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THE INFLUENCE OF FEMORAL BALL SIZE ON THE RANGE OF MOTION THAT FULFILLS THE CRITERIA OF SAFE ZONE ORIENTATION ACETABULAR CUP

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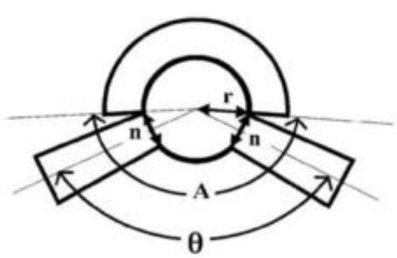
Graphical abstract



Abstract

Dislocation and edge loading are significant issues highlighted due to the acetabular component orientation during total hip replacement(THR). This study aims to define the optimum acetabular cup orientation with the most suitable femoral ball size, thus eliminating the possible issue that may arise during postoperative surgery. A numerical approach by creating a single function that enables the calculation of the cup inclination (α) and the cup anteversion (β) with respect to range of motion are developed by using a programming language namely Matlab®. Three separate studies were done by having a head neck ratio of 2.33, 2.67 and 3.0, respectively. From these data, it is clear that the size of femoral head affects the area under range of motion at the bearing surfaces. A wide area under the graph resulted in a better and greater number combination of acetabular cup thus reducing the risk of dislocation and edge loading.

Keywords: Acetabular cup, orientation, range of motion, dislocation, edge loading

1.0 INTRODUCTION

Some of the most critical issues related to hip joints are chronic pain and diseases such as osteoarthritis, rheumatoid arthritis, bone tumors or traumas[1]. For these cases, the best solution is to undergo a total hip replacement (THR) which is a surgical procedure of replacing an unhealthy hip joint with an implant. New acetabular components will replace the infected head that being removed. The cup can be use individually (polyethylene) or adding a metal backside articulated with an insert commonly polymer [2].

The number of THR procedures are expected to increase further due to an aging population and the limited life span of prostheses[3].

In total hip replacement, proper cup alignment can reduce the effect of impingement, edge loading and generation of wear debris, thus improving the lifespan of the implant[4]. with research finding that the orientation improves the postoperative total hip replacement stability[5]. Malpositioning of acetabular components may result in dislocation, impingement, reduction range of motion and sharply increase the wear debris due to elevated contact stress at bearing surfaces[6,7]. Thus, it is intended to determine the range of motion associated to the safe zone placement of the acetabular cup.

Researchers intend to have different methods for defining the cup angles, and there are research to study the inconsistency on this matter[8]. However, the concept is still the same on defining a very optimum safe zone. Thus, we will try to study the safe zone based on applying the research finding[9,10] with modification upon the range of motion intended.

The main aim of the present study was to investigate the relation of femoral ball size with the acetabular cup orientation and the achievable parameters set for common activities of daily living (ADL). All set output angles parameters are considered as general angles based on ADL of normal people irrespective of gender, race and age[13,16].

2.0 METHOD

Before, Fumihiro [9] has developed a mathematical formula for defining a suitable safe zone for acetabular cup orientation with five parameters being applied. These parameters are considered as important and must be complied in order to get the desired results. Some researches adding one more parameters which is stem-neck (CCD) on defining a safe zone[4,11] but the model are developed from a three-dimensional computerized model which differs from the formula developed by Fumihiro. Thus, we would like to combine both methods and run it in Matlab® (The MathWorks Inc, Natick, MA) with some judgment from Widmer[11] and Klingenstein[13] on defining the safe zone.

The equation (Eq. 1) that will sum up the development of the function in the Matlab® and could be considering as the critical equation denoted as:

$$\theta = A - 2\sin^{-1}\left(\frac{n/2}{r}\right) = A - 2sin^{-1}\left(\frac{1}{head/neck\ ratio}\right) \tag{1}$$

$$FL = \cos^{-1}\left(\frac{\left((-\sin\beta\cos a\sin b + \cos\alpha\cos\beta\sin a)E_1 - (\cos\alpha\cos\beta\cos a\sin\beta\sin a)\sqrt{D_1}\right)}{(1 - sin^2\alpha\, cos^2\beta)(1 - cos^2 a\, cos^2 b)}\right) \tag{2}$$

$$EXT = \cos^{-1}\left(\frac{\left((-\sin\beta\cos a\sin b + \cos\alpha\cos\beta\sin a)E_1 + (\cos\alpha\cos\beta\cos a\sin\beta\sin a)\sqrt{D_1}\right)}{(1 - sin^2\alpha\, cos^2\beta)(1 - cos^2 a\, cos^2 b)}\right) \tag{3}$$

$$IR = cos^{-1}\left(\frac{(-\sin\beta\sin b + \sin\alpha\cos\beta\cos b)E_2 + (\sin\alpha\cos\beta\sin b + \sin\beta\cos b)\sqrt{D_2}}{\cos a\,(1 - cos^2\alpha\, cos^2\beta)}\right) \tag{4}$$

