In vitro comparison of two methods of detection of the functional hip center vs. anatomical hip center in computer assisted surgery

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Introduction: In orthopedic surgery, the lower limb alignment defined by the HKA parameter i.e. the angle between the hip, the knee and the ankle centers, is a crucial clinical criterion used for the achievement of several surgeries such as, for instance, tibial osteotomy or Total Knee Arthroplasty.

The hip center used for the computation of the HKA is defined by the experts as the anatomical center of the femoral head. The methods used in the CAOS systems allow the determination of the hip center without any direct access to the femur head anatomy by using functional methods, i.e. by performing and by recording with the CAOS system a rotation motion of the femur around the pelvis. The center of rotation corresponding to the functional hip center is then computed with specific algorithms. The most common ones are the Least Moving Point (LMP) [1] and the Pivoting (PIV) [2, 3].

The accuracy of the functional hip center has been studied by several authors [1, 2, 3]. All of these studies have been performed with simulated data. This study shows in-vitro results concerning the difference between the HKA angle obtained with the anatomical hip center (HC\textsubscript{ANAT}) and those obtained with the functional hip centers coming from the LMP (HC\textsubscript{LMP}) and the PIV (HC\textsubscript{PIV}) algorithms.

Materials and Methods: Measurements have been performed by a surgeon at the anatomy lab of the University of Brest on six lower limbs coming from three specimens. An ATRACSYS® camera was used to acquire 3D positions of:

- two trackers: one attached on the femur and the other on the tibia,
- a digitizer allowing us to acquire 3D anatomical points.

A specific software was implemented in C++ and was installed on a computer with Intel (R) Core (TM) 2 Duo 2.53GHz processor and 4 GB of memory.

This software has several steps and allows the surgeon to acquire:

- The medial and the lateral points of the femur condyles with the digitizer in order to compute the knee center with respect to the femur tracker,
- The medial and the lateral points of the ankle with the digitizer in order to compute the ankle center with respect to the tibia tracker,
- The rotation motion of the femur around the pelvis with the femoral tracker, for the computation of the functional hip centers HC\textsubscript{LMP} and HC\textsubscript{PIV},
- 1000 points with a digitizer on the femoral head. A sphere is then fitted to these points in order to compute the sphere center corresponding to the anatomical hip center HC\textsubscript{ANAT}. 
The rotation motion of the femur around the pelvis and the digitization of points on the femoral head have been acquired five times per lower limbs in order to assess the intra-observer reproducibility $\text{VAR}_{\text{ANAT}}$, $\text{VAR}_{\text{LMP}}$ and $\text{VAR}_{\text{PIV}}$ of respectively $\text{HC}_{\text{ANAT}}$, $\text{HC}_{\text{LMP}}$ and $\text{HC}_{\text{PIV}}$ following these equations:

\[
\begin{align*}
\text{VAR}_{\text{ANAT}}(i,j) &= \text{dist}(\text{HC}_{\text{ANAT}}(i,j), \text{HC}_{\text{ANAT\_AVERAGE}}(i)) \\
\text{VAR}_{\text{LMP}}(i,j) &= \text{dist}(\text{HC}_{\text{LMP}}(i,j), \text{HC}_{\text{LMP\_AVERAGE}}(i)) \\
\text{VAR}_{\text{PIV}}(i,j) &= \text{dist}(\text{HC}_{\text{PIV}}(i,j), \text{HC}_{\text{PIV\_AVERAGE}}(i))
\end{align*}
\]

Where:

