https://dx.doi.org/10.22161/ijaers.6.4.9 ISSN: 2349-6495(P) | 2456-1908(O)

# Analysis of the Method for Estimating the Hip Joint Centre for determination of the Hip and Knee Joint Angles

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***Abstract*— *The study of the human gait through the joints angles is an important branch of the biomechanics. The joints angles define the behavior of a segment in relation to another and, consequently, the overload on the tissues. The hip joint centre (HJC), regression equations system based on pelvic anatomy, is a parameter frequently used as reference point to determinate the hip and knee angles, therefore, is considered in the literature as an important factor in the kinemactics analysis of the human gait. Two analytical methods are recognized in the HJC estimation, the predictive method uses the difference between the anatomical points of the human body in the data collect, and the functional method uses a sphere adjustment approach. In the present research, it was used kinemactics data from seven volunteers, collected by Qualisys® system on a treadmill, and through algorithms developed in MATLAB®, the HJC were estimated by two predictive method systems (Bell and Davis) and one system of the functional method (with sphere adjustment approach based on the StarArc movement) and the joints angles which describes the flexion/extension movement of the hip and the knee were determined. Finally, a study was carried out on the influence of the methods for HJC estimation in the determination of hip and knee joints angles. The errors presented in the HJC estimated by the three methods were documented, but did not present significant influence in the values found by the angles of the joints.*

***Keywords*— *Human gait; Biomechanics; Hip joint centre; Joints angles.***

## I. INTRODUCTION

In studies involving movement analysis of the lower members during human walking, the hip joint centre location (HJC) is an important variable used to define the femoral anatomical frame and a reference to estimate the hip muscle momentum, which affects extensively the kinematics and kinects analysis of hip and knee joints [1-3]. Unlike prominent bony landmarks, such as the superior iliac spines, the HJC cannot be palpated, and thus its estimated. Errors in the location of the HJC can propagate down the limbs in the kinematic and kinetic analysis [4,5].

The HJC can't be taken for modeling purposes, its location must be estimated [6]. Different methods based on anthropometric measurements and regression equations are proposed in the literature to estimate the HJC positions in adults [7]. Considering non-invasive methods available in the movement evaluation laboratories two of them stand out, predictive and functional methods [2, 6].The functional method is divided in two types: with sphere adjustment approach and with transformation techniques [6].The predictive methods use regression equations based on experimental data from imaging tests. In this condition, two systems are recognized for this method, one developed by Bell et al., 1990 and another by Davis et al., 1991 [6].The method developed byDavis et al., 1991 [8] should be used cautiously in dynamic analysis, as the error can be considered clinically significant. The method developed by Bell et al., 1990 [1] presents good performance with differences in the threshold of clinical significance [5].The functional method with sphere adjustment

https://dx.doi.org/10.22161/ijaers.6.4.9 *ISSN: 2349-6495(P) | 2456-1908(O)*

approach was developed byGamage and Lasenby, 2002 [9], uses the StarArc movement, (combinationof the Star movement, 7 movementsof flexion/extension, abduction/adduction combinedofneutral position, and the Arc movement)[2].

When capturing the movement of volunteers during the walk using reflexive markers positioned in the bony protuberances, and estimating the HJC position, it is possible to draw a coordinate system for each segment in analysis, which represents the segments position over time. The Cardan method application allows the determination of a rotation matrix which represents the movement of one limb in relation to another dependent on the rotation sequence[10, 11].

In this way, the objective of this research is to compare different methodologies to determine the HJC, in order to estimate the variation that can be observed in different techniques.

## II. METHODS

In an attempt to verify the influence of the location the HJC in kinematics analysis of the human gait of lower limbs, this research proposes the application of the prediction methods selected in different volunteers. The values obtained referring to HJC were used as reference points to the coordinate system of the thigh, simulating, through algorithms implemented in MATLAB®, the flexion/extension movement of hip and knee joints.

We compare the joint positions of the HJC obtained by the three methods and verify the position difference in each one of the planes in each one of the methods.

