Effects of Reaming the Femur for Bone Graft: A Study of Torsion on Normal and Osteoporotic Bone

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Introduction
The development of reaming devices as tools for the harvesting of medullary bone graft from the femur has led to an interest in the effects of this harvest on the strength of the bone. Reaming an intact human femur without subsequent stabilization potentially places the bone at increase risk of fracture. Here, we present an analytical model for predicting the weakening effect of reaming as a function of cross-sectional geometry, eccentricity, and bone mineral density (BMD) in cadaveric femora.

Methods
An analytical-graphical method to clinically predict pre-operatively the effect of ream diameter and/or eccentric reaming on the reduction in torsional strength of normal and osteoporotic femurs is developed. To identify parameters, an eccentric circular model of a femur's perosteal and endosteal perimeters was used to develop an equation for its torsional strength $T_s = G^*\tau_s$. $\tau_s$ is shear stress on thinnest bone. $G = (2J/d_p)^*E$. Size factor $2J/d_p$ is a function of perosteal diameter $d_p$ and endosteal diameter ratio $d_e/d_p$. Eccentricity factor $E$ is a function of $d_e/d_p$ and eccentricity ratio $e/d_p$. Twenty matched fresh frozen femurs were obtained: 4 pair with normal BMD, 3 osteopenic and 3 osteoporotic. One femur of each pair was radiographed, CT’ed, then reamed with single pass reamer (1.5mm or less larger than $d_e$ measured from radiograph), and then re-CT’ed. The contralateral was radiographed, CT’ed and tested un-reamed. Femurs were potted-mounted in an Instron biaxial machine to apply an initial 10 N axial pre-load and then rotate the proximal end until fracture. $T_s$ and axial force $F_a$ at fracture were determined from Instron's data acquisition record. Periosteal and endosteal circles were fit tangent to the thinnest wall of the CT scan's cross section at fracture location, from which $d_p$, $d_e$, and $e$ were measured; and $d_e/d_p$, $e/d_p$, $2J/d_p$, $E$ and $G$ calculated. $\tau_s = T_s/G$ was calculated and used with $F_a/(Area)$ to calculate the bone's effective tensile strength. Student T (two tail, unequal variance) was used to determine significance, $P<0.05$.

Results
The analytical model predicted increasing sensitivity to torsional strength reduction by over/eccentric reaming for femora with increasing $d_e/d_p > 0.4$. Compared to normal, un-reamed osteoporotic femurs were found to statistically have: a) same $d_p$ but higher $d_e/d_p > 0.7$ ratio, b) lower $2J/d_p$, E and G, c) lower bone tensile strength, and d) as a result lower torsional strength $T_s$ (Fig. 1). Reamed femurs had statistically insignificant lower $T_s$ and G than their un-reamed contralateral, osteoporotic due to ream size approximately equal to un-reamed $d_e$. Effective tensile strength correlated linearly to BMD. $d_e/d_p$ ratio correlated to BMD in an inverse linear fashion. $T_s$ correlated to $G$ in linear fashion within a group of femurs having similar bone tensile strength (normal, osteoporotic), and thus $G$ after/before reaming would predict strength reduction.

Discussion
Osteoporotic femur’s were found to have significantly compromised torsional strength, and be more sensitive to over and eccentric reaming than normal femurs due to their higher $d_e/d_p$ ratio. Clinically, femurs with $d_e/d_p > 0.7$ (osteoporotic) should not be considered as donor for intramedullary bone graft harvesting.

It was possible to predict the percent reduction of torsional strength after femoral reaming by using preoperative radiographs with our graphical model. This finding suggests the potential for a pre-operative tool to predict who will be at risk for post-reaming fracture. In the void of a biomechanical test, however, such a clinical application is not yet possible.

This study is limited by its small size and by virtue of being a biomechanical study without the dynamic interaction of the living human body and its environment. Despite these limitations, and based upon the data presented, we recommend against utilizing intramedullary reaming, for bone graft in the osteoporotic patient. If no other site of autologous bone graft exist, which should be the extremely rare occasion, the operative surgeon should choose to stabilize the femur with an intramedullary device after reaming.

![Fig. 1: Torsional Strength $T_s$](image)