Percutaneous Screws for the Treatment of Long-Bone Fracture Non-Union

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Introduction

Non-union is a disabling and psychologically debilitating health condition that affects 8% of long-bone fractures fixated by intramedullary means [1], and arises in the final stages of healing when an overly compliant construct permits magnitudes of inter-fragmentary motion beyond that which can be tolerated by bone [2,3]. The current gold standard for non-union treatment is to exchange the original construct for a stiffer one. However, this is a costly and highly involved procedure with which complications are common. Clinical data suggests that the shear arising from oblique fracture angles has a key role in non-union development, and that this can be countered minimally invasively through the percutaneous insertion of interfragmentary strain reduction screws, as part of an outpatient procedure [4]. Therefore, the aim of this study was to develop an intramedullary fracture fixation model, before exploiting this to biomechanically assess the efficacy of percutaneous screws (PSs), as compared to exchange nailing, for the treatment of non-union.

Materials and Methods

A homogenous and anisotropic Sawbones 3401 tibial bone model (representative of a medium sized, middle-aged, 80 kg female adult) was first prepared for non-linear finite element analysis within ABAQUS. Next, this was osteotomized to create a simple, oblique, diaphyseal fracture of AO classification 42A2b encased within a granulation tissue callus, prior to being reamed, and finally fixated with a reverse engineered Stryker T2 nail of 10 mm outer diameter (OD). Each screw-bone contact was thought to comprise a softened normal component, as well as an axial component, governed by friction and a set of 8 linear springs. Furthermore, hard, frictional contacts were defined for both the screw-nail and bone-nail interfaces, whilst the callus was tied to the tibia's periphery. Physiological joint reaction and muscle forces were applied to the tibia to simulate the phase of the gait cycle when deformation of the mid-shaft is greatest for 50% weight-bearing, with all degrees of freedom being simultaneously fixed at three nodes situated upon the distal epiphysis to prevent rigid body motion (see Fig.1).

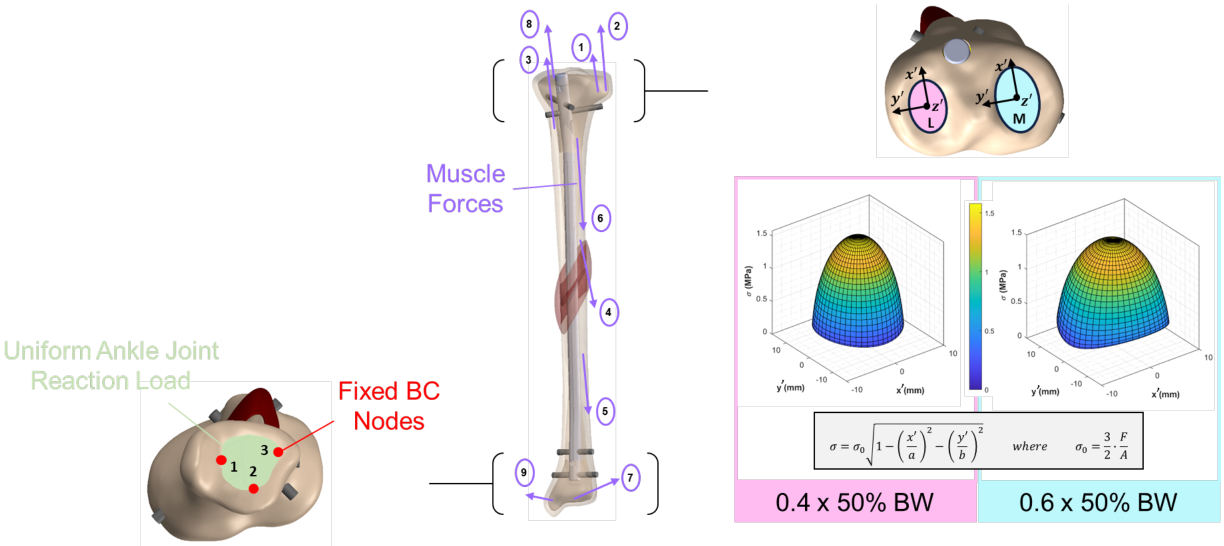

Fig. 1: Physiological loading and boundary conditions defined with the finite element model.

