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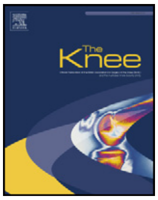

Finite element comparison of retrograde intramedullary nailing and locking plate fixation with/without an intramedullary allograft for distal femur fracture following total knee arthroplasty

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ABSTRACT

Purpose: Periprosthetic distal femur fracture after total knee arthroplasty due to the stress-shielding phenomenon is a challenging problem. Retrograde intramedullary nail (RIMN) or locking plate (LP) fixation with/without a strut allograft has been clinically used via less invasive stabilization surgery (LISS) for the treatment of these periprosthetic fractures. However, their biomechanical differences in construct stability and implant stress have not been extensively studied, especially for the osteoporotic femur.

Methods: This study used a finite-element method to evaluate the differences between RIMN, LP, and LP/allograft fixation in treating periprosthetic distal femur fractures. There were sixteen variations of two fracture angles (transverse and oblique), two loading conditions (compression and rotation), and four bony conditions (one normal and three osteoporotic). Construct stiffness, fracture micromotion, and implant stress were chosen as the comparison indices.

Results: The LP/allograft construct provides both lateral and middle supports to the displaced femur. Comparatively, the LP and RIMN constructs, respectively, transmit the loads through the lateral and middle paths, thus providing more unstable support to the construct and high stressing on the implants. The fracture pattern plays a minor role in the construct stabilization of the three implants. In general, the biomechanical performances of the RIMN and LP constructs were comparable and significantly inferior to those of the LP/allograft construct. The bone quality should be evaluated prior to the selection of internal fixators.

Conclusions: The LP/allograft construct significantly stabilizes the fracture gap, reduces the implant stress, and serves as the recommended fixation for periprosthetic distal femur fracture.

1. Introduction

Distal femur fractures adjacent to total knee arthroplasty (TKA) present a rare and yet complex problem, with an incidence ranging from 0.3% to 2.5% after primary surgery and from 1.6% to 3.8% after revision surgery [1,2]. The occurrence of periprosthetic supracondylar femur fractures can be attributed to the stress-shielding effects around the periprosthetic region [3–6]. Successful treatment requires regaining a painless, well aligned knee with a satisfactory range of motion and maintaining good alignment of the entire lower limb.

A wide variety of orthopedic devices had been used for the internal fixation of these fractures including angled blade plates, dynamic condylar plates, buttress plates, and flexible or rigid intramedullary nails [7]. Recently, periarticular locking plate (LP) or retrograde intramedullary nail (RIMN) fixation has become a popular treatment option with the less invasive stabilization system (LISS). The major advantage of LP is the ability to implant them with minimal soft tissue dissection, periosteal stripping, and multiple fixed-angle screws fixation around the fracture site to maintain distal fixation. Rigid RIMN can also be an effective device for minimally invasive stabilization of these fractures, and is considered if the patient has an open box femoral component for device access and adequate distal fracture fragments for locking fixation [8,9].

With unstable nail-bone contact, the construct stability of antegrade nailing for a periprosthetic fracture is weaker than that of the locking plate [10–12]. Comparatively, the retrograde nail makes deeper contact with the subchondral bone and operates in a minimally invasive fashion [13]. Consequently, RIMN has been recommended as an alternative for the treatment of periprosthetic fracture [14–17]. For LP fixation, the multiple points of cortical screws can provide better angular stability and secure bony anchoring for constructing stiffness and preservation of vascular supply [18–21]. However, the stress-shielding effect around the periprosthetic region potentially makes proximal screw loosening a major concern when using LISS plates [10–12,22,23]. Gardner et al. [24]

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used an intramedullary strut allograft to serve as the mechanical support supplemented to the LISS plate (LP/allograft) fixation, and declared that the hybrid use of LP/allograft can significantly stabilize the construct and facilitate the bony union. However, the complication rate is still 15–20% due to nonunion, malunion, infection, hardware failure or mortality even after RIMN or LP fixation for distal femur fractures following TKA [16,17,20,22,24]. However, biomechanical comparisons among RIMN, LP, and LP/allograft have not been extensively investigated.

Therefore, this study used the finite-element method to compare the construct behaviour subject to the variations of three internal fixations, two loading conditions, two fracture patterns, and four bony strengths. The convergence and stiffness of the intact model was validated. Then, the construct behaviour was evaluated in terms of construct stiffness, fracture micromotion, and implant stress. The purposes of this study provide biomechanical information about the differences among RIMN, LP, and LP/allograft, and point to which one should be indicated individually for various types of periprosthetic fractures following TKA. This study hypothesized that LP/allograft construct significantly stabilized fracture gap, reduced implant stress, and is potentially suitable for the treatment of periprosthetic distal femur fracture with comminution, deficient bone stock, and severe osteoporosis.

