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Survey of Formal Methods of Hip Joint Center Calculation in Human Studies

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Abstract

Functional hip joint center (HJC) calculation involves recording movements of femur relative to acetabulum through markers placed on skin around thigh and pelvis. This non-invasive method of finding hip joint center involves either fitting a geometric sphere onto marker trajectories or coordinate transformation techniques which find the point with least movement in local frame with respect to global frame. A survey study by Ehrig et al has evaluated both categories of formal methods through virtual simulation and also contributed another algorithm known as “SCoRE”(Systematic center of rotation estimation). This algorithm gives an accuracy of *0.5 cm* with *20* degree range of motion (ROM) and claimed to be most accurate with both segments in motion. This paper reviews the studies using this method to calculate hip joint center. Also a review of studies using Ultrasound as a validation method has been provided. This forms the basis to the possibility of using Ultrasonic sensors to be placed along with markers to measure the relative movement of markers with respect to bone in vivo. This paper provides a survey of studies performed on human subjects either in vivo (live humans) or ex vivo (cadaver) to help an experimenter or researcher pick the best relevant technique matching their experimentation requirement including soft tissue artifact factor.

Keywords: Hip Joint Centre, Functional method, Ultrasound, SCoRE Algorithm, Human

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1. Introduction

There are presently various techniques used to test the functionality of formal methods which can be divided into one of the these categories : 1) Virtual simulations [6]: This mode of testing is good for numerous algorithms to be tested with a known centre for validation but are far from reality as the artificial noise cannot properly imitate the real world artefacts [6], 2) Mechanical linkage [2]: This method provides with better replica of the real hip than virtual simulations but still lack the soft tissue component present in vivo, 3) Cadaver studies [9]: These are well suited for studying algorithms with transcutaneous bone pins or Intracortical pins [10], which are needed to characterise the soft tissue artefact (STA) component to human motion analysis, 4) In vivo [8],[7],[11]: Studies which provide with the best case similarity to actual hip joint, although problems in such experiments come with validation methodology. Either X-Ray[12], or MRI [8][11],are used for validating results for in vivo testing which is considered invasive or expensive, respectively

It was found that after Ehrig et al [6], there was no survey which procvides details of the newly developed algorithms for finding hip joint centre using functional method exclusvely for studies on humans. Also, it was found that results from synthetic data , [6] were quite different when implemented on humans [7][8], possibly due to the subject specific muscular artefact inclusion [14]. Some compensation [11] as well as optimized marker placement approaches have been designed to compensate for the same [16].

Hence an exclusive review study is required for human based experiments in order to provide a summary of best practices when the experiments are to be conducted on humans so as to get better results for surgical navigation systems as well as gait analysis.

2. Comparative study of Experiments on Humans In vivo and Ex vivo

As opposed to Ehrig et al [6], which claimed SCoRE to be the best algorithm when both segments, Pelvis and femur, were in motion, Cereatti et al [9], performed an experiment on cadavers which showed that Quartic sphere fit method with bias compensation, Halvorsen et al [4], is more robust than SCoRE method with decreased ROM in presence of STA. The difference between two studies is the mode of experimentation. Whereas Ehrig et al [6] performed virtual simulations and tested their algorithm on synthetic data, Cereatti et al [9], performed study on cadavers with bone pins and skin markers where bone pins exclude the STA and are considered to provide true HJC value for validation [14].

The maximum error in functional calculations is posed by soft tissue artefacts [1] [15]. These errors are reported in the human studies as opposed to virtual simulation, cadavers with bone pins or mechanical linkage studies The method proposed by Heller et al [11] involves defining weights to optimize the marker set position in order to have a time invariant cluster position which replicates the bone pin data without its presence. It is said to have accuracy within *3 mm* which is very precise as needed in surgical navigation systems as opposed to raw data that gives *14.4 mm* accuracy [11]. The functional method used here is SCoRE algorithm, Ehrig et al [6]. The accuracy is measured using SCoRE residual which is a derived parameter which checks how close the calculated centres are to each other in consequent time frames, [13].

