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MECHANICS OF ELEVATION OF GLENOHUMERAL JOINT

Its Application in Rehabilitation of Flail Shoulder in Upper Brachial Plexus Injuries and Poliomyelitis and in Replacement of the Upper Humerus by Prosthesis

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In man the head-neck axis of the humerus is set at an angle of 120° to the axis of the shaft. In addition, the head-neck axis has an angle of retrotorsion open postero-medially with the plane passing through the transepicondylar line parallel to the axis of the shaft, and which is 20°-30°. The evolution of the radial groove depends on the amount of retrotorsion.

In quadrupeds the head is set almost on the top of the humeral shaft and the tuberosities have acquired an unusual prominence in conformity with stability of the forelimbs. The sagittal plane bisecting the head is perpendicular to the plane passing through the transepicondylar line parallel to the axis of the shaft. There is no torsion.

The presence of the neck-shaft, the retrotorsion angles of the humerus, the versatile movements of the glenohumeral joint and other causes make the joint unstable during movements (dynamic instability).

The torsion (the complement of the retrotorsion angle) in its evolution is less marked in primates than in man i.e., that the glenohumeral joint is more unstable in arboreal primates is a paradox. Therefore, some compensatory mechanism should be present to prevent dislocation in primates.

The necessity for study of the mechanism of the shoulder and dynamic stability (Saha 1969, 1971) thus becomes apparent. As we studied the mechanism of the shoulder, we evolved the concept of a "zero-position" and its applied importance, and minimum requirements for elevation of the glenohumeral joint without impairment of the dynamic stability.

