INTRODUCTION
Radiostereometric Analysis (RSA) is an accurate in vivo measurement technique using two simultaneous radiographs to examine rotational and translational changes between bones or an implant and bone. The measurement accuracy offered by this technique make it an invaluable clinical research tool, however it does involve ionizing radiation, which can be a concern to the patient and clinician when used for research purposes. Larger exposures are typically needed in RSA studies involving the spine, particularly the lumbar region, in comparison to RSA studies on the extremities. The purpose of this study was to determine the effective dose of patients undergoing RSA of the lumbar spine.

METHODS
Twelve patients (5 female, 7 male) with total disc replacement prosthetic devices in the lumbar spine participated in an IRB approved clinical study to examine the sagittal and coronal range of motion using RSA. Motions were obtained at 6 weeks, and then 3, 6, 12, 18 and 24 months. In order to generate the motion data at each time point, standing radiographs were collected in neutral, flexion, extension, and left and right lateral bending positions.

A wall mounted uniplanar calibration cage with tantalum beads was placed between the subject and the films (RSA Biomedical Innovations AB, Umea, Sweden). The cage defined the 3-D coordinate system and was used to calculate the position of the roentgen foci and subsequent locations of the beads in each vertebra. The roentgen tubes were 1.6 m from the film, level with L3, and angled 20 degrees off midline. The beams of both tubes were collimated to the two grids on the cage. High speed (ISO) screens that allow less radiation were utilized. The location of each patient was approximately 0.6 m from the film. Five simultaneous image pairs were acquired corresponding to each position examined.

The amount of radiation exposure varied for each patient based on body habitus. The primary objective of the radiographic examination was to enable an identification of the tantalum markers within the vertebra, therefore anatomical resolution and contrast was less important than for a conventional skeletal radiographic examination. As per typical RSA exams, high voltage techniques (kVp) were used and kept relatively constant, while the mAs was adjusted for patient size. Radiographic techniques were recorded for all acquired images.

For the analysis, patient mass was used to estimate abdominal AP thickness. Tube output and half value layers were measured at the appropriate tube accelerating potentials. The imaging geometry and beam characteristics were used to determine the entrance skin exposure and the Exposure-Area Product (EAP). The EAP was then used to calculate the energy imparted to the patient for each stereo image pair, which was converted into effective dose using the equation:

\[ E = \varepsilon \times \left( \frac{E}{\varepsilon} \right) \times \frac{70}{m} \]

In the above equation, \( \varepsilon \) is the energy imparted to the patient, \( \left( \frac{E}{\varepsilon} \right) \) is the effective dose per unit energy imparted conversion factor, and the \( \frac{70}{m} \) accounts for differences in mass from the standard 70 kg adult used to calculate the effective dose. For this study, only AP projections of the lumbar spine are acquired, which has an \( \left( \frac{E}{\varepsilon} \right) \) conversion factor of 23.2 mSv/J.

RESULTS
The average technique used was 141 kVp and 11.6 mAs. The amount of mAs varied with the size of the patient (Fig 1). The mean effective dose per image pair was 0.304 mSv, and the mean per visit (5 image pairs) was 1.52 mSv with a standard deviation of 0.7 mSv. The relationship of effective dose per image pair and patient thickness is shown in Fig 2. The average for the entire two year study was approximately 9.1 mSv. This compares very favorably with the value of 18 mSv reported in the 2000 UNSCEAR report for a single diagnostic lumbar spine study.

DISCUSSION
Image quality requirements for RSA are not the same as for general diagnostic imaging. The use of high kV techniques that would result in unacceptable low contrast images for general diagnostic purposes are adequate for visualizing fiducial beads used in RSA. Low doses allow for the acquisition of multiple image sets to detect motion of prosthetic devices with total effective doses that are much lower than a typical diagnostic lumbar spine examination.

In this study examining the lumbar spine, the mean effective dose per image pair and per visit (for 5 stereo image pairs) was 0.304 mSv and 1.52 ± .70 mSv, respectively. The total for the 2 year study was approximately 9.1 mSv. Therefore, the effective dose (and risk) was far less than a typical L-spine radiographic procedure, which has an UNSCEAR mean value of 18.0 mSv per procedure.

REFERENCES
1. K.M. Ogden et al., Health Physics 86(4): 397-405, 2004

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