Proximal Tibial Bone Mineral Density Mapping Using Phantomless CT Scans

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INTRODUCTION: Cementless total knee arthroplasty (TKA) offers the benefit of biologic fixation, preservation of native bone and improved surgical efficiency [1,2]. Successful cementless TKA relies on initial stability and biological osseointegration which is influenced by patient bone quality and host bone viability [1]. Pre-operative bone mineral density (BMD) assessment can provide early insight into quality of a host bone. Intra-operatively, although surgeons focus on maintaining quality and integrity of a host bone, it can be difficult to assess bone quality below the resection plane. Understanding of how BMD changes near resection planes can assist surgeons in determining if a patient is a candidate for a cementless TKA. Furthermore, it can help implant developers in designing cementless devices. Therefore, the objective of this study was to assess how BMD changes on and near the resection plane in the proximal tibial region.

METHODS: For this study, pre-TKA CT scans of 427 lower legs were used. Phantoms with known densities have been routinely used to determine the BMD. Recently, in CT scans without Phantom, air-fat-muscle densities have been used to determine BMD [3]. The validation of this methodology using subset of same CT scans has been reported previously [4]. The root mean square error between Phantom and Phantomless BMD in proximal tibiae ranged between 9.1-17.1mg/cc [4]. The same methodology was utilized in this analysis. For each tibia, its proximal mid-point, medial-lateral AP width, and medial-lateral dwell points were determined. A virtual resection plane was prepared at 9mm from the unaffected tibial plateau, to simulate proximal tibial cut of the TKA (Fig. 1). The CT slice closest to this plane was selected (referred as slice L1, Fig.1), and a grid of 3x3 points on the slice was identified (Fig. 1). Anterior and posterior points of the grid were 30% of the tibial medial AP width, from the proximal tibial center, and medial-lateral dwell points. At each point, the BMDs within the virtual cube of 3x3x3mm were estimated using Phantomless technique, and later averaged to represent a single density value. Same process was repeated at two additional slices (referred as slice L2 and L3, Fig. 1), 3mm and 6mm distal to the resection plane. These steps were repeated in rest of the tibiae. Average BMDs across each slice (L1 to L3) and its change across these slices for all tibiae were recorded. Significant differences in the mean BMD values within studied slices and medial and lateral plateau were reported (p<0.05).

RESULTS: The demographic details are (Avg±SD): Weight:178±36lbs, Height: 66.1"±4.1", BMI: 28.7±5.6, M/F: 186/241, L/R: 205/222. The average BMD at L1, L2 and L3 were 79.8±27.3mg/cm^3, 75.8±25.3mg/cm^3, 75.3±24.8mg/cm^3, respectively (Fig. 2). The BMD at the resection plane (L1) was slightly higher than those of L2 and L3, but the difference was significant (p<0.05). At L1 to L3, the average BMDs at the anterior-medial location were the highest, and they were the least at posterior-lateral region (Fig. 2). Additionally, the posterior-central region demonstrated second highest average BMD magnitudes at all studied slices. In medial plateau, the BMD values dropped significantly from anterior to posterior direction at all three slices: L1 to L3. Similar trends were observed on lateral plateau; however, they were significantly smaller than their corresponding BMD values on the medial plateau (Fig. 2-b). When medial and lateral BMDs at three slices were averaged, the BMD values located on medial compartment were significantly higher than those of the lateral compartment (Fig. 2).

DISCUSSION: Good host bone quality is an essential requirement for successful osseointegration of press-fit implants [1,2]. Clinicians have recommended avoiding utilizing cementless implants in patients with decreased bone density [1]. However, during TKA, complete assessment and examination of a host bone quality may occur after making primary resections. Therefore, preoperative understanding of how BMD changes within and across tibiae could assist surgeons intraoperatively, and implant developers in designing process. Our results demonstrated that the average BMD was higher on the anterior-medial compartment, which reduced in posterior-lateral direction. Mechanical loading has been known to stimulate bone formation [5]. In native knee, the medial compartment carries more compressive load than that of the lateral [6]. Moreover, the medial compartment is larger and more conforming than lateral [6]. The unique anatomy has shown to produce smaller condylar AP motion medially, concurrent with the larger AP motion laterally. Such a kinetic and kinematic combination potentially creates higher and more concentrated compressive loads on medial compartment, which may have contributed to the higher medial BMDs observed in this study. The cementless tibial trays typically have design features, such as keels, pegs, nails etc., which are intended to produce initial stability. These fixation features penetrate on a tibial bone right below the proximal tibial resection plane. We observed that the average BMD reduced slightly at 3mm below the resection plane, but it remained constant for 3mm distal to L2. It may imply that by visually assessing quality of a host bone at the resection level, surgeons can anticipate quality of the underlying bone, where tray fixation features mate with the underlying bone. In summary, the research highlighted ability of Phantomless BMD technique in mapping BMD of the proximal tibia.

SIGNIFICANCE/CLINICAL RELEVANCE: Use of Phantomless techniques to determine tibial BMD mapping at the resection plane of primary TKA can provide insight into the quality of a host bone in Cementless application.

REFERENCES: 1. Asokan *et al.*-2021, 2. Meneghini *et al.*-2018, 3. Stitzerl *et al.*-2015, 4. Mane *et al.*-2023, 5. Waldorff *et al.*, 2010, 6. Iwaki *et al.*-1999

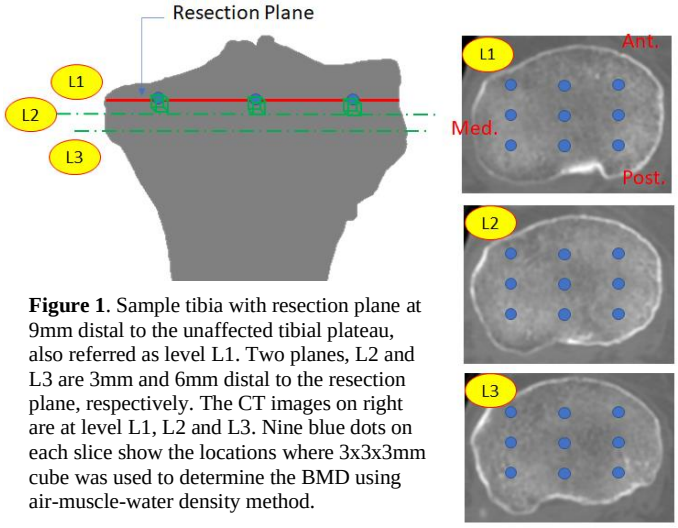

Figure 1. Sample tibia with resection plane at 9mm distal to the unaffected tibial plateau, also referred as level L1. Two planes, L2 and L3 are 3mm and 6mm distal to the resection plane, respectively. The CT images on right are at level L1, L2 and L3. Nine blue dots on each slice show the locations where 3x3x3mm cube was used to determine the BMD using air-muscle-water density method.

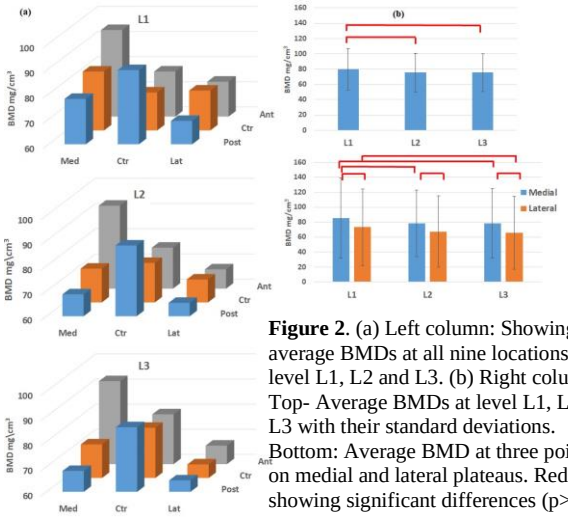

Figure 2. (a) Left column: Showing average BMDs at all nine locations for level L1, L2 and L3. (b) Right column: Top- Average BMDs at level L1, L2 and L3 with their standard deviations. Bottom: Average BMD at three points on medial and lateral plateaus. Red lines showing significant differences (p>0.05)