- $\text{dist}(X,Y)$ is the 3D distance between two points $X$ and $Y$;
- $\text{HC}_{\text{ANAT}}(i,j)$ is the $\text{HC}_{\text{ANAT}}$ obtained with the $j^{th}$ acquisition of the $i^{th}$ lower limb;
- $\text{HC}_{\text{LMP}}(i,j)$ is the $\text{HC}_{\text{LMP}}$ obtained with the $j^{th}$ acquisition of the $i^{th}$ lower limb;
- $\text{HC}_{\text{PIV}}(i,j)$ is the $\text{HC}_{\text{PIV}}$ obtained with the $j^{th}$ acquisition of the $i^{th}$ lower limb;
- $\text{HC}_{\text{ANAT\_AVERAGE}}(i)$ is the average of all $\text{HC}_{\text{ANAT}}(i,j)$ obtained for a given lower limb;
- $\text{HC}_{\text{LMP\_AVERAGE}}(i)$ is the average of all $\text{HC}_{\text{LMP}}(i,j)$ obtained for a given lower limb;
- $\text{HC}_{\text{PIV\_AVERAGE}}(i)$ is the average of all $\text{HC}_{\text{PIV}}(i,j)$ obtained for a given lower limb.

The impact on the HKA has been also analyzed. The differences $D_{\text{LMP}}$ and $D_{\text{PIV}}$ have been computed for all specimens $i$ ($0 < i < 6$) and all acquisition $j$ ($0 < j < 5$) and correspond to:

\[
\begin{align*}
D_{\text{LMP}}(i,j) &= |\text{HKA}_{\text{LMP}}(i,j) - \text{HKA}_{\text{AVERAGE\_ANAT}}(i)| \\
D_{\text{PIV}}(i,j) &= |\text{HKA}_{\text{PIV}}(i,j) - \text{HKA}_{\text{AVERAGE\_ANAT}}(i)|
\end{align*}
\]

Where:

- $\text{HKA}_{\text{AVERAGE\_ANAT}}(i)$ is the HKA obtained with $\text{HC}_{\text{ANAT\_AVERAGE}}(i)$;
- $\text{HKA}_{\text{LMP}}(i,j)$ is the HKA obtained with $\text{HC}_{\text{LMP}}(i,j)$;
- $\text{HKA}_{\text{PIV}}(i,j)$ is the HKA obtained with $\text{HC}_{\text{PIV}}(i,j)$.

**Results:** The figure 1 shows the boxplot concerning the intra-observer variability in mm as defined by $\text{VAR}_{\text{ANAT}}$, $\text{VAR}_{\text{LMP}}$ and $\text{VAR}_{\text{PIV}}$. The average variations are respectively 0.9mm, 9.0mm and 7.5mm with a standard deviation of respectively 0.6mm, 5.2mm and 4.0mm for $\text{VAR}_{\text{ANAT}}$, $\text{VAR}_{\text{LMP}}$ and $\text{VAR}_{\text{PIV}}$.

The figure 2 shows the boxplot concerning the differences in degrees as defined by $D_{\text{LMP}}$ and $D_{\text{PIV}}$. The average differences are respectively 1.0° and 0.8°, and the standard deviation are respectively 1.2° and 1.1° for $D_{\text{LMP}}$ and $D_{\text{PIV}}$.

**Discussion:** Several papers in the literature have studied the accuracy and the robustness of methods allowing CAOS systems to determine the functional hip center [1, 2, 3]. All of these studies have been performed with simulated data. This study shows results coming from in-vitro data.

The results concerning the intra-observer variability shows that the procedure is very robust and reproducible for the determination of $\text{HC}_{\text{ANAT}}$. The anatomical HKA is therefore extremely reproducible with a maximum variation significantly lower than 1° (0.2°). However, functional methods are much less reproducible even if the Pivoting method seems to be a little better.

Given these results, the impact of the functional methods on the HKA has been analyzed. We have therefore compared the HKA obtained with $\text{HC}_{\text{ANAT}}$ with those obtained with $\text{HC}_{\text{LMP}}$ and $\text{HC}_{\text{PIV}}$. The results are extremely encouraging since, despite the intra-observer variability, the differences between the anatomical and the functional HKAs are, on average, less than 1° with a maximum inferior to 4°.
For sure, the quality of these results depends mainly on the surgical application. However, adequate filters could definitely improve these results.

References