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 are 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-implant fracture are not well understood. We therefore propose to study the effect of different length rIMN on the location and extent of fracture in an osteoporotic femur using finite element analysis (FEA) and validate it using a synthetic femur model.

METHODS:

Two models were used and compared: finite element (FEA) and synthetic femur. A 3D model based on a synthetic osteoporotic femur was developed for FEA with distinct cortical and trabecular layers. Eight rIMN virtually rendered models, each with a 9 mm diameter distances of 170 mm, 130 mm, 90 mm, 70 mm, 30 mm, and 10 mm below the lesser trochanter and 10 mm above the lesser trochanter. Using image processing software, material, 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. Real nails and synthetic femurs (n = 5 per nail) were purchased from the respective manufacturers. The loading scenarios were the same for both FEA and synthetic femur rIMN models. 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 distally around the femoral condyles. In LIF, the femoral head was fixed in rotation and translation and elements of the lateral surface of the greater trochanter were displaced at a rate of 150 mm/sec. Ultimate tensile stress (UTS), a measure of the limit of stress beyond which a material fails, was 76 MPa. 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. Synthetic femurs were also loaded in SLS and LIF. Stiffness was compared to FEA using a paired two sample t-test.

RESULTS:

In SLS, there appeared not to be any notable changes in maximum stress from distances 70 mm to 170 mm below the lesser trochanter, but we then observed a decrease in maximum stress from 70 mm below the lesser trochanter to 10 mm above the lesser trochanter. For LIF, maximum stresses all exceeded the cortical UTS, indicating that across all lengths, fracture occurred in LIF. The trend in maximum stress was somewhat like SLS, where from 70 mm to 170 mm below the lesser trochanter, there was some increase, but from from 70 mm below the lesser trochanter to 10 mm above the lesser trochanter, there was a notable decrease in maximum stress. All fractured elements were only found in the greater trochanter, proximal to nail termination. Maximum stresses were below the UTS across all rIMN lengths in the SLS scenario. There was no notable difference in the percentage of failed elements in the LIF scenario. There were no fractured elements adjacent to the proximal termination of the rIMN. A paired t-test demonstrated no significant difference between FEA and synthetic femur models ($p=0.22$).

DISCUSSION AND CONCLUSION:

Failure and the most significant stresses in LIF were limited to the greater trochanter and femoral neck regions, discounting the risk of rIMN length-dependent peri-implant fracture. These results demonstrate that, although there are rIMN lengths that are associated with increased stress, there is no apparent biomechanically relevant risk of peri-implant fracture in our FEA scenarios. Observational clinical studies are recommended to determine whether femoral nail length is correlated with fracture healing or whether there are any differences in outcomes of proximal femur fractures when femoral nails of different lengths are involved. The stress trends observed in both SLS and LIF with rIMNs may or may not prove clinically significant. Such types of observational studies will aid in assessing the clinical impact of rIMN length.

Figure 1: Examples of (a) greater trochanter and (b) greater trochanter and femoral neck fractures.

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

	Loading Scenario					
	Single-Leg Stance		Lateral Impact/ "Fall"			
Distance (mm) from rIMN tip termination below Lesser Troch.	**FEA Max. Von Mises Stress (MPa)**	**FEA Location of Maximum von Mises Stress on the Synthetic Femur**	**FEA Max. Von Mises Stress (MPa)**	**Perc. Failed Elem. Of Total Femur**	**FEA Location of Maximum von Mises Stress on the Synthetic Femur**	**Type of Fracture in Synthetic Femur**
170	22.93	Medial side, level of the second-most proximal screw.	147.40	0.0249%	Lateral most aspect of greater trochanter	Greater Trochanter
130	23.63	Lateral side, 1-3 cm proximal to most proximal screw	157.60	0.0359%	Lateral most aspect of greater trochanter	Greater Trochanter, Femoral Neck
90	18.11	Medial side, 1-3 cm proximal to most proximal screw	134.30	0.0125%	Lateral most aspect of greater trochanter	Greater Trochanter, Femoral Neck
70	21.57	Medial side, 1-3 cm proximal to most proximal screw	173.00	0.0323%	Lateral most aspect of greater trochanter	Greater Trochanter, Femoral Neck
50	16.13	Medial side, level of the second-most proximal screw.	170.70	0.0343%	Lateral most aspect of greater trochanter	Greater Trochanter
30	13.25	Medial side, level of the proximal-most screw.	134.50	0.0312%	Lateral most aspect of greater trochanter	Greater Trochanter
10	11.35	Medial side, level of the proximal-most screw.	124.50	0.0140%	Lateral most aspect of greater trochanter	Greater Trochanter
10 above lesser troch.	9.87	Medial side, center of the femoral diaphysis	140.20	0.0140%	Lateral most aspect of greater trochanter	Greater Trochanter, Femoral Neck