2. Methods

This study used the abbreviations LP and RIMN to denote the periarticular locking plate and retrograde intramedullary nail. The LP, RIMN, and LP/allograft fixations were compared in terms of two fracture patterns: transverse (TP, TN, and TA) and oblique (OP, ON, and OA). The femoral strengths were simulated by the three osteoporotic conditions: ost-1 (mild), ost-2 (moderate), ost-3 (severe).

2.1. Models of femur and implants

A femoral model was developed from the CT-scanned images of a mild-aged male (age: 45 years, weight: 60 kg, and height: 176 cm). The femur consists of cortical shell and cancellous core (Fig. 1a and b). Periprosthetic fracture was simulated as a displaced 1-cm gap that is the worst-case condition for transferring the femoral loads (Fig. 1c and d). This study used two patterns of the periprosthetic fractures (transverse and oblique) to evaluate the effects of the fracture pattern on the construct stability. Prior to instrumentation, the intact femur was validated by comparing the predicted stiffness with the experimental data of Koval's study [25]. This study used ANSYS version 12.0 (ANSYS Inc., USA) to perform construct stiffness analysis. The mesh size of the intact femur was determined by a convergence test of the construct stiffness *vs.* element number.

Three implants were instrumented into the fractured femur, including a knee prosthesis, RIMN, and LISS plate (Fig. 1). The knee prosthesis was a Zimmer Natural-Knee II PS (Zimmer Inc., Indiana, USA). The RIMN was 10 mm in diameter and 240 mm in length (TRIGEN, Smith and Nephew, USA). The LISS plate was 240 mm in length and 3 mm in thickness (AO Synthes, Pennsylvania, USA). The outer diameter, inner diameter, and length of the allografts were 17, 10, and 60 mm, respectively. All implants were instrumented into the femoral models according to standard surgical procedure.

A 9-hole LISS plate was fixed to the distal femur with five proximal and six distal cortical screws according to the manufacturer's instructions (Figs. 1 and 2). The RIMN was secured by two proximal and two distal interlocking screws. For the LISS plate with an allograft, the allograft was fixed using distal locking screws without penetrating the allograft surface. The allograft was secured against the medial cortex of the femur to ensure maximal medial support (Fig. 2c). In total, there were six variations of three implants and two fracture patterns (Fig. 2).

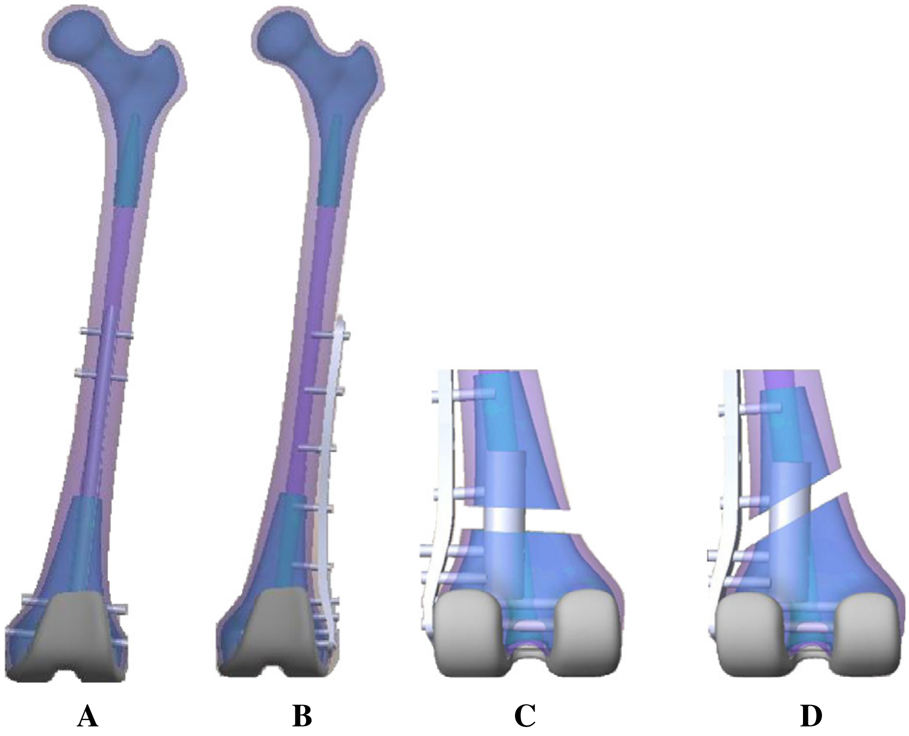

Fig. 1. Internal fixators and fracture patterns used in this study. (A) Retrograde nailing. (B) LISS plating. (C) Transverse fracture. (D) Oblique fracture.