3D Computer Modelling – A Way For Studying The Glenohumeral Joint Biomechanics

R. Melinte, G.S. Dragoi, M. Niculescu, R. P. Melinte, R. C. Dogaru

Anatomy Department, University of Medicine and Pharmacy, Petru Rares street, no. 4, Craiova, RO-1100, Romania
Email: mpr_1100@yahoo.com

Abstract. *Our main goal was to develop a biomathematic and biomechanic model that could help us study the sequence of movements in the glenohumeral joint in a way that could explain their mysterious complexity. We determined the equations of the glenohumeral cartilaginous articular surfaces and based on this equation we demonstrated and we applied mathematical formulas for calculating the curvature rays of the humeral articular surface, the 3D co-ordinates of the centers of the curvature of the humeral head and the thickness of the humeral articular cartilage. There is an orderly distribution of the curvature radius of the cartilaginous articular surfaces of the glenohumeral joint, which corresponds to certain specific paths of glenohumeral joint movements that explains the fact that any glenohumeral movement takes place in more than one movement plane.*

Keywords: glenohumeral joint, biomechanics, biomathematics, movement, curvature radius, articular surface

1. Introduction

We proposed ourselves to determine and demonstrate the important role played in the glenohumeral biomechanics by the geometric shape of the humeral head and glenoid cavity articular surfaces.

Taking into account that the bony articular surfaces of the glenohumeral joint are not congruent, one can emphasize the functional role of the cartilaginous articular surfaces ([1], [2], [3], [4]), by means of a geometric study of the articular cartilage.

Our main goal was to develop a biomathematic and biomechanic model that could help us study the sequence of movements in the glenohumeral joint in a way that could explain their mysterious complexity.

2. Materials and methods

This study has been carried out on castings of the bony and cartilaginous surfaces of the humeral head, and of the cartilaginous articular surface of the glenoid cavity. These castings made of a poliacrilic resin (Duracrol®), have been obtained by using a reversible hydrocolloid mould (Dublaga®). We have used a special algorithm for determining the equations of the articular surfaces (*Mandrila and Melinte P. R.,* 1999)[5]. The main parts of this algorithm are the following:

- we have defined a special 3D rectangular co-ordinates system by fixing three points to the one surface (Fig. 1);

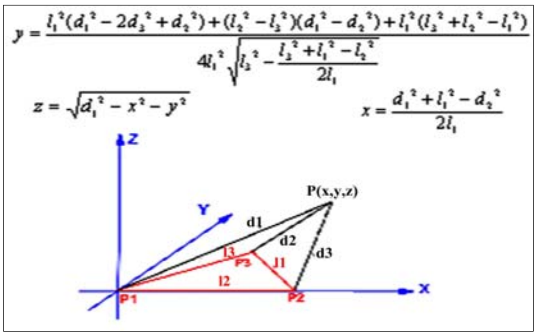


Fig. 1. The 3-D co-ordinate system attached to the studied surface, and the mathematical formulas used for determining the 3D coordinates of the points belonging to the surface.

- after choosing these three points we have measured the distances between them (l_1,l_2, l_3); we picked a large number of point belonging to the studied surface and we measured the distance from this point to the three reference points (d_1,d_2,d_3) (Fig. 1);
- we have applied mathematical formulas in order to obtain the 3D co-ordinates of some points belonging to the studied surface (Fig.1);

$$x = \frac{d_1^{\,2} + l_1^{\,2} - d_2^{\,2}}{2l_1} \qquad y = \frac{l_1^{\,2}(d_1^{\,2} - 2d_3^{\,2} + d_2^{\,2}) + (l_2^{\,2} - l_3^{\,2})(d_1^{\,2} - d_2^{\,2}) + l_1^{\,2}(l_3^{\,2} + l_2^{\,2} - l_1^{\,2})}{4l_1^{\,2}\sqrt{l_3^{\,2} - \dfrac{l_3^{\,2} + l_1^{\,2} - l_2^{\,2}}{2l_1}}}$$

$$z = \sqrt{d_1^{\,2} - x^2 - y^2}$$

- we used the least squares method for determining the equation that best suited those points, that is the equation of the studied surface;

$$z_i = a_0 + a_1 x_i + a_2 y_i + a_3 x_i^2 + a_4 x_i y_i + a_5 y_i^2$$

- the coefficients of the above equation are obtained by solving the following system:

