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Surgery of the Paralysed and Flail Shoulder

By

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PREFACE

While writing the monograph "Theory of Shoulder Mechanism—Descriptive and Applied", published by Messrs Charles C. Thomas in January 1961, I had to be content, in the introductory chapter, with mentioning the possibilities of assessment and rehabilitation of the paralysed shoulder on the basis of the new concepts. Clinical data were then insufficient to append a chapter on this.

Since then more than a hundred cases of post-polio flail shoulder were studied with reference to incidence, distribution, degree of paralysis and treatment. The study is confined to the post-polio paralysed shoulder, which is on the wane in North America, Europe and Japan with successful active immunisation against poliomyelitis. It is felt that the methods described in this monograph are equally applicable in brachial plexus injuries which are unhappily on the increase in the above-mentioned countries due to modern mechanisation and speed.

Most of the operative procedures described in this monograph are designed to restore active mobility to the flail shoulder which would otherwise possibly be arthrodesed in presence of strong girdle muscles or disarticulated at the shoulder when the function of the distal portion of the limb is beyond the scope of surgical rehabilitation and, specially, if girdle muscles are weak. The presence of strong girdle muscles has been shown to contraindicate arthrodesis contrary to the current belief and practice. Nay, even in presence of weaker muscles where arthrodesis is of little avail, an actively mobile shoulder becomes a possibility.

Several methods of power transfer have been tried in various combinations in flail shoulder. Although a number of methods have been indicated in the text, all have not been used for want of suitable cases.

The results of these methods have been shown to be gratifying when the muscles to be transferred are given a proper scrutiny of their residual power and their ability assessed to replace the paralysed muscles. Of course, the principles underlying the mechanism of elevation have to be strictly adhered to while carefully selecting the surgical procedures.

The results of the study were given to one of my retiring residents in 1962 for his thesis for the Master of Surgery Examination of the University of Calcutta. This he submitted in April in 1964 and, therefore, the statistical analysis has been omitted in this monograph.

I take this opportunity to thank Dr. S. K. Banerjee, M.B.B.S., D. Phys. Med. (Eng.), Consulting Physician, Physiotherapy & Rehabilitation Dept., B.C. Roy Polio Clinic and Institute of Child Health for his help in providing most of the clinical materials and in writing the chapter on "Clinical and electrical assessment of power of normal and paralysed shoulder".

I convey my sincere gratitude to my Clinical Tutor, Dr. H. Deb, M.B., M.S., my colleagues Dr. A. K. Das, M.B.B.S., F.R.C.S. (Edin & Eng.), Dr. G. K. Chowdhury, M.B.B.S., F.R.C.S. (Edin), and my Resident Senior House Surgeon, Dr. S. A. Momen, M.B.B.S., for their ungrudging assistance to develop the operations in the cadaver and in the living.

I will be failing if I do not extend my gratitude to my Senior Anaesthetist Dr. Mrs. A. Banerjee, M.B.B.S., F.F.A.R.C.S., and all my staff for their spade work behind the scene without whose help management of the cases would be impossible.

Lastly, I tender my thanks to Dr. S. K. Dutta, M.B., M.S. (Cal.) and Dr. A. Sen Gupta, M.B.B.S., F.R.C.S. (Eng.), for the excellent diagrams used in this monograph and Messrs. Charles C. Thomas for permitting me to utilise 6 diagrams already published in the previous monograph.

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INTRODUCTION

Paralytic sequelae of poliomyelitis are the commonest of all causes of crippling in the childhood in this country and constitute a problem of considerable importance surgically and socially. In India as elsewhere the disease affects children, the incidence being the highest at the age of 2 years. Paralysis or weakness of one or all muscles controlling elevation of the shoulder is a common finding following poliomyelitis involving the upper extremities. The usefulness of the upper limb depends to a large extent upon the ability to raise the arm from the body. Such common functions as eating, combing, shaving and putting the hand in trouser pockets etc. depend on this movement and, therefore its loss results in gross diminution of functional ability of the affected limb. Past workers in this field of surgery recognised the role of scapular stability while the shoulder is elevated. This stability, they agreed, is of dynamic nature. The scapular movements contribute about 33 per cent of the total elevation of 180° in a normal person. In polio-affected persons we therefore expect one or all of the following deficiencies. There may be incompetence in fixation of the scapula in various stages of elevation, impairment or loss of the scapular rotation in antero-posterior and vertical axes and its elevation with forward migration to set the glenoid surface in optimum position for the humeral head to play, and lastly, inadequacy of power of the muscles moving the gleno-humeral joint during elevation which most commonly presents the greatest hurdle in rehabilitation.

Compensatory and alternative power in paralysis of the deltoid acting at the gleno-humeral joint is plentiful. This was recognised by different workers in this field and various explanations were given for elevation in absence of power of the deltoid. One of the workers, Pollock developed mechanical models to explain the action of the accessory muscles and the way these help elevation in the absence of deltoid power. Staples and Watkins added some new explanations. All these point to the want of precise knowledge of the shoulder mechanism. They could only reach the fringe of the problem on the basis of results observed clinically.

Bunts in 1903 reported 7 spontaneous recoveries of abduction in a total of 19 cases. Of these though four patients did not recover their power of deltoid they could raise the arm overhead. Duchenne in 1867, Pollock in 1922 and Staples and Watkins in 1943 similarly observed and stated that the clavicular head of the pectoralis major with the help of 'Inner muscle group' could elevate the shoulder overhead in absence of deltoid power.

Though not specifically pointed out by earlier observers it is obvious that if some trick movement could raise the shoulder to about 90° in any plane the rest of abduction could be performed by the accessory muscles in absence of the deltoid. These accessory muscles are no doubt the muscles fixing and moving the scapula and the short rotators and depressors of the gleno-humeral joint. Premature girdle movement in some of these cases might be required for elevation in the initial stage of abduction.

Lewis in 1910, Payr in 1913, Gallie and Le Mesurier in 1921, Mayer in 1927 and 39, Haas in 1935 and Bateman in 1955 transferred the power of trapezius by various modifications to take over the function of the deltoid. The inherent difficulty of obtaining uniform results obviously led these workers to modify and use various techniques of trapezius transfer.

Stoffel, Mayer and Haas, who had quite a number of poor and indifferent results following trapezius transfer tried to explain this by (a) elongation of the reconstructed tendon with fascia lata (b) adhesion to the surroundings and (c) poor selection, power of trapezius being insufficient to raise the arm. Haas of his 30 cases obtained 110° abduction (defined as good result) in 12 cases. Though not mentioned separately, he stated summarily that the muscles moving the scapula, pectoralis major, infraspinatus, triceps and biceps had good power in 9 cases. It is felt he must have included the remaining three short rotators, the latissimus dorsi and the teres major et minor with these. The remaining 3 cases which benefited from the operation, though this has not been stated, probably belonged to the group of 10 cases having fairly good power of accessory muscles. He did not specifically mention the role of short rotators but asserted a direct relationship between the strength of accessory muscles and the functional result, the transposed muscle being assumed to have good power.

The subluxation of the head of the humerus in post-polio paralysis of the shoulder was taken up by Kiliani in 1910 and successfully treated by looping the long tendon of the biceps through a pulley made by the folded capsule detached near the glenoidal margin and resutured to the humerus. This was later modified by Nicola to a simpler procedure.

Sloman in 1915 substituted paralysed middle fibres of the deltoid with the help of the long head of the triceps rerouted to the acromion process. Reidel in 1928 reconstructed posterior deltoid by transfer of both the origin and insertion of the teres major to the acromion process and to the posterior surface of the shaft of the humerus respectively without disturbance to the nerve and vascular supply.

Ober in 1932, Davidson in 1936 and Harmon in 1950 transferred the short head of biceps and the long head of triceps to the anterior and posterior margins of the acromion process to take over the function of the deltoid. Haas reported the result of similar operation in 2 cases earlier in 1935.

Hildebrandt in 1906 and Haas in 1935 reported transfer of the origin of the pectoralis major for deltoid power. The patients had successful abduction to about 90°.

In differential paralysis of the deltoid where either anterior, middle or posterior fibres are paralysed with residual power in remaining fibres, Moor in 1935, Harmon in 1947 and 1950 transferred anterior portion of the deltoid posteriorly and posterior fibres of the deltoid anteriorly to obtain the function of the deltoid as an abductor.

Harmon in 1950 stressed the importance of the latissimus dorsi when available, taking it posteriorly to the lateral lip of the bicipital groove after detaching it from the medial margin in front of the teres major. This, according to him, helped external rotation of the limb necessary during elevation in the coronal plane.

Unlike that in the gleno-humeral joint the reserve is less in number in paralysis affecting the girdle muscles moving the scapula. Fortunately, this is compensated by the comparatively rare incidence of complete paralysis of these muscles. The cause of this low incidence is not definitely known. Many of these muscles have multisegmental innervation. Relative inactivity during the incubation, prodromal and febrile stages may be an added factor. Restoration of scapular fixation and mobility in paralysis during elevation of the shoulder was taken up by various workers. The various disabilities that may occur are: a) dropping of the shoulder due to weak trapezius, rhomboids, levator scapulae and unopposed action of the serratus anterior, (b) failure to rotate the scapula in the antero-posterior axis due to paralysed serratus anterior with gross winging of the scapula, (c) inadequate balanced power of the force couple to rotate the scapula with the arm fixed in partial abduction(here there is no winging of the scapula, but the arm cannot be raised beyond a certain range due to the inability of the scapula to rotate) (d) failure to lift the scapula bodily upward and move forward on the chest wall due to paralysis of the trapezius and levator scapulae on one hand and pectoralis minor and upper fibres of serratus anterior on the other and (e) failure of fixation of scapula when deltoid contracts with supraspinatus to initiate the elevation.

Fortunately, the aforesaid conditions have been rare in our group of cases. The correction of the deficiency mentioned in (a) has been done by bony fixation (Spira 1948). This corrects the deformity of the scapular drop but removes the possibility of the valuable accessory movements even with the best of his modifications during elevation.

Brockway in 1939, Lowman in 1963 (interscapular fascial transplant) fixed the affected scapula to give stability to the glenoid by tying both scapulae together with fascia lata nearest to the centre of the rotation of the scapula. This gave good results in their hands, because it does not deprive the scapula of the residual movements during elevation. Whitman in 1932 fixed the vertebral border of the scapula by four fascial strips.

Brunnstrom in 1941 devised methods of shoulder blade fixation in severe cases to help the initial stage of abduction. This fixation is necessary for essential adjustment in the "setting phase of the scapula" during movement up to 60°. The methods outlined above help scapular stability, correct deformity and indirectly in some help movements if there is residual power with the help of contralateral girdle.

Restoration of the mobility of the scapula and thus of the girdle has been devised from time to time by either muscle transfer or fixation of the scapula by fascial strips to the active muscle to help movement in desired directions.

The movements of the accessory joints have their role in the elevation of the arm. Impairment of the function of the muscles which bring about these movements has attracted attention of the earlier workers and they found the methods of restoration of these movements. Normally rotation of the scapula in the antero- posterior axis on the thoracic cage is done by the force couple formed by lower six digitations of the serratus anterior on the one hand and trapezius (upper, middle and lower fibres) on the other. The upper digitations of the serratus anterior and levator scapulae and rhomboid major et minor are mainly the stabilisers of the shoulder blade while elevating the arm.

The rotation of the clavicle is done by subclavius and by inevitable force transmission from movement of the scapula. Therefore, the paralysis of the subclavius does not neccessarily handicap the rotation of the clavicle during elevation.

Elevation and forward migration of the shoulder blade are done by trapezius, levator scapulae, pectoralis minor and the upper two digitations of serratus anterior. Their paralysis invariably drops the scapula. It rolls forwards as well when there is weakness of the rhomboids.

Dickson in 1937 fixed the scapula with the paravertebral group of cervical muscles by a strip of fascia lata and with the 1st thoracic spinous process by a second strip. This, in his cases helped partial correction of the paralytic scoliosis and improved the stability of the scapula. Similarly, he tried to fix the inferior angle of the scapula with strips of fascia lata to pectoralis major and latissimus dorsi to give transmitted mobility in cases of paralysed serratus anterior and rhomboids. Durman in 1945 restored the power of serratus anterior by using the lower third of the pectoralis major detached from its insertion and fixed through a hole in the lower angle of the scapula. Tubby earlier in 1904 tried to restore the power of the serratus anterior with the help of the sternal portion of the pectoralis major divided into 4 or 5 digitations and sutured to serratus anterior near its insertion. Chaves in 1951 used pectoralis minor to replace the power of serratus anterior. Herzmark in 1961 tried to improve the residual rhomboids function by reattachment of their insertion outward with trapezius overlapping. Haas quoted by Lindstrom and Danielsson rerouted teres major detached from its insertion to the 5th and 6th ribs at the level of the origin of the serratus anterior. This gave good results in isolated paralysis of the serratus anterior. Steindler in 1954 reported cases where he used levator scapulae to the acromion to replace the paralysed upper trapezius. He used pectoralis major and/or minor to the lower angle of the scapulae to act as one limb of the torque to help the rotation of the scapula in antero-posterior axis.

Lastly, when the girdle muscles were strong and the patient unable to elevate the arm, they performed various forms of shoulder arthrodesis in optimum position, though results were far from satisfactory. The largest series was studied by Barr et al. in 1942; amongst 142 cases 101 cases had shoulder fusion. The prerequisite of a fusion operation in his opinion is good power in serratus anterior and trapezius. This explains the low figure of success in this series. Only 10 per cent gave good results.

Arthrodesis in children is discouraged by all on the basis of (a) failure of the fusion (b) tendency to bend downward at the (i) joint line and (ii) epiphyseal line and (c) possible growth disturbance after fusion.

The foregoing discussion conclusively proves that the surgical rehabilitation of a paralysed shoulder was approached without full knowledge of the shoulder mechanism. Trial and error procedures were followed with indifferent results. The approach was negative. We find quite a number of patients having flail shoulders who are discouraged to have any surgical rehabilitation and if at all, they are given the benefit of arthrodesis. This monograph is intended to place surgical rehabilitation on a scientific basis, anatomically, functionally and to some extent mathematically. Indeed, this leads to a positive approach to the problem of flail shoulder. Quite a number of hopeless cases who were unsuitable for arthrodesis and in whom disarticulation would possibly be seriously considered have been rehabilitated quite successfully.

BIOMECHANICS OF SHOULDER MOVEMENTS: FUNCTIONAL CLASSIFICATION

~~Multichanneled electromyograph enabled~~ to obtain precise state of contraction of different muscles acting on the girdle and gleno-humeral joint during elevation overhead in different planes against gravity. All the muscles of the two groups contract during elevation overhead in any plane. The rise of the action potential which denotes their increase in strength is not simultaneous but phasic.

How this phasic rise of strength of different muscles help elevation was not fully understood; neither their role at each instant of elevation worked out. The studies were mostly static instead of dynamic.

An attempt has been made to explain this phasic contraction of different muscles acting on the gleno-humeral joint and their importance and therefore, which of these can be dispensed with without loss of function of the joint.

This has been made possible by (a) re-evaluation of the electromyograph of muscles of the gleno-humeral joint published earlier in a monograph by the author, (b) study of a large group of cases with varying degrees of residual paralysis following poliomyelitis affecting one or all the muscles of the gleno-humeral joint (c) study of the functional restoration of elevation against gravity by multiple muscle transfer (d) electromyographic study of the transferred muscles during overhead elevation against gravity in the sagittal and scapular planes and correlation of their new action with those of the muscles having similar action in a healthy joint.

Before embarking on the discussion on the biomechanics, the relevant features of the shoulder mechanism may be recalled briefly to appreciate the action of the forces bringing about the desired elevation.

The ratio of the contributions of the gleno-humeral and the scapulo-thoracic joints when the arm is brought to the final overhead position is 2 :1, *i.e.*, for 180° the movement of the scapula contributes 60°.

Stability is as important as the mobility of the girdle and gleno-humeral joint. These are inseparable. The gracefulness of movements is obtained only when they act in full co-ordination; disturbance in any of them not only takes away the available power but the scapulo-humeral rhythm is lost even in the presence of adequate power to lift the shoulder overhead.

The shoulder joint is a multiaxial joint. The articular surface of humerus is nearly exhausted when the arm is raised to 90° in the scapular plane. Without allowing the arm to rotate outwards to change the position of the limb in space, the final overhead position cannot be reached. During elevation in the forward sagittal plane the rotation of the arm takes place in the opposite direction. Elevation overhead in the backward sagittal plane is not possible. Mechanical block by the acromion process and the adjoining spine of the scapula prevent elevation beyond 80°. Thereafter, it has to come to a more forward plane by gliding of the humeral head on the glenoid. This gliding and/or rolling is translated into external rotation of the arm till the final common position of the arm is attained. The precise action can be understood if it is borne in mind that the change-over of the contact surface as the arm is elevated in any plane to the overhead position would eventually bring the contact point in the neighbourhood of the lesser tuberosity (zero-position).

The upper end of the humerus has got its axis set at an angle with the axis of the shaft. Therefore, the movement of the distal end of the humerus is not exactly what is happening at the articular surface. For instance, in external rotation there is forward gliding and/or rolling of the humeral head and the reverse in internal rotation with the arm by the side (Figures 1 and 2). In the zero-position, however, when the mechanical and anatomical axes coincide, the movements of the articular end is directly transmitted to the distal.

