# COMPARISON OF METHODS FOR ESTIMATING THE HIP JOINT CENTER

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***Abstract.*** *Biomechanics is a science that describes, analyzes and models the movements of the human body. To model the lower limbs, came across a point rarely discussed in bibliographies, the estimate of the hip joint center localization by means of kinematic data. Today, two methods for this analysis, the functional method and the predictive method. This work aims to analyze and compare the methods mentioned above through a routine in Matlab. The Kinematic data were collected through the Qualisys system and analysis will be carried out considering angles of flexion/extension, adduction/abduction and internal/external rotation of the lower limbs.*

***Keywords****: Biomechanics, Center of rotation of the hip, Kinematic Data*.

## 1. INTRODUCTION

The location of the hip joint center is an important part of any gait analysis study that involves movement calculation for the inferior members. Some studies estimate the rotation centre through known external points, others through radiographic pictures for a more precise location and others using stereophotogrametry, recording the movement.

The calculation methods for the hip joint center identifies the center of rotation of the femur and the pelvis during human movement. In this study were used three methods to estimate this data: two predictive, Bell and Davis; and one functional. The data for such were colected through the software Qualysis™, treated and analised in the MATLAB.

## 2.ANATOMICAL POINTS

According Hilal (1999), for biomechanics conventions, the reference anatomical landmarks are:

1- Pelvic, represented in the figure 1:
- ASIS: Anterior Superior Iliac Spine right/left (rasis e lasis).
- EIPS: Posterior Superior Iliac Spine right/left (rpsis e lpsis).

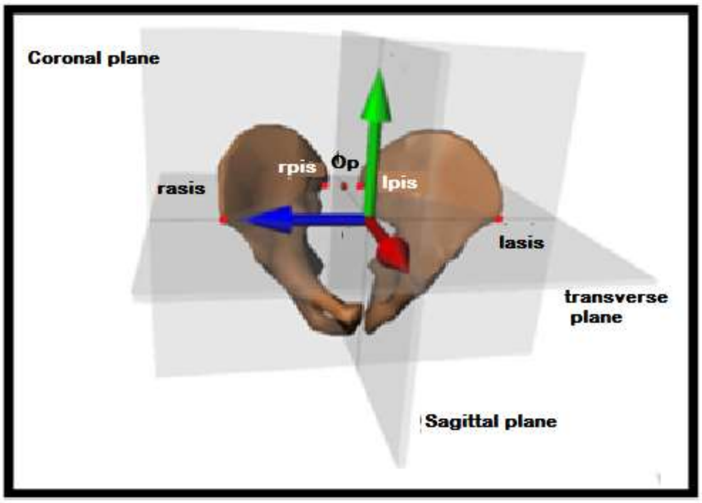


Figure 1- Pelvic anatomical frame. (Hilal, 1999)

2- Femur, represented in the figure 2-a:

- fh: Centre of the femoral head.
- le: Lateral epicondyle.
- me: medial epicondyle.

3- Tibial/Fibula, represented in the figure 2-b:

- tt: prominence of the tibial tuberosity.
- hf: Apex of the head of the fibula.
- mm: distal Apex of the medial malleolus.
- lm: distal Apex of the lateral malleolus.

