poor and fixation of the proximal fragment is limited by the intramedullary femoral component. In this situation, cortical onlay strut allografts can act as biological plates, either alone or in combination with other internal fixation devices, to stabilise the fracture [64, 75]. As well as conferring mechanical stability, they may enhance fracture-healing and increase bone stock [31, 70-72, 76, 77]. If appropriately selected and prepared, allograft struts can be customised to fit almost any femur. As the modulus of elasticity of allograft struts is similar to that of the host bone, there may be less stress-shielding of the host bone in comparison with that associated with other, more rigid forms of internal fixation[63].

There is a dynamic change in allograft biomechanics during the incorporation and remodelling process. The histological and mechanical response to onlay strut allografts has been well documented in the canine model [69, 70, 76]. A zone of highly vascularised mesenchymal tissue forms at the host-graft junction. Osteoclasts subsequently create cutting cones in the graft, which is then invaded by vascular buds. As the graft remodels, it is at its weakest and is vulnerable to mechanical failure unless the fracture has already healed. Maximal weakness occurs between four and six months [78]. The construct must therefore be secure enough during the incorporation period to ensure that the fracture unites before the allograft struts weaken. In the present series, this objective was accomplished with the use of either an adjunctive plate or two cortical struts with at least three fixation points proximal and distal to the fracture. Ultimately, the graft undergoes adaptive remodelling and starts to respond to stress.

One of the limitations of this series is the short duration of follow-up. Although we saw evidence of fracture union in all of the patients, and the alignment seen at six months after the surgery did not change in the short term, we cannot describe the long-term effects of remodelling on this construct. Previous studies have suggested that cortical struts predictably unite, remodel, and mature [31, 68-71, 75]. The duration of follow-up of the majority of our patients was insufficient for us to see maturation and remodelling in all patients, but once graft-host union has occurred, the sequence of events described by Head et al. on the basis of animal experiments and radiographic observations of humans would be expected to proceed [69-71].

The ideal length, position, and fixation of cortical struts have not been determined. A number of different constructs were used in our study based upon the particular patterns of fracture and surgeon preference, with successful clinical and radiographic outcomes. The aims of treatment of these fractures are anatomical alignment, fracture union, and rapid recovery without limiting the subsequent function of the hip prosthesis. Our study shows that these aims can be achieved with the use of cortical onlay strut allografts with or without adjunctive plate fixation. However, these patients were all treated in referral centres, and a number of technical points should be emphasised. Stable fixation, with as many cables or wires as necessary, is required. This is facilitated by good apposition of the struts to the native bone. The blood supply of the femur should be preserved as much as possible. In particular, the *linea aspera* should not be stripped of its soft-tissue attachments. Autograft or morselised allograft or demineralised bone matrix may enhance both fracture union and strut-to-host bone union.

It is important to state that since the undertaking of this study, the advent of stronger plates has become an important tool in periprosthetic fracture management. One disadvantage of using them is the soft-tissue stripping that occurs and thus minimally invasive techniques have been proposed. Ricci et al. described their practice of indirect open reduction and internal fixation with a single extra-periosteal lateral plate, without the use of allograft struts, for the treatment of a femoral shaft fracture about a stable intramedullary implant; namely a similar cohort to that within this study [79]. Excluding those who died and those with inadequate follow-up, there were 41 patients included in the final analysis. At a mean of 12 weeks, the rate of union was 100%. One instance of cable fracture and one early and two late infections were recorded, each of which resolved. Restoration of functional status to pre-fracture levels was seen in 73% of patients and decreased in the remainder.

The subsequent development of locking plate technology with improved biomechanical stability [80] excellent outcomes has further strengthened the argument for plate fixation around well fixed stems [81]. However this is not universal with Buttaro et al. [82] reporting on a consecutive series of 14 B1 fractures treated with a locked compression plate following open reduction. Of these, five cases included supplemental fixation with a cortical strut allograft and the mean follow-up was 20months. Eight cases united at a mean of 5.4 months but the remaining six patients did not; three cases were attributed to plate fracture and three to plate pullout. All but one of these failures occurred in the absence of a cortical strut allograft. Of particular concern with this paper was the possible misuse of the term B1 fracture which all the patients were inferred to have suffered. This is because B1 fractures were referred within this paper as inherently unstable which is contrary to the actual definition. Thus, it is likely that the cohort included type B2 fractures that were probably wrongly classified which would probably account for the high failure rate since treatment should include femoral implant revision also.

When a periprosthetic femoral fracture occurs around a well-fixed stem, internal fixation with cortical onlay strut allografts affords the dual advantages of providing or augmenting the mechanical stability of fracture fixation and of enhancing the likelihood of fracture-healing. In this series of 40 patients, the use of cortical struts, either alone or in conjunction with a plate, led to a very high rate of fracture union in satisfactory alignment. A case example can be seen in Figures 3.3 through to 3.6 where the radiographic course of a seventy-year-old woman who sustained a fracture at the tip of the total hip stem after impaction grafting. On the basis of these findings, it can be concluded that when internal fixation of a periprosthetic femoral fracture is undertaken, cortical strut grafts could be used to augment fixation and healing.

*Figure 3.3: Anteroposterior radiograph of the right hip showing a fracture at the tip of the total hip stem after impaction grafting*

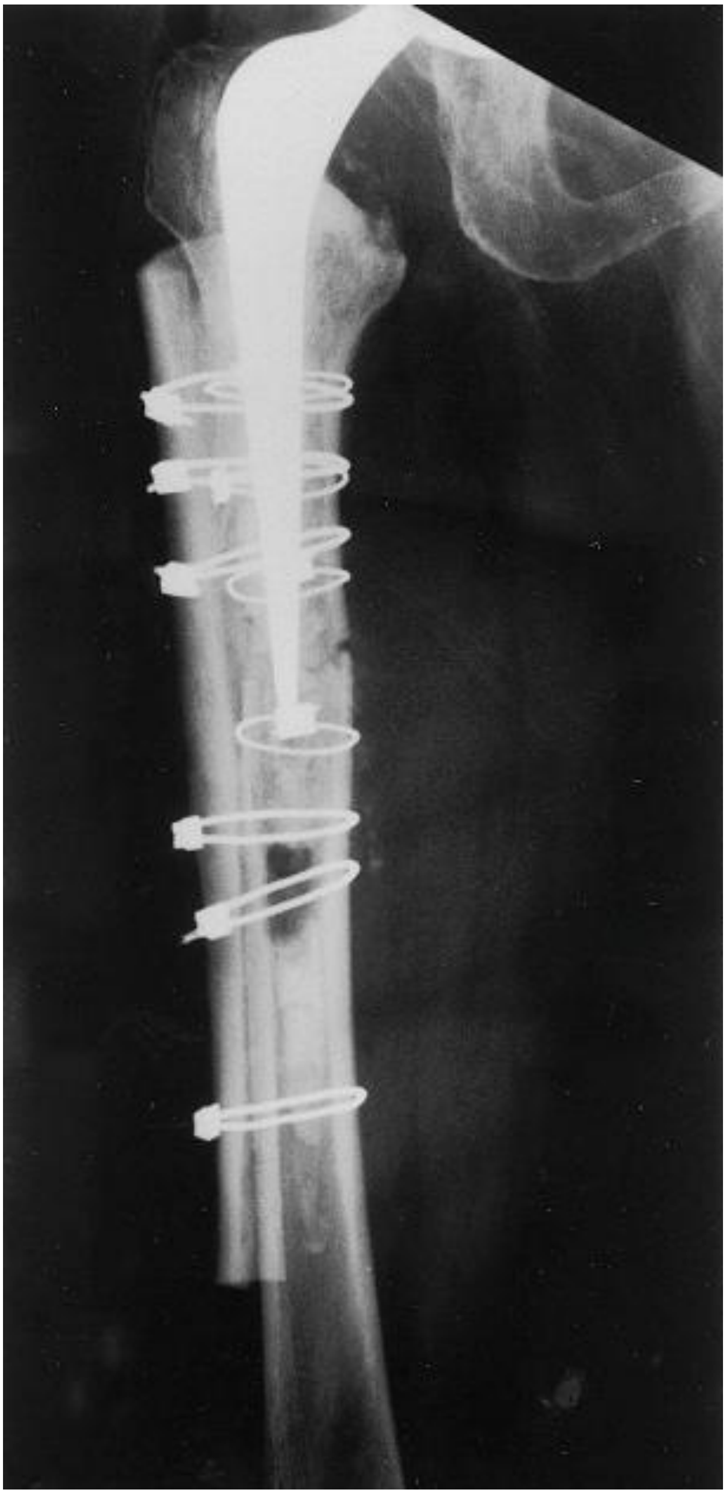

*Figure 3.4: Anteroposterior radiograph of the right hip taken in the immediate post-operative period showing that the fracture was stabilised with use of cortical onlay strut allografts and cables*

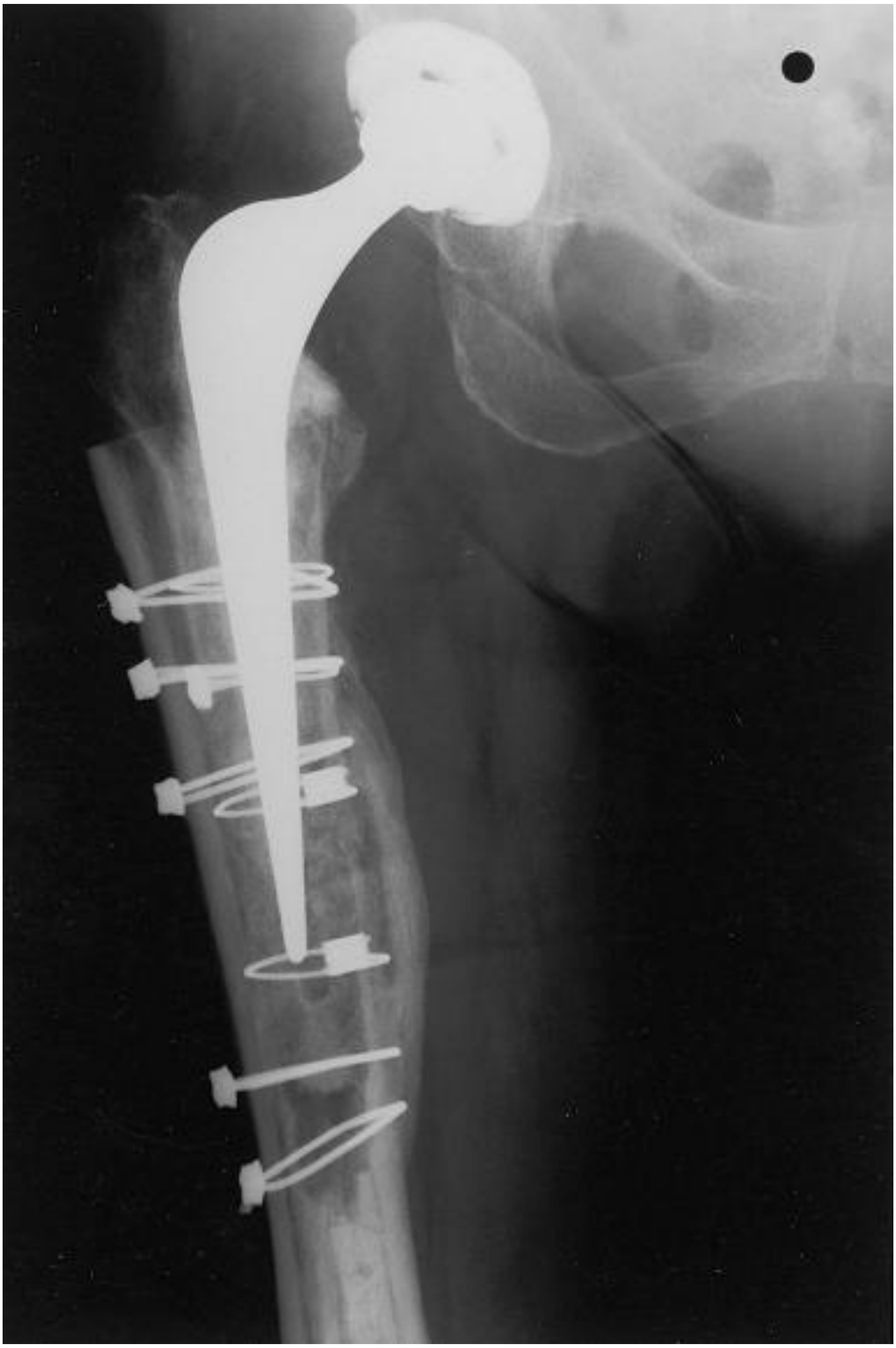

*Figure 3.5: Anteroposterior radiograph of the right proximal femur taken at 28 months showing that the fracture had united in good alignment and there was good evidence of strut incorporation*

*Figure 3.6: Anteroposterior radiograph of the right mid-shaft femur taken at 28 months showing that the fracture had united in good alignment and there was good evidence of strut incorporation*

# Chapter 4

# A biomechanical evaluation of cortical onlay allograft struts

**Rationale for Chapter –** Fracture union and improved bone stock and functional outcome have been demonstrated when using cortical onlay allograft. Chapter 3 was a retrospective analysis of patients and although the type of fracture was common, the actual patterns of fractures were heterogeneous. Consequently, from a fixation viewpoint it is not possible to randomise patients to differing amounts of struts even though it would be useful to know what support they provide. This chapter will evaluate the biomechanical properties of cortical struts to determine a theoretical optimal construct.

## Chapter 4

### 4.1 Introduction

There has been a focus on the development and refinement of fixation techniques for periprosthetic femoral fractures around stable implants. This has encompassed the use of standard plates, screws, wires and bands, as well as a number of specially designed implants. Screws, cerclage wires, cables or bands on their own are insufficient [68], and conventional plates may fail because of the difficulty in obtaining proximal fixation. Moreover, proximal screws may violate the bone prosthesis interface, may lead to cement fracture and loosening, and will act as stress risers increasing the risk of later fractures. Alternatives have included combinations of plates and cables [53, 60], Partridge bands with a variety of plates [55-57], Mennen plates [54, 58] and compression plates [59], all of which still arouse debate, and some of which are associated with high failure rates [62, 63, 83].

Cortical onlay allograft struts are increasingly employed in this situation [64, 65, 68, 75, 84] and are effective, which has been confirmed by the first part of this thesis. Allograft struts can act as biological plates that stabilise the fracture and ultimately strengthen the bone. There is however, no agreed standard practice as to the length and number of struts required, the number of fixation points necessary, and the type of allograft that should be used. Moreover, to our knowledge, there are limited data evaluating the impact of different allograft constructs and characteristics on the stability of fracture fixation [85, 86]. The purpose of this study is to identify the allograft cortical strut length and configuration, and the wire or cable number and tension that will provide optimal fixation for periprosthetic femoral fractures. It is hypothesised that an increasing number of struts and the use of cable will improve fracture stability.

## 4.2 Methods

### 4.2.1 Specimens

Sixteen fresh human cadaveric femora from sixteen donors were dissected of soft tissue, and stored at -30°C in sealed plastic bags. Radiographs of each femur were taken prior to testing in order to exclude any gross abnormalities or pathologic lesions. The mean age of the donors was 78.5 years (range: 59 - 90) and mean body mass was 62kg (range: 40 - 74). Ten femurs were cut into thirds with an oscillating saw to form cortical struts that were twenty centimetres in length. The two best fitting struts for the femur to be tested were used.

The other six femora were divided in the supracondylar region and potted individually in dental stone (Tru-Stone, HereausKulzer, South Bend, IN, USA) within an aluminium potting fixture. Once the dental stone had fully cured, transverse osteotomies were performed with an oscillating saw at a distance of ten centimetres from the base of the lesser trochanter. The bone preparation was performed by the same surgeon for all the femora. Femoral stems were not inserted into any of the femora to avoid the introduction of an unwanted variable to my simulation of a fracture.

Ten femur-strut constructs were tested. Each construct included a unique set of struts from a single femur. Of the six femurs with transverse osteotomies, four were tested twice and two were tested once. We adopted this protocol since the tests were potentially destructive to the cortical struts, but were relatively non-destructive to the femur.

#### 4.2.2 Experimental Design

These fixation variables were assessed in the following order:

1) the number of cables above and below the fracture site (two, three and four);
2) cable tension (high and low);
3) cable fixation as compared to wire fixation;
4) strut number and position:
    i) combined anterior and lateral struts;
    ii) combined medial and lateral struts;
    iii) single anterior strut;
    iv) single lateral strut;
5) strut length (20 cm, 16 cm and 12 cm)

In order to include a control, a “standard” construct was defined as the use of two twenty centimetre struts placed in the anterior and lateral positions, and held by three high tension cables above and three high tension cables below the fracture site (see Figure 4.1). This construct corresponded most closely to our standard practice in the operating room. The standard construct was retested within each group to confirm the reproducibility of our fixation technique and to exclude any time dependent effects on the femur or struts during any one test by using the most recent “standard” construct as a control.