The glenoid is retrotilted corresponding to the retrotorsion of the

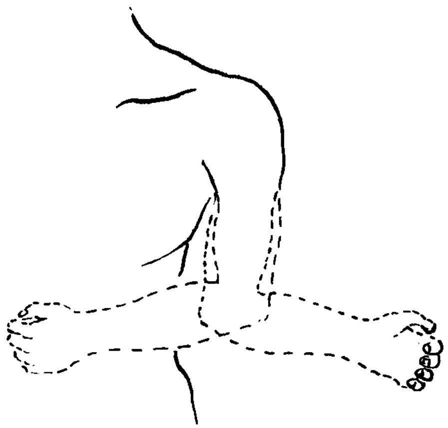

Figure 1. Shows diagramatically the rotation of the arm in the vertical hanging position.

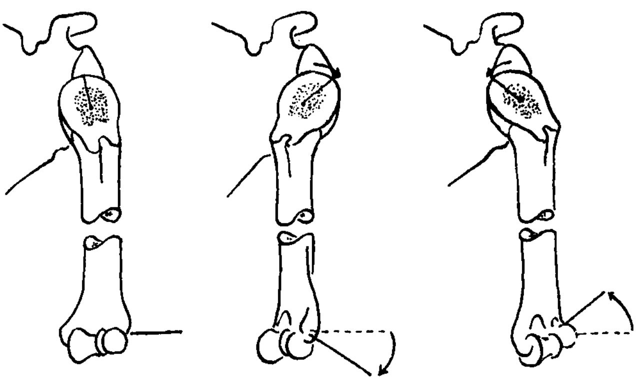

Figure 2. Showing the effect of the rotation of the arm in the vertical position in clockwise and anti-clockwise direction. The axis of the head and neck is seen after section through the oblique plane passing through it. The contact point is seen changing its position by gliding anteriorly and posteriorly.

head of the humerus. Thus the general inclination of the joint surfaces forming the gleno-humeral joint is less anterolateral owing to backward tilt with reference to scapular plane in the anatomical position of the arm. This inclination of the gleno-humeral joint helps backward elevation to about 80°.

Elevation overhead converts the retrotorsion of the humerus into relative antetorsion which necessitates the adjustment of the glenoid articular surface by upward tilt, forward migration and elevation. With relative antetorsion there is also greater need of backward rolling and/ or gliding to prevent the tendency to spontaneous forward subluxation. Thirdly, the natural backward tilt of the glenoid helps retaining the head on the glenoid in this near-vertical position.

The action of the muscles of the shoulder joint complex described in the text books is in relation to the anatomical position of the arm. They do not state the functional changes which they undergo at each instant of motion in a particular direction in a joint with such versatile range of movements.

The muscle which in a particular position has got certain action changes its function with elevation, and at the end its action may be what would look like an opposite movement; subscapularis is an example. It is an internal rotator when the arm is by the side. When elevated it becomes an external rotator towards the end. In the vertical overhead position the upper end of the humerus is its mirror-image with the arm by the side. The relative position of the lesser tubercle, the site of, the insertion of the subscapularis, gradually becomes internal to the mechanical axis. This is exactly reverse in the vertical hanging position of the arm; the lesser tubercle is external to the mechanical axis. Therefore, it is quite natural that this would in the vertical overhead position be translated into what would appear as external rotation of the arm. The action of all axio-scapulo-claviculo-humeral group of muscles acting on the gleno-humeral joint changes continuously during elevation overhead.

(a) *Electromyography in the Normal*

The pattern of muscle activity was studied in 1955 in several normal subjects with usual precautions for recording. The recording was done with the help of an eightchannel electroencephalograph (Grass instruments, model IIID-535) adopted for electromyography. Vertical calibration for amplitude in milli-volts and speed calibration for time in milli-seconds were done before recording. The angle of elevation of the limb was not recorded with the help of simultaneous photography due to technical difficulties. The limb was elevated at a uniform controlled speed during recording. The period of activity in the electromyograph was divided equally into six parts at 30° intervals (from 0° to 180°). There were slight individual variations. The representative muscle-activity during elevation was published in 1956 and 1961.

During abduction (Figures 3 and 4) in the coronal plane supraspinatus and deltoid are elevators. The power is maximum at 120° and

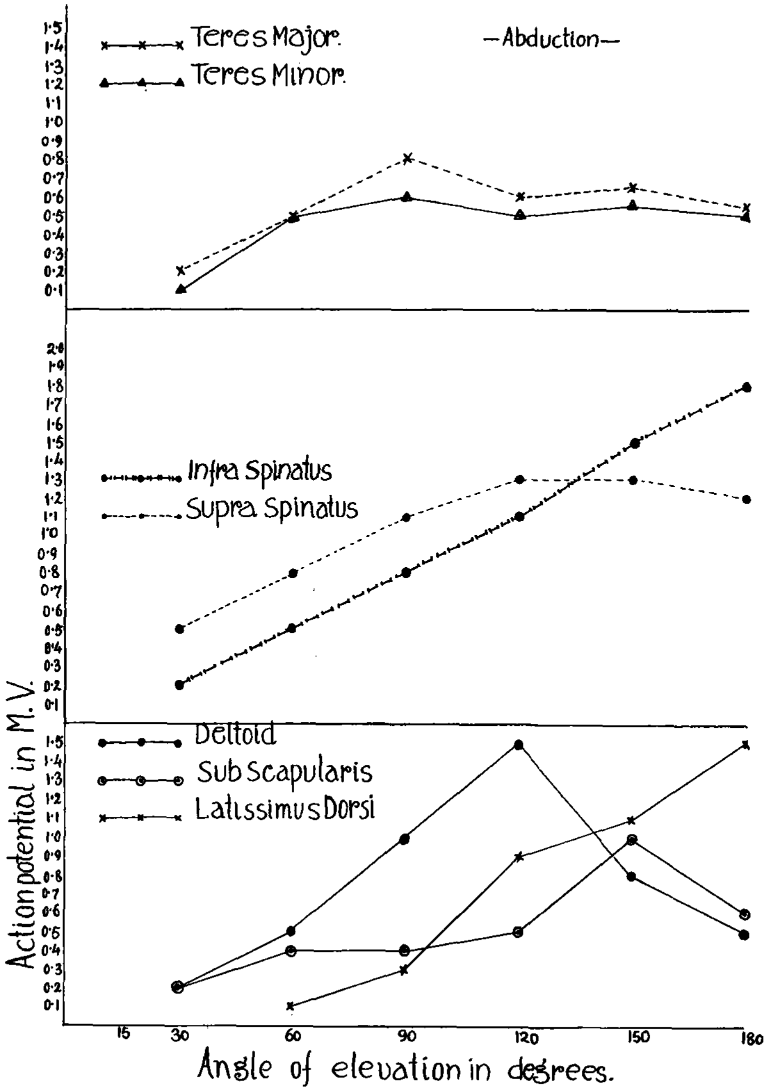

Figure 3. Showing the action potential in milli-volts of axio-scapulo-claviculo-humeral group of muscles during abduction from 0° to 180°. (Saha, A. K.: Theory of Shoulder Mechanism—Descriptive and Applied. Springfield, Ill.: Charles C. Thomas, Publisher, 1961. Reproduced by courtesy of the Publisher).

steadily decreases reaching their minimum at 180°. Subscapularis shows increasing activity from 120°–150° when its power is maximum. Thereafter, the power steadily diminishes to 180° of elevation. The rise of power is almost exponential between 60°–150°. Infraspinatus and

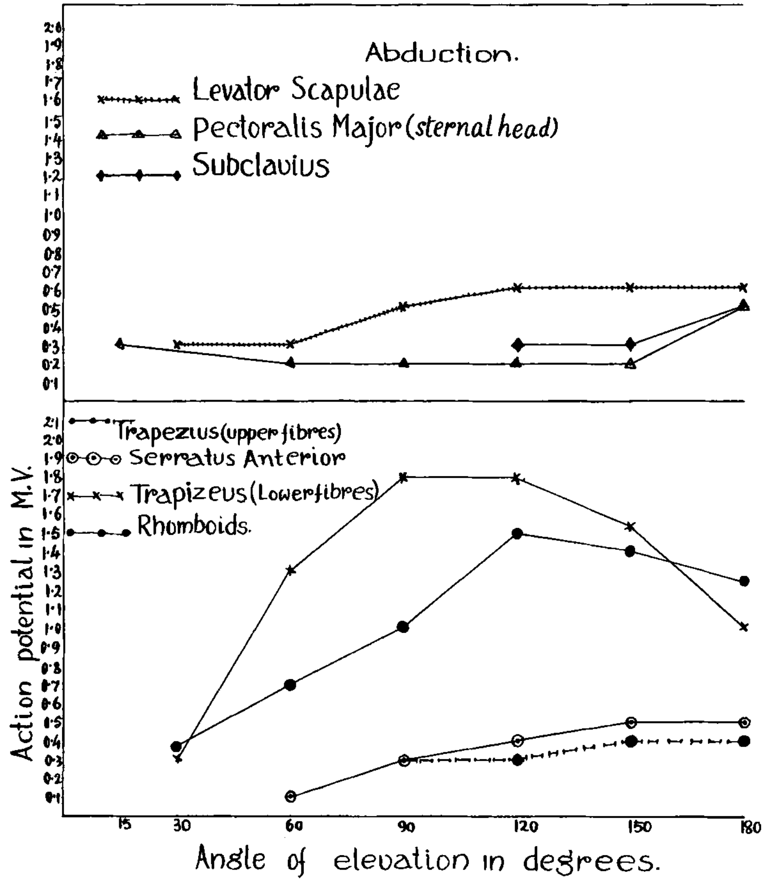

Figure 4. Showing the action potential of axio-claviculo-scapular group of muscles including pectoralis major during abduction from 0° to 180°. (Saha, A. K.: Theory of Shoulder Mechanism—Descriptive and Applied. Springfield, Ill.: Charles C. Thomas, Publisher, 1961. Reproduced by courtesy of the publisher).

teres minor show maximum activity towards the end of elevation (180°). Pectoralis major (sternal head), latissimus dorsi and teres major show more or less identical activity which is maximum at 180°. Clavicular head of pectoralis major shows no activity (Table 1).

During elevation in the sagittal plane (flexion) (Figures 5 and 6) the clavicular head of pectoralis major shows development of power which is comparable with that of deltoid during abduction. Subscapularis similarly shows development of action potential reaching its peak at 120°. These two muscles are, therefore, sagittal elevators, their action

Table 1. Activity of Gleno-Humeral Group During Abduction in the Coronal Plane.

Muscle	Onset of activity	Minimum steady activity	Increasing activity	Maximum activity	Maximum steady activity	Declining activity	Cessation of activity
Deltoid	30°	..	30°-120°	120°	..	120°–180°	..
Subscapularis	30°	30°–120°	120°–150°	150°	..	150°–180°	..
Supraspinatus	30°	..	30°–120°	120°	120°–180°	..	..
Infraspinatus	30°	..	30°–180°	180°	..	..	..
Teres Major	30°	..	30°– 90°	90°	90°–180°	..	..
Teres Minor	40°	..	40°– 90°	90°	90°–180°	..	..
Latissimus Dorsi	75°	..	75°–180°	180°	..	..	..
Pectoralis Major (Sternal Head)	15°	15°–150°	150°–180°	180°	..	..	..
Pectoralis (Claviclar Head) Major		No	Activity	Recorded			

being comparable with those of deltoid and supraspinatus during elevation in the coronal plane. Supraspinatus shows increasing activity reaching its maximum at 180°. Infraspinatus shows maximum steady activity from 150°–180°. Teres major, teres minor, latissimus dorsi and pectoralis major (sternal head) show almost identical rise of peak power at 120° and declining activity towards the terminal phase of elevation (Table 2).

We may consider the muscles acting at the gleno-humeral joint to be divided into three groups. The innermost group consisting of subscapularis, supraspinatus, infraspinatus and part of teres minor are attached to almost the two-thirds of the circumference comprising the tuberosities in one continuous tendo-aponeurotic sheet (musculo-tendinous cuff of Codman) at the level of the junction of the neck and shaft axes. These muscles do not act as isolated units; only those fibres that fall in the plane of elevation give supplementary power in the direction in which the elevation is carried out and produce inevitable rolling (gliding) in that plane. The action commences with the initiation of elevation and is in the direction of gliding (coplaner). The other fibres of the cuff act at a later phase of elevation to steer the head of the humerus by gliding to assume such position as is suitable for further elevation in that plane. Study of the action potential and frequency

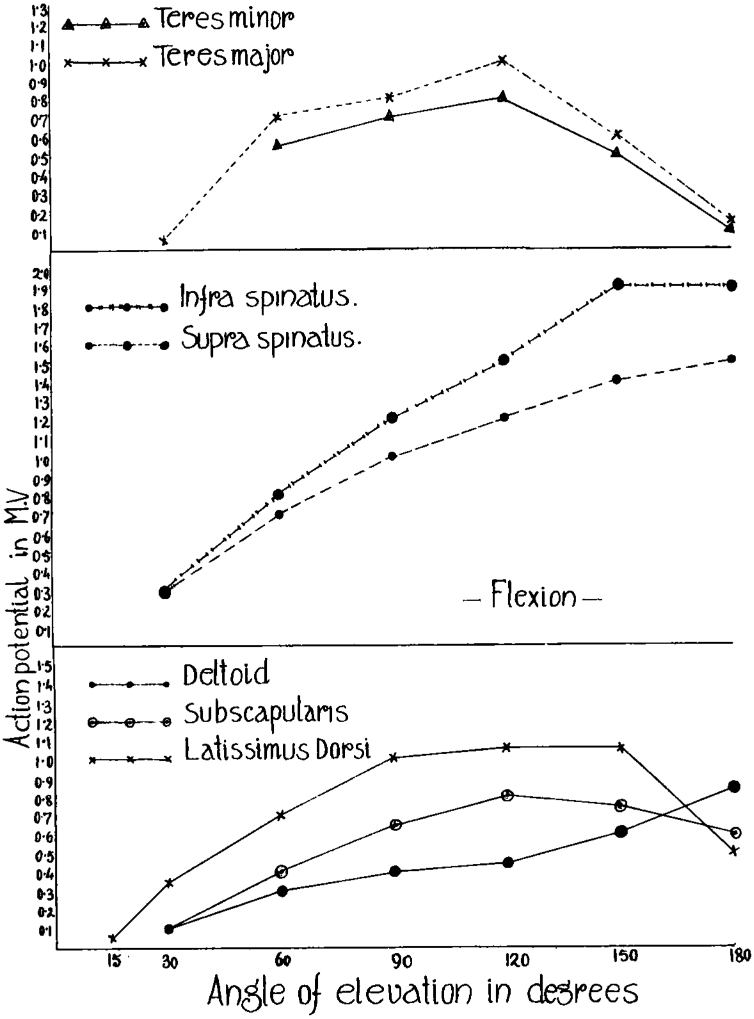

Figure 5. Showing the action of axio-scapulo-claviculo-humeral group of muscles during flexion from 0° to 180°. (Saha, A. K.: Theory of Shoulder Mechanism—Descriptive and Applied. Springfield, Ill.: Charles C. Thomas, Publisher, 1961. Reproduced by courtesy of the Publisher).

of discharge in electromyographic tracings confirms this. In abduction the supraspinatus rises *pari passu* with the deltoid power and is maximum at 120° wherefrom it steadily declines to 180°. The subscapularis power shows a steady increase from 120° till the maximum is attained at 150°. Thereafter it shows a slight decline possibly due to

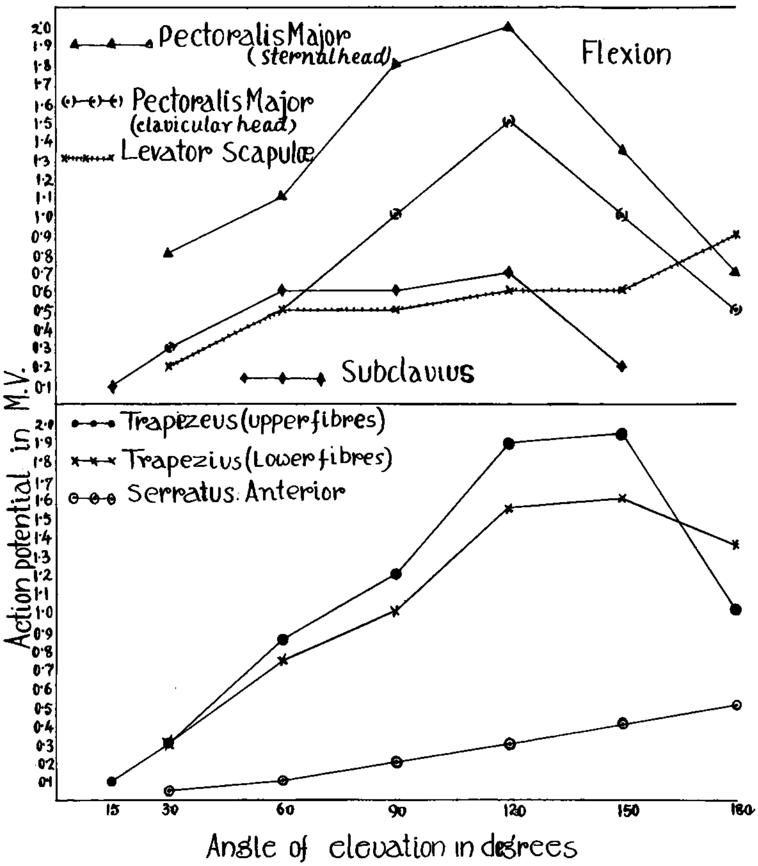

Figure 6. Showing the action potential of axio-scapulo-clavicular group of muscles including pectoralis major during flexion from 0° to 180°. (Saha, A. K.: Theory of Shoulder Mechanism—Descriptive and Applied. Springfield, Ill.: Charles C. Thomas, Publisher, 1961. Reproduced by courtesy of the Publisher).

mechanical disadvantage when its action is taken over by the infraspinatus, whose power steadily increases to 180°. Thus its action is helpful to the subscapularis and keeps the head in the socket, which otherwise would tend to dislocate owing to relative antetorsion of the head-neck of the humerus in the overhead position of the arm.