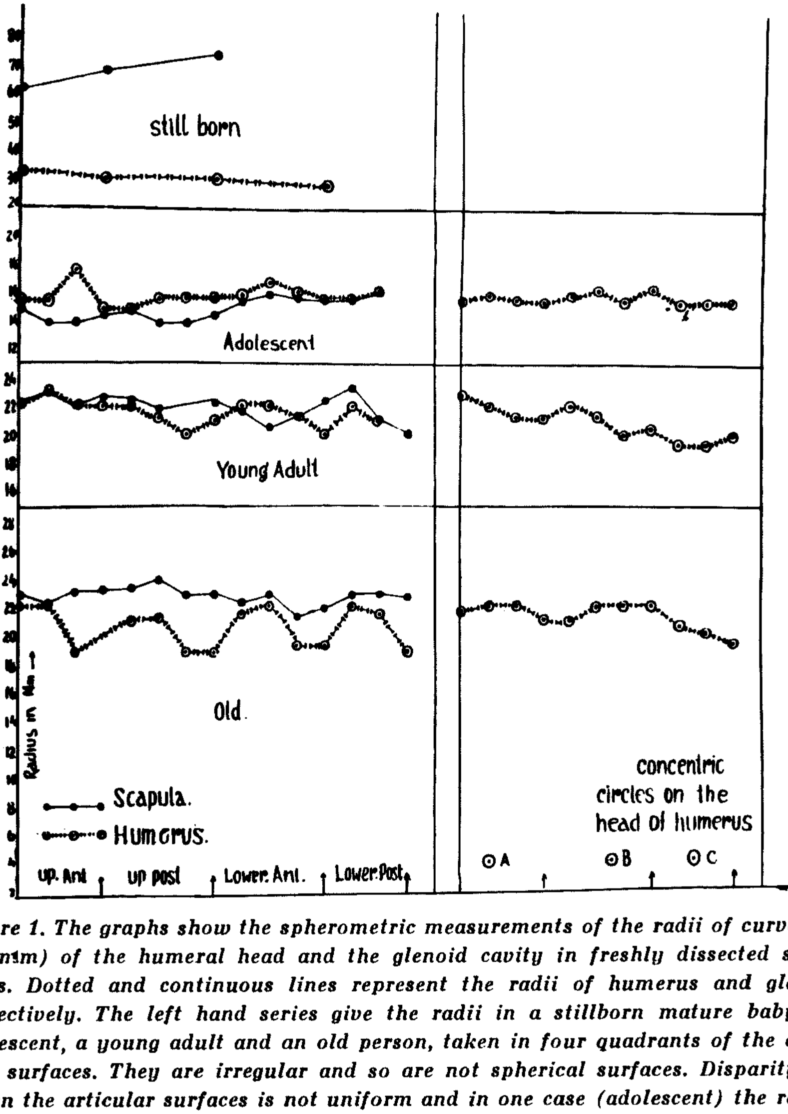

Figure 1. The graphs show the spherometric measurements of the radii of curvature (in mm) of the humeral head and the glenoid cavity in freshly dissected specimens. Dotted and continuous lines represent the radii of humerus and glenoid respectively. The left hand series give the radii in a stillborn mature baby, an adolescent, a young adult and an old person, taken in four quadrants of the articular surfaces. They are irregular and so are not spherical surfaces. Disparity between the articular surfaces is not uniform and in one case (adolescent) the radius of curvature of the humerus is greater than that of the glenoid. The graphs on the right hand side represent the radii of two concentric bands and a central circle of the head of the same humeri used in the previous determination. The radii are more uniform towards the central part of the articular surface than at the periphery.

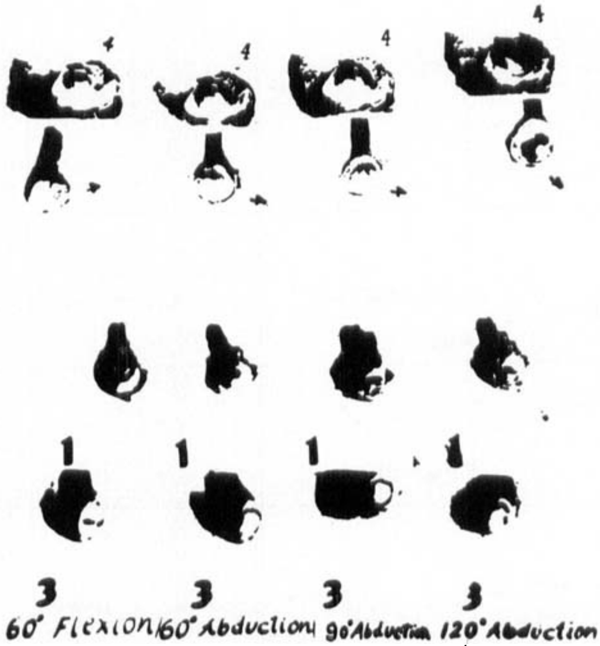

Figure 2. Lamp-black impression photographs of the glenoid and the humerus in the upper two and of the humerus in the lower two in 60° flexion and abduction and 90° and 120° abduction in a typical Type C joint where the humeral articular surface has greater radius than that of the glenoid. The irregular circular bands migrate considerably less with different elevation in the glenoid than they do on the head of the humerus. The migration of the contact areas is similar on all the specimens of Type C joint.

Curvature of the joint surfaces (Saha 1958)

Material: Freshly dissected and disarticulated glenohumeral joints with incised capsule.

Methods: Spherometry—special devices are fitted in the three legs and the central rotating pin so that the pressure and weight of the spherometer do not give false readings.

Reciprocal lamp black impression of the humeral and glenoid articular surfaces are taken separately while elevating the humerus controlled by identical position of the arm in the living.

Conclusions: The glenohumeral joint is not a perfect enarthrosis (Figure 1).

There are three types of joints. In none of them is the contact between the articular surfaces a geometrical point, but a nearly circular

Figure 3. Theoretical concept of three types of joints and their contact surfaces on the basis of Figures 1 and 2. The articular surface has been assumed spherical.