The kinematic data collection was approved by the ethic committee of Friedrich-Schiller- Universität Jena (0558-11/00). The clinical examination was carried out in the KIP-Labor of the Friedrich-SchillerUniversität Jena, Germany. All volunteers signed the consent form for the test. [12, 13]

For the analysis of the movement of lower limbs, 20 reflexive markers were placed in the bony protuberances of the lower limbs, as specified by the International Society of Biomechanics (ISB) [14]. The volunteers were subjected to a walk on a treadmill, with controlled speed of 4,5 Km/h. The two-dimensional data of the limbs were captured by 8 infrared cameras, processed and converted in three-dimensional through of the algorithms of the Qualisys system. To the collect, we calibrate the Y axis was calibrated as antero-posterior, X as mid-lateral and Z as proximal-distal.

Participated in the study seven volunteers, with age range between 21 to 31 years old, corporal mass, height, body mass index (BMI), and variables PW (pelvic width), D (anterior- posterior component of the distance (mm) from the ASIS to HJC in the sagittal plane) and L(leg length), belongs to the Equations of preditives methods to the HJC estimation, are represented in Table 1.

*Table.1: Subject details with variables PW, D and L, measured through coordinates of the markers positioned in bony protuberances*

| Voluntary | Age | Mass (Kg) | Height (m) | BMI ($kg/m^2$) | PW (m) | D (m) | L (m) |
|---|---|---|---|---|---|---|---|
| **1** | 30 | 79,4 | 1,77 | 25,34 | 0.265 | 0.071 | 0.871 |
| **2** | 21 | 77,4 | 1,68 | 27,42 | 0.281 | 0.074 | 0.904 |
| **3** | 29 | 93,3 | 1,79 | 29,11 | 0.256 | 0.069 | 0.923 |
| **4** | 31 | 77,5 | 1,72 | 26,206 | 0.253 | 0.068 | 0.896 |
| **5** | 22 | 61,7 | 1,57 | 25,034 | 0.239 | 0.067 | 0.786 |
| **6** | 25 | 55,3 | 1,65 | 20,31 | 0.234 | 0.072 | 0.849 |
| **7** | 24 | 66,8 | 1,71 | 22,84 | 0.204 | 0.057 | 0.843 |

The average coordinates of the left and right HJCs ( x, y, z ) for each subject were calculated using two predictive methods and one funcional method with widespread use in clinical gait analysis (Table 2). Method I developed by Bell et al., (1990) [1]using PW (distance between the ASIS). Method II developed Davis et al., (1991) [8], using PW, , L ( given by the difference between the ASIS and the MM) and D ( given by the distance between an approximated point of the hip joint centre and the ASIS). Method III, functional method system with sphere adjustment approach was used the system developed by Gamage and Lasenby (2002) [9], with performing of the StarArc movement. Where, m is the position vector of the hip jointcentre, $r^p$ is the radius of the sphere defined by p marks, M is the number of marks, N is the number of frames and $v_k^p$ is the mark position p in the instant k [2, 4].

*Table.2: Equations from the literature for estimation of the hip joint centre (HJC) coordinates in the pelvis.*

| | Method I | Method II | Method III |
|---|---|---|---|
| HJCx | -0,19PW | -095D + 0,031L - 4 | $f\left(m,r^{p}\right)=\sum_{m=1}^{M}\sum_{k=1}^{N}\left[\left(v_{k}^{p}-m\right)^{2}-\left(r^{p}\right)^{2}\right]^{2}$ |
| HJCy | -0,30PW | -031D – 0,096L +13 | |
| HJCz | 0,36PW | 0,5PW – 0,055L + 3 | |

From the coordinates of the bony protuberances and the HJC, it was possible to define a coordinate system for each of the lower limbs.The limb movement in relation to another can be represented by a rotation matrix defined by Cardan Method. The rotation sequence established for the determination of the angles by the Cardan method was defined: flexion / extension movement (α) in x, adduction / abduction (β) in and and internal / external rotation (γ) in z.

Ten points were analyzed per volunteer, and the mean value, for each coordinate, was used to compare the methods and their magnitude differences were presented. Subsequently, using the HJC, the flexion / extension angles of the hip and knee were determined for each volunteer. Finally, the significance of the differences found between the methods and their respective angles was evaluated.