S = m^{-1} b

$$m_{0,0} = n \qquad m_{j,k} = \sum_i (x_{j,i} x_{k,i}$$

$$m_{0,j} = \sum_i x_{j,i} \qquad b_0 = \sum_i y_i$$

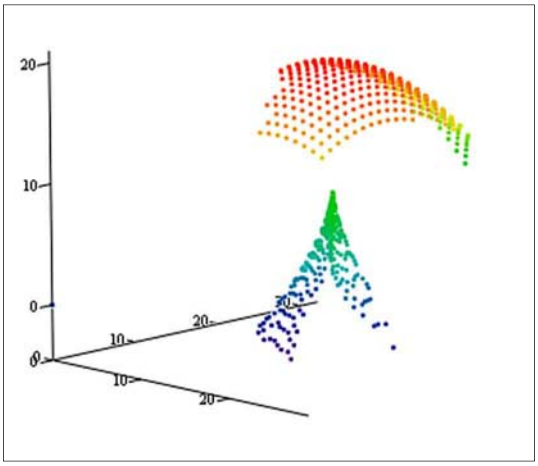
$$m_{j,0} = m_{0,j} \qquad b_j = \sum_i (x_{j,i} y_i)$$

- based on this equation we demonstrated and we applied mathematical formulas for calculating the curvature rays of the of the humeral articular surface (R_{1i} and R_{2i}), the 3D co-ordinates of the centers of the curvature of the humeral head (Fig. 2) and the thickness of the humeral articular cartilage ([6], [7], [8]).

$$k_{1i} = \frac{1}{R_{1i}} = \frac{(E_i N_i + G_i L_i - 2F_i M_i) + \sqrt{[(2F_i M_i - E_i N_i - G_i L_i) - 4(E_i G_i - F_i^2)(L_i N_i - M_i^2)]}}{2(E_i G - F_i^2)}$$

$$k_{2i} = \frac{1}{R_{2i}} = \frac{(E_i N_i + G_i L_i - 2F_i M_i) - \sqrt{[(2F_i M_i - E_i N_i - G_i L_i) - 4(E_i G_i - F_i^2)(L_i N_i - M_i^2)]}}{2(E_i G_i - F_i^2)}$$

where L, M, N, E, F, G are coefficients specific to a given surface and they can be easily calculated by using the equation for that surface.



$$x_{c_i} = \frac{\pm pR_i}{\sqrt{p^2 + q^2 + 1}} + x_i$$

$$y_{c_i} = \frac{\pm qR_i}{\sqrt{p^2 + q^2 + 1}} + y_i$$

$$z_{c_i} = -\frac{\pm R_i}{\sqrt{p^2 + q^2 + 1}} + z_i$$

Fig. 2. 3D graphic representation of the studied points on the humeral head cartilaginous articular surface and their corresponding centers of curvature. On the right, there are the equations of the center of curvature.

3. Results and discussion

The biomathematic algorithm we have been applying, fundaments itself on the finding of the 3D co-ordinates of some points belonging to the studied surface, in order to use these co-ordinates with the least squares method for determining the equation of the surface that could be then investigated concerning its curvature radius.

The least squares method succeeds in approximating the best equation that best suits a number of given points, and it also offers the possibility of calculating a coefficient of correlation in order to sustain the truthfulness of the results. Taking into consideration the large number of points studied and the values of the coefficient o correlation (0.99 out of maximum 1), we can say that statistically speaking our results are good.

Using the same 3D coordinates system, we have represented graphically the equations of the bony and cartilaginous articular surfaces of the humeral head, and thus, we have obtained the qualitative shape of the articular cartilage. This geometric shape confirms the quantitative results given by the mathematical formulas, and it also indicates that the articular cartilage is thicker in its central area (2-2.5mm) than in its peripheral regions (1-1.5mm) (Fig. 3).

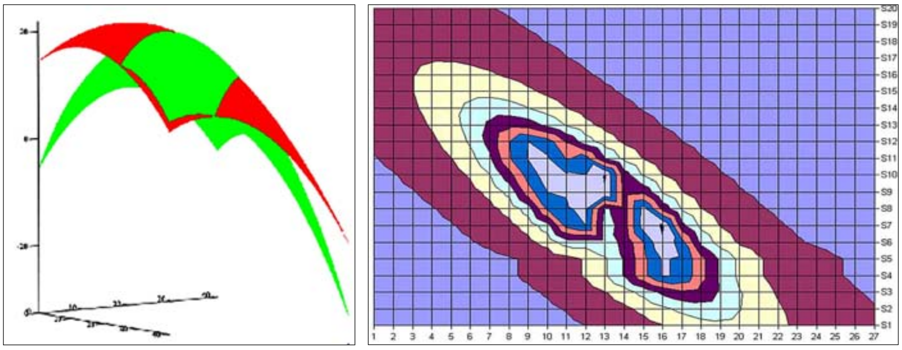


Fig. 3. 3D graphic representation of the bony (red color) and cartilaginous (green color) articular surfaces of the humeral head (left image); "level curves"-like representation of the thickness of the humeral head articular catilage (right image).