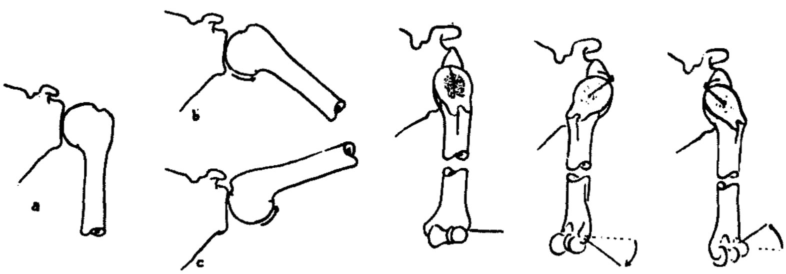

Figure 4. Diagramatical representation of the vertical and horizontal rolling of the head of the humerus in the glenoid. These enable change of contact surfaces.

area of variable radius. In the third type, the contact surfaces produce a circular band without any impression on the central part thus proving that the radius of curvature of the glenoid is less than that of the humerus (Figures 2 and 3).

During elevation in multiaxial joints change of contact surface takes place by rolling. It is neither a stationary spinning nor a true rolling where the distance travelled by a single roll is equal to the circumference of the sphere. The glenoid articular surface on which the head of the humerus rolls being limited, translatory movement of the head is much less than rotation. (Figure 4).

Electromyography (Saha 1958)

Method: Simultaneous eight-channel electromyographs were taken for eight muscles with coaxial needles during elevation of the arm at uniform angular speed.

Conclusions: The power of steerers (short rotators) including the upper part of teres minor rolls the humeral articular surface in the glenoid and stabilises the joint at each instant.

The power required is resolved into vertical and horizontal components. Muscle fibres of steerers which lie in the plane of elevation give co-planar vertical rolling and the remainder provide power for horizontal rolling for that particular movement. The resultant of these two components in successive phases gives the consecutive positions of the actual path taken by the humeral head.

In abduction the supraspinatus acts as a vertical steerer *pari pasu* with the deltoid. Initially the horizontal steerers require minimal power to roll and steady the head but later when the head becomes more unstable due to retrotorsion their power rises (Saha 1961, 1964, 1967). The infraspinatus and teres minor muscles thus show a later rise as the instantaneous axis of the head (being not exactly spherical) between the articular surface adjoining subscapularis and the lowest part of the head which touches the glenoid shifts clockwise on the left to give stability to the joint while the arm is being raised (Figure 5).

In flexion the scapula rotates on the vertical axis; the head of the humerus is not in the same relation to the glenoid as in abduction. The anterior portion of supraspinatus and the adjoining portion of subscapularis now act as vertical steerers as seen in electromyographs (Figure 5). The other fibres act as horizontal steerers to prevent forward slipping as the arm is raised.

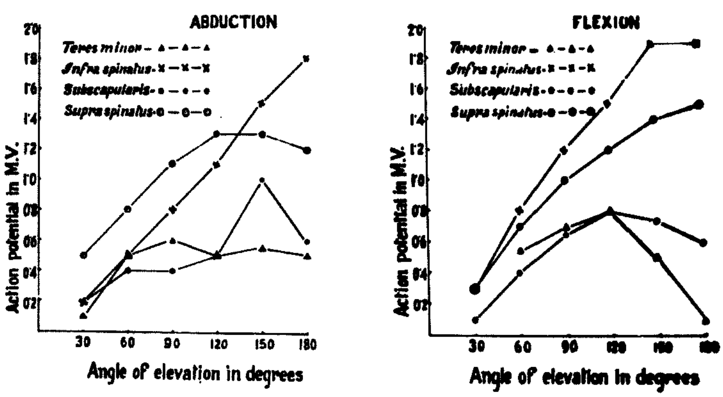

Figure 5. Simultaneous electromyographs of steerers (short rotators) in flexion and abduction at uniform angular speed. The ordinate represents action-potential in milli-volts and the abscissa elevation in degrees.