In flexion the subscapularis shows continuous rise to its maximum at 120° just as the clavicular part of pectoralis major and deltoid (anterior fibres) rise to their maxima. The supraspinatus and infraspinatus which steer the head show delayed rise of action potential which is maximum at 180° and 150° respectively.

Table 2. Activity of Gleno-Humeral Group of Muscles During Flexion in Sagittal Plane.

Muscle	Onset of activity	Minimum steady activity	Increasing activity	Maxi-mum activity	Maximum steady activity	Declining activity	Cessation of activity
Deltoid	45°	45°–120°	120°–180°	180°	..	..	..
Subscapularis	40°	..	40°–120°	120°	..	120°–180°	..
Supraspinatus	30°	..	30°–180°	180°	..	..	..
Infraspinatus	30°	..	30°–150°	150°	150°–180°	..	..
Teres Major	40°	..	40°–120°	120°	..	120°–175°	175°
Teres Minor	60°	..	60°–120°	120°	..	120°–175°	175°
Latissimus Dorsi	20°	..	20°–120°	120°	120°–150°	150°–180°	..
Pectoralis Major (Clavicular Head)	30°	..	30°–120°	120°	..	120°–180°	..
Pectoralis Major (Sternal Head)	30°	..	30°–120°	120°	..	120°–180°	..

Though it has not been possible to prove it experimentally, indirect evidence in support of the action of the infraspinatus in the later phase of elevation is available. In total paralysis of all three short rotators, replacement of supraspinatus and any one of the remaining two gives adequate steering force to elevate the arm overhead. It may be either a reconstructed short rotator acting from behind or from the front. Secondly, in recurrent dislocation of shoulder where subscapularis has lost some of its effective power from elongation of its tendon and/or anatomical defect in the anterior hemiring of the glenoid, reinforcement by a strong posterior glider acting from behind (latissimus dorsi) helps the infraspinatus to steer the head and prevent recurrence of shoulder dislocation. Thirdly, electromyographically the power of infraspinatus continues to rise from 150° to 180° during abduction, while subscapularis shows a relative fall. In flexion similarly the power of infraspinatus shows a high level of maintenance of action potential and that of supraspinatus continues to rise during this range of elevation, proving that both these muscles act as posterior gliders.

The intermediate group of muscles are pectoralis major (sternal head), latissimus dorsi, teres major and teres minor. In the anatomical position, none of these muscles runs the shortest course for its insertion to the shaft of the humerus. All these muscles are inserted between the innermost short rotators and the outermost elevators, pectoralis major (clavicular part) *cum* deltoid. In the phase of near-vertical elevation the mechanical axis almost coincides with the anatomical axis of the shaft; the rotation of the head is directly transmitted to the shaft. This intermediate group of muscles besides adjusting the final position by rotation act as strong depressors of the head to bring about the last few degrees of elevation. Their obliquity downwards helps the depressor action. In abduction their power either maintains a plateau or rises continuously (latissimus dorsi) from 150° to 180°. Pectoralis major (sternal head) shows a rise of action potential though to a lesser extent while remaining comparatively quiescent in the earlier phase till 150°.

In flexion all the four muscles have a fall of action potential from 150° to 180°. This fall is due to the difficulty of raising the arm by its depressor action in the plane which is different from that in which the muscles act to their best advantage. Relative overaction of the supraspinatus, infraspinatus and subscapularis shows that the steering of the head requires more power than elevation in the scapular plane (abduction) possibly owing to lack of adequate power from the intermediate group.

The outer group comprises the pectoralis major (clavicular head) and the deltoid. These are primarily concerned with giving adequate power for lifting heavy weights. It may be noted that the clavicular head extends its insertion to the anterior part of the deltoid impression. These muscles act their best when the steering muscles are active.

(b) *Observations in Post-polio Paralysis*

103 cases with residual paralysis of the muscles of the shoulder following poliomyelitis were studied. Cases with complete paralysis of the muscles moving the gleno-humeral joint showed absolute helplessness even in presence of good girdle muscles. Cases with paralysis of the deltoid and retention of some residual power in the short rotators and depressors were not all helpless. Some of them could raise the arm overhead in flexion unaided, if the power of the clavicular head of pectoralis major was retained. In others when the arm could be raised through the critical angle of 60°–90° with a little jerk the remaining arc could be lifted with ease. Cases without presence of any depressors

could also raise the arm overhead. They all confirm the views held by Duchenne, Pollock, Staples and Watkins and Bunts. Briefly stating, if the limb can be raised in any plane by active power or trick movement to 90°, rest of the elevation is carried out by the active short rotators.

(c) *Functional Restoration in Post-Polio Paralysis*

Cases with complete paralysis of the muscles moving the gleno-humeral joint were studied after restoring the deltoid and two of the short rotators; (1) a vertical rotator (to replace supraspinatus) and (2) either an anterior (to replace subscapularis) or a posterior (to replace infraspinatus and teres minor) short rotator. These cases were rehabilitated to lift the arm overhead in the sagittal and scapular plane. None of these can elevate the limb backward even through a few degrees for obvious reasons. The muscles that were chosen for transfer depended on their availability without compromising the efficiency of girdle movement. They were trapezius, levator scapulae, sternocleidomastoid, upper two digitations of serratus anterior, latissimus dorsi and pectoralis minor in various combinations. This simplified system of the gleno-humeral joint gave excellent material for electromyographic study and provided confirmatory evidence of minimal requirements for elevation overhead against gravity in any plane.

(d) *Electromyography after Functional Restoration by Multiple Muscle Transfers*

Simultaneous recording of action potential of 3 different muscles was studied with specially adapted electroencephalograph (model 6, Grass instruments) during vertical elevation in the scapular and sagittal plane through 180° against gravity. For this purpose the patient was seated on a stool. Three disc-electrodes were placed to take the recording of the transposed muscles. These three outputs were fed separately to 3 of the 8 channels of the E.E.G. and with another common electrode the body was earthed. Simultaneous recording of the action potential of the 3 muscles during elevations was done. The elevation was carried out in the scapular and sagittal plane at constant speed by previous practice. Calibration for sensitivity and time was made before each recording (Table 3).

G.B. (Figures 38 and 39 p. 72) had trapezius, levator scapulae and latissimus dorsi transferred for deltoid, supraspinatus and infraspina-

Table 3.

Name	Movement	Muscle	Onset of activity	Minimum steady activity	Increasing activity	Maximum activity	Maximum steady activity	Declining activity	Cessation of activity
G. B.	Abduction in scapular plane	Trapezius	0°	..	0°– 30°	30°	30°– 90°	90°–180°	..
		Levator scapulae	0°	..	0°– 60°	60°	..	60°–180°	..
		Latissimus dorsi	0°	0°–120°	120°–180°	180°	..	..	..
	Flexion in sagittal plane	Trapezius	0°	..	0°– 60°	60°	..	60°–180°	..
		Levator scapulae	0°	..	0°– 60° & 90°–120°	60° & 120°	..	60°– 90° & 120°–180°	..
		Latissimus dorsi	0°	..	0°– 60°	60°	60°–180°	..	..
M. M.	Abduction in scapular plane	Trapezius	0°	..	0°– 90° & 120°–180°	90° & 180°	..	90°–120°	..
		Levator scapulae	0°	..	0°–120°	120°	..	120°–180°	..
		Serratus anterior	0°	..	0°– 90°	90°	..	90°–180°	..
	Flexion in sagittal plane	Trapezius	0°	..	0°– 60° & 120°–180°	60° & 180°	..	60°–120°	..
		Levator scapulae	0°	..	0°– 90° & 150°–180°	90° & 180°	..	90°–150°	..
		Serratus anterior	0°	..	0°– 60°	60°	..	60°–180°	..

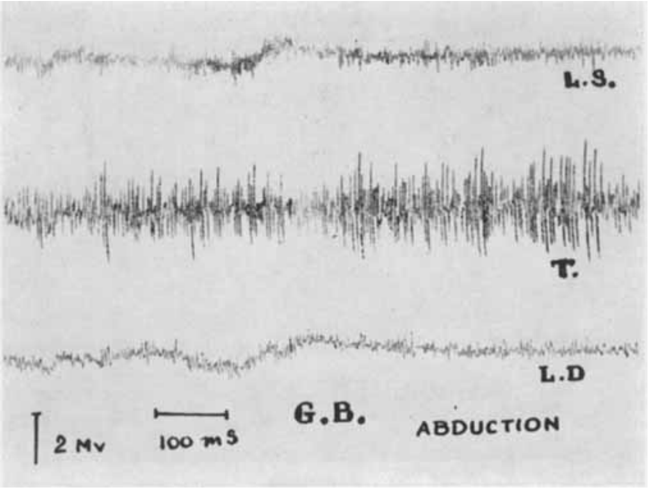

Figure 7.

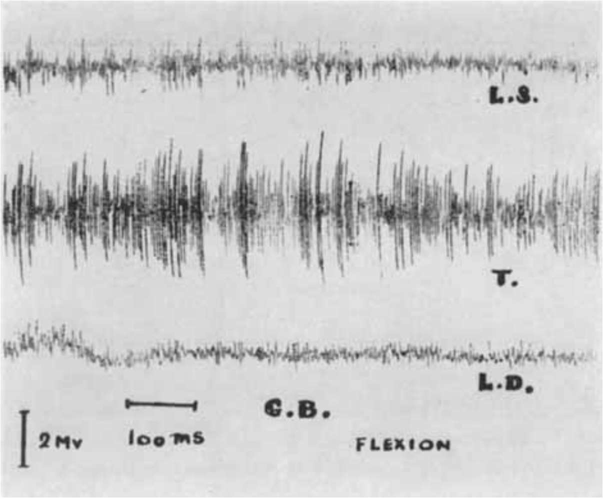

Figure 8.

Figures 7 and 8. Simultaneous recordings of rerouted trapezius, levator scapulae and latissimus dorsi during elevation overhead against gravity in the scapular and sagittal (forward) plane at constant speed. Standardisation for action potential; 1 cm = 2 milli-volts and for time, 1.2 cm = 100 milli-sec.

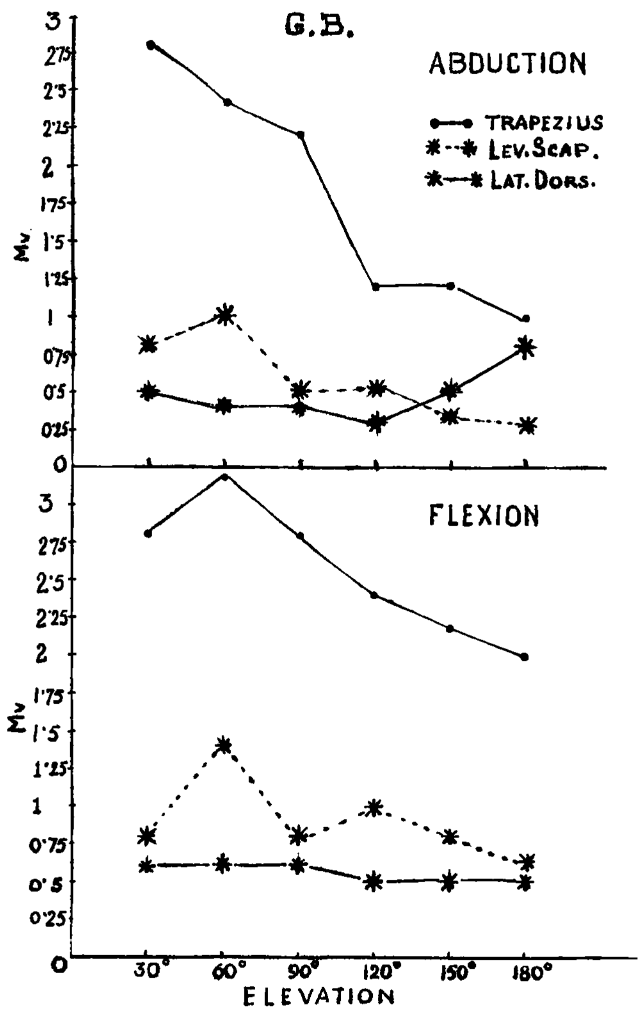

Figure 9. Shows varition of action potential of the electromyographs shown in Figures 7 and 8. To avoid overcrowding, action potential above 0.2 m.v. noticed with the commencement of elevation is not shown between 0° and 30°.

tus. The subscapularis power was not replaced. In abduction trapezius shows the maximum rise at 30° with a steady decline to 180°. Levator scapulae shows steady rise of power to 60°, thereafter declines at 90° maintaining a steady minimum to 180°. Latissimus dorsi shows a minimum activity to 120°, thereafter it shows a steady rise till it is maximum at 180°. In flexion trapezius shows a later rise of maximum

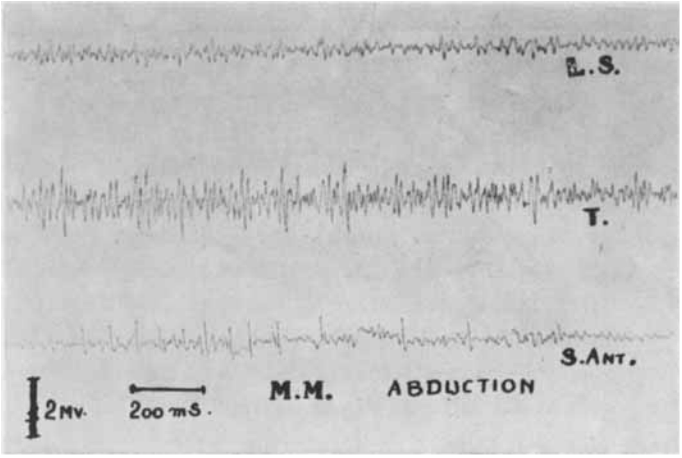

Figure 10.

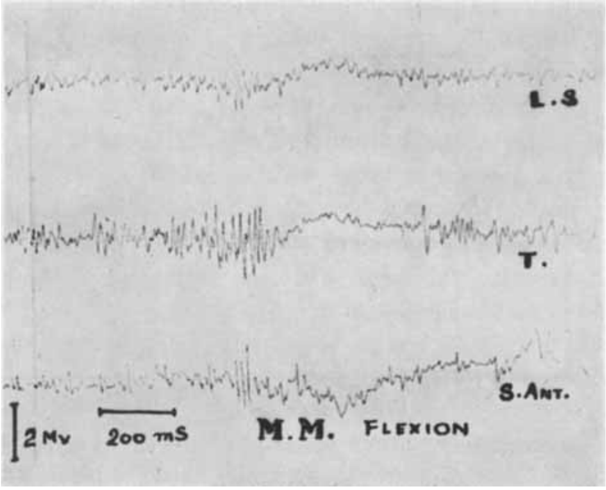

Figure 11.

***Figures 10 and 11.** Simultaneous recordings of rerouted trapezius, levator scapulae and upper two digitations of serratus anterior during elevation overhead against gravity in the scapular and sagittal (forward) plane at constant speed. Standardisation for action potential; 1 cm = 2 milli-volts and for time 1.2 cm = 100 milli-sec.*

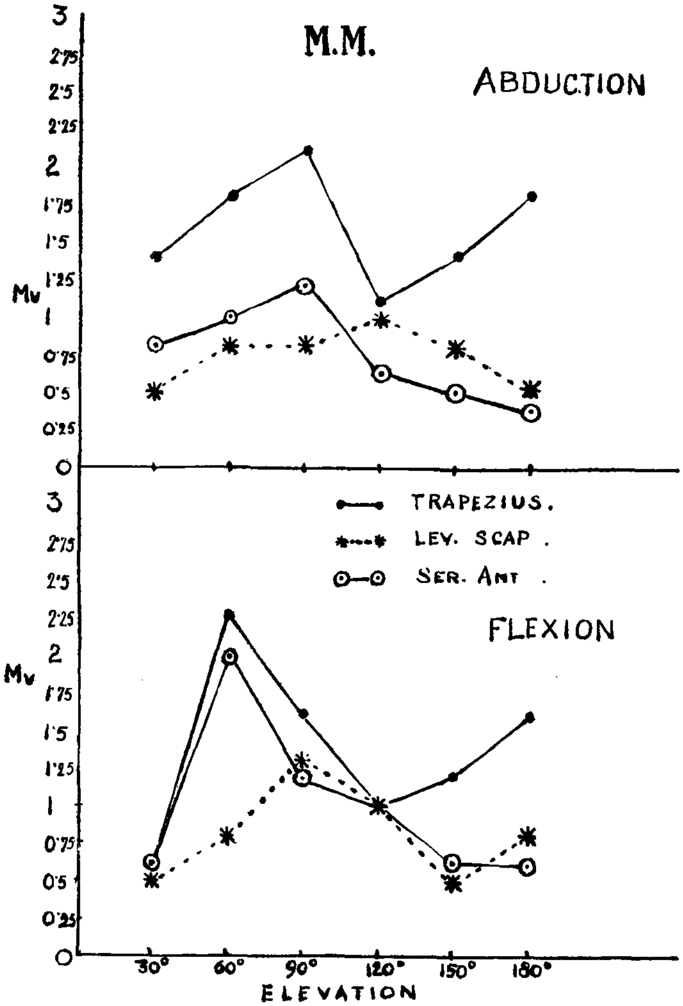

Figure 12. Shows variation of action potential of the electromyographs shown in Figures 10 and 11. To avoid overcrowding action potential above 0.2 m.v. noticed with the commencement of elevation is not shown between 0° and 30°.

power though the pattern is just like that of abduction. The levator scapulae shows rise at 60° and again at 120°. Though the power declines from 120° to 180° yet it is twice as much as that in abduction. Latissimus dorsi rises to the maximum at 60° and maintains a slightly declining but steady activity to 180° (Figures 7–9).

M.M. (Figures 51 to 54 p. 80) had trapezius, levator scapulae and upper two digitations of serratus anterior transferred for deltoid, supraspinatus and subscapularis. In abduction, trapezius shows maximum rise till 90° and again a slightly less second rise at 180°. The declining phase of activity is between 90°–120°. Levator scapulae shows a steady rise from 0° to 120° and thereafter it shows a decline to its minimum at 180°. The serratus anterior shows rise from the beginning to its maximum at 90°, thereafter it shows a steady decline to its minimum at 180°. In flexion, the serratus anterior shows rise of power at an earlier phase at 60° from where it declines to its minimum at 180°. The levator scapulae shows a distinct later rise to its maximum at 90° maintaining its strength till 120°; thereafter, after declining a little at 150° it shows a terminal rise at 180° (Figures 10–12).

These prove that in abduction the trapezius harnessed for deltoid acts as a prime mover. It requires a short rotator (levator scapulae or sternocleidomastoid) to fix and glide the head in the scapular plane. The action is synchronous with the action of the transferred trapezius. After elevation through 60° to 90° the other short rotator comes into play. It helps further elevation by posterior gliding/rolling of the head. This may be by a muscle acting from the front (serratus anterior or pectoralis minor) or from behind (latissimus dorsi). This is seen by the later rise of action potential irrespective of the muscle chosen. They may show certain irregularities in contraction even after training as evidenced by terminal rise of the action potential in some transfers.

In flexion overhead the pectoralis minor or two digitations of serratus anterior show earlier rise of action potential synchronous with the anterior fibres of trapezius. The levator scapulae gives a later rise. In case of a posterior glider a terminal rise is seen which is consistent with the rise expected when infraspinatus is active.

Plea for Functional Classification of Muscles

The power distribution for the gleno-humeral joint is at three levels. Firstly, three muscles exert their power at the junction of head-neck and shaft axes. Secondly, an intermediate group of four muscles exert their power on the upper fourth of the axis of the shaft, and thirdly, the outer deltoid acts in three directions with the help of the clavicular part of the pectoralis major at the junction of the upper and middle third of the axis of the shaft of the humerus. In a system where the proximal end (fulcrum) has to glide on a surface producing each time a new area of contact of the joint surfaces from which the arm has to be elevated two types of power are necessary. The effective steering power which should be close to the end of the head-neck axis has better control over the proximal end and thus over its gliding phase of elevation. This also helps in fixing the head at the constantly changing point of contact. The lifting power on the other hand should act as far away from the joint as possible on the anatomical axis of the shaft. Thoug this power has a minor role in fixing the head on the glenoid and on gliding, it is more concerned with providing adequate motor power for lifting. The intermediate group of four muscles act both as fixators on the glenoid and also help gliding (depressor action). Their power can be dispensed with without any apparent disability though the performance of the limb in lifting heavy weights above the head would lessen.

Thus functionally, the muscles moving the gleno-humeral joint may be subdivided into three groups:

(a) *Prime movers*—These are deltoid and clavicular head of pectoralis major. Their function is to give power in lifting.

(b) *Steering group*—These are short rotators, subscapularis, supraspinatus and infraspinatus. These primarily steer and fix the head of the humerus with a minor contribution in giving the lifting force to the arm.

(c) *Depressor group*—These are pectoralis major (sternal head), latissimus dorsi, teres major and teres minor. These muscles are rotators of the shaft of the humerus during elevation and depress the head to help the last few degrees of elevation overhead. They do have, however, certain minimal steering action on the head of the humerus.

Though the teres minor anatomically belongs partly to the short rotator group, its electromyographic changes conform more to the intermediate group and, therefore, it is included with these.

MATHEMATICAL CORROBORATION OF THE ACTION OF VARIOUS MUSCLE GROUPS

The variables in lifting the arm overhead are (a) the power development in short rotators, intermediate group and prime movers in different phases of elevation, (b) the range of shortening of each muscle dur-

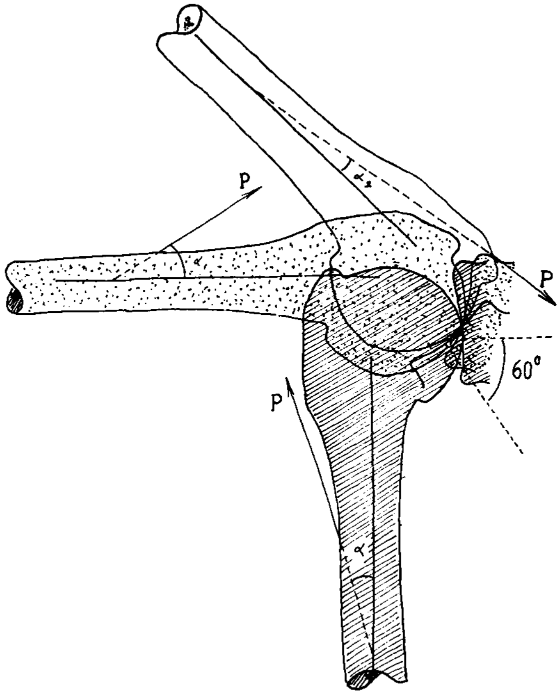

Figure 13. The figure shows diagramatically the effect of elevation on the angle which the prime mover (P) makes with the mechanical axis at different stages of elevation. For clarity the different mechanical axes have not been shown owing to the constantly changing position of the axis, humerus and scapular glenoid. The scapular rotation contributes about 60° of the total elevation.

ing the isotonic phase of contraction and thus its role in the movement of the humerus (c) variable angles which the short rotators, depressors (intermediate group) and prime movers bear with the constantly changing mechanical axes of the shaft and of the head-neck in space at each instant of elevation and (d) co-ordination of the girdle muscles, steering muscles and the intermediate group of muscles (depressors) to set the joint surfaces in optimum position to facilitate elevation. The last is primarily governed by the central nervous system(cortex) gained after training in infancy and in the present state of our knowledge is beyond the scope of possible mathematical correlation.

The joint surfaces are not perfect spheres. The centre of curvature of the glenoid (G), of the humeral head (O) and the contact point (C) are thus not colinear during elevation and add to the complexity of the problem.

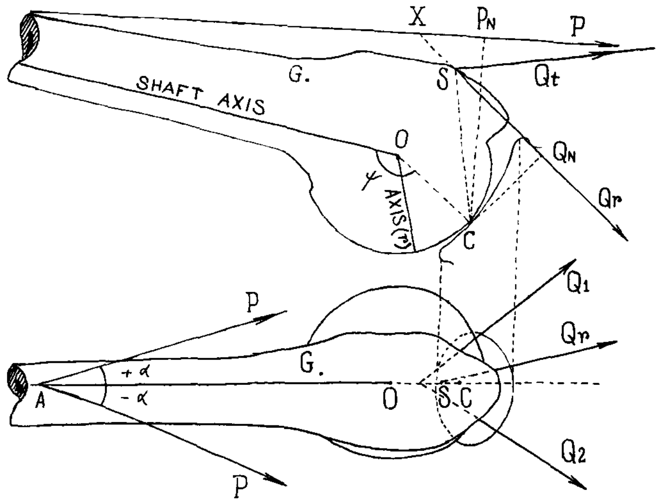

Figure 14. The diagram shows the various forces taking part during elevation of the shoulder in the sectional view in the plane of the scapula. The lower diagram shows the plan projection view with distribution of forces.

From the biomechanical standpoint this can be simplified to the study of effects of forces (a) in the scapular plane and (b) in the plane at the right angle to (a) (plan view). Such idealising simplification does not represent the actual state of affairs. It enables us to arrive at the effects of different types of forces on the gleno-humeral joint.

In the sectional view in the scapular plane (Figures 13 and 14) the articular surface of the humerus is capable of moving through an arc of about 155°. The contact point C changes its position and bears an angle of ω with the axis of the shaft. Therefore $\omega = 35° +$ angle formed by gliding of the head while lifting from the side. In a particular position, the contact point C may coincide with the axis of the head-neck whose centre of curvature is at O. The radius of curvature of articular surface *i.e.* between C and O is 'r' and in one position CO coincides with the axis of head-neck. Let the force contributed by prime mover be P acting at A on the axis of the shaft of the humerus. Let Qr be the short rotator force acting during elevation in the plane of movement at S. OS may be taken for all practical purposes equal to r. As the arm is raised from hanging position to vertical overhead position the angle which P bears with the shaft axis in different position has the nature of a half of sine curve *i.e.* its value is minimum when it hangs by the side and reaches its peak when the arm is elevated to 90°

and again declines when the arm is elevated to vertical overhead position. In arriving at this we have to take into consideration the maximum rotation of the scapula around the anteroposterior axis. The lifting mechanical advantage will depend on $Qr \times CQ_N$ and $P \times CP_N$, CQ_N and CP_N being normals on the forces Q and P respectively from the point of contact C.

Mechanical advantage of P > or < that of Qr according as

$$P \times CP_N > \text{or} < Qr \times CQ_N$$

$$\text{or, } \frac{P}{Qr} > \text{or} < \frac{CQ_N}{CP_N} \tag{1}$$

From similarity of triangles

$$\frac{CQ_N}{CP_N} = \frac{XP_N}{XQ_N}$$

1. When the arm hangs by the side and as ω reaches 90° from 60° (ω being the angle between CO and OA). CP_N increases from r to a higher value and $CQ_N = r$. This is equivalent to elevation of the arm to 30° from hanging position.

$$\text{or, } CP_N > r$$

$$\text{or, } CP_N = r + k$$

The mechanical advantage

$$\frac{P}{Qr} = \frac{CQ_N}{CP_N}$$

$$\text{or, } \frac{P}{Qr} = \frac{r}{r + k}$$

$$\text{or, } \frac{Qr}{P} = 1 + \frac{k}{r}$$

$$\text{when } \omega = 90°,\ k = r$$

$$\text{or, } \frac{Qr}{P} = 2$$

$$\text{or, } 2\,P = Qr$$

In the other words P is mechanically advantageous in the initial phase of lifting. The action potential at this stage being low, P requires reinforcement by Qr.

2. As the arm is elevated XP_N tends to diminish up to 90° of elevation, thereafter it increases as the arm is further raised. In the

vertical position the contact point being near the lesser tuberosity the direction of P becomes almost parallel to the axis of the humerus and passes close to S. In this position the angle between P and Qr becomes minimum and is designated as μ. In this position CY is CYcos $\mu = CQ_N \times \text{Sin}\ (90^\circ - \mu) = CQ_N$ which evidently cannot be less than r.

In the condition where

$$CP_N > r, XP_N < XQ_N$$

$$\frac{CQ_N}{CP_N} = \frac{XP_N}{XQ_N} < 1$$

for, mechanical advantage

$$\frac{P}{Qr} < 1$$

$$\text{or, } P < Qr$$

In other words, the mechanical advantage of P is more than that of Qr as the elevation nears the vertical position though its action potential falls to minimum. The action of the short rotators is essential for steering the head to the vertical in this cruical phase of elevation.

3. When the arm is raised to vertical $XP_N \rightarrow 0$, Qr passes near the points of contact at this stage. Therefore, CQ_N also tends to be 0. In this position, mechanical advantage of P is still greater than that of Qr which tends to 0.

Similarly, the limits of optimum role of the steering muscles (short rotators), prime movers and depressors (intermediate group) can be worked out mathematically using general notations in the plan view. In figure 14 the steering muscles in one direction have been termed Qr acting at an angle of β with the line joining C and O prolonged to the point of the action of the resultant on the tuberosity at S in the plan view. In other words, the limit of range of steering is $+\beta$ and $-\beta$ with the axis on either side. The angles are not equal in view of the presence of retrotorsion of the head-neck on the shaft axes. Let the prime movers (P) similarly bear an angle of $+\alpha$ and $-\alpha$ with the axis of the shaft in the plan view at A. The distance between A, O and C is d_2 (CO being projected on the axis in the plan view) and similarly the distance between S, O and C is d_1 (SC being projected in the plane of the shaft axis in the plan view). The steering couple will be $Qrd_1 \sin (\pm \beta) \pm Pd_2 \sin (\pm \alpha)$.

To meet the best result of steering effect, *i.e.*, to and from rolling of the head of humerus in the glenoid, the forces Qr and P should be synchronous and homodirectional in their pull.

β is always greater than α, $Qr > P$ beyond 120° of elevation, (from electromyographic study) and therefore

$$\frac{Qr}{P}\frac{\sin(\pm\beta)}{\sin(\pm\alpha)} > 1 > \frac{d_2}{d_1}$$

i.e., the steering effect of Qr is more effective than that of P. From above it is seen that P is advantageous in all stages of elevation; Qr is essential

(a) At the initiation of lifting from hanging position of the arm (vide infra).
(b) Beyond 90° of elevation, when the pull of deltoid gradually tails off (electromyographic studies).

Indeed, the maximum steering effect is required after the shoulder has reached 120° of elevation when Qr starts getting its peak action potential.

To summarise, in the initial stage of lifting the short rotators play the major role up to about 30° of elevation. Between 30° and 120° the lifting is carried out mainly by the prime movers and again from 120° to 180° the steering muscles take a major role in lifting. The steering muscles should be acting as close to the bend of the axis as possible so that the angle $\beta > \alpha$.

MINIMUM REQUIREMENT OF POWER FOR OVERHEAD ELEVATION OF THE SHOULDER: PREREQUISITES AND POSSIBILITIES OF TRANSFER OF POWER IN FLAIL GLENO-HUMERAL JOINT

Reserve muscle power of the gleno-humeral joint is in abundance. This makes the limb useful in lifting heavy weights, tackling the opponent in wrestling and other heavy duties. All of it is not needed for lifting the shoulder overhead and in performing ordinary daily chores.

The deltoid and the clavicular head of the pectoralis major are the only muscles having no alternative power to replace their function. These give motive power for lifting. Their insertion is furthest from the joint to enhance mechanical advantage.

Of the steering group, the infraspinatus has been shown to be a posterior glider of the head of the humerus during the end stages of elevation overhead. The action thus is similar to that of subscapularis in this position. Retrotorsion of the head of the humerus which changes into relative antetorsion in the overhead position predisposes to anterior subluxation. Its prevention requires extra power for backward gliding. Infraspinatus gives this power. This muscle has got a minor role during backward elevation of the limb, though the backward elevation is only possible to about 80°. It glides the head of the humerus in this plane.

Supraspinatus and subscapularis are arranged in such a manner that they are capable of steering the humeral head during overhead elevation in different planes through an arc of about 150°. The extremes (about 30° on either side) of the arc are helped by forward and backward migration and vertical rotation of the scapula. These steering muscles also fix the head of the humerus in the glenoid at each instant of elevation. Their action follows the general rule that the muscle fibres which fall in the plane of the movement give the vertical gliding of the head of the humerus with the commencement of motion. The fibres anterior and posterior to these glide the head in the horizontal plane at a subsequent stage. Therefore, it is obvious that supraspinatus and subscapularis are indispensable for elevation. The minor vertical gliding during elevation backward by infraspinatus does not however take place.

The intermediate group of muscles comprising pectoralis major, latissimus dorsi and teres major et minor are vertical depressors having a little steering and fixation action. These help lifting heavy weights overhead; therefore, the limb loses some of its effectiveness in lifting heavy weight when these are knocked out.

Scapular rotation round an antero-posterior axis through its body is the most important of all the girdle movements. Fixation of the blade during elevation of the limb is just as important. Gravity, the lower fibres of serratus anterior and rhomboids have been seen to be sufficient for this. Upward and forward migration and the vertical rotation of scapula round the chest wall during elevation is effected indirectly though inefficiently by the muscles moving the gleno-humeral joint. The remaining girdle muscles, though fewer in number, may be used for transference. They are whole of the trapezius, pectoralis minor, upper two digitations of serratus anterior and levator scapulae.

The classical methods of transfer of a single muscle or several muscles to a common attachment for abduction power do not consider the role of steering muscles when paralysed and fail to substitute their function in their absence. So both on the theoretical consideration and clinical experience we find that the arm cannot be lifted more than 90° and that too with grossly altered scapulo-humeral rhythm. This corroborates the observations of Merle d'Aubigne.

The power in absence of delto-pectoral complex is given by trapezius. Trapezius should be transferred using its full extent of its insertion to replace the anterior and middle fibres of deltoid. Wider angle of rerouting by multiple crushing of the acromion and spine helps wider pull. While rerouting, the muscle may be shifted a little forward or backward in presence of imbalance or where we want internal and external rotation of the arm in absence of a suitable substitute.

It is very important to assess the power of the steering muscles *e.g.*, subscapularis, supraspinatus and infraspinatus. The function of these muscles and in their absence their restoration is as important as replacement of a prime mover. Without their aid the prime mover is helpless as an elevator. Muscles whose distal ends can be brought to the region of the tuberosities and their general direction of pull corrosponds to that of the muscles they are going to replace are suitable for transfer. In the process the nerve and vascular supply should not suffer any damage or pull in the rerouted position of the muscle. At least any two of these require replacement.