The values found for the curvature radiuses prove that the articular surface of the humeral head is formed of *helical concentric tracts*, each tract having a different curvature radius; These tracts are different for the maximum and he minimum curvature radius and consequently the entire surface is spread with these two types that have several characteristics: each tract corresponds to a certain value for the curvature radius, that is *in every point of a certain tract the curvature radius is approximately the same*; each tract has a certain direction different from the other one; each tract is made of several other tracts (under-tracts); each under- tract is crossed by several under-tracts belonging to the other tract (Fig. 4, left image).

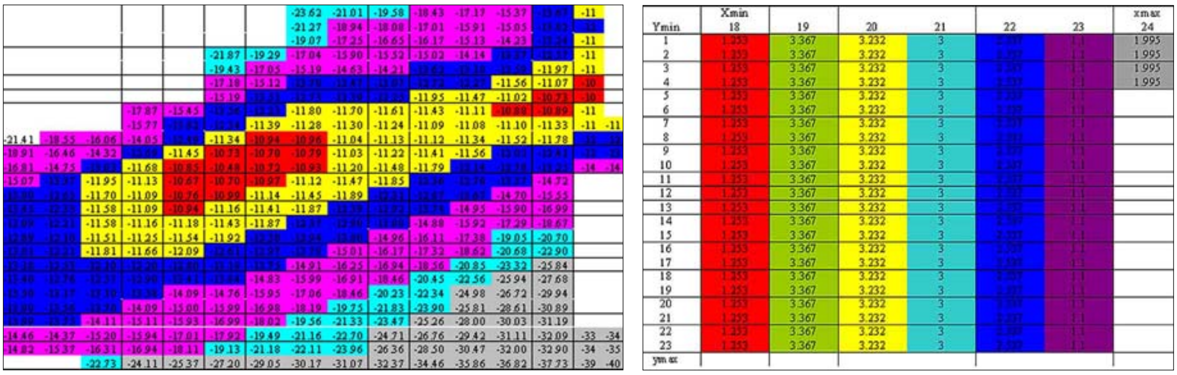


Fig. 4. *Left image* - Graphic representation of the distribution of the maximum curvature radius on the humeral head cartilaginous articular surface. Different colours represent different values for the curvature radius. The distribution of the minimum curvature radiuses have a similar aspect, the only difference is that the helical concentric tracts are oriented differently.
Right image - Graphic representation of the distribution of the curvature radiuses of the glenoid cavity cartilaginous articular surface

The glenoid cavity is made of many cylinder areas which intersect by parallel traces oriented horizontally and from anterior to posterior; these traces have approximately the same curvature radius (Fig. 4, right image).

We have also studied the curvature radiuses of these surfaces, especially those involved in the glenohumeral joint; we graphically represented in a 3D system the points standing for the curvature centers and we found out that they have a roof-like distribution; afterwards, we projected these points in the xoy plane; we repeated the method for the centers of curvature standing for the maximum and the minimum curvature radiuses of the studied surface, but at this time using the same 3D coordinates system; by studying these graphic we observed that the points representing the projection in the xoy plane of the centers of maximum and minimum curvature, have the tendency to organize themselves along two lines that form between them a sharp angle (Fig. 5).

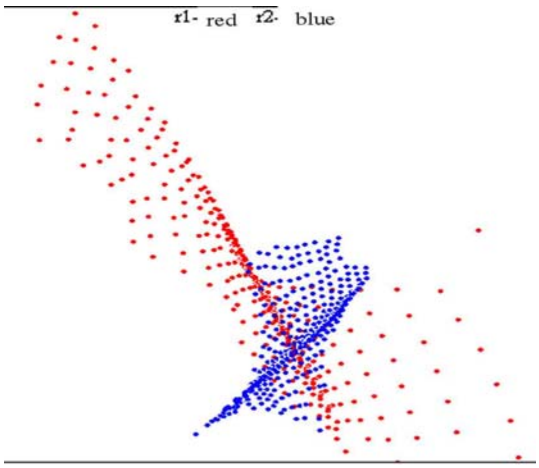


Fig. 5 2D graphic representation of the centers of maximum and minimum curvature of the cartilaginous humeral articular surface, projected in the xoy plane.

