INTRODUCTION:
Early diagnosis of osteoporosis is essential for prevention of future fractures. Trabecular structure has a significant effect on the strength of trabecular bone. The bone structural parameters, including bone volume fraction (BV/TV), trabecular thickness (Tb.Th), trabecular number (Tb.N), trabecular separation (Tb.Sp), structure model index (SMI), connectivity (C) and degree of anisotropy (DA) have been introduced to describe the structure of trabecular bone. They can be accurately quantified from high resolution computed tomography (CT) images [1]. Many of the parameters have been shown to reflect the health status of the bone, and are known to alter during osteoporosis [2].

Large variation exists in imaging resolutions (i.e. voxel sizes) applied in clinical imaging and in research (in plane resolution between 1-500µm). Several studies have shown that the image voxel size significantly affects the values of the structural parameters [3-5]. However, it is not known whether this resolution-induced error is similar in normal and osteoporotic bone. If not, it could have affected interpretation of various studies investigating structural differences in normal and osteoporotic trabecular bone. In the present study, we investigate this issue by determining the values of structural parameters for normal and osteoporotic human trabecular bone samples with various imaging voxel size.

METHODS:
For this study, 20 human trabecular bone samples were collected and analyzed (normal n=8, osteoporotic n=12, age 24-75 years, average 52). Samples were drilled from the femoral medial condyle or tibial medial plateau from human cadaveric knees (FMC n=5, TMP n=4, d=16 mm, h=8mm) or from horizontal iliac crest biopsies (IC, n=11, d=7.5 mm, h=15mm) [6]. The identification of osteoporotic samples was based on clinical information, including data on patient history, histomorphometry and/or bone structural and density measurements. The use of samples was approved by the National Authority of Medicolegal Affairs (Permit 1781/32/200/01 and 57/2007). Structural properties were determined using a high resolution microCT system (SkyScan 1072 and 1172, Aartselaar, Belgium) with an isotropic voxel size of 14 µm (IC) or 18µm (FMC, TMP). Subsequently, the raw images were resampled to voxel sizes of 1-16 times larger compared to the original voxel size, i.e. 14 – 18 µm (Fig. 1), and thresholded with the same global threshold values.

The structural parameters BV/TV, Tb.Th, Tb.N, Tb.Sp, SMI, C and DA were quantified for each sample and voxel size. Both absolute and normalized (to original voxel size) values of structural parameters were calculated. Data from TMP, FMC and IC were pooled for all parameters except SMI, for which the values were originally statistically different between the sample locations. Statistical differences in structural parameters were tested with Mann-Whitney U-test between the normal and osteoporotic samples. Significant differences were set to p<0.05.

RESULTS:
Osteoporotic bone had significantly lower BV/TV compared to normal bone with all voxel sizes. Normalized BV/TV was relatively constant for the normal group until the voxel size exceeded 150µm, whereas in the osteoporotic group it decreased rapidly already at small voxel sizes (Fig. 2). Absolute Tb.N and Tb.Sp were significantly different at the original voxel size between normal and osteoporotic samples. However, at voxel sizes larger than 80-110 µm, the difference was masked by the larger voxels (Fig. 2). Tb.Th was statistically different from small to intermediate voxel sizes (until 160 µm), but not at larger voxel sizes. Normalized Tb.N was not significantly different until voxels larger than 160 µm were used.

DA differed statistically between the normal and osteoporotic samples at the original resolution, but with voxel sizes larger than 60µm the difference was masked (Fig. 2). For FMC and TMP samples, the absolute SMI was significantly different between the normal and osteoporotic samples until voxel sizes above 200µm. This was also displayed by the normalized SMI, where the effect of sampling size was highly different in normal and osteoporotic samples (Fig. 2).

DISTRIBUTION:
This study shows that the effect of image voxel size on bone structural parameters is different depending on the health status of the bone. Several studies have determined the effect of image resolution on these parameters in normal bone samples [3-5]. In those studies, BV/TV was not affected by the sampling resolution until voxel sizes larger than 130 µm. Our data confirms this finding for normal samples, but shows that in osteoporotic samples the BV/TV decreases significantly already at relatively small voxel sizes (Fig. 2). This may be due to the lower bone volume and the thinner trabeculae in osteoporotic samples resulting in larger volume artifacts at smaller voxel sizes. Our findings regarding trabecular parameters are consistent with previous studies. For example, Tb.Th increases with larger voxels in both normal and osteoporotic groups [5]. However, in addition our study shows that the known differences in Tb.Th between the normal and osteoporotic bone is only detectable with voxel size smaller than 160 µm. Also, DA is initially different between the normal and osteoporotic samples. However, since osteoporotic samples are more anisotropic, they are affected less by the larger voxels compared to the normal samples, and with voxel sizes larger than 60µm, the difference between the normal and osteoporotic bone on DA is no longer statistically different.

Several studies have investigated the effect of scanning and reconstruction resolution, both with isotropic and non-isotropic voxel sizes, and with different thresholding algorithms [4-5]. However, no study has characterized the affect of resolution on bone with different health status. In the present study we show that structural parameters are affected differently by the voxel size in normal and osteoporotic bone. The present findings are important as various imaging resolutions are applied in vitro and in vivo. The present results also suggest that structural differences between the osteoporotic and normal trabecular bone may not be reliably detected with clinical scanner providing minimum voxel resolution between 100-300 µm.

REFERENCES:

Figure 1: Images at 18 µm (a, b) and 160 µm (c, d) resolution of normal (a, c) and osteoporotic (b, d) bone sample extracted from FMC.

Figure 2: The effect of down sampling is illustrated by normalized BV/TV and SMI (left) values and absolute Tb.N and DA (right). Significance between the normal and osteoporotic samples is indicated.