The steering muscles should have their rerouting close to the end of the axis of the head and the neck to give pure form of movement at the gleno-humeral joint. Axis being bent, rerouting distally causes loss of power for gliding the humeral head. No wonder, all muscles having this function are inserted round the bony tubercles situated at the outer end of the head-neck axis.

The subscapularis power can be replaced by pectoralis minor or upper two digitations of serratus anterior whose direction of pull corresponds closely to the direction of fibres of subscapularis. The rerouting of these muscles is done anteriorly at the site of the insertion of the subscapularis. An alternative method of replacement of subscapularis function is to provide a posterior glider by posterior transfer of latissimus dorsi and/or teres major to a point exactly opposite the site of the subscapularis insertion *i.e.* the tubercle limiting the greater tubero-

Table 4. Possible Power Replacements at the Gleno-Humeral Joint at a Glance.

Muscle requiring replacement or reinforcement	Action	Choice of muscles for transfer in order of preference
Subscapularis	Posterior glider	I. Upper two digitations of serratus anterior II. Pectoralis minor III. Pectoralis major (whole or part). These muscles act almost in the same direction as that of fibres of subscapularis IV. Levator scapulae V. Scalenus anterior VI. Scalenus medius VII. Splenius capitis VIII. Sterno-cleido-mastoid These (4–8) act from above, therefore are second class substitutes
Infraspinatus	Posterior glider acting from behind	I. Latissimus dorsi II. Teres major
Supraspinatus	Superior glider	I. Levator scapulae II. Sternocleidomastoid III. Scalenus anterior IV. Scalenus medius V. Splenius capitis All of them act from above therefore, are good substitutes
Deltoid-and-clavicular head of pectoralis major	Prime mover (lifting)	I. Trapezius as far down as possible on the shaft

sity. Here the action is from backward though identical with that of the subscapularis after elevation beyond 90°. Latissimus dorsi is a suitable muscle owing to its long fibres and mechanical advantage. It has been used successfully as a backward glider to prevent anterior recurrent dislocation of the shoulder. Besides, when transferred for paralytic shoulders, depressor action of the latissimus dorsi is not altogether abolished. In several of our cases we found this to be the only muscle available for transfer.

The levator scapulae, scalenus anterior, and scalenus medius, splenius capitis and sternocleidomastoid are suitable to replace the supraspinatus. Of these the levator scapulae is the first choice owing to its direction and the length of the fibres. All have not been tried for want of suitable cases. Table 4 shows the possible transfers.

The intermediate group of depressors if present after the required transfers are done enhance the power of lifting heavy weights. Their absence, however, does not impair the range of movement of the limb, though it diminishes its performance.

The lower six digitations of serratus anterior and rhomboids with the help of gravity are adequate to act as the force rotating the body of the scapula round the antero-posterior axis. In the absence of these we have to fall back upon one of the standard methods (vide introduction) of restoration of power.

CRITERIA OF SATISFACTORY RESULT AFTER SURGICAL REHABILITATION

The limb should be capable of elevation through a full arc of 180° in the coronal, sagittal or in any intermediate plane. Sometimes while the first 60°–90° can be elevated with ease, the remaining arc requires help for elevation. In these cases there is often premature rotation of the scapula to the point of exhaustion of its full range. Further attempt at elevation results in unnecessary bending of the body to the contralateral side. In some cases though the arm can be elevated overhead in the sagittal, it cannot be done in the coronal plane owing to the persistent internal rotation of the shoulder. There are cases where the arm can be brought up and held either in the coronal or in sagittal plane by giving a swing to the limb. The momentum carries the limb to the desired level where there is enough power to complete elevation and to balance it. In others, it has been found that while the patient cannot raise the arm overhead with the elbow extended, he can do it with the elbow in flexion. Obviously, it is due to the reduction of the moment by shortening the arm of the lever. The critical arc through which the lifting requires the maximum effort is from 60°–120°.

The scapulo-humeral rhythm should be comparable to that of the opposite side during elevation. The adjustment in the setting phase of the scapula is different from person to person, though clinically they appear to be the same. Where initiation of the elevation is difficult owing to lack of power, the scapular rotation may help in passing through this critical phase to a position where the muscle power is just sufficient to lift the arm through the remaining arc. This, of course, points to the weakness of the steering muscle in the plane of elevation. The inevitable unilateral shrugging is noticeable in these cases, *i.e.*, the point of the shoulder is elevated prematurely.

The shoulder tip must not move excessively upwards or lag during elevation in the coronal plane. The upward elevation is frequently seen when there is imbalance of power between the elevators of the gleno-humeral joint and fixators of the scapula. We frequently found this to happen after muscle transfer and by training they may eventually be corrected. The lag in elevation is also due to imbalance of the effect of gravity on the limb and the elevators of the scapula. These cases require reinforcement of power.

The vertebral border and the upper angle of the scapula should not unduly project while lifting the shoulder. This is due to lack of power of the serratus anterior, deficiency in one power-arm of the torque which rotates the scapula in the antero-posterior axis. Lack of power in prime movers or short rotators may in some cases demand greater attention of the patient. Accessory muscles contract with the muscles moving the shoulder. There may be bending of the body to the contralateral side. The patient may show undue strain or exertion and there may be tremors and jerks during maintenance of the motion and finally the position may not be sustained. All these are not desirable in a surgically rehabilitated shoulder. He should be able to lift a reasonable amount of weight and carry out normal functions demanded for his well-being.

During rehabilitation it has been found that in the initial stages they may not fulfil the criteria of satisfactory results. New functions demanded by the rerouted muscles so long dormant and/or used for other functions may require a good period of training before he accustoms himself. Improvement of power also develops with the passage of time and resistive exercises. Joint stiffness, particularly in the shoulder, may be a factor in the disturbed function of the limb after operation. The case has to be followed day to day and the cause ascertained in the presence of altered functions and treated accordingly.

To summarise, the criteria of satisfactory results after surgical rehabilitation are:

1. The limb should be capable of elevation through the full arc of 180°, either in the coronal, sagittal or in any intermediate plane.

2. The scapulo-humeral rhythm should for all practical purposes be comparable to that of the healthy side.
3. Vertebral border and the upper angle of the scapula must not unduly project while lifting the shoulder.
4. The shoulder tip should not move excessively upward or lag in the coronal plane.
5. The movement should not be jerky while elevating the shoulder and the patient must not show visible effects of undue exertion.
6. He should be able to lift a reasonable amount of weight.

CLINICAL AND ELECTRICAL ASSESSMENT OF POWER IN NORMAL AND IN PARALYSED SHOULDER

Periodic clinical assessment of muscle power is necessary to record day to day improvement or deterioration of the strength of individual muscles or muscle groups following a lower motor neurone lesion from any cause. It is also essential to know the power of each muscle before planning a reconstructive operation, which involves transference of one or more muscles. It is frequently seen that the transposed muscle is often at some mechanical disadvantage in its new position and also that the available muscle for substitution is of less bulk and consequently weaker even in the normal state than the muscle which it is going to replace. These cases fail to give expected results even in efficient hands. Clinical grading of muscle power has to be accurate and standardised. Grading according to the Medical Research Council (M.R.C.) scale appears to be quite satisfactory and easily done even in a busy outpatient department. The scale is divided into six grades as follows:

0: Complete paralysis.
1: Muscle responds with slight flicker on volition.
2: Can move the part on volition when gravity is eliminated.
3: Can move the part only against gravity.
4: Can move the part against gravity and some resistance.
5: Normal power.

Any intermediate value is denoted as + or + + affixed to the basic power. As for example, if the forearm can be extended against gravity and maintained in that position for any length of time or till any resistance brings it down, then the triceps is graded as '3'. But if the patient is able to extend the elbow against gravity only for a brief period and cannot sustain it, in that case the triceps is graded as 2^{++}.

The corroborative and supplementary assessment is done with the help of the strength duration curve. During clinical power testing the action of the associated agonist, if any, and antagonists is eliminated by the positioning of the limb. It is often extremely difficult, if not impossible, to exclude the group action during a particular movement. This often leads to rather optimistic data and on transfer these muscles are found to lack the power it was expected to replace. The determination of the strength duration curve helps to arrive at a more accurate estimation, particularly, in connection with the deeper muscles. It helps to assess the state of denervation or innervation of a single muscle.

During clinical assessment it is often necssary to instruct the patient and to explain carefully the exact movements to be performed. Cooperation of the patient is essential. The power of muscles is judged in certain positions while performing a specific movement in a specific direction. This helps isolation of a muscle action which would otherwise be difficult or impossible in the presence of group action. It is frequently necessary for the examiner to fix a particular joint or part of the body to obtain the best mechanical advantage during the performance of the act. Different portions of a large muscle may require special examination in different positions. Minor intelligent adjustment of the position and the site of application of resistance during testing may be necessary when optimum effect cannot be elicited due to paralysis of neighbouring muscles. For instance, in the test described for sternal part of pectoralis major the deltoid, serratus anterior, triceps and muscles of wrist and hand are assumed to have normal power. In paralysis of these muscles the test has to be modified. The patient sits with the arm hanging by the side. The examiner passively abducts the shoulder to 30° and resists patient's attempt to bring the arm down to the trunk by counterpressure at the elbow. A brief account of the clinical assessment of the power of the different muscles moving the shoulder joint complex (including the accessory joints) is given below. Particular attention is given to the deepseated muscles whose action is difficult to assess clinically.

Trapezius Upper: Patient sits upright. No fixation is usually necessary. Resistance is applied against the acromion and the posterolateral aspect of head *i.e.*, over the mastoid region and the patient is prevented from approximating the occiput to acromion.

Trapezius Middle: Patient lying prone with arm in horizontal abduction and in external rotation tries to lift it up from table, while the examiner presses the arm down on the table.

Trapezius Lower: Patient lies prone with the arm in about 120° abduction, extension and full external rotation. Pressure is applied on the forearm towards the table while patient tries to lift the arm from it. If the posterior deltoid and triceps are weak the examiner exerts pressure against acromion while the arm hangs from the edge of the table.

Deltoid Anterior: Lying supine with the arm internally rotated and abducted (30°–40°), elbow flexed, hand resting on the chest the patient flexes the arm against resistance at the elbow in the opposite direction.

Deltoid Middle: Patient sitting or lying on the side with elbow flexed to 90°, shoulder abducted to 45° further abducts in the scapular plane against counterpressure at the elbow.

Deltoid Posterior: Patient lying prone with the arm in 45° abduction and in slight external rotation and extension attempts further abduction and extension against counter-resistance at the elbow. No fixation is necessary in this manoeuvre.

Supraspinatus: The supraspinatus muscle lies under cover of trapezius; careful palpation and comparison of its bulk in the state of contraction with the normal side is necessary. It acts jointly with the middle deltoid; therefore, it is difficult to assess its power separately.

Patient sitting up with the arm by the side in neutral rotation and the head bent towards the same side to relax upper trapezius tries to abduct the arm while the examiner resists this with one hand at the lower end of the arm and palpates with the other the region of the supraspinatus muscle.

Infraspinatus and Teres Minor: Patient lying supine with elbow flexed to right angle and shoulder in slight abduction and neutral rotation, rotates the arm externally against resistance on the radial side of the forearm, the arm being fixed at the elbow by the other hand of the examiner.

Teres Major: Lying supine, patient's arm is abducted to 60° and is supported by one hand of the examiner. The examiner opposes internal rotation with the other hand on the inner surface of the forearm, flexed to 90°.

Levator Scapulae: Patient either lies prone or sits up with elbow flexed, shoulder extended and adducted in neutral rotation. Fixation of

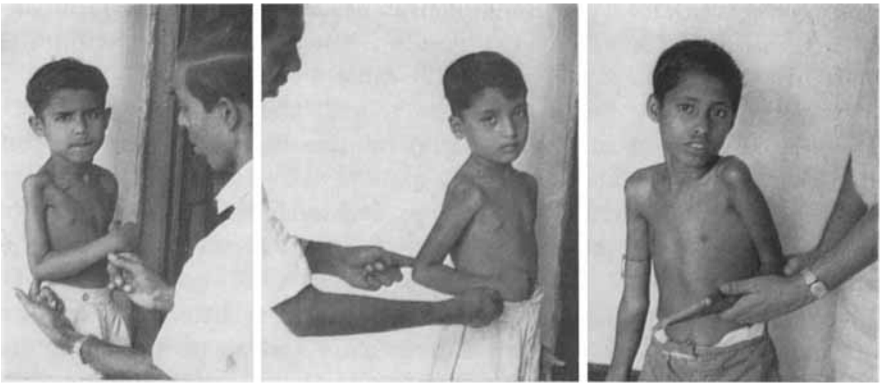

Figure 15. *Figure 16.* *Figure 17.*

Figures 15–17. The figures show the effect of internal rotation against resistance with loss of subscapularis power and presence of residual power in some of the intermediate group of muscles e.g., pectoralis major, latissimus dorsi, teres major and teres minor. In the first figure the shoulder dislocates posteriorly when internal rotation is attempted against resistance owing to the presence of pectoralis major. The second figure shows anterior dislocation when internal rotation is attempted against resistance in presence of latissimus dorsi. The third figure shows minor anterior subluxation in presence of some power (2) in subscapularis.

acromion in the normal shoulder level is done by the examiner. The patient tries to push the point of the elbow medially and backwards, while the examiner opposes with the other hand.

If the shoulder muscles are weak the patient is instructed to adduct and elevate the scapula while drawing the inferior angle medially; the examiner opposes this movement by attempting to draw the inferior angle outwards.

Rhomboids: The patient lies prone or sits up with elbow flexed and tries to appose the inferior angle of both scapulae as much as possible against resistance over both the acromions in the forward direction or over the point of the elbow when the posterior deltoid and shoulder fixators are normal.

Alternative test (Brunnstrom): The patient lying prone, relaxes the trapezius by hyperextension at the shoulder and by placing the hand across the back with elbow at right angle. The examiner inserts a finger beneath the vertebral border of scapula and the patient is asked to raise the forearm and hand slightly away from the body when the contraction of the rhomboids can be felt.

Subscapularis: Patient lies supine with arm abducted to about 120°

and externally rotated. Examiner fixes the elbow with one hand, while he resists internal rotation with the other placed on the medial side of forearm bent to 90°.

In some cases of flail shoulder with loss of power of subscapularis there is often residual power in one or more of the muscles *e.g.*, pectoralis major, latissimus dorsi, teres major and teres minor. In these cases the shoulder is seen to subluxate further forward or backward when attempting internal rotation against resistance. It is due to unopposed pull on the shaft of the humerus by the dominating muscle and want of balance due to paralysed subscapularis which fixes the head in the glenoid (Saha & Banerjee, Figures 15–17).

Latissimus dorsi: Patient lies prone with shoulder partly abducted (45°), extended and arm internally rotated and tries to adduct against the resistance of the examiner's hand on the lower arm or forearm. Fixation is not necessary in this position.

Serratus anterior (upper two digitations—Saha & Banerjee) Besides its action as a stabiliser with the help of levator scapulae in the setting phase of the scapula during the elevation, upper two digitations of serratus anterior bring the scapula forward aided by pectoralis minor in the erect position. On lying it is also a depressor of the scapula and helps to rotate the scapula in the clockwise direction on the right side when seen from behind.

Patient lies prone and his point of the shoulder and limb are allowed to hang over the edge of the table to minimise the action of the pectoralis minor. He pushes the point of the shoulder further forward against resistance applied in front of the shoulder in the neighbourhood of the coracoid process in the opposite direction.

Serratus Anterior (Lower six digitations): Standing in front of a wall the patient pushes the wall with both hands, keeping both elbows straight and arms in horizontal flexion. Any comparative weakness is easily detected by winging of scapula or prominence of its inner border.

Serratus anterior is also tested in the supine position. The patient pushes the arm perpendicularly upwards, while the examiner resists the fist of the patient with the elbow in extension, trying to push towards the table. When the triceps and deltoid are weak, the arm is placed in 90°–120° abduction and in external rotation, the examiner places a hand on the point of the shoulder to resist the forward thrust.

Pectoralis Major (Sternal part): Patient lying supine holds the upper limb in 90° flexion with the elbow extended and tries to bring the hand down towards the opposite iliac crest. The examiner resists

Table 5. Muscle Testing Chart: Shoulder Girdle and Upper Limb.

Index No.	Left Date	Nerve segments	Name Muscle	Nerve segments	Right Date	
		C5, C6	Deltoid Anterior	C5, C6		
		C5, C6	Deltoid Middle	C5, C6		
		C5, C6	Deltoid Posterior	C5, C6		
		C5, C6	Subscapularis	C5, C6		
		C5, C6	Supraspinatus	C5, C6		
Shoulder		C5, C6	Infraspinatus	C5, C6		Shoulder
		C5, C6	Pectoralis Major Clavicular Head	C5, C6		
		C7, C8, T1	Pectoralis Major Sternal Head	C7, C8, T1		
Joint		C6–C8	Pectoralis Minor	C6–C8		Joint
		XI, C.N.	Trapezius Upper	XI, C.N.		
		C3, C4		C3, C4		
		C3, C4	Trapezius Middle	C3, C4		
		C3, C4	Trapezius Lower	C3, C4		
Complex		C6–C8	Latissimus Dorsi	C6–C8		Complex
		C5–C7	Serratus anterior upper two digitations	C5–C7		
		C5–C7	Serratus anterior lower six digitations	C5–C7		
		C5	Rhomboid Major	C5		
		C5	Rhomboid Minor	C5		
		C5, C6	Levator Scapulae	C5, C6		
		C5	Teres Major	C5		
		C5	Teres Minor	C5		
		XI, C.N. C2 & C3	Sternocleidomastoid	XI, C.N. C2 & C3		
Elbow		C5, C6	Brachialis	C5, C6		
		C5, C6	Brachioradialis	C5, C6		

the movement by one hand against the volar aspect of the forearm, and the other on the opposite iliac crest to fix the pelvis.

