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Structural Analysis of Metastatic Femoral Lesions Using Clinical Computed Tomography Scans

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Background: Metastatic lesions weaken the bone potentially causing the occurrence of a pathological fracture. Historically, the fracture risk is estimated based on radiographic measurement and symptoms; however, the accuracy –specificity in particular– of these measures in predicting fracture occurrence is low.

Fracture risk depends on the strength of the bone and the load applied to it. Biomechanical studies have demonstrated that noninvasive techniques such as CT scanning can be used to estimate bone density, Young's modulus of elasticity, and strength, based on the attenuation coefficients (Hounsfield units). Subsequent studies demonstrated that structural rigidity, which combines the elastic modulus of bone with its distribution in space of the weakest transaxial cross section through the bone predicts its failure to load. However, this technique requires inclusion of a phantom in the CT scan to convert attenuation coefficients into an equivalent bone density. Our study aimed to assess if clinical CT scans –without inclusion of a phantom– can be used to assess difference in material properties of bone tissue and change in bone geometry.

Questions/Purposes: We evaluated (1) if this relative structural analysis can quantify lytic defects in patients with bone metastatic lesions compared to healthy controls; and (2) the variation within healthy controls.

Patients and methods: After approval by our institutional review board, we included 66 patients who had a metastatic, myeloma, or lymphoma lesion of the femur and underwent operative treatment between June 1999 and July 2013 at two university medical centers. Inclusion criteria were: (1) a preoperative CT scan including the complete lesion, (2) inclusion of the contralateral femur. We excluded cases with contralateral lesions or implants hindering comparison of the "affected" to the "healthy" side and cases with sclerotic lesions. Subsequently, we matched cases 1:1 with controls based on sex, age, hospital, and inclusion of the same femoral region in a CT-scan.

Computed Tomography scans were imported into Osirix Medical image viewer application. The built-in "region of interest tool" was used to delineate the femur including the lesion and the contralateral side (figure 1). The same femoral regions were delineated for the healthy controls. The attenuation coefficient (Hounsfield units) of each pixel within the regions of interest were exported per slice into Stata (statistical software). The affected side was compared to the non-affected side per CT slice using three calculations: (1) dividing the sum of attenuation coefficients in the affected side by the non-affected side; (2) dividing the sum of attenuation coefficients relative to the neutral axis in the affected side by the non-affected side; and (3) dividing the sum of attenuation coefficients relative to the centroid in the affected side by the non-affected side (figure 1).

Results: There were 35 women and 31 men with a lytic lesion; mean age of the patients with metastatic lesions was 59 years (mean age controls: 59 years; $p = 0.59$, by paired T-test). Thirty-three percent had a lung carcinoma, 23% a breast carcinoma and 12% a renal cell carcinoma. Two (3.0%) lesions were located in the neck, 35 (53%) in the trochanteric region, 19 (29%) in the subtrochanteric region, and 10 (15%) in the diaphysis. Five (7.6%) patients had previous radiotherapy. Sixteen (24%) patients had minimal pain, 17 (26%) moderate, and 33 (50%) had pain on loadbearing.

We found a 15% difference in sum of the Hounsfield units between the affected and non-affected side (mean: 85%, SD: 13, 95% CI: 82 – 88, $p < 0.001$). The difference was 18% (mean: 82%, SD: 17, 95% CI: 77 – 86, $p < 0.001$) for sum of the Hounsfield units relative to the neutral axis, and 19% for sum of the Hounsfield units relative to the centroid (mean: 81%, SD: 14, 95% CI: 77 – 85, $p < 0.001$).

Conclusions: Clinical CT scans can be used to quantify lytic defects in the femur without inclusion of a phantom in the CT-scan.

Figure 1: Top: CT scan of 65 year old female with renal cell carcinoma of the subtrochanteric femur, in white the regions of interest delineating the femur with lesion and the contralateral side; Middle: heatmaps demonstrating intensity of attenuation coefficients. Bottom: blue line indicates comparison of sum of attenuation coefficients, red line indicates comparison of sum of attenuation coefficients relative to neutral axis, green line indicates

comparison of sum of attenuation coefficients relative to the centroid per CT slice.