Clinical Biomechanics 38 (2016) 42–49

Contents lists available at ScienceDirect

Clinical Biomechanics

journal homepage: www.elsevier.com/locate/clinbiomech

Lecture

Role of the fibula in the stability of diaphyseal tibial fractures fixed by intramedullary nailing

John G. Galbraith [a], Charles J. Daly [b], James A. Harty [a,c], Hannah L. Dailey [b,*]

[a] Department of Trauma and Orthopaedic Surgery, Cork University Hospital, Wilton, Cork, Ireland
[b] Medical Engineering Design and Innovation Centre, Department of Biomedical Engineering, Cork Institute of Technology, Rossa Avenue, Bishopstown, Cork, Ireland
[c] Department of Surgery, University College Cork, Cork, Ireland

ARTICLE INFO

Article history:
Received 15 October 2015
Accepted 16 August 2016

Keywords:
Fracture fixation
Osteosynthesis
Cadaver
Biomechanics

ABSTRACT

Background: For tibial fractures, the decision to fix a concomitant fibular fracture is undertaken on a case-by-case basis. To aid in this clinical decision-making process, we investigated whether loss of integrity of the fibula significantly destabilises midshaft tibial fractures, whether fixation of the fibula restores stability to the tibia, and whether removal of the fibula and interosseous membrane for expediency in biomechanical testing significantly influences tibial interfragmentary mechanics.

Methods: Tibia/fibula pairs were harvested from six cadaveric donors with the interosseous membrane intact. A tibial osteotomy fracture was fixed by reamed intramedullary (IM) nailing. Axial, torsion, bending, and shear tests were completed for four models of fibular involvement: intact fibula, osteotomy fracture, fibular plating, and resected fibula and interosseous membrane.

Findings: Overall construct stiffness decreased slightly with fibular osteotomy compared to intact bone, but this change was not statistically significant. Under low loads, the influence of the fibula on construct stability was only statistically significant in torsion (large effect size). Fibular plating stiffened the construct slightly, but this change was not statistically significant compared to the fibular osteotomy case. Complete resection of the fibula and interosseous membrane significantly decreased construct torsional stiffness only (large effect size).

Interpretation: These results suggest that fixation of the fibula may not contribute significantly to the stability of diaphyseal tibial fractures and should not be undertaken unless otherwise clinically indicated. For testing purposes, load-sharing through the interosseous membrane contributes significantly to overall construct mechanics, especially in torsion, and we recommend preservation of these structures when possible.

1. Introduction

Intramedullary (IM) nailing is often the treatment of choice in the management of tibial shaft fractures (Phieffer and Goulet, 2006). IM nailing works on the principle of relative stability, which allows the fracture to achieve union by secondary bone healing. The speed of this healing process is influenced by the magnitude and direction of the interfragmentary motion (IFM) allowed within the fracture site. Factors that are known to influence IFM include weight bearing, nail diameter, number and orientation of locking screws used, and specialised implant design features such as angular-stable locking, compression locking, and controlled axial micromotion (Brown et al., 2007; Dailey et al., 2013; Kaspar et al., 2005). Less attention, however, has been given to the role of the fibula in tibial IFM after IM nailing.

Biomechanically, the fibula has been traditionally viewed as a static lateral strut for the talo-crural joint that provides the origin for several muscles of the foot. However, a number of studies on cadaveric lower limbs have estimated that the fibula bears between 6% and 30% of the axial load, depending on the orientation of the foot and ankle (Goh et al., 1992; Lambert, 1971; Takebe et al., 1984; Wang et al., 1996). In vitro studies have also demonstrated load transfer through the interosseous membrane, which connects the tibia and fibula (Skraba and Greenwald, 1984; Thomas et al., 1995; Vukicevic et al., 1980; Wang et al., 1996). In addition to its axial load-sharing role, the fibula has also been shown to contribute to the rotational stiffness of the lower leg (Thambyah and Pereira, 2006).