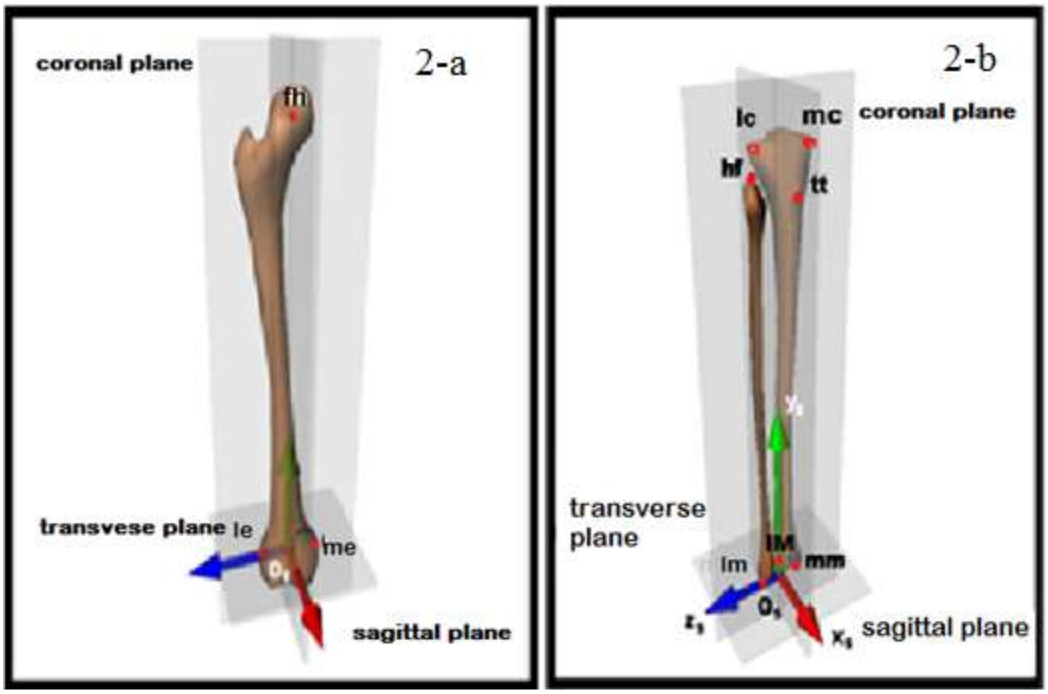


Figura 2-a Femur anatomical frame. 2-b Tibial/Fibula anatomical frame (Hilal, 1999)

## 3. PREDICTIVE METHODS

Predictive methods to estimate the hip center of rotation based on anthropometric data collected, or through images, X-rays or magnetic resonance imaging, the region to be studied.

Davis and Bell, show equations for the hip joint center, acknowledged in the literature as the more accurate predictive method.

According Bell (1990), some researchers have developed methods for determining the center of rotation of the hip. Of them can cite Andriacchi and Tylkwoski, which based the development of its method. For his method, were made two considerations:

1. The thigh is a rigid body
2. The hip center is the center of a sphere that describes a 3D rotation of a point of the body.

Bell through experiments, arrived at the following system of equations 1.1, to determine the coordinate system of the center of rotation of the hip:

$$\begin{aligned} X &= -0.19PW; \\ Y &= -0{,}30PW; \\ Z &= 0{,}36PW; \end{aligned} \tag{1.1}$$

Where PW is the distance between ASIS.

According Leardini (1999), another predictive method, already tested and used, for the hip center of rotation analysis is developed by Davis, whose systems of equations, 1.2, can be given by:

$$\begin{aligned} X &= -0.95D + 0.031L - 4; \\ Y &= -0.31D - 0.096L + 13; \\ Z &= 0.5PW - 0.055L + 3; \end{aligned} \tag{1.2}$$

Where L is the distance between the ASIS and homolateral medial, D is the anterior/ posterior component of distance between a point approximating the hip center of rotation and the homolateral ASIS, and PW, the inter-ASIS distance.

## 4. FUNCTIONAL METHOD

Four functional methods were known for determination of hip joint center, however, Camomilla (2006), after a series of experiments, arrived to conclusion that the functional method called S4, developed for Gamage and Lasenby (2002), present the results more approximate to the real hip joint center. This method present some consideration, such as:

1. The movement considered for analyze of the hip joint center used with best result is the StarArc. This movement consists in the junction of the Star, seven displacement of flexion/ extension, adduction/abduction, rotation extern/intern combined of neutral position, and the Arc, flexion of 30º, half circumference for extinction of 30º, returning to neutral. This movement can be represented by figure 1.
2. The amplitude of movement must be the greatest possible in the relative movement between pelvic and femur.
3. Localization of the marker of centroid closest possible of the hip joint center.
4. Localization of the marker with greatest distance possible.

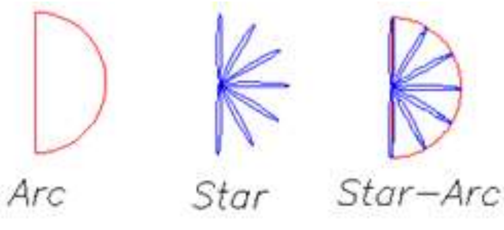


Figure 3. Star - Arc movement for calculation of the hip joint center. The lines indicating the trajectory of the foot seen from above.

The hip joint center was determined by of an algorithm of minimization of next quadratic function:

$$f\left(m,r^{p}\right)=\sum_{m=1}^{M}\sum_{k=1}^{N}\left[\left(v_{k}^{p}-m\right)^{2}-\left(r^{p}\right)^{2}\right]^{2} \tag{1.3}$$

Where m is the coordinate of hip joint center, rp is the Sphere radius defined by p markers, M is the number of markers, N is the number of frames and $v_k^p$ is the position of markers p in the instant k, present in the figure 4.