This distribution of the tracts of the same curvature radius could explain in our opinion the sequence of movements in the glenohumeral joint [9]. We propose the following sequence:

- the movement starts by rolling the humeral head on the glenoid cavity along a certain under-tract; while the movements increases, the articular congruence decreases and soon it would be necessary the leaving of the movement plane;
- the leaving of the movement plane after a rotation along humerus longitudinal axis; the humeral surface would now be in contact with the glenoid cavity by another under-tract;
- the movement increases on this new under-tract until again the articular congruence is lost and there is a need for another rotation.

In our opinion, every movement in the glenohumeral joint takes place by following these three steps sequence (Fig. 6).

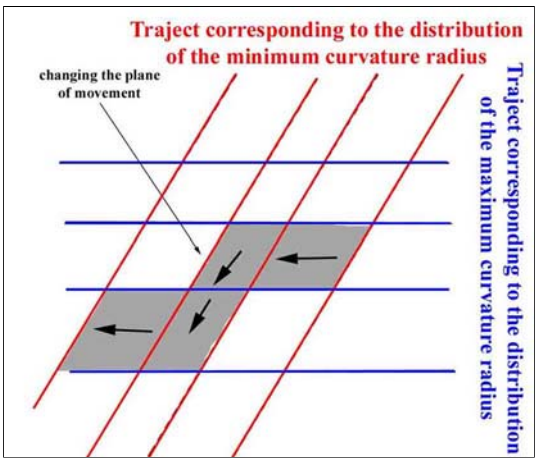


Fig. 6. Diagram showing our concept about the 3D movements in the glenohumeral joint

4. Conclusion

This easy to apply method proves itself to be a cheap and convenient way for mathematically studying the shape and geometric properties of some human anatomic surfaces; it can also improve the understanding of joint biomechanics.

There is an orderly distribution of the curvature radius of the cartilaginous articular surfaces of the glenohumeral joint, which corresponds to certain specific paths of glenohumeral joint movements that explains the fact that any glenohumeral movement takes place in more than one movement plane.

References

[1] Bailie D. S., Moseley B., Lowe W. R. – Surgical anatomy of the posterior shoulder: effects of arm position and anterior-inferior capsular shift. J. Shoulder Elbow Surg. 1999 July; 8(4): 307-13.

[2] Curl L. A., Warren R. F. – Glenohumeral joint stability. Selective cutting studies on the static capsular restraints. Clin. Orthop. 1996 Sep.; (330): 54-65.

[3] Drăgoi S.G., Rinderu E.T., Drăgoi S., Rinderu P.L., Alina Drăgoi, A study of glenoidal labrum innervation, The Way to Win - International Congress on Applied Research in Sports, Finland, Helsinki, August 9-11, 1994, Abstract Book, 1994, p.14.

[4] Itoi E., Horng Chaung Hsu, Kai – Nan An.- Biomechanical investigation of the glenohumeral joint.J. Shoulder Elbow Surg. 1996. 5: 407 – 424.

[5] Dragoi S. G., Rodica Melinte, Mindrila I., Mihaela Niculescu, Melinte V. R. - Contributions to the evaluation of the handicap and prejudices brought to the shoulder articular system. Legal medicine implications, Romanian Journal of Legal Medicine, Volume 7, Number 3, September, 1999, pages 216-232

[6] Melinte Razvan, Raluca Dogaru, Musetescu Anca Emanuela, - Geometric Study of the Articular Surface of the Humeral Head, 4-th Balkan Congress of Medicine and dentistry for students and young doctors, Craiova, Romania, 2-4 october 2000, Abstract Book, page 115.

[7] Melinte P. R., Dogaru C. R., Musetescu A. E. - Humeral Head - A biomechanical Model, 17th International Medical Sciences Student Congress, Istanbul, May 3-6, 2001, Abstract Book, page 3

[8] P. R. Melinte, R. Melinte, G.S. Dragoi, C.R. Dogaru, M. Niculescu - The geometric form of the articular surface of the glenoid cavity. A biomathematic study - The XVII International Symposium of Morphological Sciences, september 11-15, 2002, Tmioara, Romania, pag. 626.

[9] Melinte Rodica, Dragoi G.S., Melinte P. Razvan, Dogaru C. Raluca - A new Concept for describing the movements in the glenohumeral joint - The 13th European Conference of Biomechanics, september 2-4, 2002, Wroclaw, Poland. In: Acta of Bioengineering and Biomechanics, vol. 4, suppl. 1, 2002, pag. 626-627.