PERFORMANCE OF A NOVEL POSE-BASED TECHNIQUE FOR MEASURING TOTAL DISC REPLACEMENT WEAR

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INTRODUCTION:

Implants to replace degenerative intervertebral discs have recently become a subject of intense interest both clinically and biomechanically. One area of concern, especially for metal-on-polyethylene bearings such as those in the ProDisc® and Charité ® total disc replacement (TDR) devices, is the potential for long term wear and osteolysis. While both physical laboratory wear measurements and computational wear simulations are of value for pre-clinical testing, implant wear performance *in vivo* is the ultimate gold standard. Currently, most of the available clinical follow-up information for TDRs is in the form of archival plane film x-rays. Penetration-based radiographic wear assessments, analogous to those widely used for total hip replacements (THRs) [1], can potentially be applied to *in vivo* wear measurements from archival x-rays of TDRs. The present paper reports a novel pose-based image analysis technique developed for that purpose, the specific embodiment being for the case of ProDisc®. The bearing for that particular device involves a convex-spherical-surface polyethylene insert, articulating with a polished concave spherical recess in the implant's chrome-cobalt upper end-plate. Techniques to infer three-dimensional information from two-dimensional silhouette images such as plane film radiographs, using pose-based methodology, have been successfully applied to various kinematic measurements of joint replacement implants [2]. Given suitable precision, this same basic pose approach is also applicable to assessing serial changes in the volume between TDR end-plates, as a metric of wear of the intervening polyethylene insert.

METHODS:

Three main steps are involved in determining pose-based volumetric wear of the TDR device. First, archival patient x-rays are digitally scanned at high spatial (600dpi) and grayscale (16bit) resolution. The boundaries of the ProDisc® endplates are detected by calculation of Matlab® -based intensity gradients across search rays generated perpendicular to a manually-identified approximate boundary. Using least squares approximations, smoothed binary silhouettes defining the edges of the metallic endplates are determined. The binary image obtained from the edge detection algorithm acts as the unique goal silhouette of a particular relative orientation of the implant's metallic endplates. An initial provisional pose of the surface model, nominally corresponding to the x-ray-apparent implant silhouette, is then iteratively perturbed, such that the model's two-dimensional projection is brought into successively closer correspondence with the radiographically-apparent implant silhouette (Figure 1 (c) and (d) and Figure 2). After pose convergence, the third step is to register the position of the superior endplate relative to the inferior endplate, and from those two positions to calculate the spherical dome volume of polyethylene between the two metal/polyethylene interfaces, assuming full/flush contact at both (spherical sector) interfaces. Repeating this volume determination process for patient x-rays taken at serial clinical follow-up visits then allows determination of the corresponding incremental polyethylene wear.

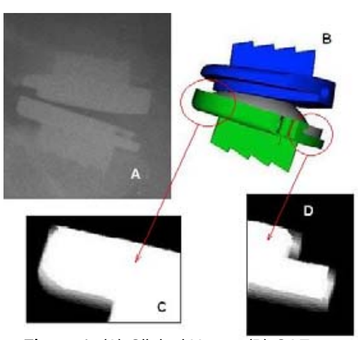

Figure 1: (A) Clinical X-ray. (B) CAE-based geometric model. (C & D) Successive adjustments of the geometric model pose.

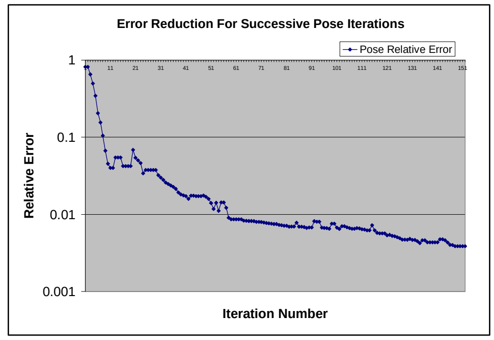

Figure 2: Typical convergence of the (circumferential average) error in position between binarized x-ray silhouette image and surface model projection, as the model's pose is successively perturbed.

RESULTS AND DISCUSSION:

To verify the precision of the pose-based volumetric wear calculation, a three-dimensional surface model of the implant was used to create surrogate x-rays. The model is implemented in the Virtual Reality toolbox of Matlab®, using manufacturer-supplied CAE files. A captured binary image taken from a projection of the ProDisc® components oriented at a known relative position in the virtual world, is modified by superimposing characteristic x-ray Gaussian noise onto the binary image and decreasing the grayscale contrast between the foreground and background. Appropriate signal-to-noise ratios (STN) and mean grayscale foreground/background intensity values were obtained by taking the average over several clinical ProDisc® radiographs, and are in the range of 0.3 to 0.9 (STN) and grayscale intensities 120/255 to 60/255 [4]. Correlation between the algorithm-defined boundary image and the original, non-modified binary image of the perturbed endplates provides a metric of error for the edge detection algorithm.

A test case was formulated where the upper endplate migrates inferiorly by 0.1mm. This corresponds to a theoretical volumetric wear of 34.32 mm^3. After the final endplate pose orientations converged to the original silhouette, the volume differential was 29.64mm^3. The absolute error was 4.68mm^3 (relative error of 0.59%). As a point of reference, clinically significant wear rates in THR implants are on the order of 76.9± 43.9 mm^3/year [3]. This indicates that the present pose methodology possesses ample sensitivity to be able to detect clinically significant differentials of wear rate among TDR patients. Parametric sensitivity studies of factors degrading pose detection accuracy under clinical conditions (e.g., blurring of implant x-rays due to soft tissue interposition [4]) are currently underway.

CONCLUSION:

An automated pose-based image analysis technique is here reported for calculation of *in-vivo* wear rates of TDR implants, using archival plane-film x-rays. Pilot data indicates that the technique possesses ample resolution for detecting clinically significant wear rate differentials.

REFERENCES:

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