The order of testing within each group was randomly allocated to avoid bias due to the testing order. However, this was not possible for the assessment of strut length which always had to be performed starting with the longer twenty centimetre struts and ending with the twelve centimetre struts.

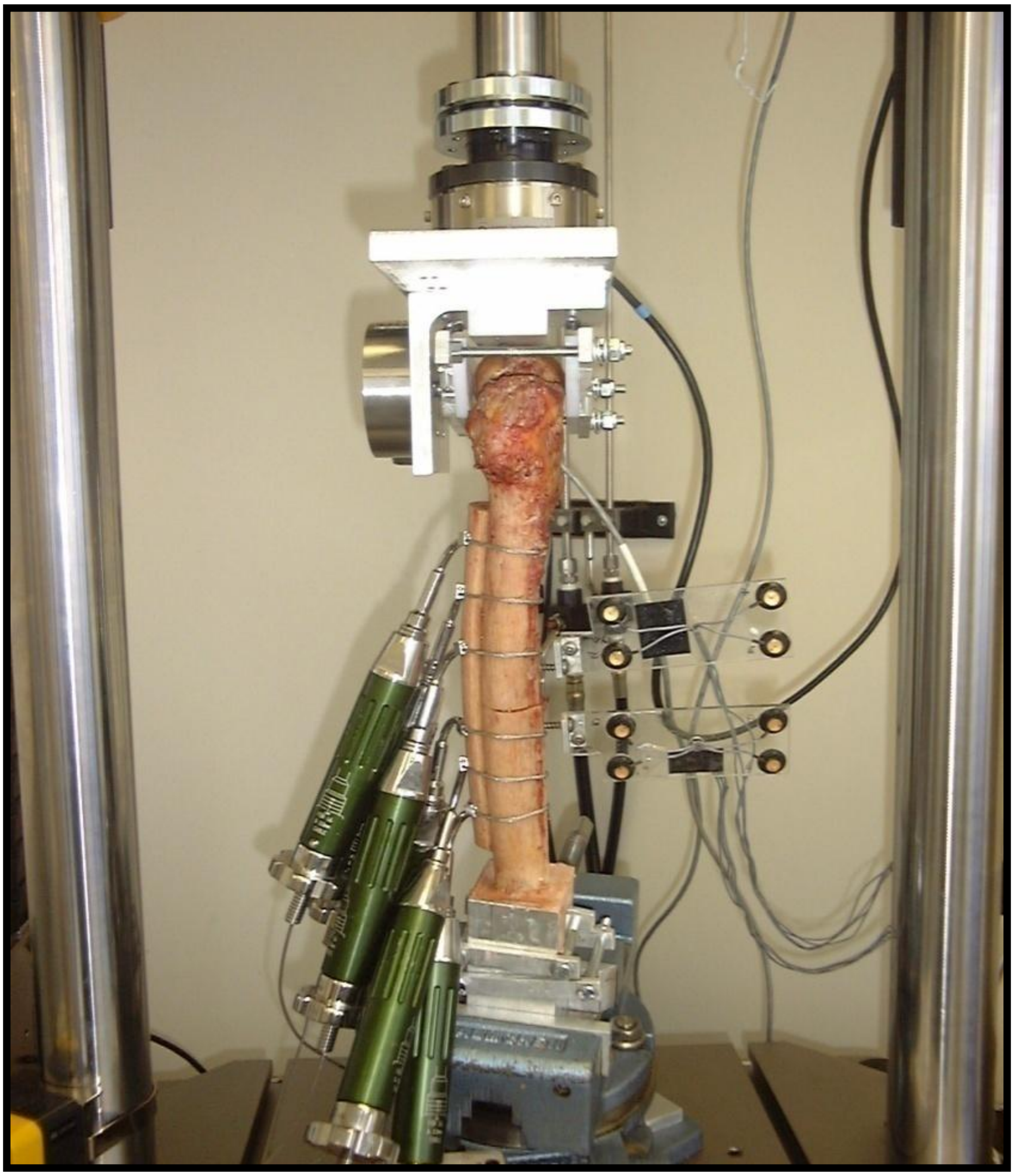

*Figure 4.1: Photograph depicting the loading setup with a custom designed loading jig with a 20 centimetre cortical struts placed laterally on the femur using three high tension cables above and below the fracture site. The anterior strut has not been placed in this example so that the site of fracture can be seen.*

### 4.2.3 Fracture Fixation

A transverse osteotomy was used to simulate the fracture as this represented a reproducible scenario for a fracture around a well-fixed femoral stem. All fracture fixations were performed by the thesis author. The struts were applied to the femur at an equal excursion above and below the fracture, and were applied to get the best possible fit. However, no strut was burred or re-cut to shape them specifically for the femur to be tested in order to prevent the introduction of additional unknowns to the experiment. When the various strut configurations were tested, the fracture was routinely destabilised between tests.

The two millimetre cables used (Howmedica, Rutherford, New Jersey) were applied with calibrated tensioners (Howmedica, Rutherford, New Jersey). Low and high tension were defined by those that would routinely be accepted in the operating theatre. The cables were retightened to the pre-calibrated levels for every test. Luque wires (Zimmer, Warsaw, Indiana) were used to simulate the wire fixation used in the operating room at our institution. These were tightened to the point that would be accepted in the operating environment.

Preliminary tests in our laboratory were conducted on a wooden model with a load cell to quantify the degree of compression imposed on the struts by the low and high cable tension and by the tightened wires. Low cable tension yielded 320N compressive force on the struts while high cable tension produced 520N and wire tightening 300N.

Great care was exercised to ensure that two struts were never in intimate side to side contact. This ensured that the compression generated by the wires or cables was concentrated at the strut-host interface rather than at the interface between the struts.

The struts were shortened symmetrically, with two centimetres removed from the proximal and distal portion of the strut on two occasions in order to assess sixteen centimetre and twelve centimetre struts.

### 4.2.4 Loading Procedure

The femur-strut construct was fixed to the base of a biaxial servohydraulic materials testing machine (Instron 8874, Canton, MA) at an adduction angle of twelve degrees. Cranial-caudal and anterior-posterior loads were applied to the head of the femur using a custom designed loading jig affixed to the actuator of the machine. The goal of the loading design was to approximate physiological loading of the femoral head for normal gait, as measured in patient telemetric studies [87-89]. Bergmann et al. resolved the resultant load into three component forces at the femoral head [87]. These comprised a proximal-distal force (Fpd) directed along the femoral shaft, a mediolateral force (Fml), and an anteroposterior force (Fap). During normal four kilometre per hour gait, Fpd was approximately 2.8-3.0 times bodyweight, Fml was 1.3 times bodyweight, and Fap was +/- 0.2 times bodyweight. Both Davy et al. and Kotzar et al. measured slightly higher anteroposterior forces, and lower mediolateral forces by approximately half the magnitude [88, 89]. The force components that we applied to the femora in this study are a good approximation of the force proportions recorded in the aforementioned hip telemetry studies for normal gait, but were applied at half the magnitude due to the lack of ligamentous and muscular stabilisation seen *in vivo*.

The cranial-caudal load (Fcc) was applied by the linear actuator of the servohydraulic machine, and the anterior-posterior load (Fap) was applied by the rotary actuator via the custom designed loading jig (see Figure 4.2). The femoral head articulated against three ultra high molecular weight polyethylene (UHMWPE) platens: one superiorly, one anteriorly and one posteriorly. A controlled craniocaudal load was measured using a load cell (Sensordata Technologies, model M211-113, Sterling Hgts. MI, USA). The loading jig was offset from the axis of the actuator, allowing the angular motion of the actuator to produce an anterior-posterior load on the femoral head. The three UHMWPE platens allowed the head of the femur to slide freely in the medial-lateral direction to produce pure, unconstrained anterior-posterior (AP) loading. The AP load was measured and controlled using feedback from a second load cell (Sensotec model 41/0571-07; Columbus, Ohio, USA).

The specimens were loaded sinusoidally in the cranial-caudal (CC) direction for one hundred cycles at a frequency of one Hz and simultaneously loaded in the anterior-posterior direction at a frequency of one half Hz as described previously [90]. The two loads were applied so that the peak AP loads occurred concurrently with the peak compressive CC loads (see Figure 4.2).

The femur was loaded in force control with an Fcc of 1.53 times bodyweight, and an $F_{ap}$ of +/- 0.15 times bodyweight. Using the angle of adduction of the femur, the Fcc was resolved into a Fpd along the diaphysis of the femur of 1.5 times bodyweight, and a Fml that was 0.32 times bodyweight.

During all tests, the specimens were kept moist with physiological saline solution that was sprayed onto the bone surfaces.

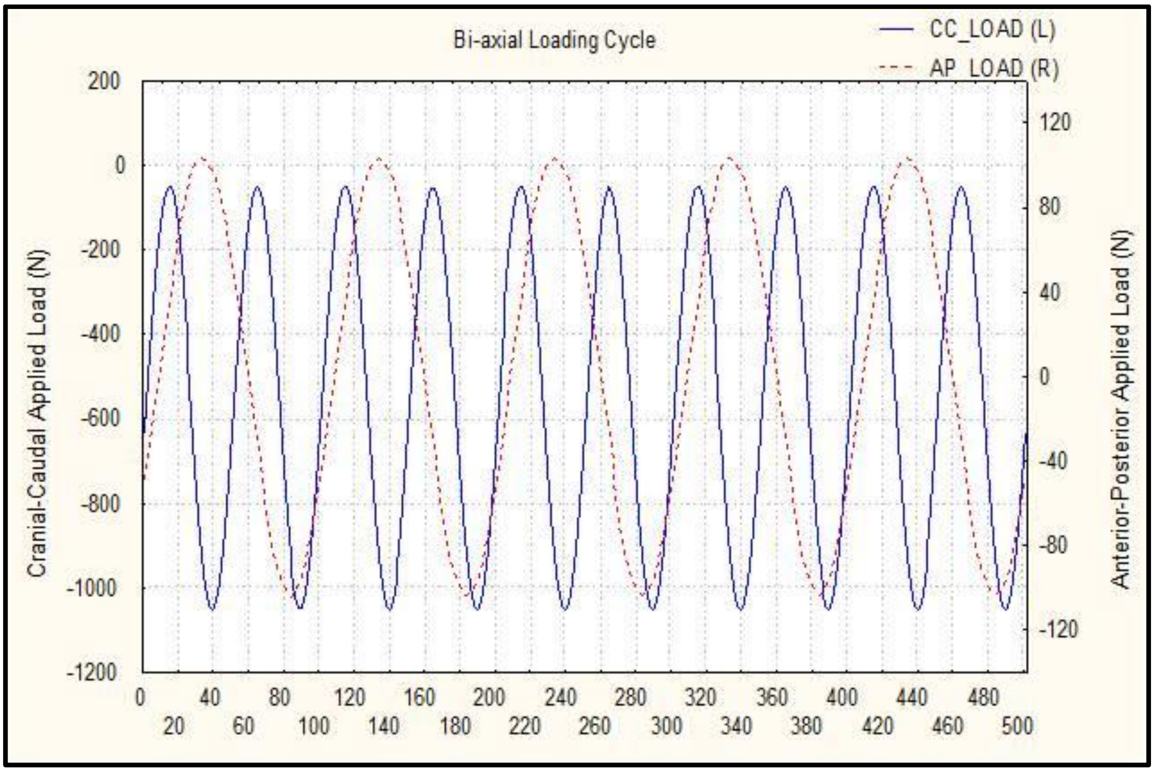

*Figure 4.2: The biaxial loading cycle used to simulate gait. Two sinusoidal loads were applied to the femur, a cranial-caudal (CC) load, and an anterior-posterior (AP) load. The CC load was applied in compression from a preload of 50 N to a maximum load of 1.53 times bodyweight. The AP load was cycled to plus or minus fifteen percent of bodyweight. When the AP load was negative the femur was loaded posteriorly, and when the AP load was positive, the femur was loaded anteriorly.*

### 4.2.5 Measurement of Interfragmentary Motion

A precision optoelectronic three-dimensional camera system (OptoTrak 3020, Northern Digital Inc., Waterloo, Canada) was used to measure motion at the site of the transverse osteotomy. This system measures the spatial position of infrared light emitting diodes (i.e. markers) with an accuracy of at least 0.1 mm parallel to the camera and 0.15 mm perpendicular to the camera. The recordings were made at 50Hz for the duration of the tests. Two marker carriers, each with four markers arranged in a rectangular shape, were rigidly fixed onto the femur. Both carriers were fixed onto the posterior side of the femur, one just proximal to and one just distal to the transverse osteotomy. The positions of the marker carriers with respect to the fracture were digitised such that the actual fracture site translations were determined. The right-handed coordinate system for the fracture was set so that the positive y-axis ran superiorly along the diaphysis of the femur, the positive z-axis was oriented in the anterior direction, and the positive x-axis was lateral for the left femur, and medial for the right femur. Motion of the proximal fragment relative to the distal was characterised by six degrees of freedom: anterior-posterior bending (Rx), axial rotation (Ry), medial-lateral bending (Rz), medial-lateral translation (Tx), inferior-superior (axial) translation (Ty) and anterior-posterior translation (Tz). Translations were referred to the most posterior points of the fracture line.

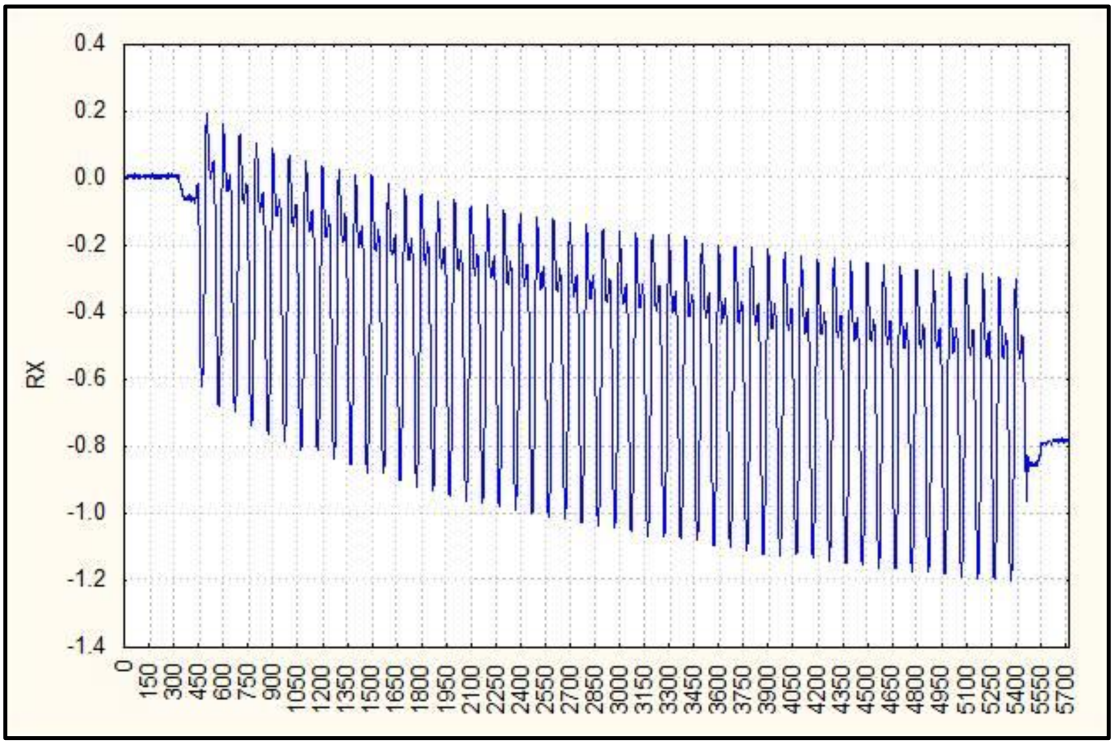

*Figure 4.3: A typical one hundred cycle curve showing interfragmentary motion in one degree of freedom, for one test. Both total motion and range were measured at the 95th test cycle.*

For each motion degree of freedom, a curve of one hundred cycles was recorded. From this curve a range of motion and a total motion were defined. As illustrated in Figure 4.3, range describes the cyclic motion at the 95th cycle, while total motion is the midpoint of the motion at the 95th cycle.

