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Assessment of the initial viscoelastic properties of a critical segmental long bone defect reconstructed with impaction bone grafting and intramedullary nailing

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ABSTRACT

Introduction: This study compared the initial viscoelastic properties of a segmental tibial defect stabilized with intramedullary nailing and impaction bone grafting to that of a transverse fracture stabilized with intramedullary nailing.

Materials and methods: Seven sheep tibiae were tested in compression (1000 N), bending and torsion (6 Nm) in a six degree-of-freedom hexapod robot. Tests were repeated across three groups: intact tibia (Intact), transverse fracture stabilized by intramedullary nailing (Fracture), and segmental defect stabilized with a nail and impaction bone grafting (Defect). Repeated measures ANOVA on the effect of group on stiffness/phase angle were conducted for each loading direction.

Results: The Intact group was significantly stiffer than the Fracture and Defect groups in bending and torsion ($p < 0.022$ for both loading directions), and was marginal for the Defect group in compression ($p = 0.052$). No significant differences were found between the Fracture and Defect groups ($p > 0.246$ for all loading directions) for stiffness/phase angle. In compression and bending, phase angles were significantly greater for the Fracture and Defect groups compared to Intact ($p < 0.025$), with no significant differences between groups in torsion ($p = 0.13$). Sensitivity analyses conducted between the Fracture and Defect group differences found that they were not of clinical significance.

Conclusion: The initial properties of a segmental defect stabilized with intramedullary nailing and impaction bone grafting was not clinically significantly different to that of a transverse fracture stabilized with intramedullary nailing.

1. Introduction

Adequate fracture stability is paramount not only for healing but also for minimizing complications, such as malunion and failure of fixation. Equally important, the stability of a fracture-internal fixation construct has a great influence on patient rehabilitation. These injuries can take between 3 and 12 months or more to heal [1], and even longer periods for complex and complicated cases, and are recognized to have a high cost burden [2]. Therefore, regaining early unrestricted loading through the affected limb is of major importance, not only for the patient, but also for reducing the cost burden on society and the health system. The association of a segmental bone defect compounds the healing of a long bone such that they require a longer time to heal [3,4], and pose increased difficulty in providing the stability that allows safe mobilization with functional loading, which we defined as weight bearing as tolerated by pain, as well as healing.

The most common treatment for femoral and tibial shaft fractures is intramedullary nailing [5–7]. Stabilizing a simple mid-diaphyseal fracture by an intramedullary nail allows interfragmentary load sharing and immediate weight bearing [8]. Although loading and dynamization is thought to stimulate bone healing across a fracture/nonunion site [9–11], this process was shown to be detrimental to healing in situations with bone defects and/or unstable fixations [7]. Cancellous bone allograft has been successfully used as an adjuvant bone filler in fracture nonunion and to reconstruct segmental bone defects [4]; however, without compaction the construct has to be protected from physiological

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loading until advanced stages of healing and bone graft integration are achieved [12]. By contrast, immediate stability and weight bearing (as tolerated) has been achieved when bone defects were reconstructed using compacted cancellous bone allograft with the technique of impaction bone grafting [13–16]. However, the role of impaction bone grafting in orthopedic trauma is yet to be established. Such a technique could be very beneficial to the treatment of some complex human posttraumatic pathology, which would otherwise involve lengthy periods of restricted weight bearing [4]. A recently published study investigated the concept of impaction bone grafting to treat critical segmental bone defects as a salvage procedure in patients in which none of the established techniques were thought to be applicable [16]. The technique proved to be successful in all three cases in which it was applied and, importantly, it also provided a strong enough construct to allow the patients to recommence immediate postoperative weight bearing for the first time in 8–36 months [16].

We hypothesized that the initial viscoelastic properties (stiffness and phase angle – a measure of energy absorption) of a critical segmental diaphyseal defect treated with intramedullary nailing and impaction bone grafting is not clinically significantly different to a transverse fracture treated with intramedullary nailing. To test this hypothesis we measured the initial stiffness and phase angle of a critical segmental diaphyseal defect [17] stabilized by a combination of intramedullary nailing with impaction bone grafting contained with compliant mesh wire in a sheep model. This was compared with the stability of a transverse diaphyseal fracture stabilized with an intramedullary nail, as well as with the mechanical properties of the intact bone as a control.