Pectoralis Major (Clavicular part): Patient lies supine with the upper limb in 90° flexion and the arm in slight internal rotation. The examiner fixes the opposite shoulder with one hand while he applies pressure with the other hand against the volar surface of the forearm to resist the arm being brought across the chest towards the opposite shoulder.

Pectoralis Minor: Patient lying supine with hand by the side, tries to thrust the point of the shoulder forward and downward without any pressure of the hand on the table, while the examiner tries to press the shoulder backwards towards the table.

A modified muscle testing chart is used for recording the results of the clinical power assessment. Repeated examinations are done in doubtful cases (Table 5).

Strength Duration Curves

Strength duration curves were done in most of the cases. This was done to eliminate doubt in such patients who did not co-operate properly to elicit contraction of a particular muscle. Sometimes it was necessary to assess the contractility in cases of overstretched muscles and also in cases of partially denervated muscles. In some cases due to trick movements it was difficult to assess individual muscle action, when strength duration curves were plotted to eliminate doubt. To assess the ratio of denervated to innervated fibres in a muscle after residual lower motor neurone type paralysis, strength duration curve plotting was done. From the gradient of the curves it was possible to ascertain the amount of denervation and also to evaluate the muscle power. The clinical power assessment was thus further corroborated by plotting the strength duration curves.

The constant voltage type of apparatus was used with a range of 0–200 volts. It was used because it was well tolerated even by children. The pulse time bases in this machine were as follows: 300, 100, 30, 10, 3, 1, 0.3, 0.1, 0.03, 0.01 m. sec.

The part to be examined was cleansed with soap and water and a preliminary heating with an infra-red lamp kept at a distance of 3 ft. for 10 minutes was done prior to the examination.

Deep-seated muscles *i.e.*, the muscles which are covered by another superficial muscle *e.g.*, supraspinatus, rhomboids, etc. often presented difficulties in the plotting of strength duration curves. In such cases contraction of the whole muscle bulk was observed by a slightly stronger stimulation on the motor point. The volume and outline of the muscle in contracted state were compared with that of the normal side. For stimulation of subscapularis and serratus anterior, the arm was kept fully abducted and externally rotated to obtain an easy approach.

POST-POLIOMYELITIC DISTRIBUTION OF PARALYSIS OF THE SHOULDER: SELECTION OF CLINICAL MATERIAL FOR A PARTICULAR TYPE OR GROUP OF OPERATIONS

In considering surgical rehabilitation of the paralysed shoulder the residual function is assumed to be retained in the elbow joint and hand. If and when their function is impaired, there should be possibility of restoration by one or more of the recognised procedures. Without their useful function the limb is useless even when the shoulder is rehabilitated. The residual stage of the disease begins approximately 30 months after the onset of illness treated by a well-planned rehabilitation programme and continues for the remainder of the patient's life. During this period surgery renders its greatest contribution to the welfare of the patient though there is a definite place for physical therapy, occupational therapy, vocational guidance and social services in his eventual rehabilitation after surgery. During this stage of the diesease when conservative treatment has failed, two methods of surgical treatment *e.g.*, arthrodesis of the gleno-humeral joint and power transfer are practised and, if successful, these restore the function of the paralysed limb to a certain degree. Each of these methods has its advantages and disadvantages.

For an arthrodesis to be successful the axio-claviculo-scapular group of muscles must have excellent power. Nay, the power should exceed that in the normal multi-jointed member owing to the increased length and consequent mechanical disadvantage due to the extended leverage. No doubt in favourable circumstances it gives strength and power to the limb's performance at the expense of mobility. Elevation is usually restricted to 90°–120° and many useful movements like putting the hand in the pocket, to back of the head, to the opposite side of the body, etc. cannot be performed gracefully. There is a greater likelihood of fracture in falling or when an abnormal strain is put on the already atrophied bone. Scoliosis may be produced or exaggerated by arthrodesis. In bilateral paralysis arthrodesis would be rather cumbersome and leave the patient more amenable to injury. Movable shoulder joint with greater range of motion will be preferable in cases in which it will be necessary to ankylose the elbow joint. When there is associated paralysis of the other extremity that precludes the possibility of hard work, a movable joint is preferred to a stiff joint. In females for cosmetic reasons a muscle transference operation is advisable rather than arthrodesis. In the latter the arm projects from the side. Under 12 years of age an arthrodesis may not be successful while a transplanted muscle operation may give good results. A frequent cause of failure of arthrodesis is the loss of contact between the head of humerus and glenoid due to difficulty in immobilising the shoulder in plaster spica. Another cause of failure in children is the predominance of cartilage and lack of good solid bone in the components of the shoulder joint. Arthrodesis in children may affect the growth of the humerus.

Thus the pre-requisite of shoulder arthrodesis, *i.e.* the presence of strong residual power is the axio-claviculo-scapular group of muscles tends to frustrate the aims for which the arthrodesis is done. If some of the power of the girdle muscles could be spared as they can be in the majority of the cases there is a greater chance of having a mobile shoulder capable of greater and more useful performance (*vide infra*).

We have followed the results of Mayer's trapezius transfer prolonged to the insertion of the deltoid combined with stabilisation of the gleno-humeral joint by Nicola's procedure. We had tried the Bateman procedure combined with the tenodesis in some cases. In neither of these the results came up even to the expected minimum, especially if the short rotators were weak or completely paralysed.

Analysis of 103 consecutive cases of residual paralysis of the upper limb and some with bilateral affection from the B.C Roy Polio Clinic are tabulated below (Table 6). The muscles having power less than 3 (M.R.C.) are considered unsuitable for transfer and are tabulated in percentage of the total number. These cases had also varying degrees of paralysis of the elbow, wrist, fingers and thumb. The observations tabulated in muscle charts covering a period of more than 7 years do not conform to the tabulation now practised in the clinic. Nevertheless, the data give a sufficient indication of the type of muscle that is most affected in this country. From this group we have excluded all cases that could lift the shoulder overhead even in the absence of deltoid power.

Table 6.

Muscle	Number affected power below 3	Percentage of total of 103 cases
Deltoid (total paralysis)	61	59.2
Deltoid with some residual active fibres	42	40.7
Spiniti	64	62.1
Rhomboids	24	23.3
Trapezius	12	11.7
Serratus anterior	12	11.7
Teres major	46	44.7
Latissimus dorsi	46	44.7
Levator scapulae	16	15.5
Pectoralis major	49	47.6

The muscles having power less than 5 were given pre-operative physiotherapy and exercise to improve their function. It is curious to note that paralysis affecting the upper exremity may be mostly in connection with the activity imposed on the limb during the period of incubation and the early phase of manifestation of the disease. Therefore, it was found mostly on the right side in right-handed persons.

Less frequently affected muscles are the ones we have chosen for transfer in various combinations to restore power. These muscles are trapezius, levator scapulae, sternocleidomastoid, latissimus dorsi, teres major, upper two digitations of serratus anterior and pectoralis minor.

Further close studies of the series enabled us to sub-divide the cases into the following five groups:

1. In this group, fortunately extremely rare in our country, the girdle muscles are badly affected, particularly the serratus anterior, levator scapulae, rhomboids and trapezius in addition to the deltoid and short rotators of the gleno-humeral joint. The rest of the muscles of the limb are in good shape. Over a period of about two and half years we have not been able to find a single case of this nature.

2. The second group presents a minor affection of a portion of the deltoid, the posterior fibres generally retaining power with varying degrees of weakness of the short rotators and practically normal power in the rest of the limb, including the shoulder girdle. There is a gross flattening of the shoulder and sometimes a subluxation is present. In some cases the patient retains the ability to raise the limb vertically with assistance. The most crucial stage where he needs assistance is 60°–120° abduction.
3. There is complete paralysis of the deltoid, supraspinatus, infraspinatus with paresis of teres minor et major, subscapularis, biceps, brachialis and supinator of the forearm. Otherwise the hand, forearm and elbow have for all practical purposes fairly good power. If at all, the girdle muscles in this group are affected to a very minor extent. There is forward and downward subluxation of the limb at the shoulder and on attempted movement it is exaggerated.
4. In this group there is complete paralysis of the abductors, the short rotators of the arm, pectoralis major, latissimus dorsi with a slight weakness of the trapezius, elevators of the shoulder blade and serratus anterior. In this group we very often find that the elbow is flail, the forearm long flexors and extensors affected to a great extent and intrinsic muscles particularly of the thenar eminence occasionally paralysed. The limb is subluxated to a greater degree than in the preceding group and the subluxation does not change very much on attempt to move the limb at the shoulder.
5. In the last group complete paralysis is found in the abductors, short rotators, pectoral group of muscles, latissimus dorsi, flexors and extensors of the elbow, pronators and supinators of the forearm and greater involvement of the long flexors and extensors and the intrinsics and may be, only one or two tendons of long extensors and/or flexors are left. The whole extremity is useless to serve any function. This group has been found to have a fair amount of residual power in serratus anterior, levator, rhomboids and trapezius. Sternomastoid, scalenus anterior, scalenus medius and splenius capitis in all these groups have not been found to be affected. Such limb is very often a useless load to the patient and he himself often asks for its removal. These cases have often scoliosis with a primary curve on the side of the paralysed limb.

Selection from amongst these cases for a particular type of operation is dependent on very careful assessment of power of the functioning muscles and the paralysed group. In our experience we did not find two cases exactly similar. Decision is to be taken as to the possibility of the elbow and hand rehabilitation so that the patient is able to carry out at least the bare minimum that is expected of him for his well-being.

In the first two groups the standard operations that are practised can be chosen to rehabilitate the shoulder. Reinforcement of the force couple rotating the scapula, multiple muscle transfer of Harmon, Ober's transplant or Bateman's procedure may be adopted.

In the last three groups one or more of the methods outlined in this monograph should be undertaken to rehabilitate the shoulder movements. It is curious to note that the muscles which are multisegmental in origin tend to retain some power. Such muscles are trapezius, serratus anterior and the pectoral group. How the rhomboids and levator scapulae are spared in most of the cases though they have supply mainly from a single segment is not known.

In some of the present cases where, according to the previous knowledge of surgery, muscle transfer operations could not be attempted nor arthrodesis done owing to weak girdle musculature, there is now hope of restoring power on the basis of the new concepts of the shoulder mechanism and rehabilitation. Till recently these cases had to be satisfied with a flail shoulder with possible surgical restoration of the fingers and hand, or in case this was not possible they had to be amputated.

The importance of these procedures should not be considered lightly. From the socio-economic point of view crippling conditions of childhood are a burden not only to one's family but also to society. The gradually extending scope of surgery may make some positive social contribution by enabling patients with residual paralysis to earn a livelihood by undertaking some sort of work.

SURGICAL PROCEDURES FOR REHABILITATION OF FLAIL SHOULDER

Either two or more of the procedures described below were used in the rehabilitation of the flail shoulder. Power in all the cases operated was zero for deltoid with loss of power of one or all of the short rotators of the upper end of the humerus. The power of latissimus dorsi, pectoralis major et minor, teres minor et major in many cases was zero either singly or in all. Trapezius, latissimus dorsi (when present), levator scapulae, pectoralis minor (when present), upper two digitations of serratus anterior and sternocleidomastoid were transferred to give elevator and short rotator power in various combinations.

The sabre-cut incision has proved to be suitable for all types of transfer. Supplementary incisions may be used in the floor of the axilla near the posterior axillary fold for the dissection of latissimus dorsi and for the delivery of the upper two digitations of serratus anterior detached from the vertebral border of scapula before rerouting to the lesser tuberosity. In all the procedures where trapezius requires rerouting, the deltoid is severed along the whole length of its origin except for a few posterior fibres. Its power being zero in all the cases, the cut edge is not resutured. The bundling due to gravity of the severed deltoid helps give a round contour of the flat shoulder. It also facilitates delivery of the head of the humerus with the tuberosities and the upper two to three inches of the shaft in the wound. The sites where rerouting is done are made raw either by the formation of a periosteo-aponeurotic pocket or erasion of the periosteum.

The patient should be placed on the sound side and fixed with roller bandages in such a way that the tip of the affected shoulder can be tilted 30° forward or backward during the operation.

There is a considerable amount of haemorrhage from the sabre-cut incision, from the cut edge of the deltoid, the tissue beneath the acromion and the outer end of the clavicle. This is minimised by a liberal infiltration with one in 500,000 adrenaline hydrochloride in normal saline and use of diathermy. The skin incision, however, should not be made with a diathermy knife. In our experience it delays healing and leads to hypertrophied scars and keloid, this being a particularly favourite site.

Glucose-saline transfusion is required in all the cases during the prolonged procedure. The suture material used in all cases was silk from size number 2 to 4.

1. *Modified Procedure of Trapezius Transfer as Advocated by Bateman*

It is known that the longer the muscle fibres, the greater the shortening and, therefore, the greater the excursion of the segment where such a muscle is transferred. Besides, the greater the distance from the joint of the rerouted muscle the better its mechanical advantage. While transferring the trapezius for deltoid power Mayer extended the site of rerouting of the muscle sandwiched between the two leaves of fascia lata. The principle is sound though the fascia lata ultimately stretches with loss of considerable amount of lifting power. Bateman modified the procedure by transferring the whole of the acromion process with the trapezius to the neighbourhood of the tuberosity of the upper end of the humerus. Here again, the leverage is too short and, therefore, there is a waste of available power.

It has been found that the upper and middle trapezius can be mobilised from its insertion throughout its length. This mobilisation does not affect the blood or nerve supply and gives an extra length of over two inches permitting rerouting on the shaft well below the tuberosities.

The classical vertical incision does not facilitate this extensive mobilisation of the trapezius. The sabre-cut incision has been found most suitable. It is given with convexity inwards starting from a point a little above the lower border of the anterior axillary fold at about its middle to a little below the base of the spine 1″ lateral and parallel to the vertebral border of the scapulae. Flaps are dissected to expose the trapezius to 1″ beyond the vertebral border of the scapula where it turns round the base of the spine to be attached to the spinous process, acromion process, capsule of the acromio-clavicular joint and the outer ⅓ of the clavicle. The fibrous paralysed deltoid is exposed throughout its origin and the distal flap is dissected so that the head, neck and upper part of the shaft of the humerus may be brought through the incision. Further infiltration of the solution (adrenaline saline) is given along the origin of deltoid which is subsequently severed by diathermy. The head, neck and shaft of the humerus is now free to be dislocated above the severed deltoid. The anterior border of the trapezius is defined at its insertion to the clavicle. The conoid ligament is identified and the clavicle cut through immediately distal to this ligament. The scapular notch is felt and the acromion process with an adjoining portion of the spine of the scapula is defined; the spine is severed bevelling posteriorly with Gigli's saw. The detached portion of the trapezius with the distal end of the clavicle, capsule of the acromio-clavicular joint, acromion process and the adjoining portion of the posterior border of the spine is raised and further mobilised along its posterior border with the help of a rougine from the upper border of the remaining portion of the spine to its base where the lower fibres

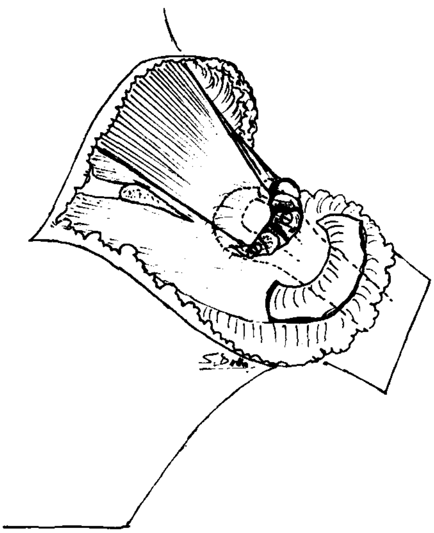

Figure 18.

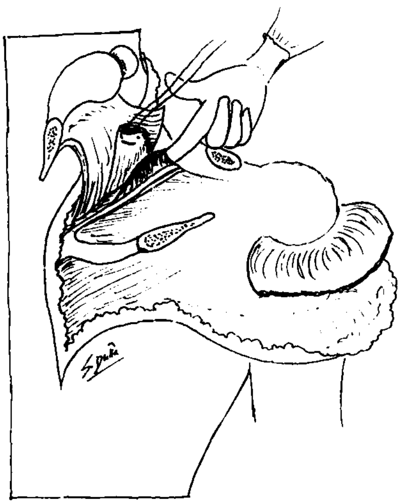

Figure 19.

Figure 18. The figure shows trapezius rerouted to the upper end of the shaft of the humerus below the tuberosities. Multiple crushing of the acromion helps coaptation with the curve of the shaft of the humerus. Levator scapulae is seen transferred to lesser tuberosity.

Figure 19. The figure shows reflected deltoid, trapezius and levator scapulae as seen from behind through a sabre-cut incision. The levator scapulae is doubled on itself and fixed with loose transfixation silk suture. Index finger is passed behind the upper part of serratus anterior and hooks the first two digitations of the muscle with its attachment still at the vertebral border of the scapula.

glide over the triangular area. The muscle is raised from its bed for rerouting after freeing the remaining part of the anterior border from the investing layer of deep cervical fascia.

The lower surface of the divided portion of the clavicle, acromion process and the adjoining spine is denuded of all soft tissues and periosteum to expose the raw bone. The bones thus exposed are broken with bone forceps at several sites, but continuity of the periosteum is maintained to facilitate its taking the contour of the shaft of the humerus at the site of fixation (Figure 18). The site of rerouting on the humerus is also denuded of periosteum where the acromion with trapezius is fixed with two screws. The muscle is to be kept in maximum relaxation to ensure adequate lowering of the site of the rerouting. This is done by adjusting the limb in the zero-position or thereabout.