Following validation of the model by way of sub-modelling, conducting sensitivity studies and making comparisons with published experimental data, the effectiveness of 4 different PS configurations (see Fig. 2) were assessed alongside that of an 11 mm and 12 mm OD exchange nail. This was achieved through numerical quantification of axial and shear inter-fragmentary motion (IFM), alongside a healing performance index, which was derived from the outputted elemental deviatoric callus strains using mechano-regulation theory. Finally, all possible implications of fracture gap width, fracture angle, fracture orientation and degree of weight-bearing on the findings were investigated.

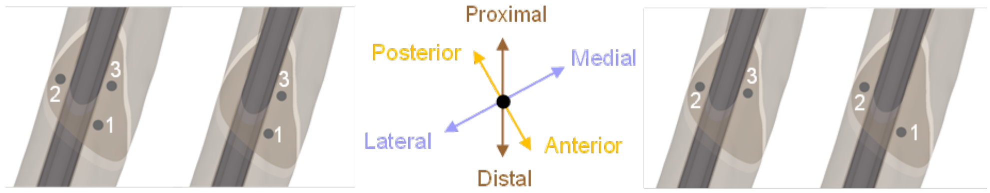

Fig. 2: The four different percutaneous screw configurations biomechanically analysed as part of this study.

Results

Although exchange nails of 11 mm and 12 mm OD had little effect on shear IFM, they suppressed axial IFM by ~15% and ~30%, respectively. As such, it was found that healing potential (HP) increases at an increasing rate with increasing nail outer diameter. Conversely, all PS configurations comprising a screw positioned close to the medial border reduced both axial and shear IFM by ~15%, giving rise to a similar net effect on HP as an 11 mm OD exchange nail (see Fig. 3).