### 4.2.6 Data Analysis

Statistical analysis was performed on the range and total motion values for the 95th cycle of each test sequence. This protocol was followed to allow settling to occur prior to data analysis.

For each variable under investigation, a Kolmogorov–Smirnov test was used to confirm normality of each sample and a paired statistical analysis was performed. This analysis consisted of a Student’s t-test for two factor tests such as the comparison of cables and wires, or the comparison of high and low tension cables. For three or four factor tests, a repeated measures analysis of variance was performed with the post-hoc Student-Newman-Keuls tests. For each comparison the “standard” construct from that variable group was used. The repeatability of the results for this “standard” construct was assessed by comparing the identical tests for each specimen tested and calculating a standard deviation of those measures as an indicator of the test precision. The average standard deviations of the “standard” construct tests were 0.04 mm for translation and 0.10 degrees for rotation. For each analysis a 95% level of significance was used.

### 4.3 Results

The average interfragmentary ranges of motion were small in these tests, being typically less than one degree of rotation and one millimetre of translation. The exact magnitude of the motion is less important than how the motion changes with respect to each test variable, therefore the relative changes in motion will be described. A graphical representation of the range of motion in all the six planes assessed is shown for cable tension (see Figure 4.4), cable number (see Figure 4.5), cable versus wire fixation (see Figure 4.6), the various strut configurations tested (see Figure 4.7) and the strut length (see Figure 4.8). In general, the greatest motion ranges were seen in axial rotation and anterior-posterior bending.

Although the total motion was also measured for all the tests, there were no clear trends in this parameter. Magnitudes of change in motion for these tests were generally small (less than 0.2 mm or degrees), however there were several outliers in each test that showed much larger changes in motion.

### 4.3.1 Cable Tension

High cable tension showed a general trend towards less motion in all motion directions (see Figure 4.4) with the only significant decrease being in mediolateral translation ($p<0.05$).

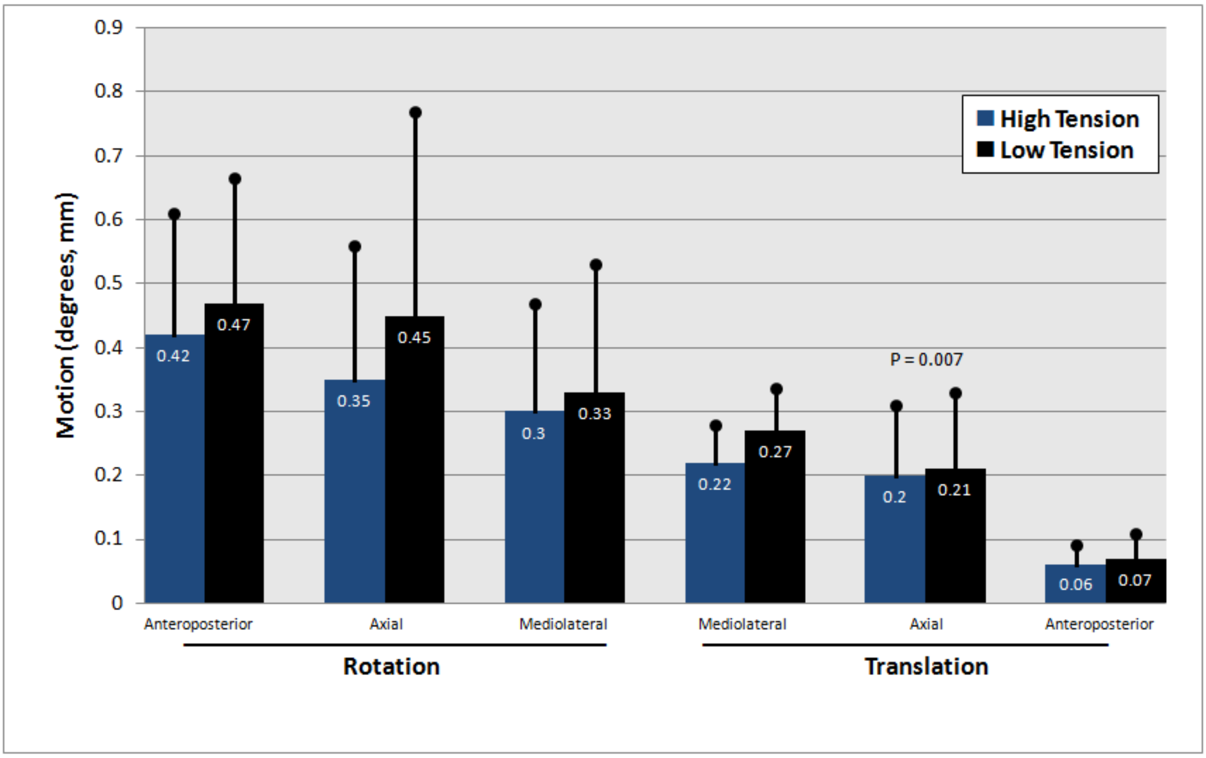

*Figure 4.4: The effect of cable tension on mean interfragmentary motion (n = 10, mean ± SD) in six degrees of freedom. Note that the motion under low tension was always greater than motion under high tension, although only significant for mediolateral translation.*

### 4.3.2 Cable Number

The fracture motion decreased as the number of cables increased in all directions except anterior-posterior translation and medial-lateral rotation (see Figure 4.5). The changes were statistically significant for anteroposterior rotation, mediolateral translation, and axial translation. Post-hoc analysis demonstrated statistically significant differences between two cables and four cables for anteroposterior rotation, between two cables and three cables as well as three cables and four cables for mediolateral rotation, between two cables and four cables for mediolateral translation, and between two cables and three cables as well as two cables and four cables for axial translation.

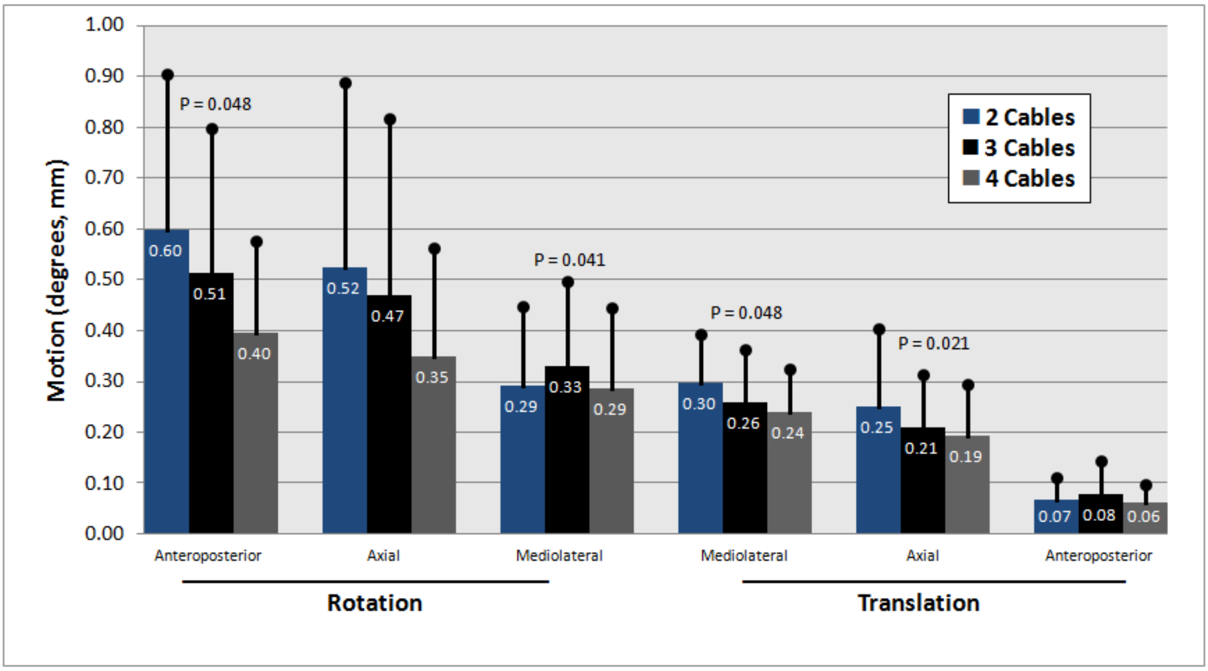

*Figure 4.5: Comparison of the mean interfragmentary motion of struts with 2, 3 and 4 cables above and below the osteotomy site (n = 10, mean ± SD). In general, motion was less with greater cable numbers.*

### 4.3.3 Wires

There was a clear trend towards increased motion with the use of wires rather than cables for all motion degrees of freedom (see Figure 4.6). The differences were significant in axial rotation, anteroposterior bending and axial translation (p<0.05).

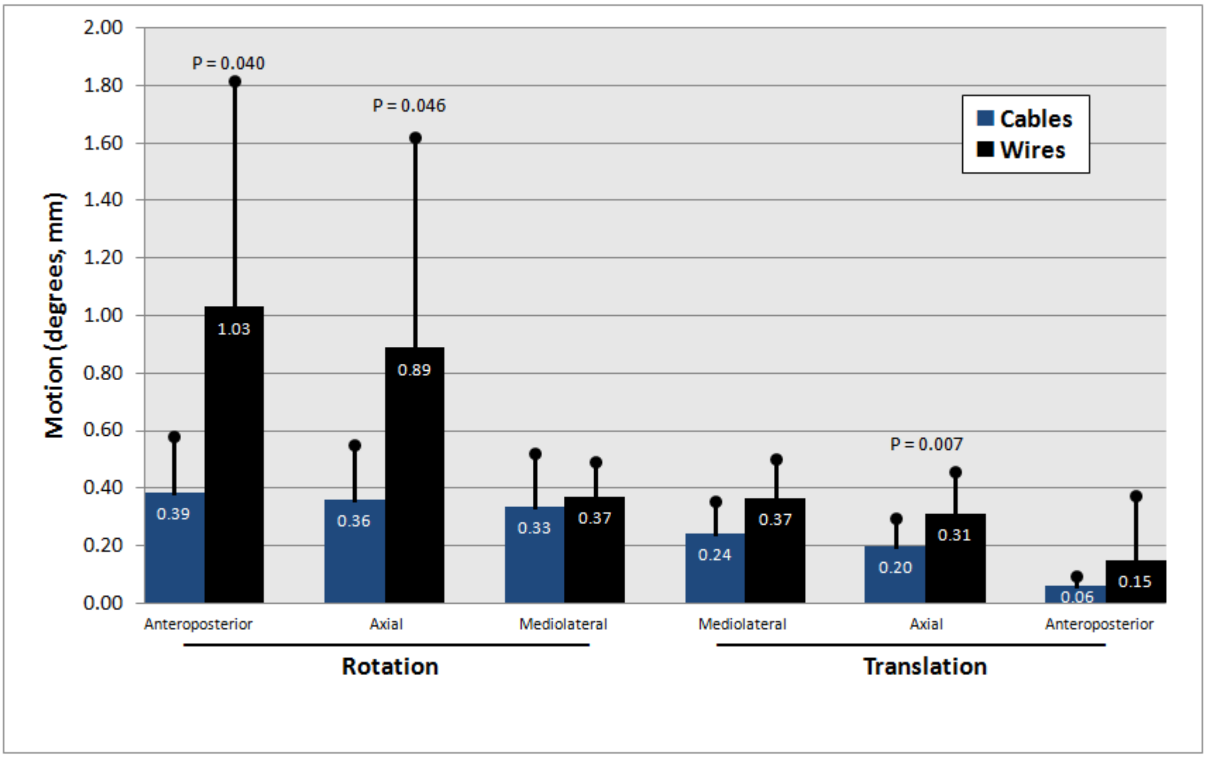

*Figure 4.6: Graph comparing the effect of cables versus Luque wires on mean interfragmentary motion (n = 9, mean ± SD). One specimen was excluded from the analysis because the Luque wire construct failed immediately, leaving no motion data. Note that the motions with cables were always less than the motions with wires and that the statistically significant differences are identified.*

### 4.3.4 Strut Position

Strut fractures were observed in four cases when a single strut alone was used to stabilise the fracture. In three cases the strut was in the anterior position, and in one case it was lateral. There was a strongly significant decrease in fracture motion for all degrees of freedom if two struts were used rather than one ($p<0.01$) (see Figure 4.7). There was no significant difference between the anterior and lateral single strut configurations. There was also no significant difference between the medial and lateral two strut configurations. The effect seen was therefore in relation to strut number rather than strut position.

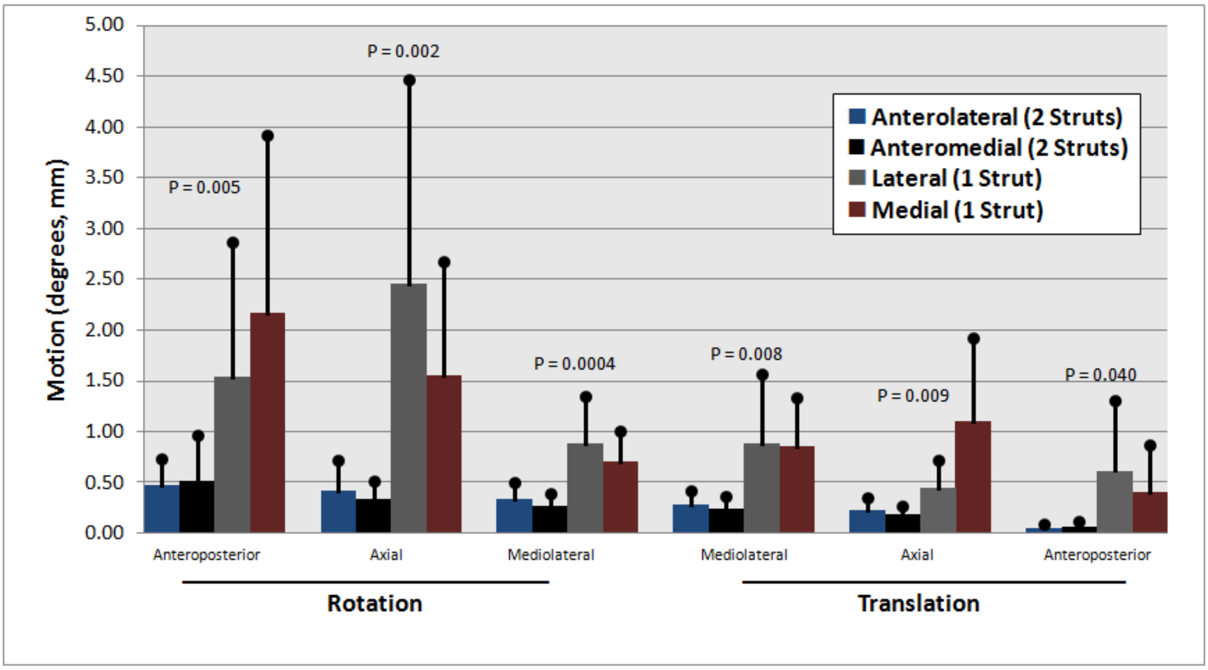

*Figure 4.7: Graph comparing the effect of four different strut configurations on mean interfragmentary motion (mean ± SD). The sample number was 10 for all constructs except the anterior strut construct where sample number was eight. Two of the anterior struts fractured immediately after the commencement of the test leaving no motion data. Two other struts fractured, a lateral strut at ninety-two cycles, and an anterior strut at sixty cycles. We used the motion data available for those two fractured struts in our analysis. In total three anterior struts and one lateral strut fractured during testing. The differences were significant in all directions between the single and double strut constructs, but there were no differences within the single strut constructs or the double strut constructs.*

### 4.3.5 Strut length

Decreasing the strut length from 20cm to 12cm led to a significant decrease in axial rotation ($p<0.05$) (see Figure 4.8). Post-hoc testing found the rotation with the 20cm length to be significantly greater from the 12cm length. However, there was no clear trend in all the other directions of motion.