The rerouting may require a little forward and backward shifting depending on the lack of suitable replacement of the external or internal rotators. The forward shifting will restore the external rotation and the backward shifting the internal rotation of the arm.

Fixation with the screws is done last with other muscles when these are to be transferred so that there is very little adjustment of the arm required during the rest of the operation.

The limb is plastered in the "zero-position" with special care to ensure positioning of the arm in the scapular plane.

2. *Transfer of the Upper Two Digitations of Serratus Anterior to Replace or Reinforce Subscapularis as a Glider Towards the Second Half of Abduction (90°–180°)*

The patient is placed on the sound side and fixed so as to be able to be tilted 30° backward or forward. Liberal infiltration with 1:500,000 solution of adrenaline in normal saline is done in the line of the incision and over the spine of the scapula, acromion and the outer end of the clavicle.

After mobilisation of the trapezius through a sabre-cut incision as described earlier for its transfer, it is further reflected upward and backward to expose the upper part of the vertebral border of the scapula and the levator scapulae at its insertion. After defining the lower and upper borders of the levator scapulae near its insertion, the muscle is erased from the dorsal upper third of the vertebral margin of the scapula with the periosteum taking care of the nerves to rhomboids and vessels lying deep and more medially. The muscle may be used for fixation as an elevator, fixator and a glider when and where necessary. By raising the vertebral border of the scapula in its upper part the upper two digitations of the serratus are defined at its upper border hooking it with a blunt instrument or index finger introduced near the upper angle of the scapula between the serratus anterior and subscapularis (Figure 19). The insertion is erased throughout the upper part of the vertebral border to the level of the base of the spine with the help of a rougine working from the cut edge of the periosteum left after detachment of levator scapulae. This insertion merges with medial limit of the origin of the subscapularis which is left undisturbed. The junction between the erased serratus anterior and subscapularis has to be divided with a scalpel keeping its edge more towards the subscapularis. The freed upper two digitations can now be

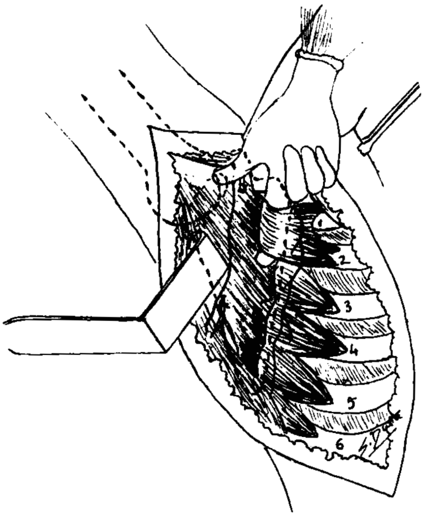

Figure 20.

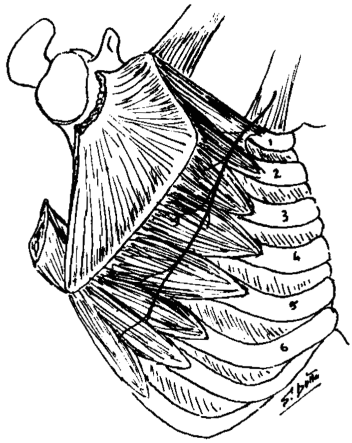

Figure 21.

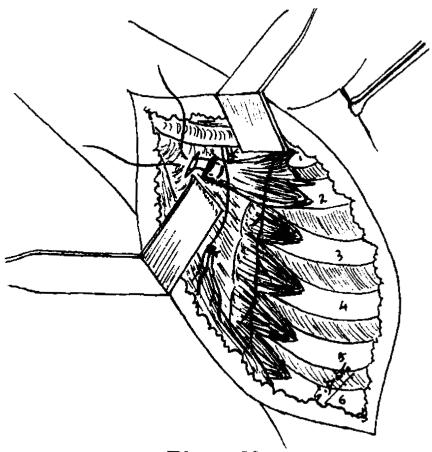

Figure 22.

***Figure 20.** The figure shows the upper two digitations of serratus anterior exposed and held by the index finger through an axillary incision close to the posterior wall. The subscapular vessels are seen tied and divided between ligatures.*

***Figure 21.** The figure diagramatically represents the origin and insertion of serratus anterior with its nerve supply. Being close to the origin of the upper two digitations, the nerve is free from danger.*

***Figure 22.** The figure shows rerouting of the serratus anterior folded on itself by three interrupted sutures to a periosteo-aponeurotic pocket over the lesser tuberosity. Transfixation sutures are seen drawn through the pocket before tightening. The neurovascular bundle is seen retracted upwards and laterally.*

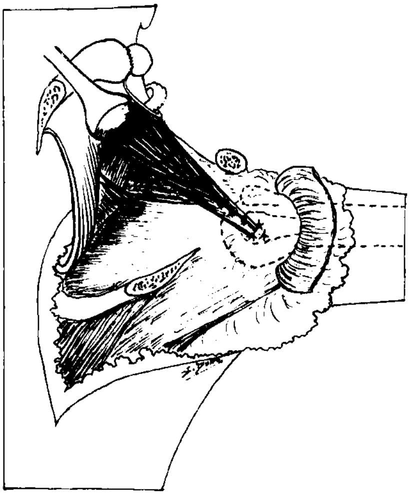

Figure 23.

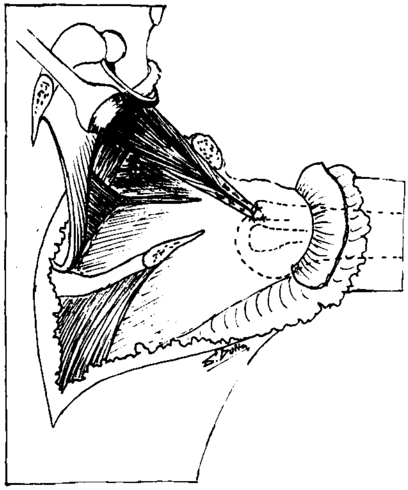

Figure 24.

Figure 23 and 24. The figures show further dissection of levator scapulae to enable it to be drawn to the tuberosities of the humerus. It may be rerouted to the greater tuberosity to replace supraspinatus. It may also be rerouted to the lesser tuberosity when there is no other muscle available to take over the function of subscapularis.

folded on itself by three interrupted sutures and transfixed by long stout (No. 3) silk for rerouting. Section of the denuded upper medial angle of the scapula and its adequate retraction help the above procedure. The limb is elevated to about 130° and axilla is incised in its floor close to its posterior wall taking care of the subscapularis vessels which often require ligation and the thoracodorsal nerve in case the latissimus dorsi has residual power. Retraction of the neuro-vascular bundle upward and laterally helps the finger to be pushed above the upper border of the serratus anterior to the 1st rib (Figure 20). The nerve to the serratus anterior being near its origin in this region is not liable to injury (Figure 21). The transfixed silk thread with upper two digitations is pulled out anteriorly to the axilla. Rerouting on the lesser tuberosity is done in the usual way, exposing it behind the neuro-vascular bundle by blunt dissection (Figure 22).

3. *Transfer of Levator Scapulae as a Short Rotator, Fixator and Glider*

Owing to its long fibres the levator scapulae may be given a choice of rerouting depending on the deficit of power. The exposure and detach-

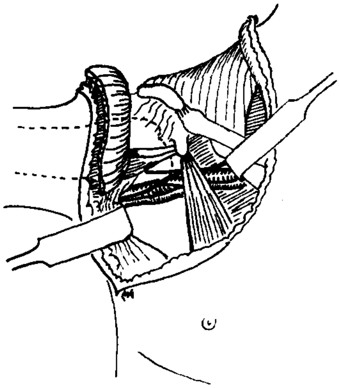

Figure 25.

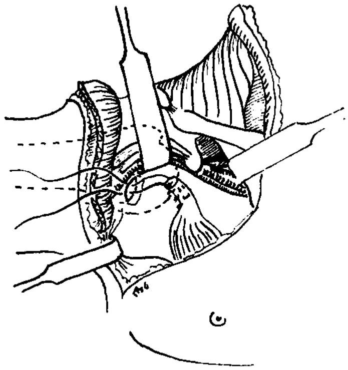

Figure 26.

Figure 25. The figure shows exposure of pectoralis minor with its insertion to the coracoid process through a sabre-cut incision as seen from the front. In all the cases where this muscle was used the pectoralis major muscle power was 0 and therefore, there was no difficulty in the dissection of pectoralis minor. The nerve to the muscle is more medial and is not visible during the operation.

Figure 26. The figure shows pectoralis minor being drawn through a pocket on the lesser tuberosity behind the neurovascular bundle which is retracted laterally and upwards.

ment of the insertion from the vertebral border of scapula has been described (*vide supra*). Only the upper skin flap has to be dissected a little more to expose the belly to about its middle so that it can be drawn either to the greater or lesser tuberosity. The method of re-routing is the same as that of serratus anterior (Figure 34 and 24).

4. *Transfer of Pectoralis Minor to Replace Subscapularis*

This muscle can be transferred in those cases where the pectoralis major has lost its power and there is no alternative muscle to take over the gliding function of the subscapularis *i.e.*, latissimus dorsi or the upper fibres of the serratus anterior. This is a fairly strong muscle and has long fibres. Its insertion is aponeurotic, which helps rerouting. The sabre-cut incision is used over the shoulder as described above. The insertion of the pectoralis minor to coracoid process is exposed (Figure 25). Its nerve supply being more medial there is no chance of any injury to it. The tendon is erased from the coracoid process and a No. 3 silk mattress suture is applied with loose ends (Figure 26). The

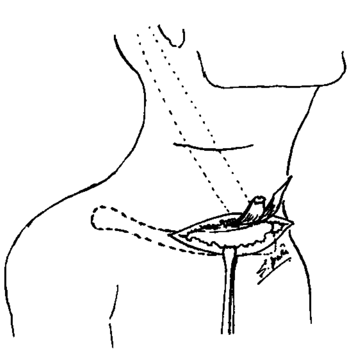

Figure 27.

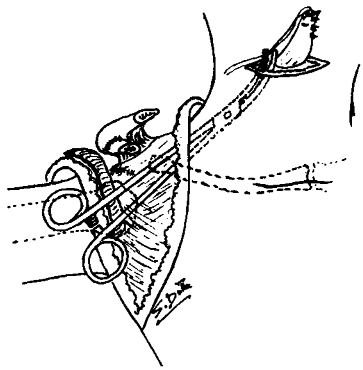

Figure 28.

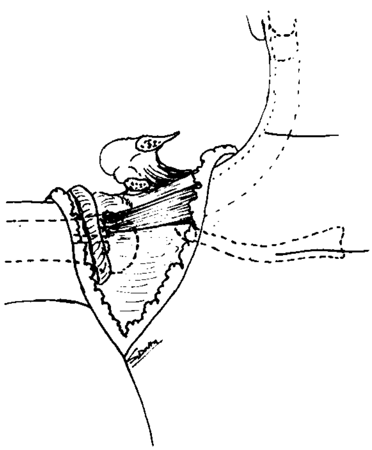

Figure 29.

Figure 27. The figure shows the severed origin of sternocleidomastoid. Second crease incision is seen.

Figure 28. The figure shows sternocleidomastoid delivered through second incision before being drawn through subcutaneous tunnel. Sabre type incision with severed deltoid is shown. Trapezius with acromion and clavicle is also visible.

Figure 29. The figure shows the muscle rerouted to the greater tuberosity to replace the supraspinatus.

arm is abducted and externally rotated bringing into prominence the lesser tuberosity below the retracted neuro-vascular bundle. A periosteo-aponeurotic pocket is made over the lesser tuberosity and rerouting is done in the usual way.

5. *Transfer of Sternocleidomastoid to Act as an Elevator*

Sternocleidomastoid has been used as a flexor of the elbow with good results. It was felt that it could as well be used as an elevator of the shoulder, the only drawback being that on contraction it may produce a web in the neck. A curved incision is given from the middle line to the junction of the medial fourth and the outer three-fourths of the homolateral clavicle. The two heads of origin are isolated from the sternum and clavicle and severed (Figure 27). The muscle is raised from the deep cervical fascia to about its lower third retracting the upper skin flap. Transfixation suture is applied after narrowing the two origins by interrupted silk sutures. A second incision is given in the neck fold at about the middle of the sternocleidomastoid. The muscle is freed from above and below without injuring the vessels and the nerves supplying it, which come from above. The muscle is withdrawn to the second incision and brought subcutaneously through the sabre-cut to be fixed to the greater tuberosity (Figures 28 and 29).

6. *Transfer of Latissimus Dorsi and/or Teres Major to Take over the Function of Subscapularis (Posterior Glider)*

The patient lies with 70° tilt on the sound side. The arm is controlled by an assistant and is elevated to 135°–140°. An incision is given in posterior axillary fold extending from a point about 2½″–3″ below the crease of the axilla in the upper arm to the inferior angle of the scapula crossing the crease in a zigzag fashion. The insertion of the latissimus dorsi is exposed and severed. The muscle is raised from its bed taking care of its nerve and blood supply. Retraction of the neurovascular bundle with coracobrachialis helps the dissection when isolated transfer of latissimus dorsi is needed and its tendon has to be freed from the teres major below. If it has to be reinforced by teres major then both these structures have to be dissected free from the surrounding tissues. The tendon is blended with teres major close to the insertion.

The tendon or the tendon-and-muscle is folded on itself to reduce the width by three interrupted silk (No. 2) sutures. The reduced tendon is transfixed with stouter silk (No. 3 or 4) by a mattress suture with long loose ends (Figure 30).

The interval between the deltoid and triceps (long head) is dissected with a blunt instrument. The finger is insinuated to palpate the tubercle at the posterior lower limit of greater tuberosity of the humerus. This, when the deltoid is severed from the acromion in complete paralysis, can be located by inspection (Figure 31).

The tendon of the latissimus dorsi is now free to be taken through this interval to the tubercle just mentioned and fixed by mattress sutures, holding the limb in the 'zero-position' (Figure 32).

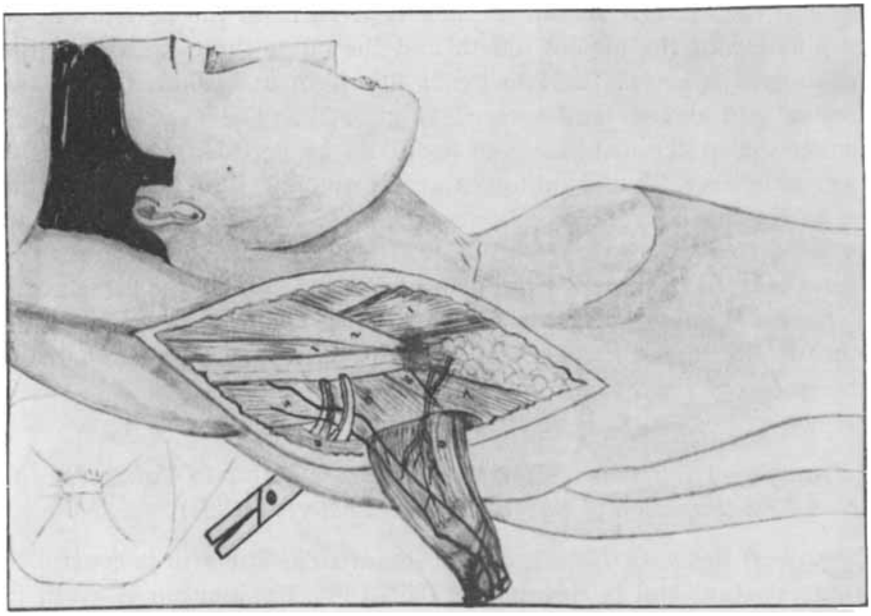

Figure 30. The figure shows latissimus dorsi severed from its insertion and folded upon itself by interrupted sutures. A long stout mattress suture fixing the tendon is seen being passed through the second incision on the deltoid ready to be pulled deep to the muscle (Saha, A. K.: Theory of Shoulder Mechanism—Descriptive and Applied Springfield, Ill.: Charles C. Thomas, Publisher, 1961. Reproduced by courtesy of the Publisher).

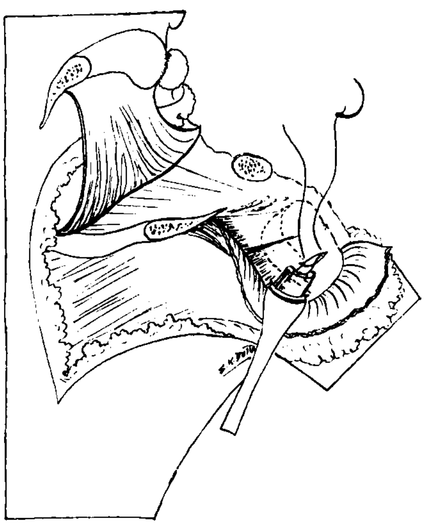

Figure 31. The figure shows a transverse periosteoaponeurotic pocket on the shaft below the insertion of infraspinatus which is located by palpation after reflection of the paralysed deltoid. The latissimus dorsi is seen drawn through this pocket for rerouting.

