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Review Article

UNDERSTANDING THE BIOMECHANICS OF HUMERAL HEAD SPINNING STYLES FOR VALID EXERCISE INNOVATIONS IN THE DOMAIN OF SHOULDER STRENGTHENING AND REHABILITATION

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ABSTRACT

Humeral head spinning styles on glenoid fossa during various upper extremity movements are not fully explored. Multiple strengthening exercises and hands-on techniques have been evolved in treating shoulder joint dysfunctions to reestablish the axis of humeral spinning and kinetic maneuvers for normal shoulder joint functions. This innovative article elucidates the scopes of different types of perfect humeral head spinning to give new researching foundation for valid exercise innovations in the domain of shoulder strengthening and rehabilitation.

KEYWORDS: Humeral head spinning styles, elastic tube exercises, valid exercise innovations.

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INTRODUCTION

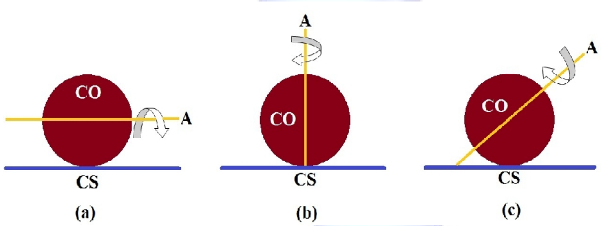
Exercise innovations in the domains of strengthening and rehabilitation are quite challenging for Physiotherapists and fitness professionals. Without a deeper understanding of all commonly prescribed exercise techniques, the next level of productive exercise innovation may not be possible or any such innovation may get created as a less effective or counter productive technique. Undoubtedly, except few, there is a common propensity of Physiotherapists to just gain the superficial knowledge about various exercise techniques, lacking enthusiasm to exactly know the biomechanical background of the exercise techniques opted for prescription. Dealing with humeral head spinning biomechanics, this article is expected to encourage all burgeoning Physiotherapists to spend productive time in understanding the deeper parts of exercise biomechanics in order to excel as an exercise researcher and innovator. Before discussing about the biomechanical play of curved humeral head on the glenoid fossa, the three common interactions of a spherical object in contact with a surface should be understood (Figure-1).

1. A circular object rotating around an axis, in contact with a surface that is parallel to the axis, will tend to roll in the direction of rotation and the magnitude of linear displacement gained by this circular object as a result of this rolling will be directly proportional to the product of diameter of the object, number of revolutions of the circular object and 3.14 [1].

2. A circular object rotating around an axis in contact with a surface that is perpendicular to the axis, will not tend to roll in the direction of rotation but spin at the same place without undergoing linear displacement [1].

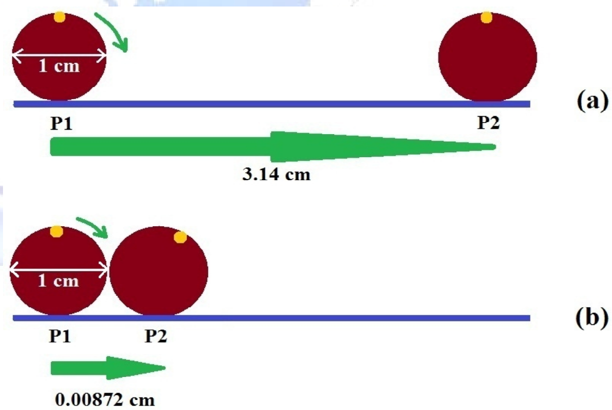
3. Conditions in which the relationship between the axis of circular object and its contact surface is oblique, the magnitude of linear displacement will be decreased and determined by cosine angle between the axis and the contact surface[1].

Fig. 1: CS - Contact surface, CO - Circular object, A - Axis of rotation. 1a shows the parallel relationship between the axis of rotation and the contact surface in which the circular object can roll and undergo linear displacement in the direction of its rotation. 1b shows the perpendicular relationship between the axis of rotation and the contact surface in which the circular object can spin in the direction of torque at a stationary point. 1c shows the oblique relationship between the axis of rotation and the contact surface in which spinning and rolling are mixed but the magnitude of rolling and linear displacement is always lesser than what is possible with circumstance as shown in 1a. Not only that, the mechanisms on the basis of 1c will also result in motion in the unintended direction. Either for perfect spinning or rolling, the axis of rotation must pass through the center of the circular object.



