Proximal Failure in Retrograde Intramedullary Nail Fixation of Distal Femur Fractures

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INTRODUCTION: Retrograde femoral intramedullary nails (rIMN) are used to treat fractures of the diaphyseal, distal metaphyseal, and distal articular femur. rIMNs are being used increasingly in the geriatric population who are at risk for recurrent falls and additional femoral fractures. The factors that impact the risk of peri-implant fractures adjacent to these nails is not known. Decisions made by surgeons on which length of rIMN to choose are based on extrapolation from mechanical principles and consideration of patient anatomy. The effects of modifiable nail characteristics, such as nail termination level, on the risk of peri-prosthetic fracture are not well understood. We therefore propose to study the effect of different length rIMN on the location and extent of failure in an osteoporotic femur model using finite element analysis (FEA).

METHODS: A virtual model of a standard synthetic osteoporotic femur was developed with distinct cortical and trabecular layers. Five virtual rIMN models, each with a 9 mm diameter, of lengths 200 mm, 240 mm, 280 mm, 300 mm, and 320 mm, and interlocking screws were obtained from an orthopedic device manufacturer. Using image processing software, material properties, mesh, and contact properties were defined. Material properties specified by the manufacturer of the synthetic femur for epoxy cortical bone and foam trabecular bone were defined as homogenous materials. A 2 cm – wide transverse fracture was produced in the distal metaphysis of all scenarios. The loading scenarios tested were single-leg stance (SLS) and lateral impact/ "fall" (LIF). In SLS, femurs were loaded axially through the femoral head with 80 kg of body weight (784 N) and fixed in rotation and translation ("encastered") at the distal femur around the femoral condyles. In LIF, the entire femoral head was encastered and a perpendicular force was applied to the lateral surface of the greater trochanter. Ultimate tensile stress (UTS), a measure of the limit of stress beyond which an element in FEA fails/ experiences fracture, was calculated to determine locations of likely fracture. Maximum stress for each nail length and loading scenario were tabulated with corresponding heat map of stresses in addition to a map of fractured elements.

RESULTS SECTION: For cortical elements, the UTS was 181.39 MPa and for trabecular ones the UTS was 4.36 MPa. Maximum stresses were below the UTS across all rIMN lengths in the SLS scenario. The longer the rIMN, the lower the maximum stress. For LIF, maximum stresses all exceeded the cortical UTS, indicating that across all lengths, fracture occurred in LIF. In LIF, however, shorter rIMN lengths (200 – 280 mm) saw higher the maximum stresses but plateaued and even decreased with longer rIMNs (280 – 320 mm). All fractured elements were only found in the femoral neck. There were no fractured elements adjacent to the rIMN.

DISCUSSION: We were able observe a partial trend of increasing maximum stress from 200 mm to 280 mm rIMN lengths. However, maximum stress appears to plateau at a length of 280 mm and decrease somewhat with longer rIMN length. However, the location and percentage of failed elements in LIF across lengths did not differ. Maximum stress for IMN and percentage of failed elements, therefore, may be represented parabolically wherein there exists an rIMN length (280 mm in our case) or range of lengths which surgeons should avoid. Additional study of rIMN implantation with multiple samples of synthetic femurs with an expanded range of rIMN lengths is recommended for validation. Most notably, failure and the most significant stresses in LIF were limited to the femoral neck region, discounting the risk of peri-prosthetic fracture at any rIMN length. These results demonstrate that, although there are rIMN lengths that are associated with increased stress, there is no apparent risk of peri-prosthetic fracture in our FEA scenarios.

SIGNIFICANCE/CLINICAL RELEVANCE: Understanding potential location and magnitude of failure of rIMNs helps surgeons understand how to choose implant length for individual patients. Length of rIMNs will continue to be a relevant variable in outcomes for patients with distal femur fractures.

IMAGES AND TABLES:

Table 1: Maximum stresses with listed locations for each intramedullary nail length and loading scenario combination. Percentage of failed elements for LIF is included.

	Loading Scenario					
	Single-Leg Stance		**Lateral Impact/ "Fall"**			
Intramedullary Nail Lengths (mm)	**Max. Von Mises Stress (MPa)**	**Location of Maximum Von Mises Stress**	**Max. Von Mises Stress (MPa)**	**Perc. Failed Elem. Cort.**	**Perc. Failed Elem. Trab.**	**Location of Maximum Von Mises Stress**
200	64.12	Distal end of most proximal screw	258.2	1.46%	0.02%	Inferior aspect, head/neck junction
240	55.05	Approximately 1-3 cm proximal to most proximal screw	286.9	2.06%	0.08%	Superior aspect, head/neck junction
280	53.65	Approximately 1-3 cm proximal to most proximal screw	293.4	2.65%	0.22%	Superior aspect, head/neck junction
300	51.31	Approximately 1-3 cm proximal to most proximal screw	291.4	2.14%	0.09%	Superior aspect, head/neck junction
320	47.02	Approximately 1-3 cm proximal to most proximal screw	279.1	1.95%	0.12%	Inferior aspect, head/neck junction