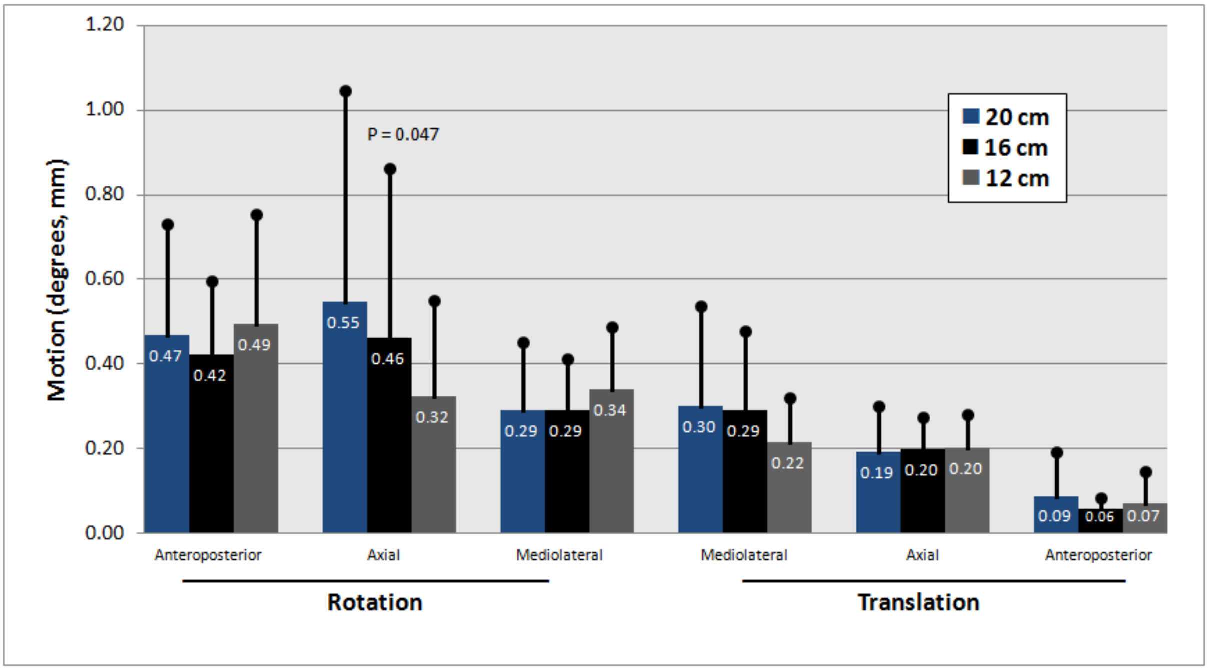

*Figure4.8: Comparison of the effect of three different strut lengths on interfragmentary motion (n = 10, mean ± SD). There were no clear trends in these data except for the decreased axial rotation with shorter strut lengths.*

## 4.4 Discussion

As patient longevity and the number of primary and revision arthroplasty procedures continue to increase, so will the prevalence of periprosthetic fractures. The majority of these will be around loose implants, and will typically be treated by revision with or without adjunctive fixation. Open reduction and internal fixation will nevertheless be required for a considerable number of fractures. The use of cortical struts to this end offers a number of theoretical advantages that can be optimised if sound stable fixation is obtained. Although the allograft struts are not viable, they confer stability at the fracture site, and can incorporate [67] and ultimately increase the femoral bone stock [68, 69, 71, 91].

In order to realise the potential biological advantages of cortical onlay allografting a mechanically stable construct is required. There is a dynamic change in allograft biomechanics during the incorporation and remodelling process. The construct used must therefore be secure enough during the incorporation period to ensure clinical success. In other words stability must be maintained until the fracture unites. To this end, the loading set up was designed to approximate physiological loading of the femoral head for normal gait, as measured in telemetric studies [87-89]. The force components that we applied to the femora in this study are a good approximation of the force proportions recorded in these telemetry studies for normal gait, but were applied at half the magnitude. These loads were nevertheless much higher than those used in previous studies [86]. The high loads tested were important in that many of the patients who require periprosthetic fracture fixation are elderly and may not be able to comply with limited weight bearing protocols. Moreover, they may be confused in the early post-operative period and inadvertently stress the fixation construct. Our choice of a transverse osteotomy for fracture simulation was made for repeatability and also clinical relevance. Clearly, one fracture model does not span the wide range of clinical fractures but a transverse fracture is relevant and difficult to stabilise, particularly with respect to rotation about the femoral axis.

In this study, no attempt was made to study the characteristics of onlay allograft cortical struts that are related to their preparation, preservation, storage or sterilisation techniques. All these factors influence the biomechanical properties of the allograft struts and may have a marked influence on the fixation obtained. For example, frozen allograft is capable of resisting larger torsional forces than freeze-dried bone, but freeze-dried allografts have been shown to be just as strong under compression loads [92].

The properties of the allograft struts themselves such as their stiffness or their deformation during the testing process have also not been addressed. The purpose of the study was to concentrate on fracture motion since it is the most relevant endpoint from a clinical point of view. Further, overall construct stiffness was not addressed since it is an indirect measure of the motion at the fracture site.

The type of allograft is also important, as shape mismatch may prevent anatomical alignment of the femur resulting in a malunion. This study tested femoral struts rather than tibial or fibular allografts which are also available in clinical practice. The rationale for this is based upon Chandler et al.'s recommendation that ipsilateral femoral allografts be used, because these provide better apposition than tibial grafts [68, 75, 84]. They also counsel against splitting the tibia (or femur) into three struts as they observed one malunion when they used such a construct.

The allograft cortical strut length and configuration, and the wire or cable number and tension that provided the optimal fixation for periprosthetic femoral fractures around a stable implant was attempted to be established. An implant was purposefully not inserted into the proximal femur for this study as loading the implant rather than the femoral head would have generated additional variables. If an implant had been inserted, the proximal femur would have had increased stiffness. The effect of this situation on the fracture site motion is not clear, but is not expected to be significant.

The interfragmentary translations reported were often less than 0.5mm, which is in the order of the system accuracy of the Optotrak camera. However, since these translations were calculated at the fracture site and this is close to the axis of rotation, they were much lower in magnitude than the marker motions that were remote from the fracture site (see Figure 1). The actual marker motions for the most stable construct averaged 1.6mm, which includes all components for eight markers. Other constructs had greater marker motions. Since this is one order of magnitude greater than the system accuracy, it can be assumed that the reported translations at the fracture site are accurate.

There is controversy regarding the method of strut preparation. Chandler et al. recommend the use of two cortical allograft struts [68, 75, 84]. The fresh-frozen allograft is bivalved and suitably tailored to closely co-apt the surface of the host femur with an interface of morsellised allograft. The allograft struts are rigidly fixed to host femur by cables or large diameter cerclage wires. The *linea aspera* should be left intact to preserve the vascularity of the host femur. They also recommend that the struts should extend at least ten centimetres proximal and distal to the fracture to allow a minimum of four fixation points either side with wires or cables [75]. On the other hand, Brady et al. suggest that the placement of strut allografts from a bivalved femur necessitates a wide exposure with extensive soft tissue stripping [43]. They recommend the application of two cortical struts, each only one third the circumference of the host femur, either perpendicular to each other on the anterior and lateral surfaces of the femur, or in parallel on the lateral and medial surfaces of the femur. In my study, it was decided to make the struts in a manner analogous to that used in our operating room. Each femur was therefore divided longitudinally into three struts, one of which usually included the *linea aspera*. This is usually the least useful for fracture fixation, and was therefore cut narrower than the other two struts and discarded in favour of those that are more likely to fit the anterior, medial or lateral femoral contour.

There are very few mechanical studies of periprosthetic fracture treatment. Mihalko et al. presented a two-dimensional finite element model to compare revision to a long stem prosthesis with the use of custom plates with proximal Parnham band fixation, and with lateral plating with cortical strut allografts and cerclage wires [63]. They were able to predict the stresses within the femur, the prosthesis and the allograft struts, but their model is difficult to extrapolate to the clinical situation, and does not allow conclusions with regards to the effects of repetitive loading, ultimate strength or rotational stability.

Schmotzer et al. used a cadaveric model to study a number of fixation options for femoral fractures around total hip replacements [86]. The constructs examined were three 160mm allograft onlay struts held either with monofilament cerclage wires or with multifilament cables; a plate held with multifilament cables proximally and screws distally; a plate held with unicortical screws proximally and bicortical screws distally; revision to a long stem prosthesis; and revision to a long stem prosthesis reinforced with onlay allograft struts held with cables. The stability of each of these testing methods was determined under semi-dynamic loading conditions. Cables gave significantly better stability than wires. When fixation was undertaken without revision, lateral plating with cables proximally and the use of allograft struts with wires both gave minimal rotational stability. The best fixation was obtained with the use of allograft struts with cables, and with the use of a lateral plate with unicortical screws proximally. The latter however failed more abruptly by pullout of the proximal unicortical screws. The authors hypothesised that the use of cables as well as unicortical screws proximally would give the optimal fixation, but they did not provide any data to show that this was more stable than cortical allograft struts held with cables. Moreover, the use of proximal unicortical screws would jeopardise the bone-cement, or the host-prosthesis interface, and may also damage the prosthesis.

My data strongly favours the use of two struts rather than a single strut alone. We could not detect any advantage to the use of a medial strut over an anterior strut in combination with a lateral strut. This implies that the extra soft tissue stripping and devascularisation inherent in placing a medial strut are not associated with any benefit with regards to fracture stability, and should therefore be avoided. Moreover if a cortical strut is to be used with a bone plate, then the anterior and lateral positions are likely to also be preferable for that combination.

Cables enhance fracture stability compared to wires. This is in accordance with the findings of Schmotzer et al., and is presumably due to increased tension and to different surface characteristics of the cable [86]. Increasing the cable tension gave greater stability although this may not fully translate to the clinical situation because the cable may garrotte or fracture the strut. Cables have the theoretical advantage of providing a more stable construct by means of the greater tension generated within the cable, and the complications associated with the use of cables to reattach trochanteric osteotomies are not typically seen in this setting [93].

The fit of the strut to the femur clearly has a major impact on fracture stability. Although achievement of good strut fit was attempted, the area of contact between the strut and the test femur was not quantified nor was the strut modified to fit the femur. As each strut was shortened progressively from 20 centimetres to 12 centimetres, it became easier to obtain a good strut fit in every test. A contributing factor to the improved strut fit at 12cm may have been the closer cable spacing, caused by the fact that the same number of cables were used for the 12 and 20cm cases. These factors may explain the significant decrease in axial rotation with the shorter struts. There was no clear trend in the other motion degrees of freedom as the struts were shortened. This further supports the importance of strut fit rather than strut length. The use of shorter struts does, however, bring the cables closer to the fracture, and this may make up for any stability lost by reducing the length of the fixation. If the use of shorter cortical struts does indeed confer greater or similar stability, fixation could be achieved with less soft tissue stripping.

Cortical onlay strut allografting is a very attractive option for periprosthetic femoral fractures around stable implants. Ideally, intramedullary fixation offers more rigid fixation especially when combine with rotational control. However this is impractical in a well fixed implant since exchange of a stable implant may compromise the final construct. In that scenario as has been identified in the previous chapter, extramedullary fixation is preferred. An alternative to a cortical onlay graft is a metal plate. Dennis et al. [94]evaluated 5 periprosthetic femoral shaft fracture fixation techniques; namely a plate with cables, plate with proximal cables and distal bicortical screws (Ogden concept), plate with proximal unicortical screws and distal bicortical screws, plate with proximal unicortical screws and cables and distal bicortical screws, or 2 allograft cortical strut grafts with cables. In their biomechanical analysis, the plate constructs with proximal unicortical screws and distal bicortical screws or with proximal unicortical screws, proximal cables, and distal bicortical screws were significantly more stable in axial compression, lateral bending, and torsional loading than the other fixation constructs studied. It can be deduced from their study that screws offer greater fixation than cables although placement of proximal unicortical screws can be technically difficult, and may cause physical damage to the cement mantle and the femoral stem. This can predispose to a theoretical risk of loosening. In addition, distal screws can violate a femoral canal that may be used for later revision and are stress risers.

Chandler et al. reviewed the outcome of nineteen fractures around well fixed femoral hip or knee implants [84]. They used fresh-frozen allograft struts and typically bivalved the ipsilateral femur at the *linea aspera*. Seventeen of the nineteen (89 per cent) had united by eighteen weeks and had returned to their pre morbid level of activity. There was one malunion where three tibial struts had been used, and two non-unions both in relation to relative devascularisation of the host femur. The remaining 16 patients all healed in anatomical alignment. They also noted that the cortical struts healed to the host femur in all the successful cases.

The cortical struts essentially represent biological bone plates. As well as conferring mechanical stability, they may enhance fracture healing and can potentially increase the bone stock. If appropriately selected and prepared, cortical struts can be customised to fit any femur. As the modulus of elasticity of allograft struts is similar to that of the host bone there is less stress shielding of the host bone in comparison to other more rigid forms of internal fixation. In conclusion, the results obtained favours the use of two struts held against the femur with cables; increasing cable number and decreasing strut length may improve fracture stability.

# Chapter 5

# A pilot evaluation of uncemented implants in Type B2 and B3 fractures

**Rationale for Chapter –** Type B1 fractures can be effectively managed with cortical onlay strut grafts and the optimal biomechanical construct has been shown. However, loose implants and fractures occurring below an implant tend to necessitate exchange of the femoral stem and consequently represent a different surgical problem. This chapter will evaluate whether a variety of second generation uncemented implants are effective devices for periprosthetic fractures.

## Chapter 5

### 5.1 Introduction

Vancouver type B fractures constitute more than 80% of late periprosthetic femoral fractures[14]. The mainstay of treatment for B2 and B3 types is revision of the femoral component using cemented or uncemented prostheses along with cerclage wires and strut grafts where indicated [11, 35, 95, 96]. Revision with a long-stem prosthesis permits stabilisation of the fracture similar to that achieved when using an intra-medullary rod. However, the proximal femur may be a poor environment for re-cementing or proximal porous on-growth if the index procedure was cemented [97].

Uncemented prostheses cannot only gain axial and rotational control of the distal femoral diaphysis which may suffer from bone loss and comminution, but also alleviate the potential concerns of cement inhibition or interposition on fracture healing [33, 98].

Chapter 7 will demonstrate a considerable efficacy in using uncemented stems with the Kent Hip system. However, the disadvantages of screw fracture and occasional need for a transverse osteotomy has led to the development of second-generation implants which are more anatomical and promote osseointegration.

The aim of this study is to prospectively analyse femoral revisions using uncemented prostheses in the presence of and treatment of Vancouver type B2 and B3 periprosthetic fractures [51, 99-103]. It is hypothesised that this treatment will improve function and lead to radiological union.

## 5.2 Methods

### 5.2.1 Patients

26 patients were diagnosed with Vancouver type B2 or B3 periprosthetic fractures between 1999 and 2005. All of them were treated surgically. The average age was 67 years (range: 36 - 81). Sixteen of the twenty six fractures were left sided, and ten were right sided. Using the Paprosky's system of femoral defects classification (Table 5.1), there were five type II, twelve type IIIA, eight types III B and one type IV femur; further breakdown by type is seen in Figure 5.1.

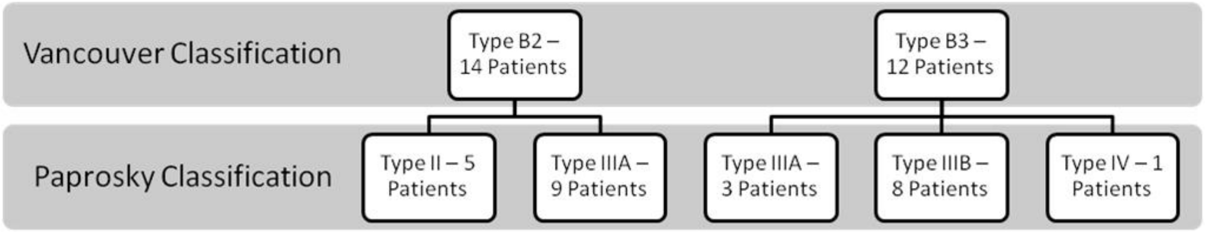

*Figure 5.1: A total of 26 patients were included in the study group. They were classified according to both Vancouver and Paprosky Classifications*

The average time from the index procedure to sustaining the periprosthetic fractures was 9 years (range: 6 months - 15 years). In 22 patients, the index procedure was cemented and in the other four the index prosthesis was cementless.

*Table 5.1: The Paprosky classification of femoral bone defects*

| Type | Defect |
|---|---|
| **Type I** | Defect has minimal loss of metaphyseal cancellous bone and an intact diaphysis. |
| **Type II** | Defect has extensive loss of metaphyseal cancellous bone and an intact diaphysis. |
| **Type III A** | Defect is one in which the metaphysis is severely damaged and not supportive and there is >4 cm of intact diaphyseal bone available for distal fixation. |
| **Type III B** | Defect is one in which the metaphysis is severely damaged and not supportive and there is <4 cm of diaphyseal bone available for distal fixation. |
| **Type IV** | Defect has extensive metaphyseal and diaphyseal damage in conjunction with a widened femoral canal. The isthmus is not supportive. |

A posterior approach was used to gain access to the hip in all cases. The incision was lengthened distally as required to allow open reduction and fixation of the fracture. A femoral osteotomy which is sometimes used in revision surgery without fracture was not required since the fracture itself was used to facilitate removal of the existing implants. Cementless stems were used in all cases.