$$ER = cos^{-1}\left(\frac{(-\sin\beta\sin b + \sin\alpha\cos\beta\cos b)E_2 - (\sin\alpha\cos\beta\sin b + \sin\beta\cos b)\sqrt{D_2}}{\cos a\,(1 - cos^2\alpha\, cos^2\beta)}\right) \tag{5}$$

$$ABD = \cos^{-1}\left(\frac{(\sin\alpha\cos a\cos b + \cos\alpha\sin a)E_3 + (\cos\alpha\cos a\cos b - \sin\alpha\sin a)\sqrt{D_3}}{\cos\beta(1 - cos^2 a\, sin^2 b)}\right) \tag{6}$$

$$ADD = \cos^{-1}\left(\frac{(\sin\alpha\cos a\cos b + \cos\alpha\sin a)E_3 - (\cos\alpha\cos a\cos b - \sin\alpha\sin a)\sqrt{D_3}}{\cos\beta(1 - cos^2 a\, sin^2 b)}\right) \tag{7}$$

These are among the main equations that has been developed by previous study that plays a significant role on developing the function into the Matlab. The details of the equation that already developed can be referred to the author's paper and Fig. 1 is the prosthetic range of motion schematic diagram[9].

By using the Matlab® software, a single function is created with theta (θ), head-neck ratio (H/N), cup inclination (α) and cup anteversion (β) as variables. The all input parameters function will be commanded with multiple values of cup anteversion ranges and the resulting outputs with flexion, extension, external rotation, internal rotation, abduction and adduction. The value of cup anteversion was ranged from 2° to 50°. Based on equations(1 to 7) from[9], we figured out that the head neck ratio plays a vital role, thus a femoral ball of 28mm, 32mm and 36mm diameter with constant neck value are set as the criteria here.

The criteria are intended to get optimum values of flexion 110°, extension 30°, external rotation 40°, internal rotation 120°, abduction 30° and adduction 40°. It is noted that internal rotation at 90° flexion are used by Fumihiro[12] without stating the exact formula on getting the values and also neglecting the abduction and adduction angle, thus we will consider the condition boundary developed by simulation[11, 13, 14] results and created a new parameters for the intended range of motion desired. Internal rotation at 90° flexion is meant by adding the values of flexion with the intended range of internal rotation[15] as simulated visually.

3.0 RESULTS AND DISCUSSION

The predicted areas for the safe zone cup orientation are shown as in Fig. 2. (The area highlighted in black) and the area increasing with respect to head-neck ratio. It is shown that femoral ball plays a much vital role in the range of motion parameters as per agreed with previous researches[9, 10, 15, 16]. Generally, the acetabular cup needs a wide common range for the cup inclination angle and the cup anteversion angle to minimize an error by the surgeon when locating the acetabular cup. If the common range area is too small, the safe error margins are difficult to achieve by the surgeon during the operation[4]. These results agreed with suggestion that inclination angle of any acetabular cup materials used in THR is should not exceeded more than 50°[18].

To the best of our knowledge, there are many sizes of the femoral ball currently being used and surgeons favor inclined towards a bigger ball to provide a better range of motion of postoperative THR. In this case, only three common sizes of femoral ball uses in this numerical approach to determine the optimum range of motion. However, there is some limitation as the neck angle stem was fixed to reduce the complexity of the function developed in Matlab® from these equations.