A recent comparison of two broad categories of algorithms for finding hip joint center formally, coordinate transformation and sphere fit, by Lopomo et al [22] was performed on cadavers. The study showed that both methods perform similar with a pelvic tracker but corrdinate transformation technique gives more accurate results (error within *2.9mm*) than geometric (error *25.2 mm*) when pelvic tracker is not present. While the geometric method used in this study has been proved to be biased by Halvorsen et al [4] in 2003. Hence the comparision and result might be biased.

A set of studies recently used Ultrasound for validation with detection of true Hip Joint Center[7][8][21] which provided an accuracy within *4 mm* when compared to MRI. This provides a new genre of inexpensive, non-invasive and portable validation techniques suitable for integration with navigation system for surgeries or gait analysis labs. An experiment utilizing this technology for validating HJC using ultrasound was implemented on normal human participants in context of gait analysis [8]. One of the algorithms tested was SCoRE [6], due to its known precision. Standardized star movement [2] was performed which gave a precision of within *20 mm* for 50% of the cases [8]. The geometric sphere fit provides this accuracy for *80%* of the cases in the same study. This is contradicting with the results shown by Ehrig et al [6]. While the experimental conditions, mode of testing and verification is different for both the studies with one involving simulated data Ehrig et al [6] and the other includes human participants [7][8]. Hence a comparison on the basis of accuracy would not be totally justifiable.

A recent study on population undergoing total hip arthroplasty, Bouffard et al [12], also used SCoRE algorithm and validated the calculated hip joint centre with Radiographs. The HJC obtained with SCoRE were significantly in agreement with the radiographs.

Table 1 Comparison of studies performed on humans to find Funtional Hip Joint Center

Paper Reference	**Mode of Validation**	**Algorithm used**	**Population Tested**
Cereatti at al 2009[9]	Pin Markers	Quartic Sphere fit	Cadavers
	Mechanical Linkage	SCoRE	
De Momi et al 2009[10]	Gold standard	Monte Carlo Pivoting	Cadavers
		Siston and Delp [23]	
Lopomo et al 2010[22]	Gold standard	Siston and Delp Geometric Sphere fit[20]	Cadavers
Sangeux et al 2011[8]	3D Ultrasound	Geometric Sphere fit	Healthy Adults
		Algebraic Sphere fit	
		CTT	
		SCoRE	
		Global Calibration	
Heller et al 2011[11]	SCoRE Residual	SCoRE	Total Hip Arthroplasty
Peters et al 2012[7]	3D Ultrasound	Geometric Sphere fit	Kids with Cerebral Palsy
		Algebraic Sphere fit	
		CTT	
		SCoRE	
		Global Calibration	
Bouffard et al 2012[12]	X - Ray	SCoRE	Total Hip Arthroplasty

Discussion

A lack of recent compilation of these studies is reflected when a literature is searched for best possible methodology for functional calculation of hip joint center. This study provides with a review of functional studies performed on humans in vivo and cadavers to find functional HJC.

The review of algorithms for finding HJC in functional manner provided in 2006 by Ehrig et al provided a new transformation technique SCoRE which was reported to give the best results. This technique has been used in most of the present studies. Although in human studies with presence of more errors than synthetic data with artificial random noise, the geometric sphere fit techniques were proved better [8], and this calls for a revision in used techniques for a precise determination of HJC. This is needed as even *20 mm* of error in HJC identification can lead to a kinetic error of upto *40%* as reported by Bouffard et al 2012 [12]. The comparative study [22] which suggests the coordinate transformation technique would perform better than geometric might be misleading if a study is being performed on live humans in vivo as this experiment was performed on cadavers which lacks the live tissue component. The worst case error reported by [22] given by biased geometric sphere fit method [20] gives an error of 1.7º which is reported to be acceptable in computer aided surgeries. Whereas the latest studies on humans by Sangeux et al [8] suggest that transformation techniques are biased to place the HJC "too inferiorly" [8].

This literature review was carried out to collectively report various methodologies currently being used to find the HJC through functional method and to point out that the results might be quite different depending upon the experimental setup being used. The readers are advised to look through the reference provided in Table 1 in more detail to carefully match their experimental conditions for expecting the similar results. Subject specific experimental errors could lead to different results and hence a standardized compilation of experimental structure for motion analysis to determine accurate HJC using functional method is to be worked upon in future.

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