### 5.2.2 Surgical Approach

All operations were undertaken by the author of this thesis. The posterior approach was employed in all cases and incisions lengthened as required for access and visualisation (see

Figure 5.2). This approach is the most commonly used approach in primary and revision hip surgery since it is considered to be the easiest to perform technically, requires only one assistant and does not requires a traction table. Furthermore, access to the joint is rapid thereby minimising operative time, whilst visualisation of the femur and acetabulum is arguably the best of all approaches.

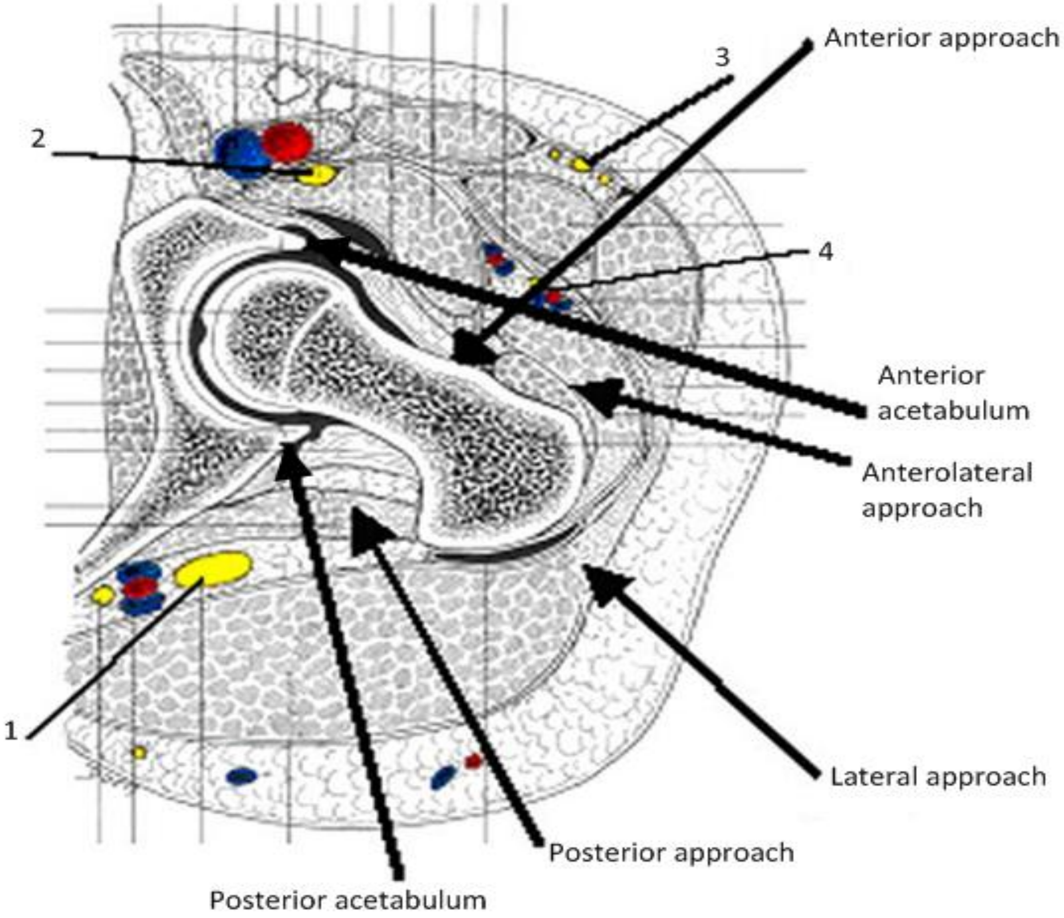

*Figure 5.2: A comparison of approaches to the hip including surrounding nervous structures - sciatic nerve (1), femoral nerve (2), lateral femoral cutaneous nerve (3), and obturator nerve (4) [104]*

Patients were positioned in the lateral decubitus position between vertical padded rests at the sacrum and pubis to secure them. For each patient, the pelvis was orientated in a neutral position, in line with the spine. In primary THA, an 8 to 15 cm incision would be made, centred over the posterior aspect of the greater trochanter, curved posteriorly across the buttock. In this case series, the original incision through which the primary operation had occurred was used. No patient had previously had an anterior approach. The subcutaneous tissue was incised down to the *tensor fascia lata*, which envelopes the lateral aspect of the thigh muscles. Fascial incisions were lengthened superiorly in line with the skin incision, and the fibres of the *gluteus maximus* gently split.

The sciatic nerve was identified posteriorly in all cases and deep within the wound as it lies over the external rotators of the hip. The posterior border of the *gluteus medius* was identified and the *piriformis* and conjoined tendons divided at their insertion onto the greater trochanter. A Kocher clamp was attached to the *piriformis*, *obturator internus* and *gemelli* tendons and these tendons were retracted posteriorly, thereby protecting the sciatic nerve during the procedure. This manoeuvre exposed the entire posterior capsule of the hip which was then incised with longitudinal incision. The femoral head was dislocated by internal rotation and flexion of the hip after the capsulotomy.

### 5.2.3 Implants Used

Following removal of the primary femoral implant, the femoral hip systems implanted were:

- Echelon (Smith & Nephew)(see Figure 5.3) – 14 patients
- Link (Wright Medical)(see Figure 5.4) – 7 patients
- Cannulok (Orthodynamics UK)(see Figure 5.5) – 2 patients

- Solution (DePuy)(see Figure 5.6) – 2 patients
- Custom prosthesis (Stanmore Implants Worldwide) – 1 patient

The choice of implant was dependent upon both availability of the prosthesis at the practicing institution and also upon the suitability of implanting it within the bony anatomy presented. Off-the-shelf prostheses were generally used, but the presence of distorted normal anatomy necessitated the use of a custom implant in one case.

*Figure 5.3: The Echelon system has Rough Coat™ porous coating which improves the implant stability by increasing friction and provides a surface for bone ingrowth. It can be seen here that a standard collar and two calcar platforms are available to match the implant to the proximal defect. They are available as both straight and bowed stems and feature a lateral proximal flare. The lateral shoulder is rounded to minimise the risk of fracturing the greater trochanter during stem insertion. A distal flute increases rotational stability whilst the distal slot eases stem insertion, reduces the risk of fracture, and reduces distal stem stiffness. It is thought that he bullet tip reduces the stress between the distal implant tip and the bone to minimise end of stem thigh pain.*

*Figure 5.4: The Link system is uncemented ,HA coated and modular. It has proximal spacers for limb length correction and fixation screws with UHMWPE locked bolts.*

*Figure 5.5: The Cannulok system is a cannulated, modular, distally locked prosthesis which is HA coated.*

*Figure 5.6: The Solution system has a Porocoat® porous coating. Its design features are similar to the Echelon system already described in Figure 5.3.*

All B2 fractures were managed with the extensively coated stems (Echelon or Solution implants) which were all 260mm in length. The other stems were all 300 mm or longer and were used for B3 fractures. The diameter of the stems used ranged from 14 to 20 mm.

### 5.2.4 Additional Materials Used

Cortical struts with inferior placement of morselised bone graft and demineralised bone matrix were used in 16 cases; in all cases, a minimum of 6 securing cables were used. Dall-Miles cable system in 8 cases. The Accord cable system was used in used in 18 cases. Concomitant revision of the acetabular was required in 13 cases; 10 of these required filling of periarticular defects with morselised bone allograft.

### 5.2.5 Post-operative Rehabilitation and Follow-Up

All patients were encouraged to touch weight-bear (TWB) for the first 6 weeks following surgery and partial weight-bear (PWB) for next 6 weeks. This was supervised by a physiotherapist trained in orthopaedic rehabilitation.

All patients were serially followed up. This comprised of a clinical evaluation including a Harris Hip Score [74] and radiographic evaluation where an assessment was made of fracture union and implant migration (see Figures 5.7 & 5.8). The minimum follow-up time was one year up to a maximum of five years.

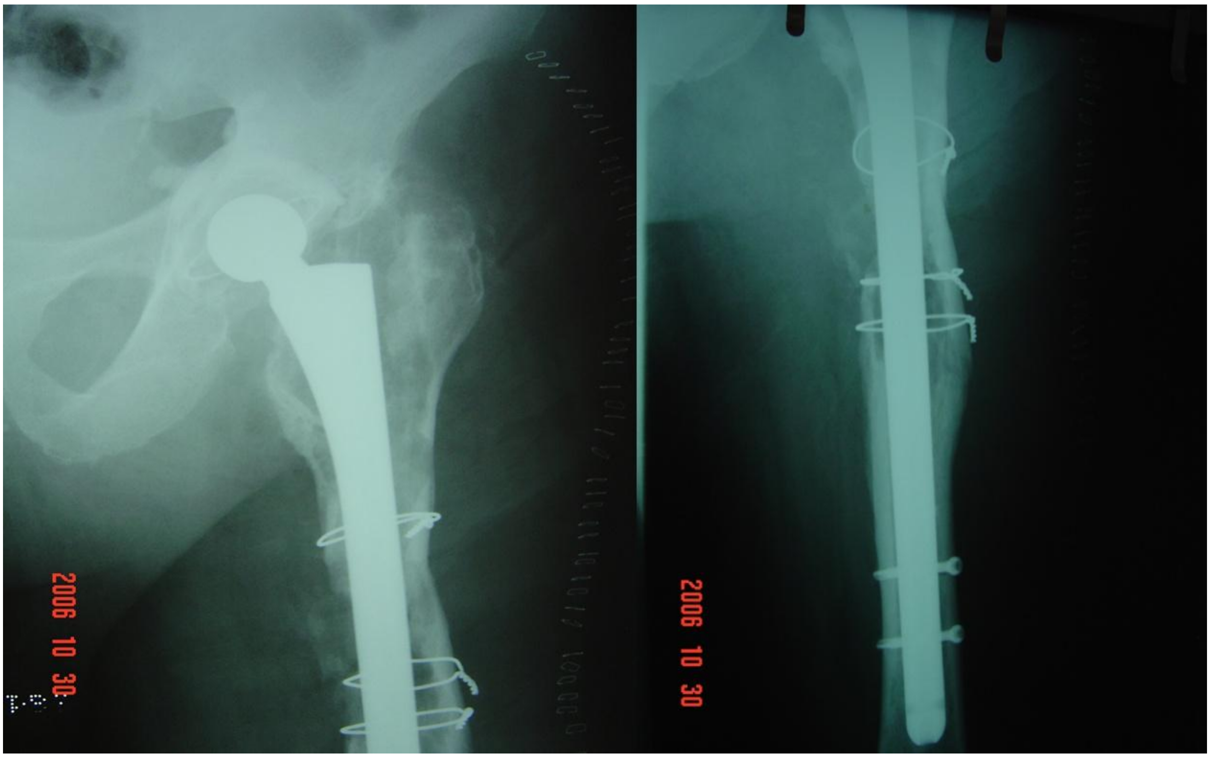

*Figure 5.7: Post-operative AP radiographs of the left femur showing fixation of a Type B3 fracture with a long-stemmed distally locked implant*

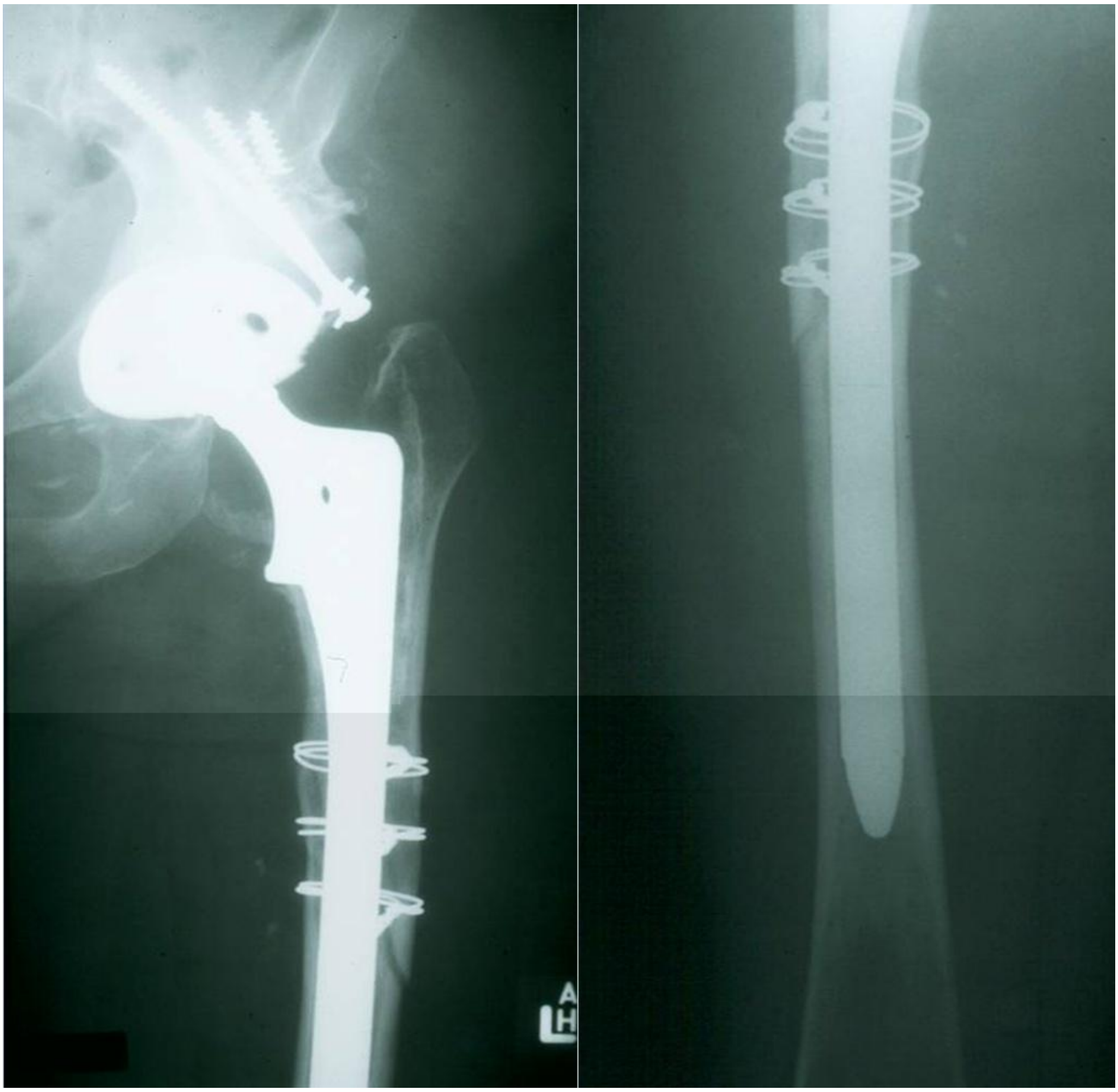

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*Figure 5.8: AP radiographs of the left femur showing fixation of a Type B2 fracture with a long-stemmed extensively coated implant supplemented with three cerclage wires*

## 5.3 Results

### 5.3.1 Clinical Evaluation

At a mean follow-up of 37 months (range: 12 - 59), all the fractures had united clinically. The mean post-operative Harris Hip Score [74] was 86 (range: 75 - 90). The satisfaction rate of surgery was 100% (26 patients).

Leg length inequality was noted in eight patients:

- Longer operated leg – 5 patients (4 patients with 0-1cm difference, 1 patient with 2cm difference).
- Shorter operated leg - 3 patients (2 patients with 1cm difference, 1 patient with 1.5cm difference).

All patients required either two sticks or a frame to act as a walking aid during the first 6 weeks. At 12 months, no patient needed more than one stick as a walking aid.

One patient was noted to have a partial sciatic nerve palsy in the immediate post-operative period. This occurred in a 68 year-old female patient with a Vancouver Type B2 fracture. She was treated with an Echelon stem. The sciatic nerve was protected during surgery and no identifiable cause could be ascertained for this complication. This was treated without surgical exploration and complete recovery was noted at 12 weeks.

There were no episodes of dislocation or sepsis noted in this series during the follow-up period.

### 5.3.2 Radiological Evaluation

Radiographic assessment demonstrated no episodes of non-union. Although evaluation of fracture union was a difficult task due to the presence of struts and cables, bony union was thought to be complete within 6 months. Strut to host union occurred between 12 to 18 months in all cases.

Femoral alignment was maintained in all cases (26 patients). There were no cases of screw breakage.

Migration of between 5 and 8 mm was noted in 3 patients with tapered implants.

