Mechanical testing of an intramedullary nail for an in vivo study in sheep

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Summary

Bone transport is a well-established technique for the reconstruction of segmental bone defects. Intramedullary nails (IMNs) are a viable alternative to external fixation in managing these defects. This research outlines the design and testing of an IMN for use in an in vivo study in sheep. The IMN underwent compression, torsion and four-point bending tests. Mechanical testing showed that the IMN withstood an axial force of 11.8 kN, representing almost ten times the axial force experienced by a sheep tibia in normal motion at 0.83 m/s.

Introduction

Significant bone loss may occur due to trauma, infection, congenital abnormalities, nonunion or cancer [1]. This may result in a critical-sized defect in the affected bone, requiring surgical intervention to reconstruct the defect to provide the patient with the best possible functional outcome whilst avoiding amputation. Current methods include those based on the Ilizarov or Masquelet techniques, which may involve the use of allogenic or autogenic bone grafts, prosthetic surgery, external fixtures, plates or IMNs utilizing bone transport [1]. Current bone transport IMNs require daily input using an active external device to achieve the required distraction. This study aimed to develop an IMN with novel bone transport technology to reconstruct critical-sized bone defects in sheep.

Methods

The IMN dimensions were based on measurements of seven sheep tibia and subsequent CT scans. An osteotomy was performed in one of the bones, and the intramedullary cavity was drilled so that the maximum outer diameter (OD) of the nail could be determined. The tibia selected had the smallest OD of 18.5 mm in the medial-lateral (ML) plane and 15.6 mm in the anterior-posterior (AP) plane. The distal bone segment was drilled in 0.5 mm increments from 8 mm to 11 mm. A crack formed after using the 11 mm drill, indicating that this was the maximum this bone could be reamed to and, therefore, the maximum OD for the nail. The inner diameter of the nail was made as large as possible to accommodate the distraction mechanism.

Figure 1: Stainless steel prototype IMN

The IMNs were fabricated from stainless steel 316 (Figure 1). PEEK was used to replicate cortical bone since it has a similar Young's modulus of 13 GPa and a bending elastic modulus of 11.5 GPa. The PEEK and IMNs were connected via four bi-cortical surgical screws (Veterinary Instrumentation) and potted in PMMA within custom fixtures (Figure 2a).

The mechanical testing was based on ASTM standard F1264-16 – Standard specification and test methods for intramedullary fixation devices [2]. The IMNs underwent compression, torsion, and four-point bending on a servo hydraulic testing machine (Figure 2). For the compression test (Figure 2a), the IMNs were pre-loaded to 100 N, after which a compressive force was applied at a rate of 0.1 mm/s until a displacement of 5 mm was recorded. For the torsion test, a torque was applied at a rate of 5 deg/min for 15 degrees. For the four-point bending (Figure 2b), a compressive load was applied in the AP plane at a rate of 0.1 mm/s for 10 mm.

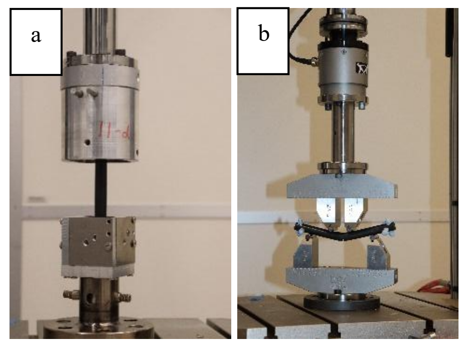

Figure 2: Mechanical testing setups; a) Compression test, b) Four-point bending test

Results

The IMN withstood a compressive force of 11.8 kN, a torque of 14.4 Nm and a peak bending force of 2580 N. After conclusion of the compression and torsion tests, it was noted that none of the samples had visible signs of deformation. The sample in the bending test had a visible crack in the PEEK and permanent deformation had occurred.

Discussion

For a sheep in normal motion, the tibia experiences an axial force of 2.12 times body weight (BW), a shear force of 0.7 times BW in the AP direction and 0.2 times BW in the ML direction [3]. The IMNs produced in this study were able to endure a compressive load almost ten times the force experienced in a sheep with an average BW of 60 kg. Additionally, the IMNs withstood over 5 times the shear force experienced in the sheep tibia.

References

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