## III. RESULTS AND DISCUSSION

Subject details with variables PW, D and L, measured through coordenates of the markers posicioned in bony protuberances are listed in Table 1. The Table 3presentstheHJC coordinates of the right leg in neutral position, by the three methods. The coordinatespresentedhaveas local reference the hip symmetry centre. Only the volunteers 1,2,3 and 7 performed the StarArc movement.

*Table.3: Coordinates of the HJC of the right leg.*

| | Method I | | | Method II | | | Method III | | |
|---|---|---|---|---|---|---|---|---|---|
| Voluntary | x (mm) | y(mm) | z (mm) | x(mm) | y(mm) | z(mm) | x (mm) | y(mm) | z(mm) |
| 1 | 95,69 | -50,5 | -79,74 | 91,98 | -45,29 | -82,92 | 76,03 | -42,52 | -68,51 |
| 2 | 101,31 | -53,47 | -84,43 | 97,97 | -50,28 | -86,77 | 83,85 | -61,85 | -79,86 |
| 3 | 92,22 | -48,67 | -76,85 | 84,28 | -41,26 | -87,18 | 88,86 | -41,97 | -73,38 |
| 4 | 91,43 | -48,25 | -76,19 | 84,66 | -41,4 | -84,37 | - | - | - |
| 5 | 86,39 | -45,59 | -71,99 | 83,76 | -43,83 | -83,41 | - | - | - |
| 6 | 84,41 | -44,55 | -70,34 | 77,52 | -46,97 | -71,17 | - | - | - |
| 7 | 73,07 | -38,57 | -60,89 | 72,4 | -36,68 | -65,3 | 75,12 | -49,98 | -78,62 |

The estimated HJC values pointed a mean difference between the methods of about 8,85mm. Comparing the values found for the HJC by the predictive methods, Method I and Method II, it was found a mean absolute difference of 4,56mm for the x coordinate, 5,25 for the y coordinate and 5,81mm for the z coordinate, pointing to a mean difference of 5,21mm. Comparing Method I and the Method III, it was observed a mean absolute difference of 10,63mm for the x coordinate, 8,62mm for the y coordinate and 9,25mm for the z, with a mean difference of 9,5mm. Finally,Methods II e Method IIIpresented a mean difference of 10,18mm, with a mean absolute difference of 9,34mm for the x coordinate, 9,09mm for the y coordinate and 12,11mm for the z coordinate. The values found have low divergence and are within the range proposed by [4], shows absolute errors of HJC estimated by regression equations for fins equal to 31mm.

With the bony protuberances coordinates and the HJC coordinates, the coordinate system for the pelvis, thigh and leg was defined for each of the three methods separately. From the rotation matrix of one segment in relation to the other, through the Cardan method, it was possible to find the angles related to the flexion / extension movement of the hip and knee. The flexion/extension movement was used in the analysis because it had a greater magnitude than the others.

The flexion / extension movements of the hip and knee found using the three methods are shown in Figure 1. Curves similar to those presented in the literature are observed for both joints [15]. For the hip movement, Figure 1(A) shows that the flexion movement stands out in two peaks, the first to 3% of the gait cycle, which represents the initial contact of the foot on the ground, and the second spare, 92% in the final balance. And the maximum extension of the hip is represented by minimum amplitude, to 53% of the gait cycle, corresponding to the pre-swing phase. The knee movement, Figure 1(B), was characterized by two flexion peaks, the first peak at 18% in the load response phase and the second at 76%, at the end of the mean balance phase, the maximum extension of the knee movement occurs at 39% of the gait cycle, in the mean phase of support.

https://dx.doi.org/10.22161/ijaers.6.4.9 ISSN: 2349-6495(P) | 2456-1908(O)