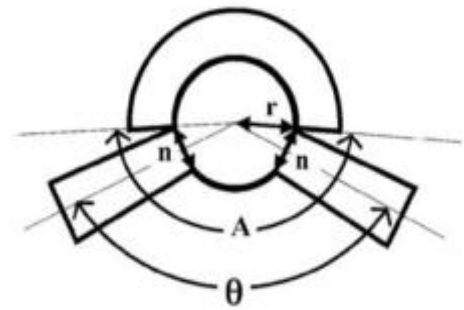
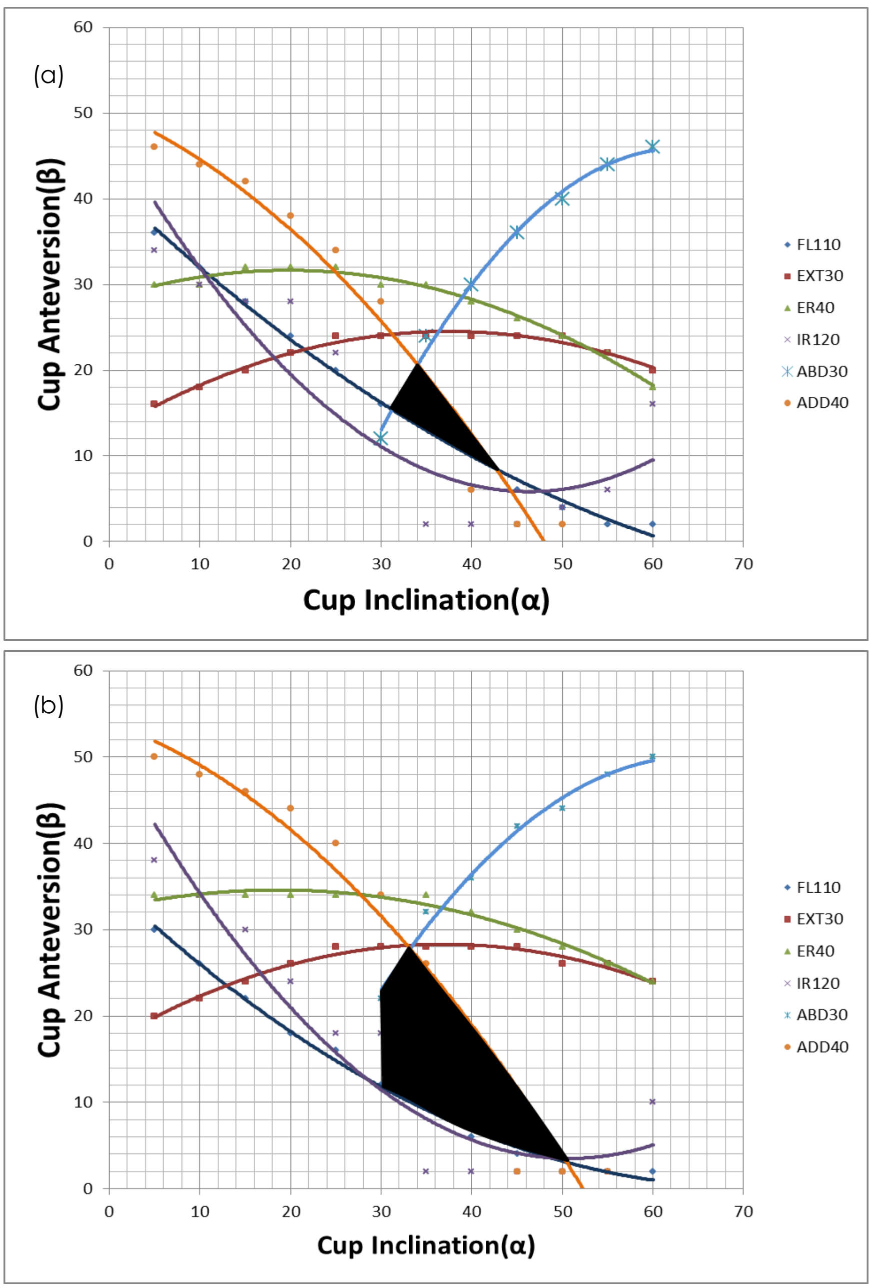


Figure 1 The prosthetic range of motion cone[9]



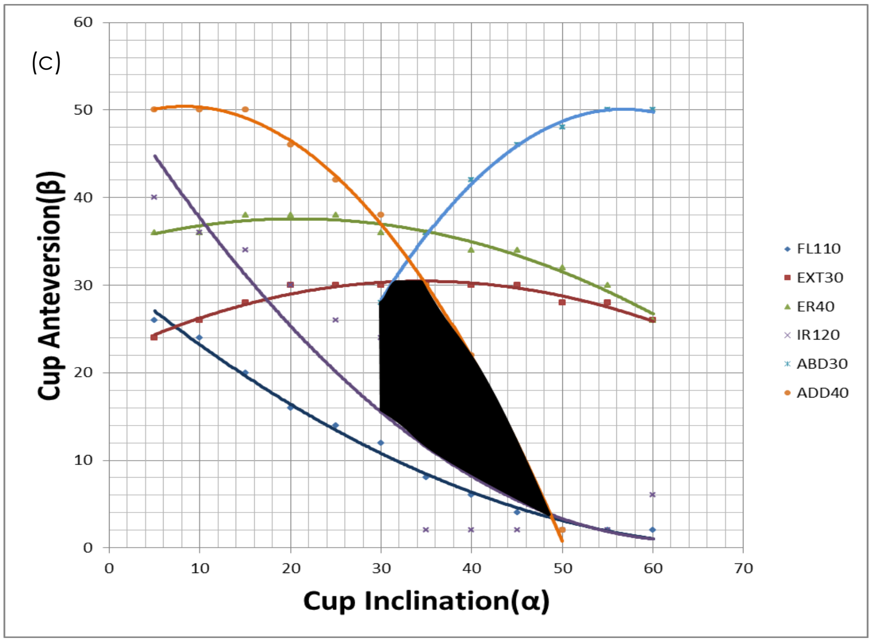


Figure 2 The optimum safe zone orientation for acetabular cup: (a) 2.33 head-neck ratio, (b) 2.67 head-neck ratio, (c) 3.0 head-neck ratio. (Parameters of FL110, EXT30, ER40, IR120, ABD30 and ADD40).

4.0 CONCLUSION

A general method of applying the equations in Matlab® shows that femoral ball sizes are affecting the allowable range of motion as the set parameters before. A bigger femoral ball size resulted into various combinations of acetabular cup placement upon THR surgery, thus minimizing the dislocation and edge loading. Each acetabular component system requires a standard recommendation for the optimal positioning and even though a universal combination has not existed yet, this method of determining a safe zone proves to be suitable approach when dealing with the acetabular cup orientation. As mentioned before, these approach is suitable for any types of combination of acetabular components with argument that femoral ball size that may influence the range of motion of the implant.

Acknowledgement

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