In recognition of the stabilising function of the fibula, some researchers have attempted to evaluate its role in tibial fractures fixed with IM nails in both a clinical and biomechanical context (Gerstenfeld et al., 2003; Kaderly, 1991; Marsell and Einhorn, 2011; Shapiro, 1988). The majority of the published work relates to distal metaphyseal tibial fractures, which are inherently less stable than midshaft fractures owing to the absence of endosteal fit of the nail

---

* Corresponding author at: Lehigh University, Department of Mechanical Engineering and Mechanics, 19 Memorial Drive West, Bethlehem, PA 18015, USA.
E-mail addresses: galbraith.john@gmail.com (J.G. Galbraith), charlesdaly1@gmail.com (C.J. Daly), jamesharty@me.com (J.A. Harty), hannah.dailey@lehigh.edu (H.L. Dailey).

http://dx.doi.org/10.1016/j.clinbiomech.2016.08.007
0268-0033/© 2016 Elsevier Ltd. All rights reserved.

within the widened metaphyseal canal and the lack of cortical contact with the nail (Morin et al., 2008). In a cadaveric study, Morin et al. (Morin et al., 2008) observed a slight increase in torsional stability by adding fibular fixation to tibial IM nailing in the treatment of combined distal-third tibiofibular fractures, which they concluded may not be clinically relevant. More recently, Attal et al. (Attal et al., 2014) used a cadaveric model to show that fibular plating does not enhance the stability of distal tibial fractures when the distal locking screws are placed in multiple planes and that this approach renders fibular fixation unnecessary.

In contrast, there is some clinical evidence suggesting an influence of the fibula on patient outcomes. A recent retrospective study of 60 patients with distal tibiofibular fractures showed a tendency toward increased non-union risk with fibular fixation and tibial nailing, but this result was not statistically significant and an opposite trend was observed when the tibia was plated instead of nailed (Berlusconi et al., 2014). Hence, clinical decision-making in fibular fixation remains subjective and this was cited as a confounding factor in a recent clinical trial to investigate angular-stable locking of IM nails for distal tibial fractures (Hontzsch et al., 2014).

Considering mid-diaphyseal tibial fractures, there is a paucity of published work on the role of fibular fixation in tibial fracture stability post-IM nailing. This is surprising, given the high proportion of tibial fractures which occur in the mid-diaphyseal region with associated same-level fibular fractures (Court-Brown and McBirnie, 1995). Some authors advocate judicious caution in approaching fibular fixation, as the possible stabilising effect of a fixed fibula must be balanced against increased soft tissue morbidity (Varsalona and Liu, 2006). In addition, the role of the fibula in midshaft tibial fracture stability may be more subtle due to the natural enhanced stability of fractures at this level arising from the tight endosteal fit of the nail in the canal. Furthermore, for biomechanical studies of tibial fracture fixation, the current body of evidence is unclear on the necessity of preserving the fibula and interosseous membrane when the focus of the investigation is on mid-diaphyseal tibial fracture stability.

In this study, we used a cadaver osteotomy fracture model to investigate the role of the fibula in the stability of diaphyseal tibial fractures. We selected four models of fibular involvement—intact, unfixed osteotomised, plated, and resected. Tibial fractures were fixed by reamed IM nailing. For each fibular configuration, we measured axial and torsional interfragmentary motion at the tibial fracture site and calculated the total construct stiffness under axial, torsion, bending, and shear loading conditions for comparison to previous investigations. We hypothesised that load-sharing through the fibula would produce observable variations in the stability of the tibial fracture.

2. Methods

2.1. Cadaveric samples

We used lower limbs from six formalin-fixed donors (two men and four women, aged 73 to 87 years). The tibia and fibula were harvested as an intact pair, preserving the proximal and distal ligamentous connections and interosseous membrane. All other soft tissue was stripped to the periosteum. Samples were held in saline throughout the testing to maintain hydration of the soft tissues.