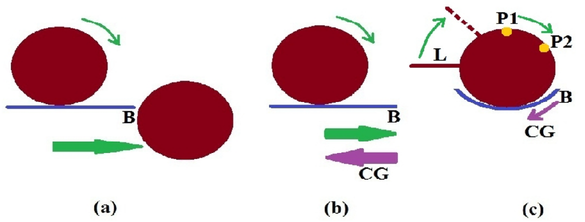
The equation for linear displacement (LD) caused by motion of circular objects in contact with a surface (Figure 1a) is; **LD = D x 3.14 x N**, where D - Diameter of the circular object, N - Number of revolutions [1]. Head of humerus is curved and this curvature can belong to portion of a perfect circle that can enable the head of humerus to roll in the direction of its rotation in contact with the glenoid fossa, on the basis of mechanism shown in Figure 1a. However in human body, this equation for LD needs to be adjusted because such curved bony surfaces will not undergo several revolutions like a wheel of a car, but always in predictable or measurable extent because the tendency of LD is biomechanically restrained enough to prevent rolling of the articular end out of the joint boundaries. Therefore, the LD tendency of curved bony surfaces in human body can be formulated as **LD = D x 3.14 x [(ø)/360°] x Cosine angle**, where "ø" is the degree of rotation, Cosine angle - the angle between the axis of rotation of the circular object and contact surface, with the perpendicular relationship between the axis of rotation of circular object and its contact surface to be considered as either Cosine 90° or Sine 0° [1]. If the axis of rotation of circular object is perpendicular (Cosine 90°= Zero), then its rotation will not result in linear displacement but spinning at a stationary point (Figure 1b). As shown in Figure-2a, 3.14 is the magnitude of linear displacement (in centimeters) of a 1 cm diameter circular object per revolution or the circumference of a 1 cm diameter circle [1].

Fig. 2: 2a shows that the total linear displacement after one revolution of 1 cm diameter circular object in contact with a surface equals 3.14 cm. 2b shows that the total linear displacement after one degree of rotation of 1 cm diameter circular object, in contact with a surface equals 0.00872 cm. P1 - Starting point, P2 - Point at which the revolution or rotation has ceased. The yellow dot on the circular object is just used as a reference point to indicate its position.



If the circular object is stipulated to continuously undergo rotation on a limited contact surface, it can roll out of the boundary (B) as shown in Figure-3a. To prevent such rolling out of the boundary, compensatory gliding or compensatory linear displacement in the opposite direction is the only choice hence the demand for an active compensatory glide force system arises (Figure-3b). The timing and magnitude of compensatory gliding should equal the timing and magnitude of LD tendency of the circular object to obtain the effect of 'spinning at a stationary point', so that there is no scope of rolling out of the boundary but this is quite challenging if the contact surface is flat or slightly concave. If the contact surface is concave, any attempt of the circular object to roll can be accompanied by passive compensatory gliding in the opposite direction without requirement of an active compensatory glide force system (Figure-3c), therefore, higher the extent of concavity of the contact surface, greater the passive compensatory gliding.

Fig. 3: 3a shows the tendency of the rolling circular object to move out of the given boundary (B). 3b shows the demand for an active compensatory glide force system to produce compensatory glide (CG) in the direction opposite to the rolling to prevent rolling out of the boundary. 3c shows that the concavity of the contact surface can give passive CG to prevent rolling out of the boundary (concavo-convex rule). The mechanism in 3b and 3c, based on the magnitude of compensatory gliding, can almost give an effect of 'spinning at a stationary point' but still any lever (L) attached to the circular object will be moved to a new place. In such circumstance where the circular object has tendency to roll, to get the effect of spinning at a stationary point, the timing and magnitude of compensatory gliding should equal the timing and magnitude of rolling.

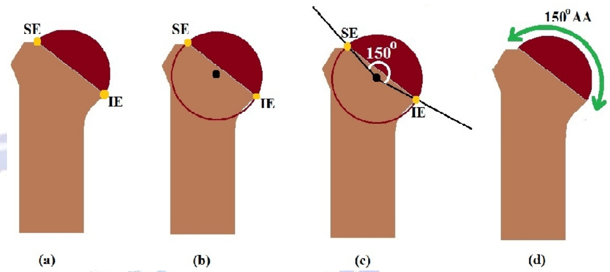


All these fundamental interactions (Figure 2 & 3) of circular object in contact with a straight or concave surface with three major types of its axis of rotation (Figure 1) should be used in analyzing the humeral head spinning biomechanics.

Humeral head spinning styles:

Humeral head is not fully circular but may possess a part or arc of a perfect circle. It is possible to construct a complete circle by forming an Isosceles triangle with the given part or curve of a circle.[1] We can understand the linear displacement characteristics of the humeral head on the glenoid fossa only after identifying the circle to which the arc of humeral head belongs. Construction of a circle by forming an Isosceles triangle with the given arc or curve of a circle is beyond the scope of this article. Humeral head diameter was found to be 42.1mm for females and 49 mm for males [2]. For easy understanding and calculation, we canassume a 5 cm diameter humeral head with 150° articular arc (Figure-4), hence for every 1° rotation with axis parallel to the glenoid fossa, in any plane possible, there will be about 0.0436 cm **(5 cm x 0.00872)** of linear displacement caused by rolling of humeral head in the direction of rotation.

Fig. 4: Schematic coronal view of right humerus (upper half) with an articular portion of a size less than a hemisphere. 4a shows the superior edge (SE) and inferior edge (IE) of the articular head. 4b shows the matching circle of the articular arc of the head. 4c shows the possible location of SE and IE at 150° interval. 4d shows the 150° articular arc (AA) of the humeral head.



For analysis of humeral head spinning styles, we shall consider only three major axes as described in table-1 to be related with Figure-5.

Fig. 5: 5a shows the axis for humeral head spinning styles in the neutral state. Yellow colored center represents the antero-posterior axis (AP) that runs parallel to the glenoid fossa (GF), Blue colored line represents the cephalo-caudal axis (CC) that runs parallel to the GF and Orange colored line represents the medio-lateral axis (ML) that runs perpendicular to the GF. The shallow glenoid fossa (GF) and little portion of lateral border of scapula are also shown. 5b shows the axis for humeral motions in a slightly abducted state where the relationship of AP, CC and ML with glenoid fossa remains undisturbed but their orientation is changed. This is because, at any given angle of glenohumeral joint there must be an axis passing through the center of humeral head to perpendicularly intersect the midpoint of GF and two axes passing parallel to the GF through center of humeral head. 5c shows the possibility of multiple axes from the superior end (SE) to inferior end (IE) of GF, if the GF is perfectly congruent, so that any part of humeral head fitting to congruent GF can also give an axis passing through the center of humeral head. 5d shows an axis zone (AZ) possibility at any given angle of glenohumeral joint if there is a chance for congruent glenoid fossa instead a shallow glenoid fossa. It should be noted here that looking at various coronal plane radiological images of glenohumeral joints, one can understand that the glenoid fossa is just half the length of humeral head articular arc.

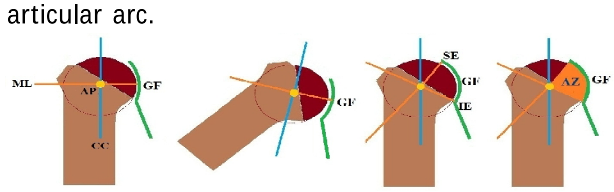
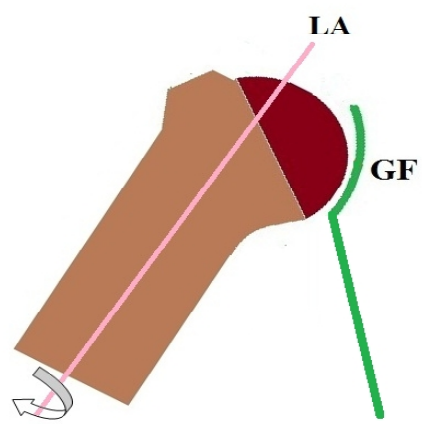


