Measurement of 3D Vertebral Body Position and Orientation Using Single Plane Fluoroscopy

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INTRODUCTION:
The increasing use of motion preserving devices in the spine has highlighted the need for accurate kinematic measurement tools to evaluate the performance of these new implants. In addition to quantifying the motion of the implant itself, it is also desirable to measure how implants affect the motion at adjacent vertebral levels. Single plane fluoroscopy has been used for over 15 years to analyze the in vivo motions of total knee replacement implants, with reported accuracies of 0.5-1.0 deg for rotations and 0.5 mm for in plane translations. Our goal is to apply this type of image registration technique to the spine, so that accurate 3D kinematics of vertebral motion can be measured in vivo. This involves a significant extension to previous work, instead of tracking silhouettes of implants, we proposed to use digitally reconstructed radiograph images generated from a CT as the basis for image registration. The purpose of this project was to develop a methodology that would enable the 3D position and orientation (pose) of a vertebral body to be accurately measured from a single plane fluoroscopic image.

METHODS:
A set of Gold Standard data was utilized to validate the image registration algorithm developed for this project. The dataset includes CT scans of two cadaver spines (thoracic and thoracolumbar) and single static lateral fluoroscopic images of each spine. A 3DRX scanner was used to acquire the fluoroscopic images, which allowed the transformations that will optimally align the 3D CT volume to the 2D fluoroscopic image to be precisely and accurately calculated. The image registration technique produces a 2D digitally reconstructed radiograph (DRR) image from the CT scan and then matches that image to a lateral fluoroscopic projection. An initial starting pose is given and then an optimization algorithm generates new poses based on the result of a similarity metric calculated between the two 2D images. At each iteration, the CT volume is transformed and a new DRR is produced and compared to the fixed fluoroscopic image. The similarity metric function has a minimum value when the two images are optimally aligned. Three different similarity metrics were evaluated to characterize their performance. A standard set of starting positions were used as initial guesses for the optimizer. Starting positions are described by the mean target registration error (mTRE), which defines the average displacement error over a grid representing the volume of one vertebral body. A total of 150 starting positions were uniformly distributed over the range of 0-1.5 mTRE, so that the capture range of the registration algorithm could be determined. Registration success was defined as mTRE in the plane of fluoroscopic image within 2mm.

RESULTS SECTION:
A total of six vertebral bodies, three each from two spines, were registered. Each vertebral body was registered at each of the 150 starting positions, so that there were a total of 900 registrations performed for each similarity metric. The starting positions were grouped into 1 cm bins for this analysis, so that at each bin there were 60 registrations with which to gauge the success of the algorithm (10 starting positions x 6 vertebrae). Using a combined gradient correlation and mutual information similarity metric produced successful registrations 88% of the time when starting within 4mm mTRE (Figure 1), compared to 75% successful registrations with the standard gradient correlation metric and 30% successful registrations with the standard mutual information metric over the same range of starting positions. For the registrations that were successful, the error was consistently between 1.2-1.6mm regardless of starting position or metric used.

DISCUSSION:
These results demonstrate that single plane fluoroscopy can be a useful tool and accurate tool for measuring 3D position and orientation of spinal vertebrae when a staring position within 4mm mTRE can be supplied by the user. Of the three metrics that were evaluated it appears that the gradient correlation based techniques are the most accurate for the images used in this study, there appears to be a slight improvement in the accuracy when mutual information is combined with the gradient correlation calculation. The next step in this project is to apply this image registration technique to measure vertebral motion in dynamic fluoroscopic image series.

REFERENCES: