Calibration of single-plane fluoroscopy using a 3D printed calibration object

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Introduction: Quantitative assessment of 3D dynamic motion in lower extremity joints under natural weight-bearing conditions allows for evaluation of joint diseases and their treatments. Fluoroscopic kinematic analyses of total knee arthroplasty (TKA) have characterized unique motions resulting from implant design relating to function and wear performance. To achieve accurate 2D/3D registration of a knee implant using single-plane fluoroscopy, it is essential to determine intrinsic and extrinsic camera parameters. Recent advances in 3D printing made it possible to accurately manufacture plastic structures in any shape, providing potential for novel calibration phantom designs. We describe a rigid 3D printed cubic calibration phantom, comprised of tantalum marker beads at known locations.

Methods: A calibration cube phantom was fabricated by fused-deposition printing in polylactic acid (PLA) plastic with a commercial 3D printer (Dremel® 3D20 Idea Builder); this phantom was then used to calibrate the system. The phantom contains eight 1.0mm diameter tantalum markers with a nominal inter-bead spacing of 130mm inside the vertices of the cube. Exact coordinates of the markers were determined using radiostereometric analysis (RSA) in a dedicated RSA lab. An RSA calibration cage containing eighteen 0.8mm diameter tantalum markers (RSA Biomedical, Sweden) was also used to calculate camera parameters. Radiographic acquisition was conducted using a ceiling-mounted x-ray fluoroscopy system (Adora RF, Nordisk Røntgen Teknik A/S, Denmark) equipped with a flat-panel detector with a 35x43cm field of view and 160µm pixels (CXDI-50RF, Canon). The intrinsic and extrinsic parameters were calculated using custom MATLAB code (MATLAB R2015a, USA) and measurements from UmRSA (RSA Biomedical, Sweden). Both calibrators were imaged (n=10) at 70 kVp, 2 mAs using 1200 mm nominal source-to-image distance (SID) without repositioning the x-ray equipment between all exposures.

Results: Inter-bead spacing of the 3D printed cube calibrator was measured at 129.66 ± 0.22mm with RSA. The intrinsic camera parameters using the 3D printed cube to be 209.45 ± 0.09mm, 182.46 ± 0.09mm, and 1224.12 ± 0.03mm for x₀, y₀ and SID, respectively. The extrinsic camera parameters were -88.12 ± 0.008°, -0.96 ± 0.003°, and 89.93 ± 0.002° for the respective x, y, and z rotations. The intrinsic camera parameters calculated using the RSA calibration cage were 196.26 ± 0.04mm, 184.61 ± 0.06mm, and 1233.61 ± 0.02mm for x₀, y₀ and SID, respectively. The rotational extrinsic camera parameters were -89.61 ± 0.002°, 1.32 ± 0.02°, and 90.95 ± 0.0008° for the respective x, y, and z planes. Statistically significant differences were observed between all camera parameters by one-way ANOVA (p<.05).

Conclusion: We have demonstrated that 3D printed objects have the potential to be a useful tool for calibrating single-plane fluoroscopy systems when studying joint kinematics after total knee arthroplasty. The data demonstrated 3D printed calibration objects produce similar results for calculating SID and extrinsic rotation parameters, in comparison to a standard RSA calibration cage. Discrepancies in x₀ and y₀ measurements can be attributed to differences between object coordinate system transforms for the RSA calibration cage and 3D printed cube.