Table 1: Showing Humeral Head Spinning Styles

Axis	Type of humeral head spinning styles
AP	This axis passes through the center of humeral head antero-posteriorly (AP) running parallel to the glenoid fossa (GF) - Yellow colored point in Figure-5. Motion around this axis can cause superior and inferior rolling of humeral head on the glenoid fossa. In order to get the effect of spinning at a stationary point, the LD tendency of this rolling should be counteracted by compensatory gliding in the direction exactly opposite to the direction of rolling. The timing and magnitude of compensatory gliding must equal the linear displacement potential of humeral head per degree of rotation, particularly if the GF is shallow. It can represent sagittal axis in some positions of glenohumeral joint. The parallel relationship of AP axis with GF will remain unchanged but the orientation of this axis can be horizontal or oblique depending on the alignment of glenohumeral joint during static and dynamic conditions of arm in different postures.
ML	This axis passes through the center of humeral head medio-laterally (ML) running perpendicular to the glenoid fossa - Orange-colored line in Figure-5. Motion around this axis can cause perfect spinning of humeral head on the glenoid fossa. It can represent coronal axis in some positions of glenohumeral joint. The perpendicular relationship of ML axis with GF will remain unchanged but it can be horizontal or oblique in orientation depending on the alignment of glenohumeral joint during static and dynamic conditions of arm in different postures.
CC	This axis passes through the center of humeral head cephalo-caudally (CC) running parallel to the GF - Blue colored line in Figure-5. Motion around this axis can cause anterior and posterior rolling of humeral head on the GF. In order to get the effect of spinning at a stationary point, the LD tendency of this rolling should be counteracted by compensatory gliding in the direction exactly opposite to the direction of rolling. The timing and magnitude of compensatory gliding must equal the linear displacement potential of humeral head per degree of rotation, particularly if the GF is shallow It can represent vertical axis in some positions of glenohumeral joint. The parallel relationship of CC axis with GF will remain unchanged but it can be vertical or oblique in orientation depending on the alignment of glenohumeral joint during static and dynamic conditions of arm in different postures.

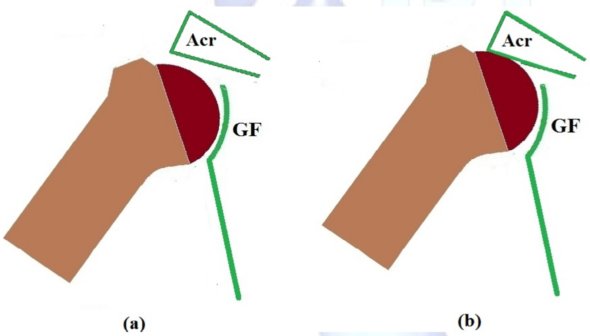
Due to inherent disadvantages, the oblique relationship between axis of humeral rotation and glenoid fossa (an example shown in Figure-6), from a hypothetical standpoint, may not be available in normal conditions but may be in pathological states. For example, if the humerus tends to rotate along its longitudinal axis (LA) when glenoid fossa is not parallel to LA, there will be limited rolling and linear displacement occurring in an unintended direction (similar to Figure-1c). So, at any given angle, for any shoulder joint functional movements, the axis for humeral rotation and its relationship with glenoid fossa can fall in the categories explained in table-1. It means, as a rule for safe and effective humeral rotations, the line of axis of humeral rotation at any angle in any plane must pass through the center of humeral head maintaining either a parallel or perpendicular relationship to the glenoid fossa. Application of this rule can enable Physiotherapists to understand the (i) normal biomechanics of shoulder joint (ii) pathomechanics of shoulder joint (iii) special tests for shoulder joint disorders (iv) value of every therapeutic exercise for shoulder rehabilitation.

Fig. 6: This is just an example of oblique relationship between axis for humeral rotation and shallow glenoid fossa that may not exist in normal conditions but in pathological conditions because there will be limited rolling and linear displacement occurring in an unintended direction due to this oblique relationship. Perhaps, even if the axis is passing through the center of the humeral head but does not have either a parallel or perpendicular relationship with the glenoid fossa, unfavorable humeral head spinning and rolling can be expected. But still this view point must be subjected to further scientific inquisition.



Innate kinetic maneuvers for perfect spinning of humeral head can successfully avoid soft and hard tissue impingement. In particular, the humeral head rotations around the AP and CC axis must be accompanied by compensatory gliding. The normal acromio-humeral interval was found to be seven to fourteen millimeters [3]. Assume that the acromio-humeral interval is 1.2 cm and the kinetic maneuvers for inferior gliding of humerus with 5 cm diameter head is completely disrupted (Figure-7). In this pathomechanical state, the acromio-humeral collision can approximately occur after 27.5° of arm abduction in coronal plane (Formula: Acromio-humeral collision angle = Acromi o- humeral interval / [0.00872 x Humeral head diameter]).

Fig.7: 7a shows normal humeral abduction with mixed upward rolling and inferior gliding to maintain the acromio-humeral interval and prevent impingement problems. 7b shows failed inferior gliding mechanism, hence upward rolling alone results in narrowing of acromio-humeral interval leading to acromio-humeral collision. GF- Glenoid fossa, Acr - Acromion process.