Gamage e Lasenby (2002) develops equations and propose the solution of the equation 1.3, considering the following system, where A is the position of a point in a instant k, b is the position of a next point on the same instant, and m is the position of hip joint center.

$$Am=b \tag{1.4}$$

Concerning the position of the point A can be given by the equation 1.5.

$$A=2\sum_{p=1}^{M}\left\{\left(\frac{1}{N}\sum_{k=1}^{N}v_{k}^{p}\left(v_{k}^{p}\right)^{T}\right)-\overline{v^{p}}\left(\overline{v^{p}}\right)^{T}\right\} \tag{1.5}$$

Concerning the position of the point b can be given by the equation 1.6.

$$b=\sum_{p=1}^{M}\left[\left(\overline{\left(v^{p}\right)^{3}}-\overline{v^{p}}\,\overline{\left(v^{p}\right)^{2}}\right)\right] \tag{1.6}$$

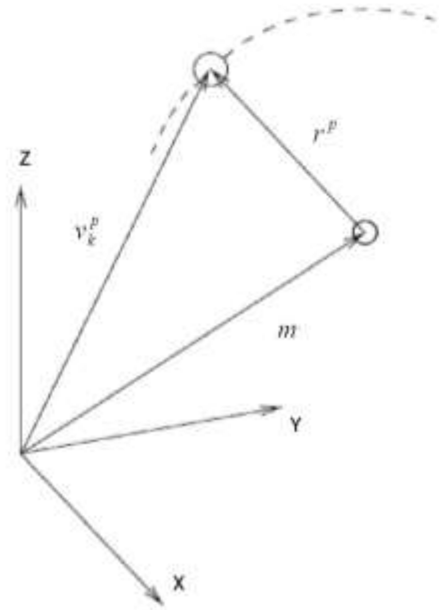


Figure 4– Definition of the vectors m, and. The marker is moving along the path of the surface of sphere with center in m. (Vimieiro 2008)

## 5. METHODOLOGY AND RESULTS

The experimented data was collected at paper of Vimieiro (2008). For experiment was Analyzed a gait under the mat seven volunteers, four male, numbered of 1 at 4, and three female, numbered of 5 at 7. First was fixed the reflexive markers in anatomicals points, to collect kinematics date. Twenty reflexives markers were fixed in the anatomicals points, Been four in pelvic, four in each knee, and two in each ankle, see the figure 5.

Fixed the reflexives markers, it was made the calibretion of the Qualisys, defined the coordinates system. The kinematics data were captured through eight infrared camera, by system of analyzes Qualysis,during the walk of each subject, and During the StarArc movement. The collect data were exported for the MATLAB, where were filtered and interpolated.

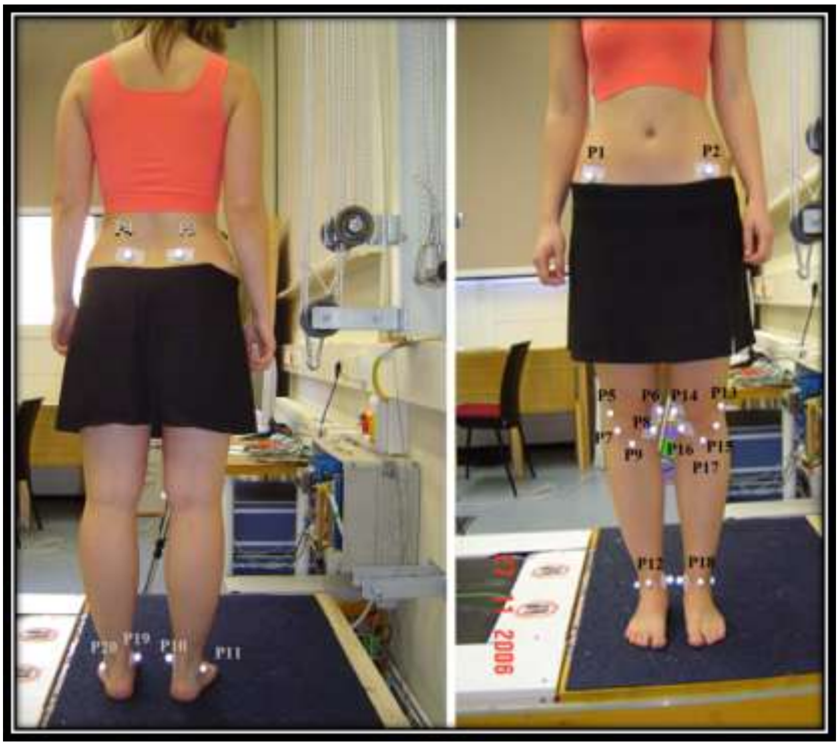


Figure 5- Reflexives markers fixed in volunteers. (Vimieiro 2008)

With the data, the first step was to find the anthropometrics measures necessary for estimate the hip joint center. The measures were acquired through the distance between the sensors correspond to the points of analyses. The table 01, presents the results of PW, D and L used in the equation of predictive method to find the hip joint center. For example, the value of PW was removed of difference between the sensors, 1 and 2, localized in the ASIS. The maximums deviation between the walk 1 and 2 of each subject, for PW was of 1.4%, for D was of 4.69% and is of L was 0.92%.