2.2. Fixation devices

Tibial fixation was done with Synthes Expert Tibial Nails and screws (Synthes, 2006). Fibular fixation was done with 6-hole one-third tubular plates and screws. IM nail diameter and length were chosen to suit the individual donor anatomy using pre-operative computed tomography scanning (LightSpeed VTC XTE, GE Healthcare, Wisconsin, USA). Two independent observers estimated appropriate nail size post-reaming using a previously-described ovalisation model of the medullary canal (Galbraith et al., 2012). Nail sizes were selected to produce the best fit with each donor as would be the case in clinical practice. The only difference between our approach and standard clinical practice is that nail size is usually chosen during reaming by the cortical chatter technique, whereas our nails were pre-ordered, so size was estimated from the CT scans and assumed to be ideal a priori. Nail sizes used were one 10-mm, four 11-mm, and one 12-mm nail.

2.3. Surgical technique

Tibiae were reamed according to standard surgical technique, with last reamer used being 1 mm larger than the nail diameter chosen for that donor. A transverse midshaft diaphyseal osteotomy (AO 42-A3) was then performed at the approximate axial midpoint using a double-bladed oscillating saw. A spacer was used to maintain a consistent 3-mm gap throughout nail implantation and locking in all samples. Free-hand distal locking was carried out under image intensification with two mediolateral (ML) 5.0-mm screws. Proximal locking was carried out using the aiming instruments and two ML 5.0-mm screws. Samples were progressively modified after each round of mechanical testing as follows:

1. Fibula intact
2. Short oblique fibular osteotomy
3. Fibula fixed with 6-hole plate
4. Fibula and interosseous membrane resected

These configurations were selected to investigate whether loss of integrity of the fibula significantly destabilises the tibial fracture (Round 1 vs. 2), whether fixation of the fibula provides additional stabilisation for the tibial fracture (Round 2 vs. 3), and whether removal of the fibula and interosseous membrane significantly changes the observable interfragmentary motions and measured stiffnesses in the tibia (Round 4 vs. 1–3). The fibular osteotomy was slightly oblique to compensate for the small gap created by the saw blade and allow for direct apposition to be achieved in plating, as would be the case in a clinical setting.

2.4. Biomechanical testing

The distal and proximal extremities of each sample were embedded in poly(methyl methacrylate) bone cement (PMMA; Technovit 3040, Heraeus Kulzer, Wertheim, Germany) using an established technique (Dailey et al., 2012; Dailey et al., 2013; Penzkofer et al., 2009). To prevent fusion of the nail and proximal bone fragment and preserve the ligamentous tibial/fibular connections, the nail entry portal and proximal/distal ends of the fibula were encapsulated in dental putty. The putty was extended to cover the entirety of the anterior and posterior ligaments and above the embedding depth of the bone cement. This procedure ensured that PMMA made contact with the tibia only during embedding. In some cases, excess putty above the bone cement was trimmed away after completion of the embedding procedure.

Following protocols developed by other investigators (Augat et al., 2008; Epari et al., 2007; Kaspar et al., 2005; Penzkofer et al., 2009; Schell et al., 2005) and applied by ourselves previously for characterisation of tibial IM nailing stability (Dailey et al., 2012; Dailey et al., 2013), we carried out testing in axial tension/compression, anteroposterior (AP) bending, and AP shear. The fixtures used are shown in Fig. 1. For axial and torsion testing, samples were mounted in a multi-axis materials testing machine (Zwick model Zwicki Z5.0TH, High Leominster, Herefordshire, UK) by means of a proximal cardanic hinge. The central mechanical axis of each tibia was aligned with the load-application axis to produce near-zero axial and torsion pre-load prior to commencement of each test cycle. Cyclic axial loading consisted of a peak compressive load of 75 kgf (735 N) and peak tensile load of 37.5 kgf, with a ramp rate of 0.25 mm/s. An extensometer (Instron model 2620, High Wycombe, Bucks, UK) was used to measure axial interfragmentary