INTRODUCTION:
Osteoporosis is characterized by low bone mass and bone microarchitecture deterioration. Trabecular bone consists of two major structure types: trabecular plate and rod, which contributes differently to bone's mechanical competence [1-3]. With the fast development of high-resolution imaging technologies, three-dimensional (3D) morphological analysis based on high-resolution bone images has been developed to quantify trabecular bone microstructure. Some of the derived parameters, such as bone volume fraction (BV/TV), have been widely used as indicators of bone's fracture resistance. However, standard morphological analyses of trabecular bone architecture lack explicit information about the quantity of plates and rods. A new 3D image analysis technique, individual trabecular segmentation (ITS), was developed to decompose trabecular bone network into individual plates and rods [3-4]. A set of morphological parameters were calculated based on morphology of each individual trabecular, and stratified by different structure types. The ITS parameters have been shown to highly correlate to computationally calculated elastic moduli and yield strength. In this study, we examined the relationship between the experimentally determined yield strength and the ITS parameters.

MATERIALS AND METHODS:
Tibiae were taken from 15 donors (age 70.6 ± 9.6 years; 11 male and 4 female) with no medical history of metabolic bone disease or cancer. Radiographs of the bone samples show no damage or bone pathologies. Forty five cylindrical bone samples were procured using protocols that have been described elsewhere [5]. Bone samples were scanned at 15µm resolution using a micro computed tomography (µCT) system (VivaCT 40, Scanco Medical, Switzerland). A material testing system (MTS810, Eden Prairie, MN) was used to perform the mechanical testing. In total, 22 specimens were loaded successfully to reach the yield point. Samples were loaded with 1 preconditioning cycle and then a ramp to the yield point with a constant strain rate 0.05%/s (1/a). The elastic Young's modulus and yield strength were determined from each stress-strain curve using the established protocol [5]. The 8 mm gage region of each sample was selected for 3D image reconstruction using a global threshold value. ITS morphological analyses were performed for thresholded bone image [3-4]. The ITS parameters included: plate and rod bone volume fraction (pBV/TV and rBV/TV), axial bone volume fraction (aBV/TV), plate and rod tissue fraction (pBV/BV and rBV/BV), plate and rod number density (pTb.N and rTb.N, 1/mm²), plate and rod thickness (pTb.Th and rTb.Th, mm), plate surface area (pTb.S, mm²), rod length (rTb.l, mm), and rod-rod, plate-rod and plate-plate junction densities (R-R, P-R and P-P Junc.D, 1/mm³). Pearson correlation coefficient was used to describe the correlation between ITS parameters and the Young's modulus or the yield strength. Partial correlation analyses between the ITS parameters and yield strength with the effect of BV/TV removed were also performed to study the independent contribution of ITS measurements to bone mechanical properties.

RESULTS:
The measured Young's modulus and yield strength of human tibial trabecular bone ranged between 293 to 1580 MPa, and 1.12 to 8.92 MPa, respectively. Not surprisingly, both modulus and yield strength highly correlated to bone volume fraction (BV/TV), r=0.93 and 0.92, respectively. New experimental data confirmed excellent correlations between Young's modulus or yield strength and ITS parameters such as pBV/TV or aBV/TV with r=0.95 for both (Fig. 1). However, there was no significant correlation between rBV/TV and yield strength. Table 1 gives the Pearson coefficients between ITS parameters and trabecular bone mechanical properties. In general, most plate derived ITS parameters correlated with experimentally determined Young's modulus and yield strength of human trabecular bone. Plate thickness, size, and Junc.D parameters showed modest correlation with Young's modulus or yield strength. From partial correlation analyses with the BV/TV effect removed, pBV/TV, aBV/TV, rBV/TV, and Tbs had significant and positive partial correlations with yield strength. rBV/TV, rBV/BV, pTb.N, rTb.N, R-R Junc.D, R-P Junc.D and P-P Junc.D showed significant and negative partial correlations with yield strength (Table 1).

DISCUSSION:
In this study, mechanical testing and micro computed tomography were performed on human tibial trabecular bone to establish the relationships between mechanical properties and novel ITS parameters. The results are significant as accurately and experimentally determined mechanical properties of human trabecular bone are considered as the gold standard, compared to computationally determined properties. In addition, this study confirmed that pBV/TV and aBV/TV (a parameter indicating aligned trabeculae) contribute strongly and dominantly to mechanical properties of human trabecular bone. With BV/TV influence removed, many ITS based parameters remained as significant contributors to mechanical properties of trabecular bone. This supports the notion that ITS based parameters may provide independent quantifiers of bone strength in addition to bone mass.

REFERENCE:

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