The steerers are arranged at the periphery of an almost spherical articular surface except in the inferior part. The direction of the muscle fibres may be assumed to be tangential to the articular surface (sphere). The moment of the force which is tangential to the curvature of the head is the product of the force and the radius of curvature. Thus the whole force is spent in rolling the head. The inadvertent motion of the distal end follows the rules for a rigid body. The angle between the force and the shaft axis when it acts away on the shaft is the sum of the supplement of the neck-shaft angle (60°) and the inclination of the force to the shaft axis. Thus, the role of the component tangential to the curve of the head is negligible. In this case, most of the power magnified by leverage is spent in lifting the arm.

The intermediate group of muscles have a certain rotating action even in the "zero-position" by virtue of their nature of insertion, and their role in steering the head is minimal and not essential.

It is obvious from the above that the minimum requirements for elevation of the glenohumeral joints are a prime mover, a horizontal and a vertical steerer.

Dynamic stability in the horizontal direction (Saha 1969, 1971)

a) Centripetal force which develops during movement: In each case, there is acceleration, deceleration and uniform angular speed. The opposite centrifugal force is balanced by power of the muscles. b) Power of the horizontal steerers (subscapularis, infraspinatus, the upper part of teres minor). c) Anatomical factors: Optimum glenohumeral indices i.e., percentage ratio of the maximum diameter of the glenoid and maximum diameter of the head of the humerus. The mean value of vertical index is 75.3 and transverse 57.6 with standard deviations ± 3.9 for vertical and ± 5.6 for transverse. These compare favourably with anthropological data.

Optimum glenoid tilt—special axial skiagrams are taken to determine the tilt of the glenoid in the living. Retrotilt of the glenoid is usual in 73.5 per cent of cases with an average of 7.4°, others have either antetilt varying from 2° to 10° or neutral tilt (Figure 6).

Optimum retrotorsion—this is between 20° and 30° and can be determined radiologically in the living. Reduced retrotorsion which is very rare produces posterior instability provided there is gross retrotilt of the glenoid. Increased retrotorsion produces anterior instability (Figure 7).

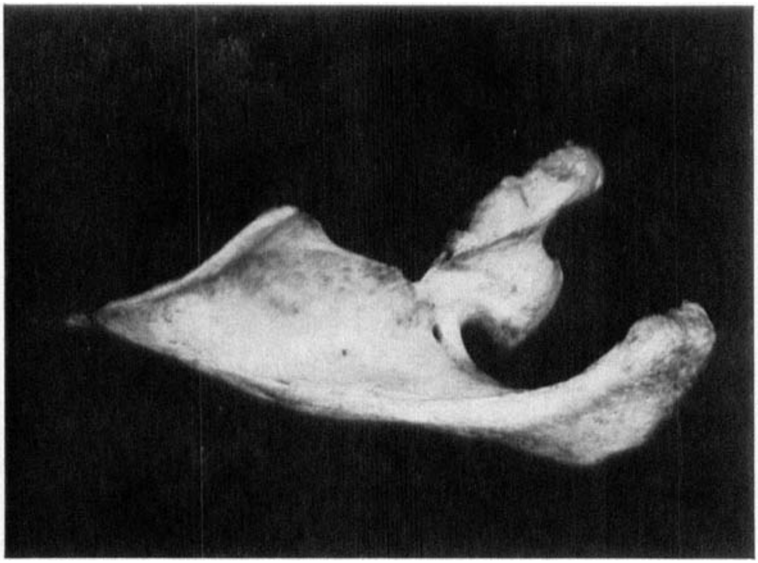

Figure 6. Exaggerated posterior tilt of the glenoid in man.

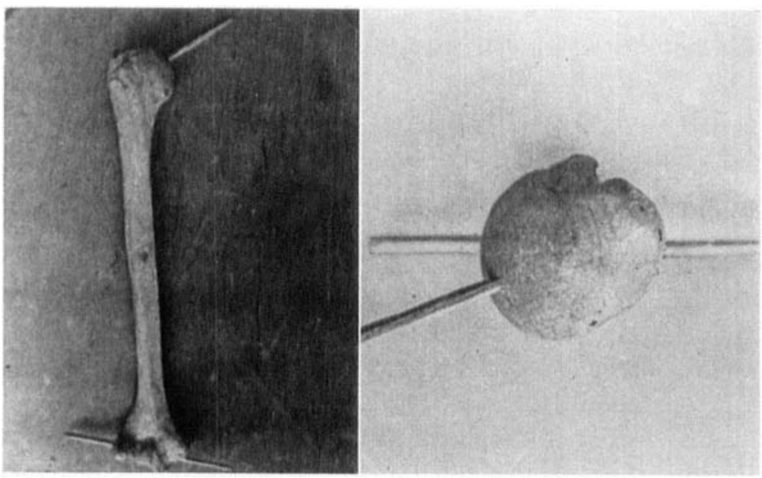

Figure 7. Stillettes are passed, one along the axis of the head-neck and another through the epicondyles. Bird's-eye view in the right hand figure shows the retro-torsion (complement of torsion angle).

Depth of the glenoid cavity—this factor has not been determined in man but it plays an important part in arboreal primates.

Mathematical treatment

Rolling and change of the mechanical axis, development of stress in different types of joints, role of steerers and development of centripetal force have been confirmed and "zero-position" of the glenohumeral joint established.

1) Steerers are mainly responsible for rolling the head in the socket in different positions of elevation in three directions while the prime mover mainly raises the arm (Saha 1950).

2) Change of mechanical axis takes place by rolling (Saha 1967). With it the instantaneous axis changes in the same direction. Subscapularis (anterior steerer) rolls the head posteriorly (c.f. pushing). The posterior horizontal steerers, infraspinatus and the upper part of teres minor also roll the head posteriorly (c.f. pulling).

With normal retrotorsion and posterior glenoid tilt, the posterior horizontal steerers help the anterior horizontal steerer by developing their power later in the act of elevation. The electromyography of these muscles confirms this (Saha 1964, 1967).

3) The position during elevation in the coronal and sagittal planes, in fact, during elevation in any plane where rolling action of the short rotators (steerers), and rotation of the intermediate group of muscles (pectoralis major, latissimus dorsi, teres major and the lower part of teres minor) are a minimum, where the mechanical axis corresponds with the anatomical axis of the shaft, where the mechanical axis is in alignment with the scapular spine and is in the newly acquired scapular plane, is defined as the neutral or "zero-position" of the glenohumeral joint. This is the relative position of the scapula and humerus which is seen in fast-moving quadrupeds to give stability to the forelimbs. This has brought about structural changes in them; the articular surface sits squarely on the top of the shaft like a 'drum stick'. In man on the other hand because of the presence of neck-shaft angle, the contact surface of the humerus in the "zero-position" will be near the lesser tuberosity with normal retrotorsion. Perhaps this position is used by Milch in reduction of dislocation of the shoulder where the three groups of muscles arrange themselves in coaxial cones (Milch 1938).

4) In the third type of joints where there is circular band contact, the whole of the stress falls on the anterior glenoid rim during elevation (Saha 1961).

5) Development of a centripetal force which is opposite and equal

to the centrifugal force has been worked out and found responsible to a minor extent for the dynamic stability of the shoulder.

Rehabilitation of the flail shoulder following poliomyelitis and upper brachial plexus injury

In a flail shoulder following poliomyelitis and upper brachial plexus injury and birth palsy where all the axio-scapulo-claviculo-humeral muscles are paralysed and the arthrodesis of the glenohumeral joint is indicated, and provided the girdle muscles have adequate power, the joint may be rehabilitated with the girdle muscles retaining all its movements. The general principles are to provide two steerers, vertical and horizontal and a prime mover. Their directions should be the same as those of the paralysed muscle fibres and should have adequate power. The prime mover is given by transferring the whole of trapezius including the clavicular head to a point as far down the humerus as possible. The vertical and horizontal steerers can be provided by levator scapulae and the upper two digitations of serratus anterior (to the top of the greater and lesser tuberosities respectively). Alternatively, the clavicular portion of the trapezius and sternocleidomastoid and pectoralis minor may be used in place of the above. In those cases where the retrotorsion is above normal the joint may dislocate anteriorly thus losing range and power due to instability. The stability is restored by derotation osteotomy. Should latissimus dorsi, teres