Table 01: Anthropometrics data collected

| Volunteer | Walking | PW (mm) | D (mm) | L(mm) |
|---|---|---|---|---|
| 1 | 1 | 265,810 | 71,896 | 871,266 |
| | 2 | 264,793 | 71,549 | 866,005 |
| 2 | 1 | 281,435 | 74,020 | 904,439 |
| | 2 | 282,099 | 75,732 | 903,267 |
| 3 | 1 | 256,188 | 69,369 | 923,755 |
| | 2 | 254,955 | 72,619 | 922,537 |
| 4 | 1 | 253,985 | 68,638 | 896,854 |
| | 2 | 253,985 | 69,359 | 888,593 |
| 5 | 1 | 239,983 | 67,580 | 786,037 |
| | 2 | 242,485 | 70,094 | 782,739 |
| 6 | 1 | 234,493 | 72,957 | 849,508 |
| | 2 | 234,694 | 72,229 | 849,691 |
| 7 | 1 | 204,177 | 57,682 | 843,361 |
| | 2 | 202,998 | 57,546 | 838,158 |

With the anthropometrics measures and the kinematics data can observed the variation of the pelvic center and to analyze the step cycle in the time, presented in the figure 06, can observed that the movement curve of hip follow a sine function, which varies with the leg which is supporting the body. In x and z, have a constant trajectory that correspond to movement of flexion/ extension, adduction/ abduction and rotation extern / intern, respectively. For y, the trajectory suffers variation due the movement of subject in the mat isn't in straight line.

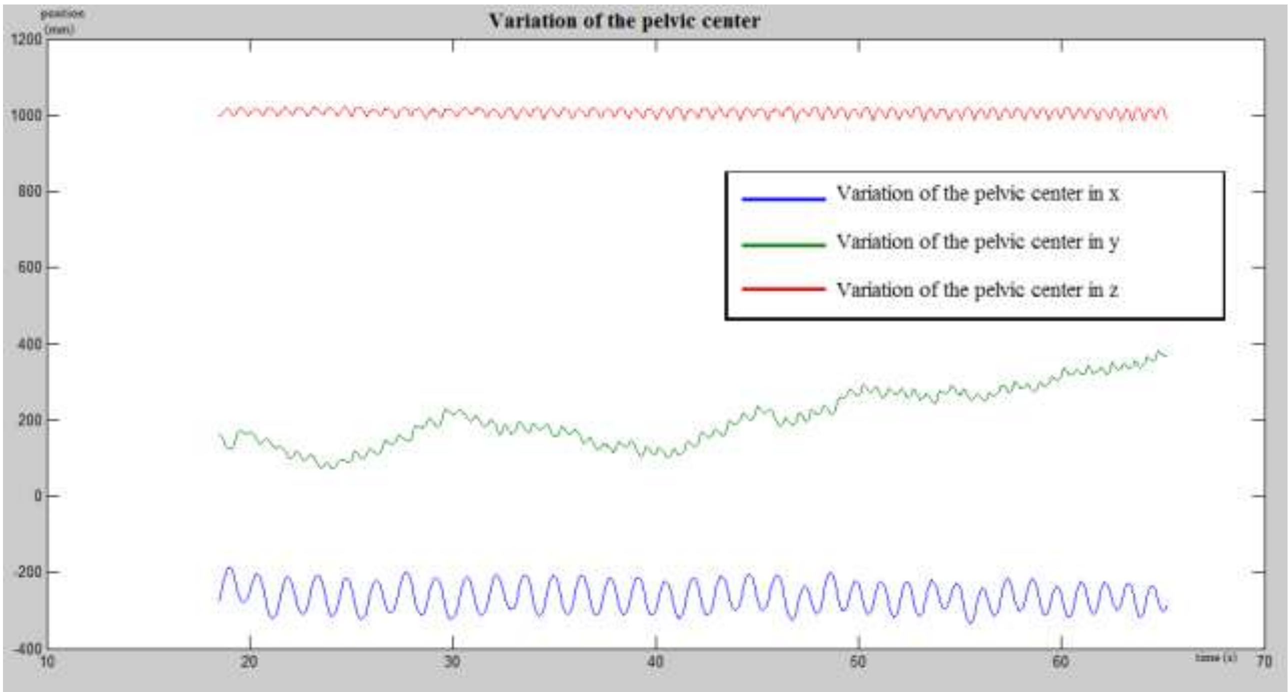


Figure 06: Pelvic Center variation

For predictive method, by Matlab rotine as previously stated, were used seven volunteers, and each subject was submitted to two walks under a mat. The data was presented in the table 02. The collected data were inserted into equations 1.1 and 1.2, for Bell's method and Davis respectively.