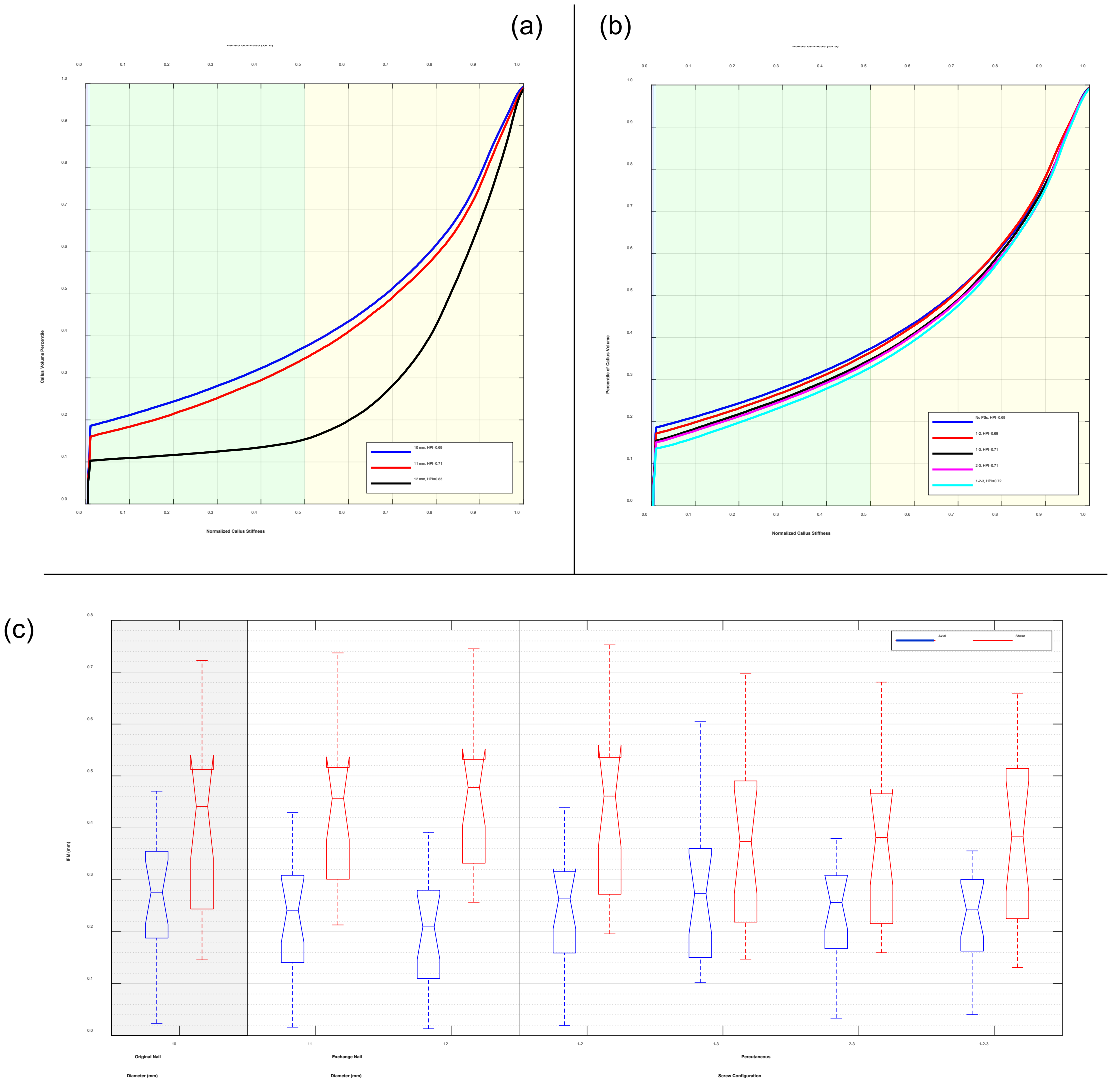

Fig. 3: (a) Healing performance plot demonstrating the effectiveness of an 11 mm and a 12 mm OD exchange nail. (b) Healing performance plot demonstrating the effectiveness of different percutaneous screw configurations. (c) Box plot of the axial and shear inter-fragmentary motion arising when an 11 mm and a 12 mm OD exchange nail is used to treat non-union, as compared to different percutaneous screw configurations.

Fracture gap width had minimal effect on axial IFM, yet larger gaps culminated in greater shear IFM, diminishing the HP. A similar trend was observed for both fracture angle and fracture orientation: heightening obliquity in the sagittal plane led to greater shear IFM and inferior HP, alongside only meagre differences in axial IFM, as compared to shallower angles in the coronal plane. In contrast, both axial and shear IFM proved smallest at 25-50% weight-bearing, resulting in HPs superior to the 0% and 75% weight-bearing cases.

Discussion

The acquired results support clinical data, biomechanically demonstrating that PSs can be as effective as exchange nailing for the treatment of non-union, although exchange nails of sizeable OD should always be preferentially adopted for the most unstable fractures. Furthermore, it is now apparent that PSs function as anti-shear pegs, supressing both axial and shear IFM. This is in contrast to exchange nails, which are solely able to stabilise fractures in the axial direction. Thus, it can be inferred that PSs become an increasingly viable option for treating steeper fractures with larger gap widths, since it is these types of geometry for which the ratio of shear to axial IFM is greatest. Additionally, there is strong evidence to suggest that surgeons should encourage their patients to bear a small portion of their weight with immediate effect following treatment, as although counterintuitive, this will help to counteract tibial muscle forces, whilst keeping instabilities caused by excessive joint reaction loads to a minimum.

Conclusion

This study provides new insight into the biomechanics of healing for long-bone fractures fixated using intramedullary methods, and supports several clinical observations, namely: 1) PSs act as anti-shear pegs, giving them the capability of enhancing healing as much as a small OD exchange nail, 2) larger fracture gaps and angles elevate shear IFM, which compromises healing and may be best countered through the use of PSs, and 3) partial weight-bearing can facilitate healing. Overall, it is hoped that these findings help to improve non-union treatment prognoses, thus alleviating the significant financial and clinical burden non-unions pose both to the UK and worldwide.

References

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