## 5.4 Discussion

The management of individual periprosthetic fractures is guided by the severity and type of the failed bone-implant entity, such as site of the fracture, available bone stock, stability of the implant and type of the implant.

In B2 and B3 fractures the best methodology of treatment is femoral revision for which either cemented or uncemented prostheses have been employed. The advantage of revision with a long stemmed cemented prosthesis is provision of fracture stability. However, cement extrusion into the fracture site and inhibition of fracture healing are noted complications. Rates of non-union has been reported as high as 31% in cemented revision [34].

Prosthetic stability is not reliably achieved in proximally coated stems in cases of poor proximal bone stock [97].In pursuit of good intramedullary fixation and long term prosthetic stability through biological ingrowth, extensively porous coated stems came into vogue. They are associated with greater survival rates and lowest incidence of non-union [99-102]. The main complications experienced using long-stem femoral revision for periprosthetic fractures are aseptic loosening, non-union and deep infection with a 12% to 20% cumulative incidence of these complications [97]. Other complications include thigh pain due to a lack of osseointegration, osteoporosis and poor bone stock, subsidence and stress shielding[105, 106].

This study is limited by having a small cohort and using different stems. Unfortunately, the small number of patients prevents a suitable comparison being made between each implant. Indeed the choice of implant used in this series was partly dependent upon which revision hip system was available to the author from the University College London Hospital NHS Trust.

Nonetheless, all fractures demonstrated evidence of clinical and radiological union. This may be attributed to a combination of factors including good stem fixation distally (where the decent bone is in order to reconstruct the stem around it) and to the use of cable plate systems, morselised allograft, cortical struts and demineralised bone grafts as evidenced by other studies [34, 70, 107].

One of the concerns of cementless stems without interlocking fixation is that of implant migration. Indeed, this was evidenced in this patient series but was only noted in three patients. Of particular concern is that all the patients in who it occurred had tapered implants. Although it did not have any adverse complications with respect to clinical outcome, there is potential to affect the biomechanical characteristics of the hip.

The management of B2, B3 periprosthetic fractures pose considerable clinical challenge. This study demonstrates that planned revision arthroplasty with cementless prostheses have a favourable outcome in most cases. Cortical struts, bone allograft, cable plating system and demineralised bone matrix may significantly aid reconstruction.

# Chapter 6

# Femoral stem stress using extensively coated stems

**Rationale for Chapter –** *‘The previous chapter illustrates that extensively coated stems are associated with clinical improvement. The optimal fixation technique should protect against future stem fracture and to that end, this would be expected to relate the stress experienced at various points along the femur. This chapter uses an ex-vivo femoral model to determine the patterns of stress in different clinical scenarios.’*

## Chapter 6

### 6.1 Introduction

The previous chapter illustrated favourable radiological and clinical outcomes using uncemented femoral stems. The follow-up period though was finite and not to the death which would ultimately provide the most useful information regarding the survivorship and *sequelae* of the implant.

In addition to the risk of re-fracture of the femur, there is also a risk of implant fracture; a phenomenon for which there is increasing awareness of within cementless revision stems as has been used in Chapters 5 and 7.

In general, fractures of femoral stems are reported in cases of proximal bone loss due to osteolysis, after fractures, or with extended trochanteric osteotomies. Indeed, there has been particular interest in stem failures of modular systems after it was recognised that poor proximal bone support contributed to stem fractures on the ZMR™ (Zimmer, Inc.) modular implant. Extensively coated porous stems can however also fracture. Busch et al. [108]found a 2.3% fracture rate of cementless, cylindrical, porous-coated hip stems in a series of 219 revision procedures. They related stem fracture to poor proximal bone support, body mass index (BMI) greater the 30, small stem diameter, and the use of an extended trochanteric osteotomy (ETO) without the use of struts and cables. These failures necessitate methods to mitigate the proximal femoral bone loss and protect the stem from fracture.

A number of techniques are employed in order to remove the original femoral component and cement. One of these is the ETO. This technique gives adequate access to a stem and its cement mantle, whether it is intact or broken [109, 110]. Reconstruction of the proximal femur is usually undertaken with the aid of cables or wires. An ETO is sometimes also required to realign the femur if there has been varus remodelling or if there is retained distal hardware. Although excellent results have been published with this technique [111, 112], it does however leave the proximal femur relatively unsupported. In view of this, it can also be used a surrogate model for proximal bone loss.

The aim of this study is to identify the strains that a femur undergoes with an uncemented stem so that the potential sites of femoral stem fracture may be ascertained. It is hypothesised that when fracture models with co-existing bone loss are simulated, an increasing amount of reinforcement is needed to lessen the strain exhibited upon the femur..

## 6.2 Methods

### 6.2.1 Specimens

Three composite femurs made of glass fibre reinforced epoxy and polyurethane foam were used. Each femur was prepared and reamed in order to facilitate implantation of an Echelon (Smith and Nephew) uncemented femoral stem as would occur in normal clinical scenario.

An Echelon stem had strain gauges applied at 45mm from the shoulder and then at 15mm intervals distally to achieve a total of 5 electrodes (see Figure 6.1). 120 ohm gages with a 1.74 gage factor (HBM part #213.18-2001) were used. An engraver was used to knock all of the beads off the backside of an Echelon stem to allow the gages and wires to sit flush. We then applied the urethane coating over them to hold them in place.

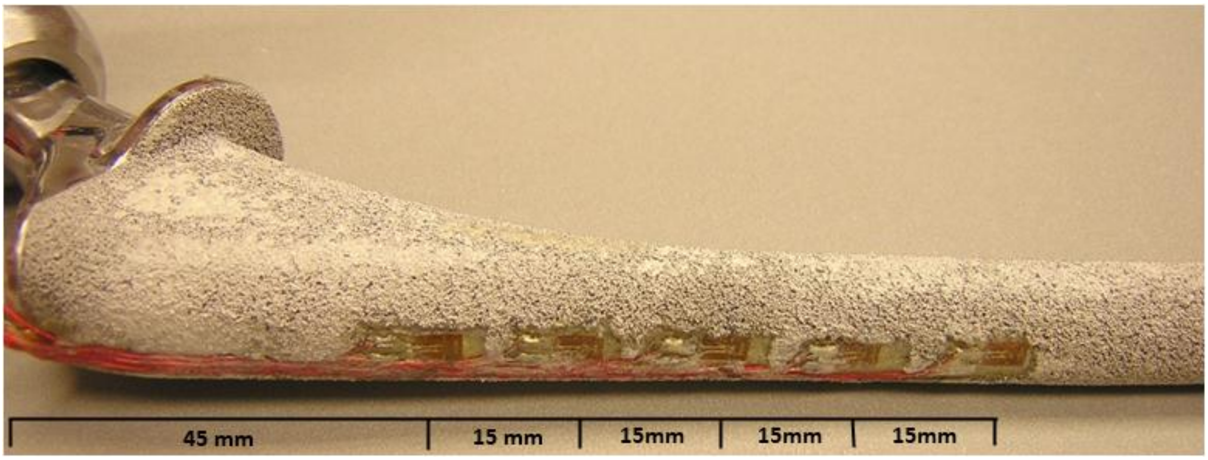

*Figure 6.1: Transducers attached at regular intervals can be seen on the lateral border of the femoral stem*

A baseline measure of femoral strain was recorded by implanting strain gauges at 45mm from the shoulder and then at 15mm intervals distally to achieve a total of 5 electrodes. Each femur was then modified sequentially to simulate seven different constructs that related to different clinical scenarios. Following each modification, the femoral stem was reimplanted and femoral strain was re-measured. The data were collected at a rate of 4 Hz. Strain gauge location 1 is the distal electrode with each subsequent electrode placed the next most proximal

### 6.2.2 Models

Seven different models were used to compare to baseline measures; each to replicate different clinical scenarios with different modes of fixation (Table 6.1). These can be seen in Figures 6.2 to 6.9.

*Table 6.1: Seven models were used to replicate seven clinical fracture scenarios*

| Model | Clinical Scenario |
|---|---|
| **Intact femur with good press-fit stem-bone interface** | Normal femur (baseline model) |
| **Overbroached proximal region** | Poor bone quality |
| **ETO** | Proximal bone loss (Vancouver Type B3) |
| **ETO with 2 cables** | Proximal bone loss with cable fixation |
| **ETO with strut and 2 cables** | First revision case |
| **ETO with strut and 3 cables** | Second revision case |
| **ETO with short trochanteric plate** | Proximal bone loss with strut and short plate |
| **ETO with long trochanteric plate** | Proximal bone loss with strut and long plate |

Using the instrumented stem, the peak strain was measured and a multifactor ANOVA was used to compare the test results to determine significance at p=0.05.

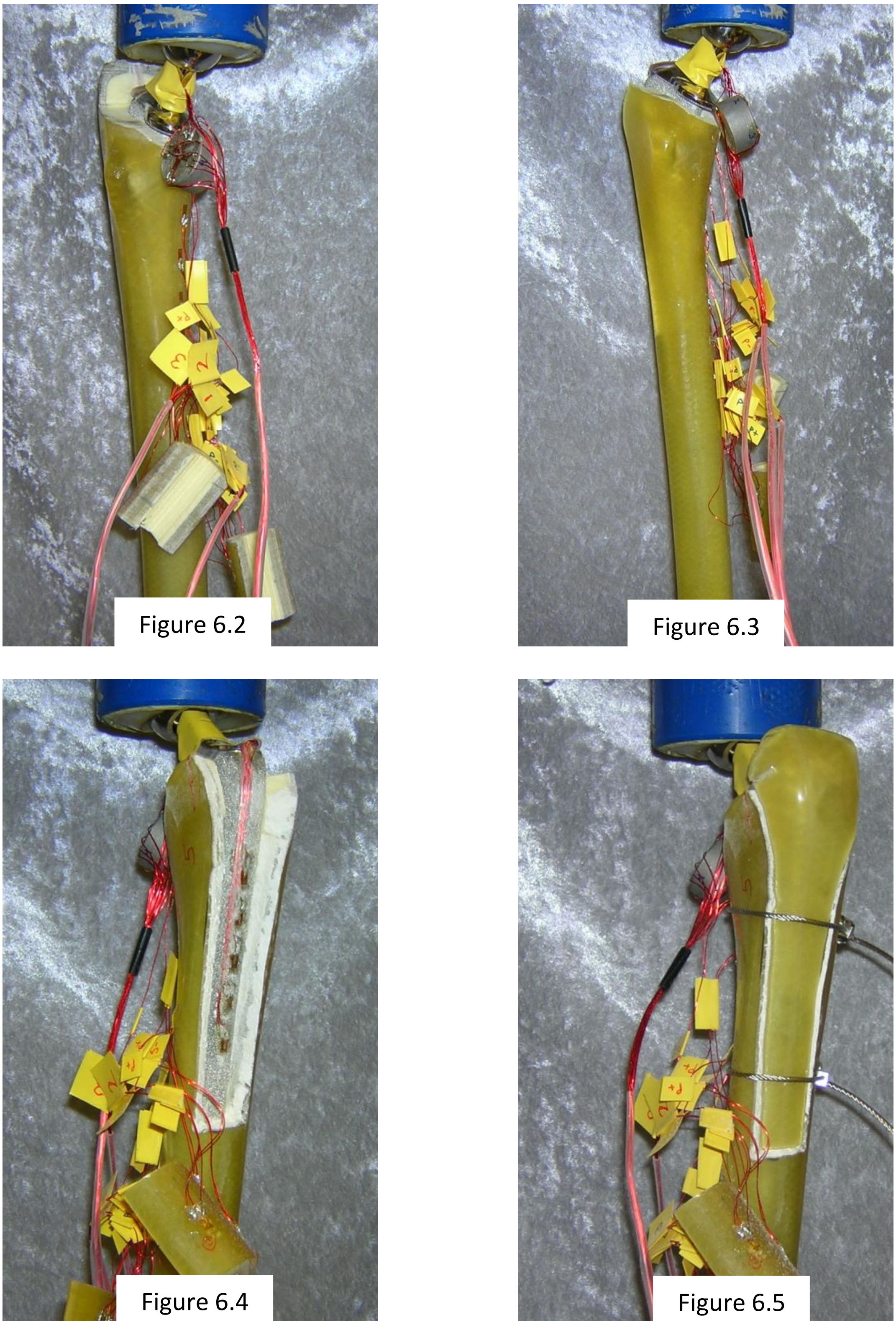

Figure 6.2

Figure 6.3

Figure 6.4

Figure 6.5

*Figures 6.2 – 6.5: Composite femur models of the baseline (6.2), overbroached proximal femur (6.3), femur with ETO (6.4) and femur fixed with 2 cables (6.5)*

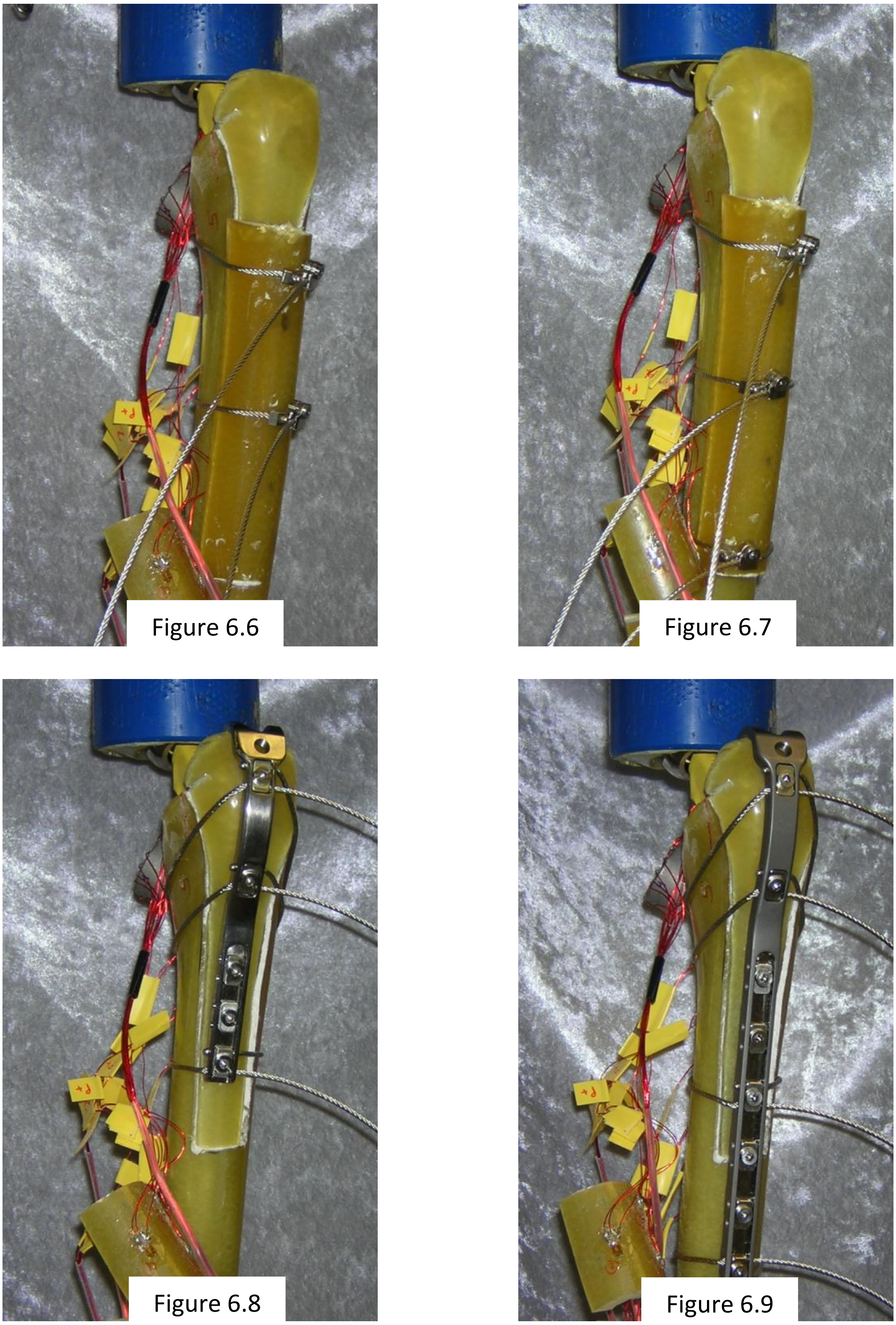
Figure 6.6

Figure 6.7

Figure 6.8

Figure 6.9

*Figures 6.6 – 6.9: Composite femur models fixed with 2 cables and a strut(6.6), 3 cables and a strut (6.7), short trochanteric grip (6.8) and long trochanteric grip (6.9)*

## 6.3 Results

The mean percentage change in strain at different electrode locations is listed in Table 6.2. In these laboratory models, it was found that over- broached femur increased the strains on the stem by over 40% when compared to the baseline model though this scenario incidentally, provided the least stress of all the situations investigated in this experiment (Table 6.2). A 98% increase in average femoral stem stress was found in the case of an unsupported stem with an ETO. This was a significantly higher result in stress than all the other test conditions, including the over-broached femoral model ($p < 0.01$).

