Analyzing Blade Plate Implant Positioning Effects on Initial Stability Following Proximal Femoral Osteotomy: A Comparative Neuromusculoskeletal Finite Element Study

Emmanuel Eghan-Acquah[1], Azadeh Nasseri[1], Martina Barzan[1], Stefanie Feih[1], Chris Carty[1]
[1]Griffith Centre of Biomedical and Rehabilitation Engineering (GCORE), Griffith University, QLD, Australia
Presenting Author Email: emmanuel.eghan-acquah@griffithuni.edu.au

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INTRODUCTION: A proximal femoral osteotomy (PFO) is a widely used surgical procedure to correct hip deformities in the paediatric population. The stability provided by the blade plate, the standard implant for fixation [1], is crucial for enabling early patient mobilization and a rapid progression to full weight-bearing. Insufficient post-surgical stability can lead to excessive micromotion (>40 µm), associated with aseptic loosening [2]. Although previous reports underline the impact of fracture fixation device positioning on implant performance [3,4], the contribution of implant positioning in the femoral neck to the risk of aseptic loosening remains underexplored in PFO. In this study, we employ a neuromusculoskeletal (NMSK)-informed finite element (FE) modelling framework to investigate the impact of blade plate placement in the femoral neck on micromotions during the stance phase of the gait cycle.

METHODS: A comprehensive NMSK-informed finite element (FE) modelling framework was developed (Fig.1a) for this study. Postoperative computed tomography (CT) images and gait laboratory data of three participants (age: 11.7 ± 0.6 years, mass: 94.4 ± 10.4 kg, height: 1.74 ± 0.04m), who underwent PFO to treat femoral neck varus and external femoral torsion, were used in this study. The gait data involved three-dimensional (3D) whole-body motion, ground reaction forces (GRF), and surface electromyography (EMG) acquired during walking at a self-selected speed. Motion and GRF data were combined in OpenSim [5] to calculate joint angles, joint moments and muscle-tendon lengths and moment arms. The OpenSim model was personalized to represent each patient's bone geometry and muscle attachment locations. OpenSim modelling outputs were then combined with EMG data and used in a calibrated EMG-assisted model (CEINMS) [6] to estimate hip contact and muscle forces over the stance phase of the gait cycle. 3D FE models of the affected femur for each patient were constructed in Abaqus (v2022, Dassault Systèmes) from segmented postoperative CT images (Materialise, Leuven). For each patient, three surgical FE models were created by inserting the blade plate at three different locations in the femoral neck: inferior, middle, and superior (Fig. 1b). Hip contact and muscle forces were applied as loading conditions for the FE models. Implant micromotions were calculated over 7 equally spaced time points across the stance phase and compared between the three locations and patients.

RESULTS: The resultant mean (± standard deviation) micromotion for the superior, middle, and inferior positions were 22.11 ± 12.10 µm, 26.00 ± 13.67 µm, and 28.64 ± 15.21 µm, respectively across the stance phase of the gait cycle (Fig 1c). The maximum micromotion observed for the three positions were 54 µm, 46.55 µm, and 52.45 µm, respectively. Multiple pairwise comparisons revealed no significant differences between the three groups ($p > 0.279$). Furthermore, the inter-participant variability exceeded the mean difference between positioning.

DISCUSSION: The findings suggest that the choice of blade plate placement in the femoral neck may not significantly affect micromotion during the stance phase of the gait cycle. Nevertheless, it is important to acknowledge that although not statistically significant, the observed variations in micromotion values highlight the importance of personalized surgical approaches and implant selections to address individual patient needs effectively. Further research, including larger sample sizes and investigations into implant stresses and strains, will be valuable in confirming these findings and refining surgical strategies for improved patient outcomes following proximal femoral osteotomy.

SIGNIFICANCE/CLINICAL RELEVANCE: This study emphasizes the significance of personalized surgical approaches for PFO. The findings of this study contribute to surgical optimization approaches, potentially reducing the risk of aseptic loosening and improving patient outcomes in the paediatric population.

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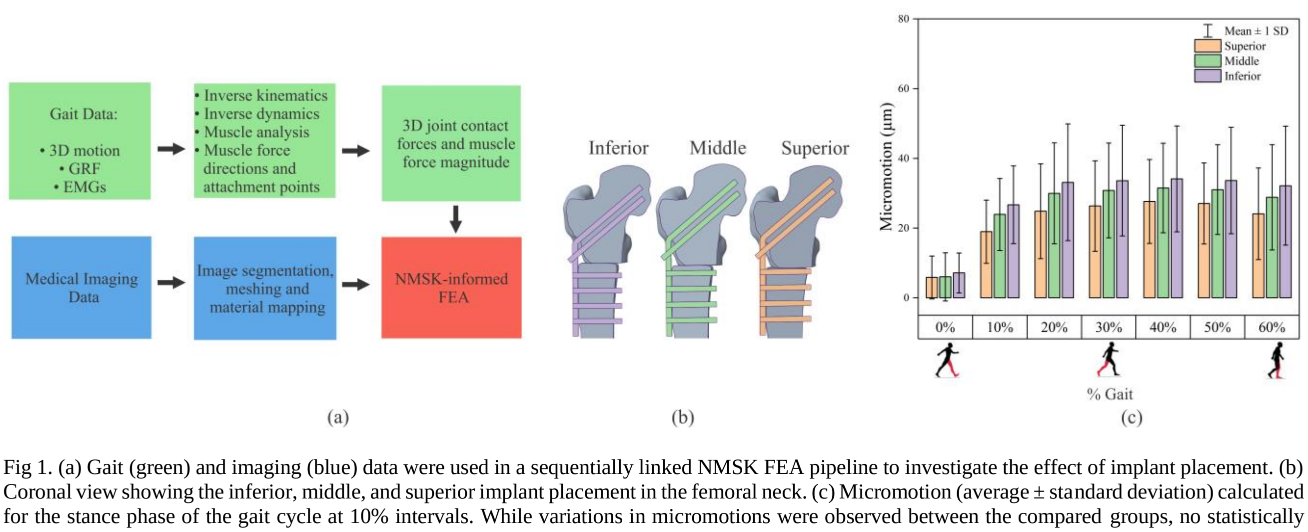

Fig 1. (a) Gait (green) and imaging (blue) data were used in a sequentially linked NMSK FEA pipeline to investigate the effect of implant placement. (b) Coronal view showing the inferior, middle, and superior implant placement in the femoral neck. (c) Micromotion (average ± standard deviation) calculated for the stance phase of the gait cycle at 10% intervals. While variations in micromotions were observed between the compared groups, no statistically significant difference ($p > 0.279$) was reported.