Non-destructive evaluation of the bone-cement-metal interface in explanted Wagner hip resurfacing arthroplasty using high resolution Region-of-Interest computed tomography

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Introduction: In 1970 Wagner began with hip resurfacing procedures using metal or ceramic for the femoral component and polyethylene for the acetabular component (1). Due to good short term results, the Wagner hip resurfacing and similar techniques were frequently used in Europe. However, early clinical experiences were discouraging. Especially, high loosening rates were reported (2). Since the bone-cement-metal interface beneath the cobalt-chrome cup is hardly accessible to non-destructive analytical methods, some open questions regarding the failure mode were left open. In this study, we want to introduce high resolution Region-of-Interest (ROI) computed tomography as a method to investigate hard accessible bone-implant interfaces in failure analysis of arthroplasty.

Materials and Methods: The study was performed with a v|tome|x s high resolution CT System of phoenix|x-ray equipped with a high contrast digital 16 bit flat panel detector for highest contrast resolution and a 240 kV/320 W microfocus X-ray tube for scans of high absorbing samples as well as an additional 160 kV/15 W high power nanofocus® tube for highest resolution scans of lower absorbing samples. The maximum achievable voxel size of the system is 2 microns, the maximum sample size is 300 mm in height and 250 mm in diameter. The system includes phoenix|x-ray proprietary acquisition and reconstruction software datos|x which includes innovative software tools like geometry calibration, detector calibration, noise and beam hardening reduction and region-of-interest-CT which is very useful for scanning segments of larger samples at very high resolution. The Wagner hip resurfacings were aquired from revision surgeries. Plastik embedded hip cups were cut and grinded to thin sections to confirm the CT findings.

Results: Each composite of the bone-cement-metal interface could be visualized at a high resolution (30 μm voxel edge length) using Region-of-Interest (ROI) tomography (Fig.1a and insert in Fig.1b). It could be visualized that osteopenic areas appeared beneath the Wagner hip cup leaving some zirconium containing cement areas unbonded, while the cement-metal interface was intact (Fig.1b). The high resolution of ROI tomography enabled the analysis of single trabecula beneath the cobalt-chrome alloy hip cup. The ROI findings were confirmed by standard plastic embedded histology.

Discussion: Local CT or ROI CT (Region-of-Interest-CT) overcomes the requirement that the object has to be fully projected horizontally on the detector in each scanned angle. Hence, it is possible to scan and reconstruct only the segment of the sample which is really of interest for the CT analysis – this can be performed during image acquisition by rotating even larger samples much closer to the focal spot of the X-ray tube. The resulting CT data is a high resolution section of a larger object providing much more information about the internal 3D microstructure than by using only a software zoom to analyse a section of a larger sample scanned complete with a much lower resolution. Thus, ROI tomography revealed that post-operative stress shielding beneath the Wagner hip cup resulted into osteopenic bone which could be the cause for secondary unbonding of the bone-cement interface. This might have been the reason for early aseptic loosening and implant failure.