Two further findings were found. Firstly the use of struts reduced the stem stresses, but was more effective when the strut spanned the distal edge of the ETO; see Figures 6.8 and 6.9 for comparison with the greatest reduction was seen with the long trochanteric grip, which reduced the stresses by up to 37% and showed no significant difference to the over-broached condition. Secondly, the strain in all models in the proximal regions was similar

*Table 6.2: The percentage change in stem stress from baseline reduces in the more proximal sections of the femoral implant*

| **Model** | **Percentage change in stem stress at each Strain Gauge Location** | | | | |
|---|---|---|---|---|---|
| | **1** | **2** | **3** | **4** | **5** |
| **Overbroached proximal region** | 58 | 54 | 42 | 36 | 24 |
| **ETO** | 98 | 82 | 62 | 44 | 32 |
| **ETO with 2 cables** | 76 | 64 | 52 | 41 | 30 |
| **ETO with strut and 2 cables** | 70 | 59 | 48 | 36 | 30 |
| **ETO with strut and 3 cables** | 74 | 61 | 50 | 37 | 28 |
| **ETO with short trochanteric plate** | 70 | 59 | 51 | 39 | 36 |
| **ETO with long trochanteric plate** | 61 | 53 | 44 | 34 | 18 |

## 6.4 Discussion

There has been a move towards the use of cementless stems to avoid the failure associated with cemented revisions [113, 114]. Paprosky et al. reported a survivorship of more than 95% of extensively porous-coated uncemented stems in a study of 170 patients with a mean follow up of 13.6 years [115]. Such a high survivorship makes a strong case for the use of these stems in revision surgery. However, there is a small stem fracture rate which the author believed may be related to a lack of proximal bone support. A surrogate model of extremely poor bone supports the ETO because even if the surgeon crimps the osteotomy down, there is still lack of support proximally. With normal bending the calcar is still intact in this model and this would support the stem.

Nonetheless, we know from the Chapter 6 and the literature that extensively coated porous stems do very well and have excellent results [116]. Also, the good long term outcome of extended trochanteric osteotomies is well documented [109, 117]. The problem arises when we are faced with a high risk patient undergoing a revision arthroplasty. Such a risk situation would be characterised by a heavy patient, the use of a small stem of less than 14mm diameter, a high activity patient, or a patient with poor proximal bone in the femur. In such cases, the surgeon must be extremely cautious and think about providing further support to the stem and protect from the high stresses proximally. This study was used to identify when the largest change in femoral stress occurs. Femoral implant stress increased close to double that of the baseline when a model mimicking proximal bone loss was employed. This was observed in the most distal electrode transducer suggesting that it is important to reinforce the construct at this area.

It is in those scenarios that the findings of this study apply and I would recommend using a strut graft or a trochanteric plate following the biomechanical advice outlined in this study.

In conclusion, cementless stems are commonly used in revision hip arthroplasty. These may be used in conjunction with an extended trochanteric osteotomy. Failure of uncemented stems in revision surgery has been described in the distally well fixed stem associated with certain risk factors which include obesity, poor proximal bone support, need a small femoral stem, or a high activity patient. In these situations one must think of the possibility of fatigue fractures of the femoral stem, though this may be minimised by suitable construct reinforcement to limit stress risers.

# Chapter 7

# Use of the Kent hip prosthesis in periprosthetic fractures around loose implants

**Rationale for Chapter –** Interlocking stems have a theoretical advantage over other designs in that they provide greater stability by linking a broken bone and an implant directly. This chapter will use data collected to specifically determine the outcomes of a cohort of patients treated using the Kent Hip prosthesis.

## 7.1 Introduction

Whilst cortical struts and plates are effective tools in stable implants, loose femoral implants and fractures below the tip frequently necessitate implant exchange to bypass the fracture.

The Kent hip (Biomet Europe, Dordrecht, The Netherlands) was first implanted in 1986, and was specifically designed for distal fixation alone. It was made to overcome the difficulties of loosening of the femoral component and is indicated in periprosthetic fractures or in revision cases with osteolysis. It has a straight stem made from a cobalt-chromium alloy (see Figure 7.1). It is available in two sizes, of 12.5 and 14 mm in diameter. The manufacturers recommend using the 14-mm diameter implant with the 12.5-mm stem indicated only for lighter patients. There are four lengths, 190, 239, 295 and 340 mm, with 6, 9, 13 and 16 screw holes, respectively. Two offsets are available.

It has a straight stem it and may press against the anterior cortex because of the anterior curve of the femur. There is therefore, a risk of penetrating the femur, particularly in osteoporotic bone. For this reason, in cases where it is used in patients without a fracture or where the fracture still does allow easy passage of the implant, a transverse osteotomy should be performed to allow safe insertion of the prosthesis. 36 patients in whom a periprosthetic fracture had been treated with revision of the femoral component using the Kent Hip prosthesis were investigated. It is hypothesised that using this implant would improve the clinical and radiological outcomes of treated patients.

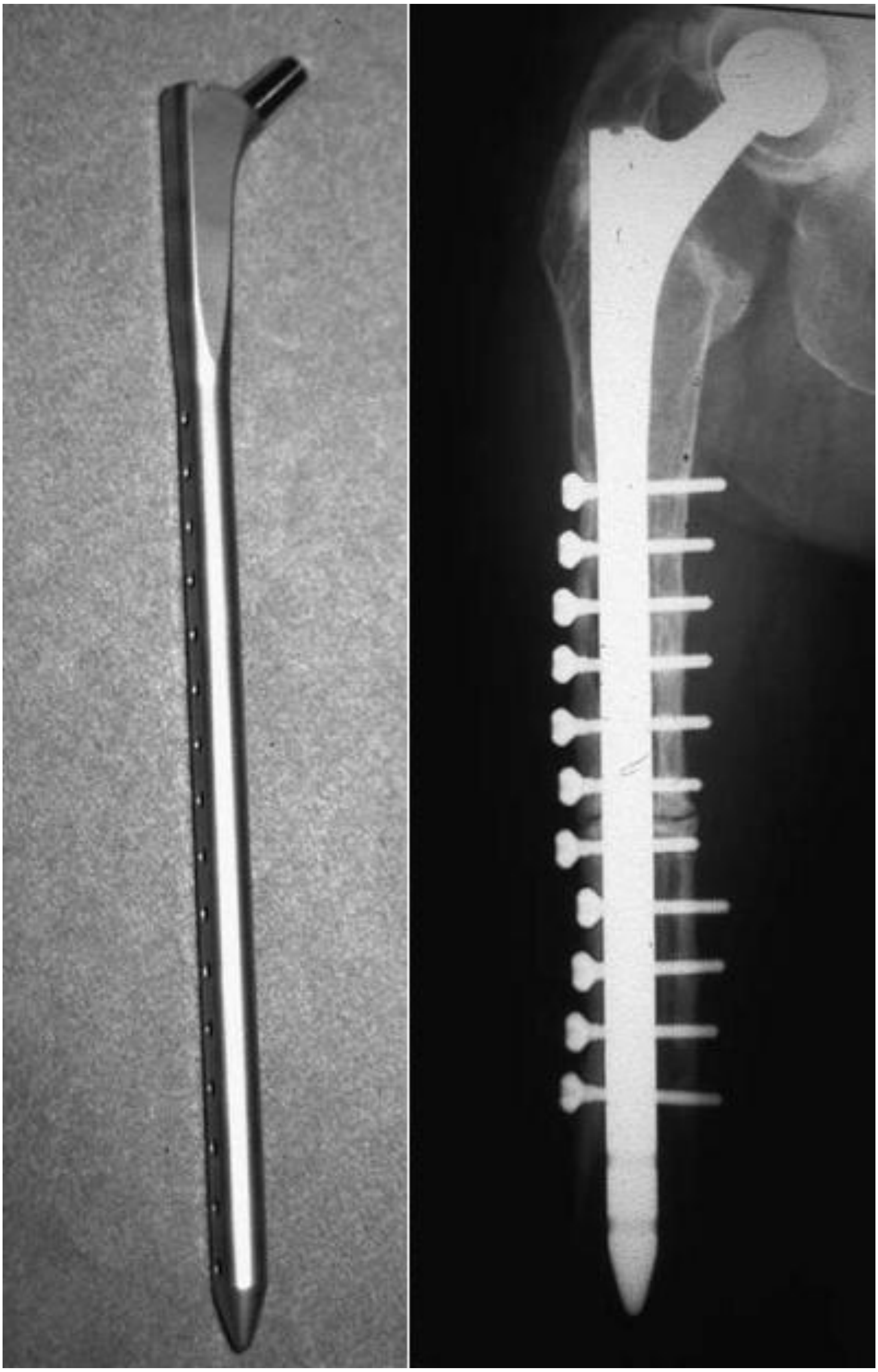

*Figure 7.1: The Kent Hip System is a long-stemmed and offers options for locking along the stem allowing for fixation both above and below a fracture as seen in radiograph*

## 7.2 Methods

### 7.2.1 Patients

A survey of two centres (University College London Hospital and Maidstone District General Hospital) identified 36 patients in whom a fracture around a loose femoral stem or distal to the stem had been treated with revision of the femoral component using the Kent Hip prosthesis. Two patients who underwent simultaneous revision of an aseptically loose acetabular socket were included. All of the patients were followed until fracture union or until a reoperation was performed.

There were 20 men and 16 women, with an average age of 66 years (range: 52 - 79). The average weight of the patients was 83 kg (range: 52 - 108).

The cause of fracture was either:

- Major trauma – 2 patients
- Minor trauma – 33 patients
- No obvious cause – 1 patients

Only osteoporosis was identified as a cause for fracture; this occurred in 8 patients. 6 patients, including two in whom the fixation failed, smoked tobacco.

Serial radiographs were reviewed with regard to:

- Fracture union
- Screw breakage
- Stem migration

Postoperative pain and mobility were compared with the preoperative status. Whenever possible, a Harris hip score[74] was recorded at the time of the clinical review or was estimated from questionnaire data.

In all patients, the fracture was around a loose femoral stem - Type B2 (n = 25), Type B3 (n = 11). The final classification was based upon both initial radiographic imaging and surgical findings regarding mobility of the stem. Ten of the fractures were transverse, and the remainder were spiral or oblique. 24 patients had two-part fractures; the remainder had three-part fractures.

### 7.2.2 Surgical Technique

All patients were placed in the lateral position and all femurs were accessed using the posterior approach described in the previous chapter. The operation technique for each case will now be outlined.

The first step involved preparation of the femoral canal which included removal of the pre-existing implant, cement and plug if applicable. An olive tipped guide wire was then inserted down to the distal end ensuring apposition of the fracture ends to ensure the guide wire went down into the distal part of the canal. It was then inserted until it hit bone in the distal end of the femur to be sure it had not gone out through the femoral shaft into the soft tissues. Reaming was undertaken using the flexible reamers increasing in size in a sequential manner. The proximal trochanteric area was reamed up to 18 mm to accommodate the larger proximal diameter of the Kent Hip stem. A proximal rasp designed with a forward cutting edge was employed to remove any hard bone or residual cement. The appropriate length Kent Hip stem was mounted on the introducer and inserted in to the femoral canal. A mallet was only used for light pressure; where more pressure was needed, the stem was removed and the canal was reamed again. A drill-guide was used to drill through the proximal cortex, screw-hole within the implant and distal cortex. Appropriately, sized screws were placed with a minimum of three above the fracture and a total of at least 12 cortical screw engagements across the length of the femur.

### 7.2.3 Post-operative Rehabilitation

All patients were allowed to partial weight bear under the supervision of a trained physiotherapist for the first three days progressing to full weight-bearing thereafter.

## 7.3 Results

### 7.3.1 Follow-up Period

All patients were followed up at a mean of 38 months (range: 3 - 82) after the fracture. Two patients died during the follow-up period, both after union of the fracture.

### 7.3.2 Fracture Union

34 (94%) of the 36 fractures united. The first failure of fixation occurred in a 63 year-old, 71-kg man who smoked 20 cigarettes per day during the recovery period and had a 60 a day ?history of smoking. He had a Type B2 fracture and despite good reduction, serial radiographs taken in clinic showed minimal cortical union and he described persistent pain at the fracture site with a painful limp on mobilising. At 12 months, he was diagnosed with non-union. He underwent removal of the Kent Hip implant, implantation of a long-stemmed HA coated stem secured with a plate secured and cables. He continued to complain of pain at the fracture site at 12 months despite evidence of radiological union. The second failure of fixation occurred in a 72 year-old, 90-kg male who presented fell at home 3 weeks after the original fixation and sustained breakage of all three screws fracture below the original fracture line. This patient had an exchange of the broken screws and had protected weight-bearing for three weeks in a rehabilitation unit after discharge.

There were no cases of malalignment.

### 7.3.3Screw Breakages

Broken screws were observed in four patients. One of the cases has been described above. The mean time to screw breakage in the remaining patients was 21 months (range: 7 – 35).

There was no history of trauma observed in these patients and were presumed to be related to metal fatigue. Two of these three patients required additional surgery; both noted pain at the level of the broken screws and requested removal. In both cases the prostheses remained in place until the end of the follow up period.

### 7.3.4 Additional Surgery

In addition to the cases outlined above for failure to unite, there were three additional cases that underwent surgery. Two patients required removal/exchange of symptomatic broken screws and one patient required exchange of acetabular shell for asymptomatic progressive osteolysis in Gruen zone 1.

### 7.3.5 Functional Outcome

A very broad range of Harris hip scores was observed both before the fracture (range: 34 - 90 points; mean: 82 points) and at the final review (range: 18 - 99 points; mean: 82 points). Statistical analysis between the groups did not identify any difference between these groups ($p = 0.88$). All patients returned to their preoperative functional level within one year and back to using the same level of walking aids within 18 months.

## 7.4 Discussion

This study has used a cohort of patients taken from two units to investigate the use of the Kent Hip prosthesis in patients with Type B2 and B3. To date, there is only one previously published study [118] which outlines the outcomes of this implant. It also included the cohort of patients from Maidstone District General Hospital used in this chapter. Whilst the present study may therefore be seen as an extension of the work by Sexton et al., it is difficult however to directly compare the results since the published data has not differentiated patients by indication.

This study is limited by its use of a single treatment arm and thus does not allow comparison to another treatment group. Furthermore, overall numbers of patients are small though it is worth noting that two units were required to collate the number of patients over a number of years.

The Kent hip was designed to address the difficulties in controlling length and rotation, by allowing per-operative adjustment. Because the component is locked distally, early full weight-bearing and discharge from hospital is also possible comparing favourably with many of the other prostheses used in this type of patient [101]. The overall 5- and 10-year survivorship has been demonstrated to be 93% and 89% respectively which is comparable to other systems. However, it drops to 77% at 15 years [118]. Whilst there are wide confidence intervals in many other studies and the indications are not limited to periprosthetic fractures alone, it would appear that the survival of this implant after ten years does deteriorate when compared with other systems [105, 119, 120]. Although, the numbers in this study and length of study duration are too small to confidently determine a survivorship analysis, it would appear that the early results of 32 out of 36 cases (89%) requiring additional surgery related directly to the implant (including removal or screw exchange) suggests that the presence of a periprosthetic fracture may confer additional barriers to survivorship.

Although functional outcomes are not easily compared to other implant groups, the mean Harris Hip score did not change from prior to the fracture event to final follow-up in this study. This suggests that the Kent Hip is an effective tool in restoring function back to its pre-morbid state.

In spite of the favourable outcomes reported in this chapter, it is paramount that surgeons are aware that since the implant is a first-generation locking device, it has several disadvantages. The first is related to fixation; this only occurs within the distal portion of the stem is and provided by screws alone. The lack of proximal fixation and absence of osseointegration to any part of the stem may lead to proximal stress shielding and a risk of screw fracture. As was mentioned in the Results section of this chapter, this was the finding in a few patients. The second is related to the implant's geometry; namely it is a straight stem and does not follow the curvature of the femur. A transverse osteotomy is therefore sometimes required to avoid penetrating the anterior cortex of the femur. We now use second-generation implants which offer the potential for bone in-growth, a greater range of sizes, customisation and better proximal fill at the same as distal locking (for example– The Cannulok, Orthodynamics Ltd, Dorset, UK or Reef, DePuy, Leeds, UK, systems).