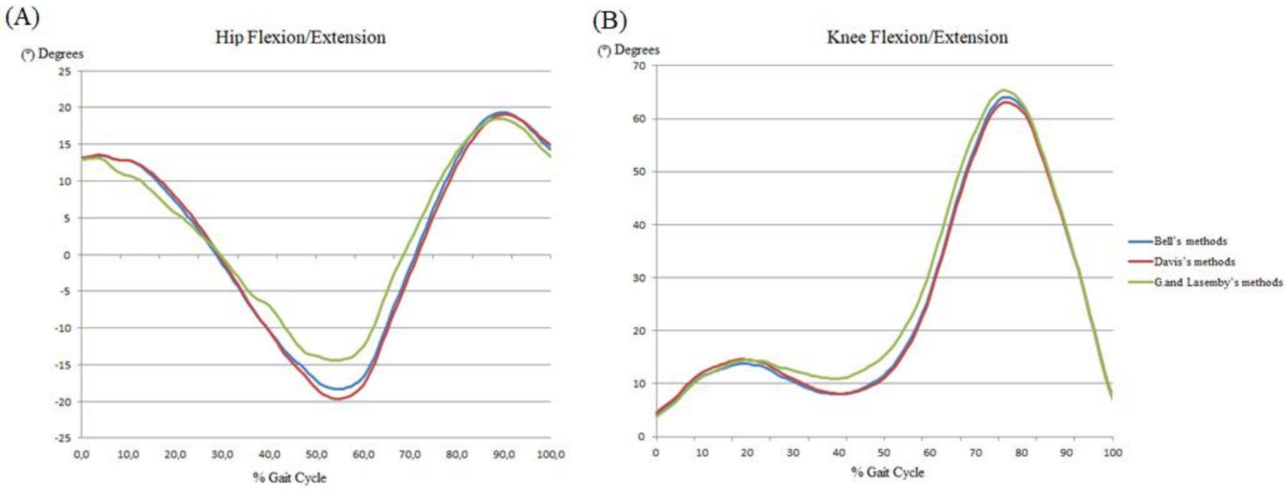


*Fig. 1: (A) Hip flexion/extension by the three methods of HJC estimation, (B) Knee flexion/extension by the three methods of HJC estimation.*

The mean values of maximum and minimum amplitude calculated from the HJC to the hip flexion/extension movement, for each individual, by the three methods are arranged in Table 4.

*Table.4: Amplitude of hip angles flexion/extension from HJC methods.*

| Voluntary | Method I | | Method II | | Method III | |
|---|---|---|---|---|---|---|
| | Minimum amplitude | Maximum amplitude | Minimum amplitude | Maximum amplitude | Minimum amplitude | Maximum amplitude |
| 1 | -17° | 19° | -18,3° | 18,8° | -15,1° | 19,4° |
| 2 | -17,9° | 18,4° | -18,5° | 18° | -13,7° | 18,2° |
| 3 | -18,2° | 18,6° | -19,3° | 17,8° | -15,9° | 18,3° |
| 7 | -18,1° | 19,2° | -18,3° | 18,3° | -15,1° | 19,2° |

In Table 4 is observed that the flexion movement, maximum amplitude, found from the hip jointcentre by the three methods, presented similar values with an absolute maximum difference of 0,9°. Comparing the values found for the extension movement, a greater absolute difference of 4,8 was observed when Method II was compared to Method III. This behavior implies in reducing the total movement amplitude of the hip movement for the functional method and, consequently, a decrease in stride length. This greater variation in relation to the other methods during the preliminary data phase was expected. However, even though deviations during the preliminary analysis would remit to a possible inconsistency during the simulation, the result did not diverge enough to discard the Method III.

The mean values of the minimum and maximum amplitude of the angles of the knee flexion/extension movement for each voluntary, defined from the three HJC estimation methods, are represented in Table 5.

*Table.5: Amplitude of Knee angles flexion/extension from HJC methods.*

| Knee | Method I | | Method II | | Method III | |
|---|---|---|---|---|---|---|
| Voluntary | Minimum amplitude | Maximum amplitude | Minimum amplitude | Maximum amplitude | Minimum amplitude | Maximum amplitude |
| 1 | 65,2 | 6,7 | 64,3 | 7,1 | 64,3 | 6,2 |
| 2 | 62,1 | 4,8 | 61,5 | 4,6 | 62,4 | 3,8 |
| 3 | 59,6 | 5,8 | 60,4 | 5 | 59,7 | 5,5 |
| 7 | 63 | 4,8 | 62,2 | 4 | 62 | 4,4 |

It was observed for both the flexion movement and the extension movement a maximum absolute difference between the methods, of 1º, and the variation occurred between the volunteers that did not follow a pattern throughout the comparison between the values found for each method.