The glenoid fossa and humeral head are incongruent surfaces; the convex humeral head is not parallel to the concave fossa [4]. If the convex humeral head is not parallel to the concave fossa or if the axis of humeral head and the glenoid fossa is neither parallel nor perpendicular, then it may possess inherent disadvantages (Fig. 1c & 6). There is a possibility of the unparallel state of convex humeral head and concave fossa when the arm is just hanging relaxed at the side where the muscular role may be totally absent. All the muscles of the shoulder complex are electrically silent in the relaxed, unloaded limb and even when the limb is tugged vigorously downward.[5] So, till the muscles become sufficiently active in elevation, there can be a struggle in obtaining a fixed axis for perfect spinning and rolling of humeral head around all three axes explained in Table-1. When all equilibrium factors are intact and operating normally, the head of the humerus rotates on a relatively fixed center of rotation, with the only significant excursion of the axis occurring in the early range of elevation [6].

Full range of movement around any one of the axes shown in Fig. 5 may not occur without additional movement around at least one more axis. For example, abduction of humerus must be associated with lateral rotation to avoid collision of greater tuberosity with acromion process. When the humerus is laterally rotated, the greater tubercle will pass under or behind the acromion, and abduction continues unimpeded [7]. The restricted range of medial-lateral rotation with arm at the side is due to the impact of the lesser tubercle on the anterior glenoid fossa with medial rotation and the impact of the greater tubercle on the acromion with lateral rotation but when the arm is abducted, these bony restrictions play little role, so the checks of motion become capsular and muscular.[7] Hence it is better to integrate all the concepts so far discussed for valid exercise innovations (Photo 1 - 5) and detailed researches to explore the meticulous role of shoulder muscles in supporting the three major humeral head spinning styles.

Photograph 1: Shows the commonly used elastic tube exercise to strengthen the medial rotators of shoulder joint through movement around one axis. 1a shows the exercise preparation position and 1b shows exercise execution position.

(a) (b)

Photograph 2: Shows the refinement of the exercise model shown in Photograph-1. The same medial rotators of the shoulder joint can be strengthened using elastic tube combining horizontal adduction and, the foundation for this technique is not just normal standing posture but static lateral lunge posture. 2a shows exercise preparation position and 2b shows exercise execution position. This compound exercise technique is very functional as it incorporates core and lower extremity muscles also.

Photograph 3: Shows the commonly used elastic tube exercise to strengthen the lateral rotators of shoulder joint through movement around one axis. 3a shows exercise preparation position and 3b shows exercise execution position.

Photograph 4: shows the refinement of the exercise model shown in Photograph-3. The same lateral rotators of the shoulder joint can be strengthened using elastic tube combining horizontal abduction and, the foundation for this technique is not just normal standing posture but static lateral lunge posture. 4a shows exercise preparation position and 4b shows exercise execution position. This compound exercise technique is very functional as it incorporates core and lower extremity muscles also.

Photograph 5: Shows the refined elastic tube exercises using static lunge posture instead neutral standing posture. Throw execution (5a,5b) and throw preparation (5c,5d) techniques are compound exercises and are very functional by incorporating the role of core and lower extremity muscles.

CONCLUSION

For perfect spinning and rolling mechanics of a circular object, the axis for rotation must pass through its center and maintain a perpendicular and parallel relationship to the contact surface, respectively. Humeral head may possess an articular arc belonging to a portion of a circle; hence the line of axis of humeral head rotation at any angle in any plane must pass through the center of humeral head maintaining either a parallel or perpendicular relationship to the shallow glenoid fossa in normal conditions. At any given shoulder joint angle either at resting or dynamic state, two axes will be running parallel to the glenoid fossa (AP & CC) and one axis will be running perpendicular to the glenoid fossa (ML), so that the humeral head can choose any of these axes for purposeful arm motions. Though the relationship of these three axes with glenoid fossa remains unchanged but their orientation can continuously change with arm activities in different body postures. Not only that, the oblique relationship between axis for humeral rotation and the glenoid fossa may only exist in pathological conditions where motion around this oblique axis can result in imperfect spinning and also diminished rolling in the unintended direction. Full range of movement around any one of these axes may not occur without additional movement around at least one more axis and this principle can enhance joint safety as well. All these innovative concepts can be researched further in detail for improved understanding of shoulder joint biomechanics and application in the field of shoulder rehabilitation that includes various types of active-free exercises and resisted exercises using resistance bands, medicine ball, free weights and strength training machines. Humeral head spinning styles explained in this article can also be applied in understanding the biomechanics of other bones (like femur) with curved articular ends.

Conflicts of interest: None

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