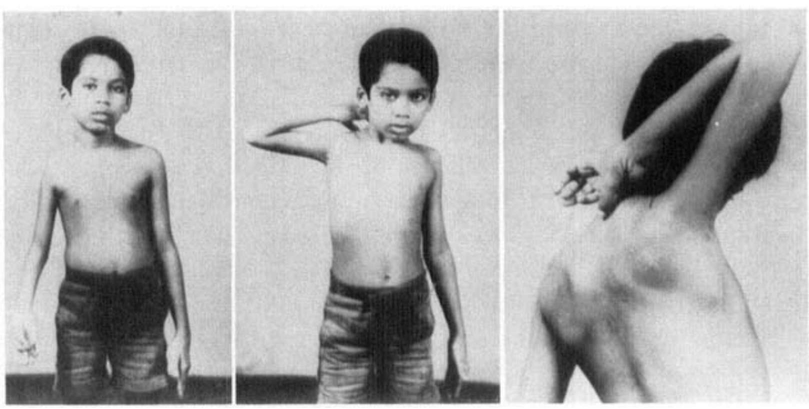

Figure 8. Functional recovery of the rehabilitated post-polio flail shoulder where trapezius was used as a prime mover, levator scapulae as a vertical and latissimus dorsi as a posterior horizontal steerer. The joint is stable during abduction (vide *text). The operation was done in November, 1970.*

Table 1. Possible live muscles or part of a muscle replacements, with their sites of implantation, in paralysis of the prime movers and vertical and horizontal steerers in flail shoulder.

Paralysis	Replacement	Site of implantation
Prime movers		
Deltoid and clavicular head of pectoralis major	Trapezius	Well down the shaft of the humerus
Vertical steerer	1. Levator scapulae 2. Sternocleidomastoid 3. Clavicular head of trapezius	Top of the greater tuberosity
Horizontal steerers		
Anterior	1. Pectoralis minor 2. Upper two digitations of serratus anterior 3. Residual part of pectoralis major	Lesser tuberosity of the humerus
Posterior	1. Residual part of latissimus dorsi 2. Teres major	Posterior lowest limit of the greater tuberosity

major and portion of pectoralis major have residual power they may be used as horizontal steerers (Saha 1967). If a posterior horizontal steerer is provided by latissimus dorsi, the question of instability mentioned above can be adequately compensated without derotation osteotomy (Figure 8). Table 1 shows the possible transfers of live muscles or parts of a muscle. These have been tried in flail shoulder following poliomyelitis, brachial and birth palsy (Crenshaw 1972).

Prosthetic replacement of upper end of the humerus

In certain cases where the upper fourth of the humerus has to be replaced (e.g., osteoclastoma) by a prosthesis—it should have the following requirements for proper functioning of the new glenohumeral joint.

The upper end of the prosthesis should have the shape of the upper end of the humerus. The shaft axis should coincide with the axis of the prosthesis and it should be immovably fixed to the humeral shaft.

When fitted, the prosthesis should have 5° to 10° of retrotorsion with respect to the plane passing through the transepicondylar line parallel to the axis of the shaft.

Three small tunnels at the site of insertions of subscapularis, supraspinatus and infraspinatus for fixing a vertical steerer and any one of the horizontal steerers, whichever is convenient. Such replacement will enable the arm to be raised overhead without instability.

SUMMARY

The mechanism of the shoulder joint has been studied in man with the help of comparative and anthropological studies, measurement of curvatures of the joint surfaces, simultaneous electromyographic studies in the normal and rehabilitated flail shoulder and mathematical treatment.

The study enables us to arrive at the concept of "zero-position" of the shoulder, minimal requirements of elevation of the shoulder and hence the rehabilitation of flail shoulder and requirements of a prosthesis for replacement of the upper end of the humerus.

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