2. Methods

2.1. Specimen preparation

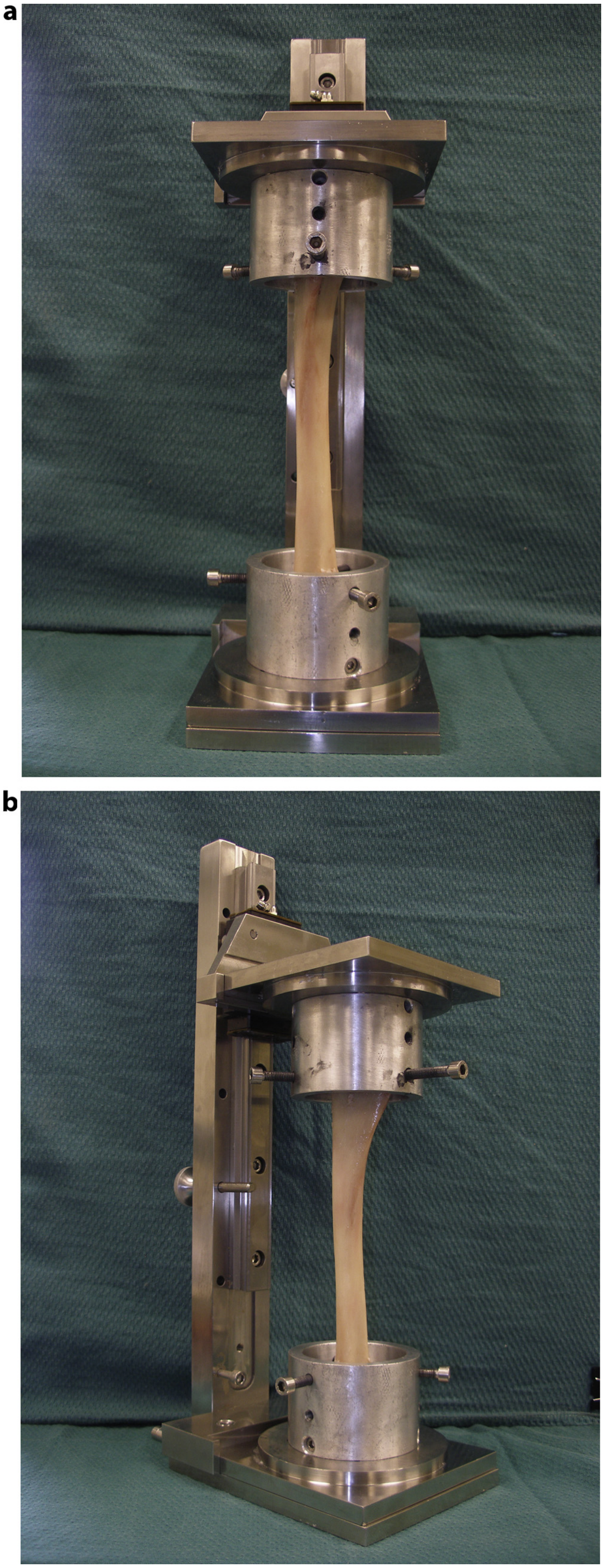
Seven fresh sheep tibiae were obtained from a local abattoir (age: three years, weight: 50–55 kg), sealed in plastic bags and frozen at −30 °C. Prior to the day of testing, all soft tissue was removed leaving the periosteum intact, after which the bone was wrapped in saline soaked gauze, re-sealed in plastic bags and frozen. The tibiae were then thawed at 4 °C overnight and stood at room temperature for a minimum of three hours prior to testing. The proximal and distal ends of each tibia were resected to the same length and cut parallel to each other using a bandsaw.

Cylindrical fixation cups were used to secure each end of the tibia. Additional fixation was achieved using three 6 mm stainless screws with pointed tips, which were inserted into the cortices of each end and tightened using a wrench. A custom-made alignment device was used to ensure that the superior and inferior cups were parallel to each other and the tibia was aligned such that its longitudinal axis was perpendicular to each cup surface (Fig. 1).

2.2. Biomechanical testing

All testing was conducted in a custom-developed six degree of freedom hexapod robot [18]. Briefly, the hexapod robot was based on the concept of the Stewart Platform and employs six servo-controlled ball screw driven actuators that precisely position a mobile upper plate with respect to a fixed base plate (Fig. 2a). Specimens were bolted between the fixed base and the mobile upper plate. Displacements and rotations of the specimen were directly measured by six linear optical encoders with a resolution of 0.5 μm (B366784180185; LDM54, MicroE Systems, Inc., MA, USA) that were positioned independently to the loading frame (i.e. actuators) and load cell. This configuration eliminated system compliance from the measurement of specimen behavior. Forces and

a



b

Fig. 1. (a and b) Front and oblique photographs of the alignment device used to ensure that the potted ends of the tibia were parallel to each other and aligned with the vertical axis of the hexapod robot. The alignment device consisted of a vertically orientated precision linear rail and bearing block to which each fixation cup was mounted.