Acetabular Cup Migration Analysis from CT Images

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Introduction:

- Methods for the accurate quantification of implants migration are of great interest to the total hip arthroplasty (THA) community.
- Stereophotogrammetry has typically been used to quantify migration measurements (Valstar, 2002); however, this method can not be used on every THA subject.
- The model based approaches have allowed the use of standard radiographs for assessing the acetabular cup migration (Burckhardt, 2005). Although these methods proved helpful, they can not be universally applicable.
- With the advance of image reconstruction methods and image processing tools, computer tomography (CT) could provide a clinically applicable method for the monitoring of any implant within the hip joint, which may be universally applicable.

Scope:

In this work, we present the application of the kinematics analysis method (Tamez-Pena, 1999 and Lerner, 2003) to measuring minute migrations of the acetabular prosthesis from CT data sets on THA volunteer subjects. Furthermore, we will asses the precision of the method and the specificity to detect abnormal acetabular migrations.

Materials and Methods:

- Migration analysis from CT images starts with the automated extraction of subject-specific computer model of the acetabular cup and the pelvic bone from the baseline timepoint.
- Once the cup and the pelvis have been modeled (**Figure 1**), an object tracking computer based analysis (Tamez-Pena, 1999) finds the best rigid transformation that fits the baseline cup's computer model to the follow-up scan of the same subject.
- The same procedure is applied to the pelvic computer model.
- The cup-pelvis rigid transformation pair is used to estimate the relative displacement of the cup with respect to the pelvis.
- The displacement measurements are mapped into anatomical migrations. The linear migrations are measured in the Medial/Lateral (M/L), Anterior/Posterior (A/P), and Cranial/Caudal (C/C) directions; while the angular migrations are measured as Ante Version, Flexion, and Abduction Angles.
- **Figure 2 illustrates an example of the tracked pelvic bone and cup models outlined over the sampled CT scan. The migration measurement is derived from the relative displacement of the acetabular cup with respect to the pelvic bone.**

- The method described was tested on a set of ten subjects with three CT scans (baseline, six months, and one year) and an average post operative period of 10.75 years.
  - One of the ten subjects had a hip revision after the completion of the study.
- The CT scans were reconstructed to achieve an average in-plane resolution of 800μm and a slice thickness of 1000μm.

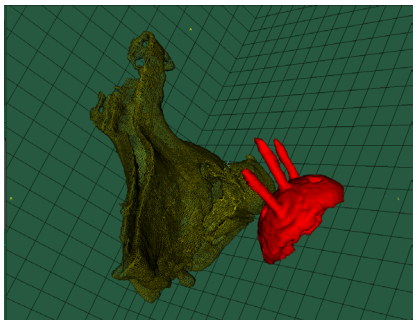


Figure 1: 3D rendering of the pelvic bone and cup model for the baseline scan.

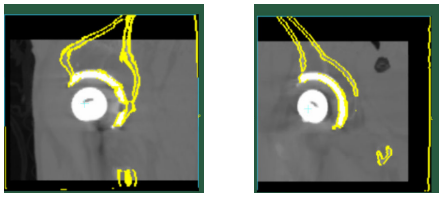
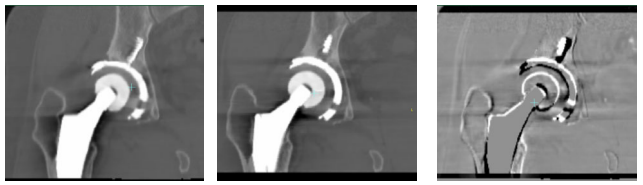


Figure 2: Pelvic bone and cup edge maps derived from tracking these structures from the baseline timepoint, displayed over the follow-up CT scan in the sagittal plane (left image) and coronal plane (right image).



(a) (b) (c)

Figure 3: Displacement between registered baseline (a) and 1 year (b) follow-up CT images for the subject with most significant migration measurement (c). This subject received the hip revision.

	Medial/Lateral (mm)	Anterior/Posterior (mm)	Cranial/Caudal (mm)
Avg.	-0.01	0.03	-0.02
STD	0.18	0.16	0.20
SE	0.05	0.04	0.05

Table 1: Translation measurements summary (short term analysis of translations (n=16)).

	Ante Version	Flexion	Abduction
Avg.	1.22°	-0.36°	-0.22°
STD	5.27°	2.86°	2.92°
SE	1.32°	0.71°	0.73°

Table 2: Rotation measurements summary (short term analysis of rotations (n=16)).

- **The subject data was used to evaluate the precision and the specificity to detect abnormal migrations.**
  - The precision assessment was based on the assumption that clinically asymptomatic subjects from this group will not have significant migrations within a short time period (i.e. less than 7 months). As a result, the baseline to six months pair and the six months to a year pair were pooled for a total of eight asymptomatic subjects and a total of 16 short time pairs.
  - The specificity of the method was evaluated by measuring the one year migration. If the measured migration was larger than the precision measurement, then a significant change was assumed and these results were compared to clinical findings.

Results:

- The 16 short time pairs were analyzed to measure the precision of the method using the small migration hypothesis. The hypothesis was confirmed using a t-test ($P<0.05$).
- Table 1 summarizes the results of the precision analysis for the Medial/Lateral (M/L), Anterior/Posterior (A/P), and Cranial/Caudal (C/C) directions. While Table 2 summarizes the measured angular displacements for the Ante Version, Flexion, and Abduction positions.
- The precision analysis results yield that the 95% confidence intervals (CI) of a single measurement is 320μm for linear measurements and 8.68° for angular measurements.
- The one year migration patterns for the ten subjects were computed. The results showed that four out of the ten subjects had significant migration during this period. The subject with a hip revision after the experiment was completed showed significant migration on the six month and one year analyses (**Figure 3**). Therefore, in this case, the CT based migration analysis was sensitive enough to detect a clinically relevant migration. The other three subjects did not show any relevant clinical findings.

Conclusion:

- Even though the precision of the proposed method is lower than other published methods, the preliminary data shows that the CT based method can be used to detect the migration of hip implants.
- The advantage of this method is that it does not require any a-priory knowledge of cup design or any surgical procedure like in the case of RSA.
- This method allows for the study of the natural progression of cup migrations on large populations in a standard clinical CT machine.

Acknowledgments:

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References:

1) Burckhardt, G. *et al.* IEEE Trans. Med. Img., **24**, no. 5, pp. 676-688, 2005.
2) Lerner, L. *et al.* J. Biomechanical Eng., **125**, no. 2, pp. 246-253, 2003.
3) Tamez-Pena, J. *et al,* SPIE Medical Img., **3660**, pp. 488-499, 1999.
4) Valstar, E.R. et al. J. Photogrammetry & Remote Sensing, pp. 376-389, 2002.