# Chapter 8

# Use of distally locked prostheses in infected Type B2 and B3 fractures

**Rationale for Chapter –** Evidence presented in the previous chapters has shown that uncemented stems carry favourable outcomes in either loose prostheses or in fractures that occur below a prosthesis. The issue of a concurrent infection around a fracture site is very much a different problem since both the infection and fracture need treatment. To that end, uncoated uncemented stems can be used as a temporary or definitive device after debridement. This chapter will evaluate the outcomes of distally locked prostheses in infected fracture cases.

## Chapter 8

### 8.1 Introduction

Infection in the presence of an unstable periprosthetic fracture poses a complex clinical challenge. The gross incidence of infection in unstable periprosthetic femur fractures is approximately 10% in our series at University College Hospital, London. Fracture stability and eradication of infection have to be addressed simultaneously. Conventional periprosthetic fracture management techniques alone cannot easily be applied in these cases. The processes involve removal of an unstable prosthesis. In addition, surgical debridement should be undertaken and antibiotic therapy commenced to eradicate infection. The placement of large or multiple metal fixation devices may act as nidus for persistent infection. Revision hip surgery in the presence of infection but without a facture is customarily managed with an antibiotic cement implant (see Figure 8.1) as a temporary spacer. This has the advantage of being a delivery vehicle for antibiotics whilst maintaining soft tissue tension in the absence of a functional prosthetic joint. It is not typically used when periprosthetic fractures co-exist since the interval spacers do not usually provide fracture stability.

Definitive management of the periprosthetic fracture without eradication of infection using either (1) an uncemented implant with a porous coating or; (2) an implant that is distally fixed with cement, could allow a functional recovery if the fracture unites. However, it risks ongoing sepsis by providing a surface on which organisms may thrive and form biofilm. In many of these cases the infecting organism is not known and the possibility of a staged approach is thus desirable.

*Figure 8.1: A pre-moulded antibiotic loaded cement spacer*

Long-stem distally-locked femoral implants are used for revision hip surgery, in the management of periprosthetic fractures [99, 118, 119, 121-124] and have been shown to be effective in Chapters 5 and6.

Stems are available with or without HA coated surfaces. They can be used as interim spacers until the fracture unites; infection is eradicated and definitive prosthetic options may then be considered. Using a non-HA coated femoral stem, it is possible to stabilise a fracture without encouraging bone attachment and thus, further revision is relatively straightforward if it is required. In elderly patients with co-morbidities, these prostheses may also offer a long-term treatment option.

The aim of this chapter is to determine the outcomes when managing unstable periprosthetic femoral fractures using non-HA coated, long-stem, distally-locked femoral prostheses. It is hypothesised that these devices would restore the clinical function of these patients and may provide a definitive prosthetic solution within the elderly.

## 8.2 Methods

A survey of two units (University College London Hospital and Queen's in Nottingham) identified 17eligible patients from two different units between 2000 and 2008. Eligible patients were those with a periprosthetic fracture in the presence of either a previously known or subsequently confirmed bacterial infection. Confirmation of the concurrent diagnosis of infection was made using a combination of elevated blood inflammatory markers and microbiological culture data from aspiration.

Both units followed similar principles for the diagnosis and management of periprosthetic infections. These included a very low threshold for diagnostic aspiration and biopsy of the local periprosthetic tissue around loose implants. Blood investigations were performed to monitor the differential white cell count and the inflammatory markers (Erythrocyte sedimentation rate and C-reactive protein).

At operation, empirical antibiotics were commenced once microbiology samples had been collected. These were continued until the definitive antibiotic of choice was established based on sensitivities of the organisms isolated from cultures. In cases with obvious infection as evidenced by raised inflammatory markers, osteomyelitic bone or purulent exudates but no identifiable causative organisms on culture, an empirical broad-spectrum antibiotic was used. Antibiotics were continued until the inflammatory markers returned to their normal range or to a static level for that patient.

Once a radical surgical debridement of all the foreign material, cement and debris had been undertaken, patients were re-draped and using clean instruments, the periprosthetic fracture was stabilised using a long-stem, non-HA coated, distally-locked, femoral prosthesis.

Two different non-HA coated prostheses were used:

- Cannulok hip system (Orthodesign UK) – 12 patients
- Kent hip system (Biomet) – 5 patients

The Cannulok system was used in the management of seven Type B2 fractures and five Type B3 fractures. The Kent system was used in two Type B2 fractures and three Type B3 fractures. Between 3 and 10 cables were used in each case in order to restore proximal bone stock and abductor tension. Post operatively patients were allowed to mobilise with the help of crutches and weight bearing was permitted as tolerated.

Pre-operatively and intra-operatively, the acetabular components were assessed for loosening but revision was only necessary in 4 cases of this series. In these cases a cemented acetabular component was loosely cemented in with antibiotic loaded cement and revised to a hemispherical porous coated component at the second stage. In the cases were there was a well fixed cementless shell, the liners were routinely changed (5 cases). In four cases where the index procedure was a hemiarthroplasty, the acetabulum was not revised until the definitive second stage procedure was undertaken. In these cases, large modular heads were used temporarily. All patients were serially followed up. This comprised a clinical evaluation including a Harris Hip Score [74] and radiographic evaluation where an assessment was made of fracture union and implant migration. The minimum follow-up time was two years up to a maximum of six years.

## 8.3 Results

### 8.3.1 General Patient Information

The average hospital stay was 2 weeks (10 days to 4 weeks). It was anecdotally noted that pain control was easily achieved post-operatively. This was attributed to early stabilisation of the fracture. No dislocations were noted in this series. All patients had radiographic evidence of initial callus formation, whilst union was again seen in all patients' radiographs (Time range: 2.5 – 6 months). There were no incidences of screw breakage at latest follow-up in this series.

One patient developed a pulmonary embolism, which was diagnosed 4 days postoperatively and treated.

All patients in this series returned to their low to moderate pre-morbid functional state following discharge from the hospital. All patients could mobilise with the spacers *in situ* and no total or proximal femoral resections had to be undertaken. The mean Harris Hip score remained unchanged from the pre-fracture state to latest follow-up (81 (range 47-90) vs. 78 (48- 82); p = 0.49).

### 8.3.2 Cannulok Group

The mean follow-up in the 'Cannulok' series was a minimum of 38 months (range: 24 – 48). Ten patients underwent a definitive revision hip replacement procedure within an average of 3.8 months (range: 3 - 6). In 6 cases, an extensively porous coated stem was used and in 4 cases, a tapered distally fixed cementless stem was used. In all these cases, inflammatory markers had come down to a stable, level within normal limits before the second definitive procedure was undertaken. No re-infections after the second stage revisions in these patients were noted.

The remaining two patients of this group continued to have persistently elevated inflammatory markers. Both were offered further staged surgery but declined since they were mobile and relatively pain free. They have been managed in the community with long term oral antibiotics and regular outpatient clinic review.

### 8.3.3 Kent Group

The mean follow-up in the ‘Kent Hip’ series was 53 months (range: 32 – 72). One patient in this series was revised to a definitive short femoral stem at 13 months. In the other four cases, the long stem locked prosthesis has been accepted as the definitive treatment remaining under close clinical supervision on an outpatient basis.

## 8.4 Discussion

The treatment of unstable periprosthetic femur fractures can be technically challenging due to the weak non-supportive bone stock. The management becomes even more difficult in the presence of local infection. The primary aim is to ensure both eradication of infection and fracture stability. An intra-medullary articulating spacer with distal fixation can add stability to the construct. The proximal portion of the prosthesis acts as an internal scaffold around which the fracture fragments can be stabilised. This approach avoids the need to sacrifice the proximal femur or to use modular oncology prostheses.

Staged revision of infected hip replacements is well described. This requires the interim use of antibiotic loaded cement [125, 126] or a spacer [127]. However, this technique requires the presence of stable proximal bone stock. Single stage revision of infected hip replacements is a safe option. It is important to collect sufficient samples for microbiology from the local tissues at the time of the procedure to attempt isolation of the infective microorganism. A locally agreed systemic antibiotic is commenced empirically and continued until it is changed to the appropriate antibiotic or the infection is controlled [128].

Periprosthetic fractures often occur in elderly patients with compromised physical state and high morbidity and mortality is reported in this population [129]. Non-operative management of periprosthetic fractures may be associated with medical complications due to the need for prolonged bed rest and traction and specifically but in the cases where there is infection this treatment cannot resolve local sepsis. Hence, a surgical treatment option that provides a microbiological diagnosis allows thorough debridement and provides stable fixation, early weight-bearing and mobilisation is the ideal option for the management of this subgroup of patients.

The results outlined in this chapter highlight that long-stemmed, inter-locked prosthesis can be used effectively as a temporary spacer as a single stage revision in these patients. This affords the opportunity to surgically treat the infection and stabilise the fracture. As the components do not have in-growth or adherence potential, they can be:

- Easily revised to alternate implant if infection persists
- Or revised to a definitive prosthesis if the patient is deemed physically fit to undergo further surgery

The interim use of these spacers converts complex infected periprosthetic fracture revision surgery into a simpler procedure and preserves bone stock for use in case of future revisions. This series establishes the advantage of early mobilisation with the use of a functional locked interim spacer for the management of infected periprosthetic fractures. Long-term follow up studies with a larger series of patients are desirable to analyse the success of these implants and the outcome of the revision procedures performed after the interval spacer procedure.

The use of non-HA coated, distally locked long femoral stems in combination with strict adherence to the principles of infection management can facilitate the management of infected periprosthetic fractures.

# Chapter 9

# Conclusions

**Rationale for Chapter –** This thesis has drawn together numerous conclusions. Together with already published data, this chapter will detail a treatment algorithm for Type B periprosthetic fractures of the femur.

## Chapter 9

### 9.1 Introduction

This chapter completes the thesis by considering the implications for practice and further research. It concludes with a reflective account by the researcher.

### 9.2 Study Aims

While the key findings of each study were provided in detail in the previous chapters, this brief review is presented as a means of focusing both on the contributions of the research and reflections on the conduct of the study.

My thesis sought to address the management of periprosthetic fractures of the femur. The guiding rationale was that this would become an increasingly important orthopaedic condition as its incidence rises. It is anticipated that the incidence will rise for two reasons. Firstly, it is anticipated that there will be an increase in patients suffering from age-related disease due to the population increasing globally with a coupled greater life-expectancy. These diseases include osteoporosis and osteoarthritis. With respect to osteoporosis, it is known that patients with disease who fall are more likely to sustain a fracture of the femoral neck than those who have normal bone density. Consequently, there will be more patients undergoing arthroplasty interventions for this. The same is true for osteoarthritis since arthroplasty is a well established treatment for arthritic hip pain. Whilst elderly patients constitute one end of the spectrum, young patients should not be ignored. The second reason for the rise is the broadening of indications for THA. Young patients are now more likely to undergo THA procedures whether it is due to underlying dysplasia, early onset arthritis, or other conditions such as vascular necrosis.

### 9.3 Implications for Practice

This starting point of the experimental part of this thesis was to ensure a valid and reliable classification tool could be used. The Vancouver Classification was demonstrated to be amongst a wide mixture of grades of doctors. As a result, it was safely used in the rest of my thesis to classify periprosthetic fractures of the femur. Further to this, the use of different constructs in different scenarios was employed with good to excellent results. It is clear that although periprosthetic fractures represent a difficult surgical problem, there are means of salvaging the situation.

With respect to cortical strut grafts, the 3rd chapter in my thesis highlighted the benefit of these biological plates around stable implants. This is not to say that this is the only option. Indeed, the presence of good bone stock means that compression and locking plates are likely to suffice [79, 130, 131] though the lack of randomised controlled trials means that direct comparison is difficult.

Further to this, the biomechanical study from Chapter 4 highlighted that two struts supplemented with cables offered the best fixation. This at least suggests that surgeons employ cortical strut grafts, or potentially struts with plates, to achieve the strongest construct.

It is widely accepted that a loose implant requires removal and consequently an implant that replaces it should bypass the fracture by at least 2 cortical diameters. This has led to the introduction of long-stemmed implants and one example of this, the Kent Hip prosthesis was investigated in Chapter 7. Since it is a first-generation design, it was both smooth and not contoured to the femur natural anterior bow. Consequently, trochanteric osteotomies were required on occasion, whilst the lack of osseointegration provided stress points around the screws resulting in frequent breakages.

The advent of second-generation designs was more successful as evidenced in Chapter 5 with less incidences of screw breakage. These implants can now be considered the standard method of fixation for Type B2 and B3 fractures. The caveat of this being that in the presence of revision procedures or bone loss, suitable reinforcement must be employed to reduce the likelihood of femoral implant fracture as was biomechanically explored in Chapter 6.

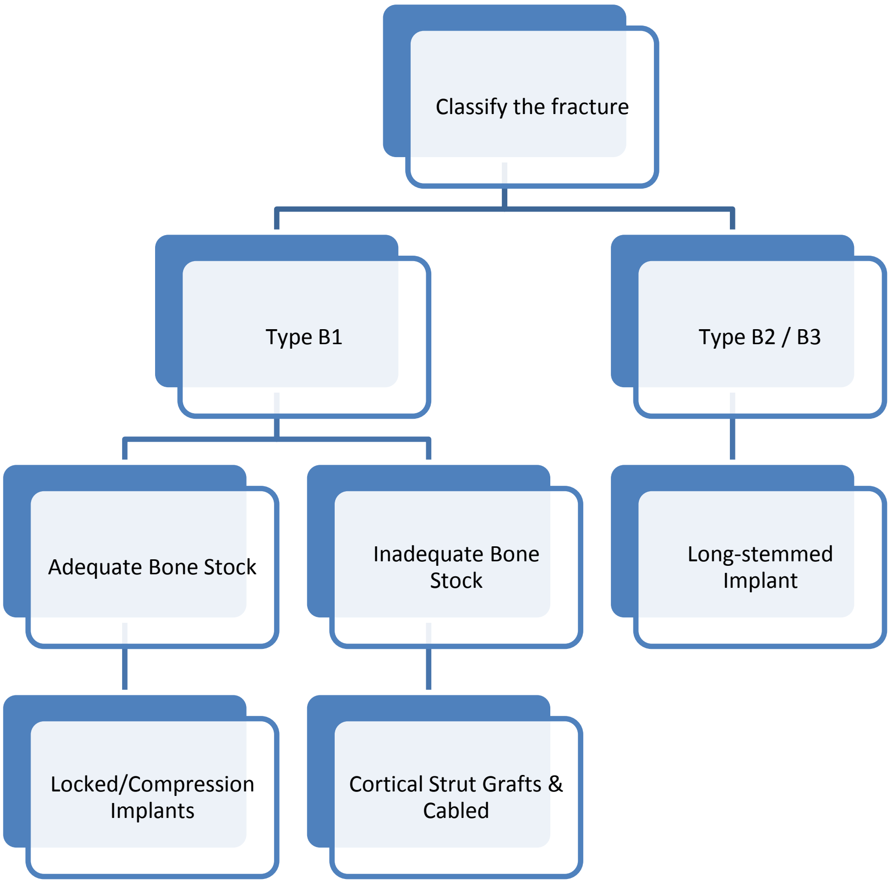

*Figure 9.1: A simple treatment algorithm for Type B fractures*

Finally, infection in the presence of a fracture remains a complex issue since bacterial pathogens can use both necrotic bone and the surface of implants as a breeding surface. Consequently, debridement of infected bone and removal of an original implant are necessary. The successful use of long-stemmed implants as either a temporary or definitive device has been demonstrated in Chapter 8.

Based upon all the findings, an algorithm for Type B fractures can be followed (see Figure 9.1).

## 9.4 Future Work

The work has been compiled over a number of years but ongoing research is required in to this area. In the short-term, construct stability is the main concern. To that end, modular devices which can be customised for individual patients should be investigated. By offering a wide variety of sizes and shapes to make up the final implant, it would be expected that more anatomical devices promote better stability and an easier surgical technique.

In the long-term, promotion of fracture healing will be a key issue. Stem cells are cells that have the ability to renew themselves through mitotic cell division and can different into a diverse range of specialised cell types. Insertion of these cells into fracture sites may lead to greater union and consequently less pain and better function.

## 9.5 Reflective account

Periprosthetic fractures represent an increasing complex problem. I anticipate there will be a rise in the number of patients affected by this condition as the number of primary THA procedures rises and as more uncemented stems are used. The body of work collected in this thesis represents my experience of periprosthetic fractures. During that time, I have strived to ensure excellent functional outcomes and this has been evidenced by ongoing study of my practice in this thesis. It is my hope that the dissemination of the work collected will be used to enhance patient care.

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