## IV. CONCLUSION

Analyzing the predictive determination techniques of the HJC coordinates and their implication during the simulation of the angular movement of the joints, it was found some variations, mainly regarding the Gamage and Lasemby method. However, this difference did not lead to a great divergence in the determination of joint angles, since the values presented for the flexion/extension movement of the hip and knee were maintained at similar amplitudes for the volunteers, thus minimizing clinical conclusions that may be divergent.

Analyzing the interference in the hip, it was observed that the values found for the functional method, during the analysis of the human walk, caused less total amplitude for the hip flexion/extension movement, restricting in approximately 4,8º the movement of extension for this articulation. Also, for the knee analysis, it was observed that the curve presented close amplitudes, and did not critically interfere in the movement of the joint to the point of discarding some method, although the Davis and Bell methods presented responses more consistent and close to each other.

## ACKNOWLEDGEMENTS

The authors are grateful for the project funding by FAPEMIG, and by Coordenação de Aperfeiçoamento de Pessoal de Nível Superior - Brasil (CAPES) - Finance Code 001.

## REFERENCES

[1] Bell AL, Petersen DR, Brand RA (1990) A comparison of the accuracy of several hip centre location prediction methods. J. Biomech23:617–621.
[2] Camomilla V, Cereatti A, Vannozzi G, CappozzoA (2006) An optimized protocol for hip joint centre determination using the funcional method. J. Biomech39:1096–1106.
[3] Palazzo A, Crenna F, Rossi GB (2016) Instantaneous centre of rotation in lhuman motion: measurement and computational issues. J. Phys. Conf. Ser772(1).
[4] Harrington ME, ZavatskyAB, Lawson SEM., Yuan Z, Theologis TN (2007) Prediction of the hip joint centre in adults, children, and patients with cerebral palsy based on magnetic resonance imaging. J. Biomech40:595-602.
[5] Kierna D, Malone A, O'Brien T, Simms CK (2015) The clinical impact of hip joint centre regression equation error on kinematics and kinetics during paediatric gait. Gait Posture 41:175 – 179.
[6] Kainz H, Carty CP, Modenese L, Boyd RN, LloydDG (2015) Estimation of the hip joint centre in human motion analysis: A systematic review. Clin.Biomech.30:319-329.
[7] LeardiniA, Cappozzo A, Catani F, Tokksvig-Larsen S, Petitto A, Sforza V, Cassanelli G (1999) Validation of a funcional method for the estimation of hip joint centre location. J. Biomech32:99-103.
[8] Davis RB, OunpuuS, Tyburski D, Gage JR (1991) A gait analysis data collection and reduction technique. Hum MovSci10:575-587.
[9] Gamage SSHU, Lasenby J (2002)New least squares solutions for estimating the average centre of rotation and the axis of rotation. J. Biomech35:87–93.
[10] Baker R (2011) Globographicvisualisation of three dimensional joint angles. J. Biomech44:1885-1891.
[11] PhadkeV, Braman JP, Laprade RF, LudewingPM (2011) Comparison of glenohumeral motion using different rotation sequences. J. Biomech: Conf. Ser44:700-705.
[12] VIMIEIRO, C., ANDRADA,E., WITTE, H., PINOTTI, M., 2013. "A computational model for dynamic analysis of the human gait". Computer Methods in Biomechanics and Biomedical Engineering, 2013
[13] ANDRADA, E. 2007. "Functioal morphological model of the trunk in walking humans.Ilmenau (Germany), 238p. Biomechatronik, TechischeUniversatatIlmenau.
[14] Wu G, Siegler S, Allard P, Kirtley C, Leardini A, Rosenbaum D, Whittle M, D'Lima D, Cristofolini L, Witte H, Schmid O, Stokes I (2002) ISB recommendation on definitions of joint coordinate system of various joints for the reporting of human joint motion—parts I: ankle, hip, and spine. J.Biomech 35(4):543–548.
[15] Mann RA, Oakland MD, Hagy JORE (1980) Biomechanics of walking, running, and sprinting. Am J Sports Med 8:346-350.