Table 02: Hip Joint Center coordinate by predictive method

| | | Bell | | | Davis | | |
|---|---|---|---|---|---|---|---|
| Volunteer | Walking | x (mm) | y(mm) | z (mm) | x(mm) | y(mm) | z(mm) |
| | 1 | 95,692 | -50,504 | -79,743 | 91,986 | -45,292 | -92,929 |
| 1 | 2 | 95,325 | -50,311 | -79,438 | 91,766 | -45,125 | -92,317 |
| | 1 | 101,316 | -53,473 | -84,430 | 97,973 | -46,281 | -96,772 |
| 2 | 2 | 101,556 | -53,599 | -84,630 | 98,370 | -47,944 | -97,191 |
| | 1 | 92,228 | -48,676 | -76,856 | 84,287 | -41,264 | -97,185 |
| 3 | 2 | 91,784 | -48,442 | -76,487 | 83,738 | -44,389 | -98,076 |
| | 1 | 91,435 | -48,257 | -76,195 | 84,665 | -41,404 | -94,376 |
| 4 | 2 | 90,954 | -48,003 | -75,795 | 84,452 | -42,344 | -93,806 |
| | 1 | 86,394 | -45,597 | -71,995 | 83,760 | -43,834 | -83,410 |
| 5 | 2 | 87,295 | -46,072 | -72,746 | 85,192 | -46,325 | -83,872 |
| | 1 | 84,418 | -44,554 | -70,348 | 77,524 | -46,975 | -91,170 |
| 6 | 2 | 84,490 | -44,592 | -70,408 | 77,614 | -46,277 | -90,961 |
| | 1 | 73,504 | -38,794 | -61,253 | 62,704 | -32,654 | -85,844 |
| 7 | 2 | 73,079 | -38,570 | -60,899 | 62,400 | -32,685 | -85,302 |

With the data presented, can observe, when compared the coordinates x, y, and z of each one of two methods, a variation for, x of 2 at 10 mm, y of 0,252 at 6,85mm and z of 11,41 at 24,4mm.

For the functional method, the data of three volunteers, that made the StarArc movement, were used. The date was presented in table 03.

Table 03: Hip Joint Center coordinates by functional method

| | Funcional Method | | |
|---|---|---|---|
| **Volunteer** | x (mm) | y(mm) | z(mm) |
| 2 | 60,850 | -61,851 | -69,863 |
| 3 | 88,864 | -41,973 | -68,3889 |
| 7 | 75,129 | -69,986 | -118,628 |

Comparing now, the hip joint center coordinates found for functional method with the each one of the predictive methods. When compared with the Bell method shows a variation of hip joint center for, x of 1,62 at 40,46mm, y of 6,46 at 31,18mm, z of 8,09 at 57,72mm. However when the functional method was compared with Davis it shows a variation of hip joint center for, x of 4,57 at 37,12mm, y of 0,709 at 37,33mm, z of 26,90 at 33,32mm. The volunteer that presented best results, when comparing the functional method with the predictive method, was the seventh volunteer.

## 6.CONCLUSION

Through the data collected, it was observed that the results obtained using the predictive methods are closer to each other if compared with the functional method. The methods Bell and Davis showed standard deviations to x of 6,93%, to y of 8,53% and z of 23,90%. Those deviations are considered high, but acceptable, when compared to results obtained in other articles. However, the functional method has shown higher deviations if compared with the predictive methods.

Some issues may be assessed to minimize those deviations. The first is the difference between the measures of the anthropometric data for different types of gaits; those anthropometric data should present the same values, since the distances are fixed, however, when reflexive markers fixed over the skin are used, they can move during the data collection and produce errors. The second issue refers to the fact that the Davis' method uses, to calculate D, an estimated dada of the hip joint center; the value used may also produce error. As the functional method presented high discrepancy in the results, if compared to the other methods, it is advisable to run a revision to the routine created in Matlab.

The certification of the utilized methods may be granted through real measurement of the hip joint center, from the patient's pelvis x-rays.

## 7. ACKNOWLEDGEMENTS

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