Introduction. Cemented arthroplasty uses doughy PMMA cement which infiltrates trabecular bone prior to curing. The cement creates a mold around the bone and could serve as a means to identify the original state of the cement-bone interface prior to any biological changes following in vivo service. The clinical significance is that identifying patterns of bone resorption could improve our understanding of how implants loosen and also point to alternative designs or surgical techniques to improve long term fixation. We asked two research questions. Can the amount of resorbed bone be estimated using the ‘mold shape’ created by viscous cement flowing and curing around trabeculae? Based on the initial mold shape, how much bone resorbs from postmortem retrievals?

Methods. Ten cement-bone specimens from a total knee arthroplasty (TKA) created in the laboratory were used for method validation and 20 specimens from two postmortem retrieved TKAs with 6 and 10 years of service were used to determine the extent of bone resorption from the interdigitated cement-bone regions. Micro-CT scans (16 µm resolution) of 4mm×4mm cross sections containing bone-cement interface were obtained (Fig 1A). Mimics was used to identify bone, isolated bone (not connected to bulk trabecular bone, Fig1B), and cement (Fig1C). An 8 voxel dilation followed by an 8 voxel erosion (‘close’ operation, Fig1D) was used to identify the cement mold shape or ‘cement cavities’. Finally, Boolean operations (Fig 1E) were used to identify interdigitated bone and estimated resorbed bone.

We developed several parameters to describe the local cement-bone morphology. Interdigitation depth described the initial extent of bone penetration into the cement. Interdigitated (inBV), isolated (isBV), and resorbed bone volume (reBV) (see Fig 1) were normalized to the cross sectional area of the specimen. Resorbed BV fraction (reBV fr) was defined as reBV/(reBV+inBV+isBV). The estimated initial contact area fraction (esCAF) between cement and bone was determined for the initial ‘mold state’. The current CAF (curCAF) was determined using the post-resorption interdigitated bone. The loss in CAF was calculated as: (esCAF-curCAF)/esCAF. For the validation study using laboratory prepared specimens where there is no resorption; if there were no gaps between interdigitated cement and bone, then: reBV=0, reBV fraction=0, and loss of CAF=0.

Results. For the validation study with lab prepared specimens, there were small errors in the estimated resorbed BV fraction (0.11) and loss in contact area fraction (0.06) (Table 1). This is because the cement does not flow in perfect apposition with the cement and small gaps are present. For the postmortem specimens, the amount of estimated resorbed bone was often quite dramatic (Figure 2, shown in blue). The estimated initial interdigitation depth was very similar for the two specimen groups, indicating that the amount of cement infiltration was the same. The initial estimated cement-bone contact area fraction (esCAF) was also similar for the two groups. In contrast, the resorbed volume fraction (reBV fr) for the postmortem specimens was 0.85, meaning that only 15% of the mold shape was still filled with bone. In addition, the loss of CAF was also extensive (0.84).

Discussion. The results of this study suggest that the mold shape left by cement that flows around trabeculae can be used to estimate the original trabecular volume in the interdigitated region. Errors with this method are on the order of 10%. The results also show that bone resorption can be extensive following in vivo service with resorbed bone volume fractions of 85% and loss of cement-bone contact area fractions of 84%.

It is interesting to note that the amount of bone resorption could vary widely in different regions from the same donor bone (Figure 3). This example shows 3 samples from the medial plateau region of the donor bone with six years in vivo service. Some interdigitated regions were almost completely resorbed while others maintained robust interdigitation. This suggests that resorption is not a biocompatibility issue, but could be due to other factors such as stress shielding or fluid flow induced resorption. Spatial and temporal mapping of the interdigitation patterns would be very useful to understand how fixation via cement-bone interdigitation changes following in vivo service.