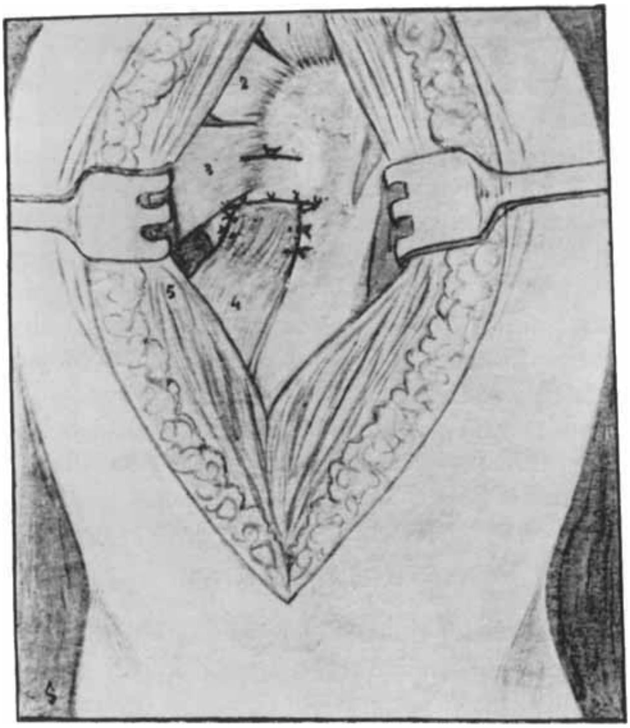

Figure 32. The figure shows the alternative method of rerouting latissimus dorsi through a vertical incision splitting the deltoid to expose the region (Saha, A. K.: Theory of Shoulder Mechanism—Descriptive and Applied. Springfield, Ill.: Charles C. Thomas, Publisher, 1961. Reproduced by courtesy of the Publisher).

Any other transfer to be done is completed through the sabre-cut incision before the limb is finally plastered.

POST-OPERATIVE MANAGEMENT

After the operation the limb is put in a thoraco-brachial spica with shoulder abducted to about 135°, in neutral rotation and flexed in the plane of the scapula. This plastering becomes easier if it is done by the two-stage procedure. In the first stage, a jacket for the trunk is applied with a crossbar over the opposite shoulder to prevent the jacket falling downward. In the second stage, after the operation the spica is completed in the position above mentioned.

After the removal of the skin sutures on the 10th post-operative day the limb is plastered in the same position and the patient is discharged after a check radiograph to prevent the possible downward subluxation of the joint, which may otherwise be a serious complication.

The plaster is finally removed after 6–8 weeks when there is a bony union between transferred acromion process and the humerus. The limb is rehabilitated for functional recovery.

Swinging the limb with the trunk bent forward is the best form of rehabilitation exercise. In the course of a week the shoulder gets free to move in any direction. Exercises in the lying-down position and crawling against the wall help develop the scapulo-humeral rhythm. Later the patient starts lifting small weights while lying on the bed from side and front. This helps develop power and co-ordination.

In some cases if pain persists the patient requires infiltration with hydrocortisone in the periarticular structures around the greater tuberosity of the humerus.

COMPLICATIONS

In our series of cases we did not require any blood transfusion even when the operation continued for 3 hours or more.

Sepsis is avoided by scrupulous adherence to routine and by sealing the incisions with a little antibiotic cream and sticking-plaster before the limb is put in plaster.

Inferior subluxation below the glenoid cavity happened in two cases. This should be forestalled and the position adjusted before the limb is put in the final plaster (Figure 33).

Detachment of the acromion from the new site of implantation occurred in three of our cases with the loosening of the screws (Figure 34). They required reimplantation at a subsequent date. This is prevented by adequate roughening of the contiguous surfaces of the acromion and humerus and fixation with the help of at least 2 screws. The muscle should be relaxed by adequate elevation during the period of immobilisation. The removal of plaster should not be done till union is complete between the acromion and the humerus. In one case the serratus anterior (upper two digitations) sutured to the lesser tuberosity of the humerus snapped with bundling of the muscle in the axilla after nine days of the commencement of rehabilitation. The patient suddenly lost the power of overhead elevation which she had gained in this short period. She could however raise the shoulder to about 90° with disturbed scapulo-humeral rhythm.

Figure 33.

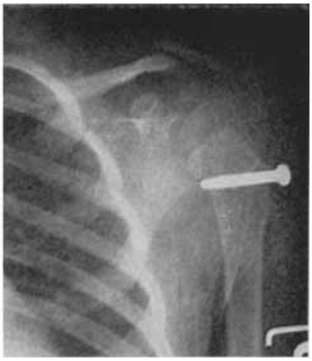

Figure 34.

Figure 33. The figure shows subglenoid dislocation of the head of the humerus as a postoperative complication.

Figure 34. The figure shows detachment of the rerouted trapezius due to faulty union with the shaft of the humerus. Only one screw was used for fixation which added to the mishap.

Inadequacy of power is the result of faulty selection of the muscle transposed for a specific purpose. This is avoided by a careful analysis of the residual power and potentialities of the usefulness of the limb when these muscles are transferred. The limb should be studied as a whole and not for a specific joint movement. Even in case of inadequacy, power can be improved by resistive exercises once the muscles transferred are correctly chosen.

The scars around the shoulder may hypertrophy or form keloid, this being a favourite site. We had a few of these. The axillary incision should be given in a zigzag fashion to prevent scar contracture. Treatment when keloid and hypertrophied scars formed was local infiltration with xylocaine 1 per cent solution with hylase and hydrocortisone acetate suspension. In most cases it cleared after two or three weekly injections.

Web formation by the transferred sternocleidomastoid may be prevented by taking the muscle beneath the investing layer of deep cervical fascia instead of subcutaneously. This also improves the mechanical advantage.

ILLUSTRATIONS FROM CASE RECORDS WITH RESULTS

In our experience no two cases were exactly similar. Each case presented a problem of its own. Therefore, it is felt that the purpose of this monograph would be better served if illustrative cases are presented with their final follow-up. For reasons mentioned in the preface the overall statistics with comparative evaluation of older methods has been withheld. Besides, the various combinations of the operations done for flail shoulder would be numerous and in any case would not help tabulation with so variable residual power distribution in each case of our limited series.

The transfer of muscles *e.g.,* scalenus anterior, scalenus medius, splenius capitis and part or whole of pectoralis major for short rotators have not been done in any of our cases though their possible use has been mentioned in the text.

Case No. 1

K. G. R., Male, 7 years, had acute attack of poliomyelitis at the age of 3 years. He was admitted with weakness of the right upper limb and inability to lift the shoulder. His right elbow, wrist and finger though less powerful than those on the left was capable of carrying out function not requiring great strength. The residual power distribution in the right shoulder joint complex was:

Deltoid		Latissimus dorsi	4+
anterior	0		
middle	0	Serratus anterior	
posterior	0	upper two digitations	5
		lower six digitations	5
Short rotators			
subscapularis	3+	Rhomboideus major	4
supraspinatus	0		
infraspinatus	3	Rhomboideus minor	4
Pectoralis major	4	Levator scapulae	4
Pectoralis minor	2	Teres major	0
Trapezius		Teres minor	2
upper	5		
middle	5	Sternocleidomastoid	5
lower	5		

The right shoulder joint was subluxated anteriorly and downwards.

On review of the power chart it appeared that the conventional trapezius transfer should be adequate to lift the arm overhead. Of the short rotators subscapularis and infraspinatus had a fair degree of power though not adequate to

Figure 35. The figure shows ability to lift the right arm overhead. He had trapezius and latissimus dorsi transfer.

prevent anterior subluxation. Therefore, latissimus dorsi transfer to act as posterior glider was considered necessary. He was operated upon under general anaesthesia, trapezius being transferred for deltoid power and latissimus dorsi to act as posterior glider. Plaster was removed after 6 weeks for rehabilitation (Figure 35).

This case had no supraspinatus power. The supraspinatus was neither replaced by a transfer though available. Elevation in the scapular plane requires action of supraspinatus. It is possibly helped by power transmission of the adjoining fibres of the subscapularis and infraspinatus through the rotator cuff. The latissimus dorsi has reinforced the power of subscapularis in the terminal phase of elevation. The presence of pectoralis major has added to the efficiency of the limb.

Case No. 2

M. K., Female, 14 years, was admitted with snapped trapezius and infraglenoid dislocation of the head of the humerus. She had Bateman procedure done with a classical longitudinal incision for flail right shoulder. Her power in the right shoulder joint complex was as follows:

Deltoid		Latissimus dorsi	4++
anterior	1		
middle	0	Serratus anterior	
posterior	1	upper two digitations	5
		lower six digitations	5
Short rotators			
subscapularis	2	Rhomboideus major	3++
supraspinatus	1		
infraspinatus	1	Rhomboideus minor	3++
Pectoralis major	5	Levator scapulae	4
Pectoralis minor	5	Teres major	3++

Trapezius		Teres minor	3++
upper	5		
middle	5	*Sternocleidomastoid*	5
lower	5		

Besides downward and forward dislocation of right shoulder she had right ape-thumb deformity with complete paralysis of the muscles of the thenar eminence.

On review of the power chart it was obvious that in addition to the trapezius transfer for deltoid power she needed at least a good short rotator to reinforce subscapularis action. Latissimus dorsi was chosen owing to its power being 4^{++}.

She was operated upon under general anaesthesia for refixation of the snapped trapezius and posterior transfer of latissimus dorsi for reinforcement of the subscapularis action. A second stage operation was undertaken to give active opposition of the thumb with the help of flexor digitorum sublimis tendon of the right ring finger through a pulley constructed from a part of the flexor carpi ulnaris tendon. She was immobilised for 8 weeks in plaster before she was rehabilitated (Figures 36 and 37).

The excellent recovery is attributed to the presence of all the remaining intermediate group of muscles, *e.g.*, pectoralis major (5) and teres major et minor (3^{++}).

Case No. 3

G. B., Female, 17 years, had right flail upper limb following attack of poliomyelitis at the age of 3 years. Her residual power distribution of shoulder joint complex was:

Deltoid		Latissimus dorsi	3
anterior	0		
middle	0	Serratus anterior	
posterior	0	upper two digitations	4
		lower six digitations	4
Short rotators			
subscapularis	0	Rhomboideus major	4
supraspinatus	0		
infraspinatus	0	Rhomboideus minor	4
Pectoralis major	0	Levator scapulae	4
Pectoralis minor	2	Teres major	0
Trapezius		Teres minor	0
upper	3++		
middle	3++	Sternocleidomastoid	5
lower	3++		

She had downward and forward subluxation of the shoulder with complete paralysis of the right elbow. The forearm was fixed in full pronation and the hand had slight residual power in the long flexors and extensors, intrinsics of the fingers and thumb.

On reviewing the power chart, the trapezius was thought to be insufficient for lifting the arm at the shoulder. The upper short rotator, *i.e.*, supraspinatus required

Figure 36. *Figure 37.*

Figure 36. The figure shows vertical scar for classical Bateman procedure which failed in her case.

Figure 37. The figure shows the ability to lift the shoulder overhead. It also shows the corrected ape-thumb in opposition.

replacement. Levator scapulae was considered to take over the function of supraspinatus if it was transferred to the anterior portion of the greater tuberosity. The subscapularis required replacement and here latissimus dorsi was considered suitable to act as a backward glider and prevent at the same time forward subluxation of the shoulder.

Elbow flexion was proposed to be given by the sternocleidomastoid with a bone block behind the humerus to limit extension. Pronation deformity was to be corrected by rotational osteotomy and minor readjustment of power in the fingers and thumb was necessary to give stability of the wrist and efficient grip of the hand.

She was operated upon under general anaesthesia. Levator scapulae was transferred to the anterior portion of the greater tuberosity. Latissimus dorsi was rerouted immediately below the insertion of infraspinatus taking it behind and below the posterior atrophied fibres of the deltoid. The trapezius was implanted in the shaft below the tuberosities covering the rerouted latissimus dorsi and levator scapulae with the help of two screws.

Immobilisation was carried out in the zero-position with a post-operative check-up for possible subluxation. No special rehabilitaton programme was given following removal of plaster after eight weeks. Review on 7. 3. 64 shows good functional recovery (Figures 38 and 39).

Though serratus anterior had better power than latissimus dorsi still the latter

Figure 38. *Figure 39.*

Figure 38. The figure shows flail shoulder with severe subluxation of the joint and absence of bulky anterior axillary fold.

Figure 39. The figure shows ability to lift the arm. The elbow though flail has been kept locked by positioning. Pronation deformity of right forearm is seen. There is visible effort on the part of patient while lifting owing to the poor status of trapezius and short period of rehabilitation.

was chosen to reinforce the subscapularis, firstly, because of simpler procedure and secondly, the whole muscle was used instead of part.

Case No. 4

D. B., Male, 4 years, had residual paralysis after an attack of poliomyelitis at the age of one year involving right shoulder, elbow and hand. The hand, though more handicapped in power than that of the left, is able to perform most of the functions. His residual power distribution of right shoulder joint complex was as follows:

Deltoid		Latissimus dorsi	0
anterior	0		
middle	0	Serratus anterior	
posterior	0	upper two digitations	3++
		lower six digitations	3++
Short rotators			
subscapularis	0	Rhomboideus major	4
supraspinatus	1		
infraspinatus	0	Rhomboideus minor	4
Pectoralis major	0	Levator scapulae	4
Pectoralis minor	4	Teres major	2
Trapezius		Teres minor	0
upper	4		
middle	4	Sternocleidomastoid	5
lower	4		

Figure 40.

Figure 41.

Figures 40 and 41. The figures show ability to lift the shoulder. The elbow being flail bends by gravity when the shoulder is lifted. Note the contracting levator scapulae in the neck and keloid in the posterior limb of the scar.

The shoulder had forward and downward subluxation. At the elbow he had biceps 1, triceps 1 and supinator 3.

On reviewing the power chart it was found that at least two short rotators, supraspinatus and subscapularis required replacement and/or reinforcement. The upper two digitations of serratus anterior or pectoralis minor were available. Of these pectoralis minor was chosen to replace the subscapularis. Trapezius considered to have enough power for elevation was transferred for deltoid. The trapezius besides acting as a prime mover needed shifting a little forward on the shaft of humerus to help active external rotation which was absent in this case. Elbow required sternocleidomastoid transfer for flexion and a posterior bone block to limit the extension.

He was operated upon under general anaesthesia by a single sabre-cut incision. Pectoralis minor was rerouted to the lesser tuberosity, levator scapulae to the anterior part of the greater tuberosity and trapezius was fixed with two screws on the upper shaft overlapping the anterior margin of the greater tuberosity by its anterior border.

Immobilisation was carried on for 6 weeks. No special rehabilitation programme was needed for functional recovery (Figures 40 and 41).

Almost complete absence of power in the intermediate group and low power in serratus anterior made us choose pectoralis minor to substitute the subscapularis. Complete absence of pectoralis major helped the dissection. Further rehabilitation will be necessary before shoulder becomes more powerful to be of greater use.

Case No. 5

M. R.P., Female, 9 years, came with residual paralysis affecting the left upper extremity following an acute attack of poliomyelitis at the age of 2 years. Power of the left hand and elbow though below normal was enough to carry out usual activities requiring little strength. Her power in the left shoulder joint complex was as follows:

Deltoid		Latissimus dorsi	0
anterior	0		
middle	0	Serratus anterior	
posterior	0	upper two digitations	4
		lower six digitations	4
Short rotators			
subscapularis	0	Rhomboideus major	4
supraspinatus	0		
infraspinatus	0	Rhomboideus minor	4
Pectoralis major (except a few fibres flickering at the lower part)	0	Levator scapulae	4
		Teres major	3+
Pectoralis minor	4	Teres minor	3+
Trapezius		Sternocleidomastoid	5
upper	4		
middle	4		
lower	4		

Review of the power chart shows that trapezius could be transferred for deltoid power though possibly it required reinforcement. The supraspinatus required replacement and could be given by either levator scapulae or sternocleidomastoid. The sternocleidomastoid was chosen for transfer. The subscapularis power being zero required replacement by either anterior or posterior transfer. Power being absent in latissimus dorsi it could be given by either pectoralis minor (4) or upper two digitations of serratus anterior (4).

She was operated upon under general anaesthesia using sabre-cut incision. In addition to trapezius transfer at the usual site, the sternocleidomastoid and pectoralis minor were rerouted to anterior portion of the greater tuberosity and lesser tuberosity respectively. Post-operative follow-up shows recovery of abduction to about 130° in recumbency. There is some stiffness of shoulder and a distinct web is seen in the neck during contraction of sternocleidomastoid which possibly could be avoided by more careful dissection and taking the muscle under the deep cervical fascia. There is also a web in the posterior fold of axilla which is seen taut preventing the arm from falling when lying in bed (Figures 42–44).

The results in this case have been very poor both from cosmetic and functional points of view. The distinct web is seen in the neck with the arm in the hanging position. The active elevation beyond 60° is difficult owing to web contracture in the axilla. There is a distinct disturbed scapulo-humeral rhythm when she is on her back. She will require revisional procedure in the neck and axilla for the webs and subsequent rehabilitation.

Figure 42.

Figure 44.

Figures 42–44. The figures show ability to lift the arm in the standing and lying position. Webs in the axilla and in the neck are seen.

Figure 43.

Case No. 6

B. C., Male, 16 years, was admitted with residual paralysis of the right upper limb after an attack of poliomyelitis in early childhood. The limb was absolutely flail, incapable of carrying out any work and dangling helplessly. The right elbow was fixed in 120° extension, forearm in supination, wrist in dorsiflexion with very little power in the fingers and ape-thumb deformity. His shoulder had anterior and downward subluxation. This is considered to be an extreme case where shoulder disarticulation might have to be considered (Figure 45). The power distribution of the right shoulder joint complex was:

Deltoid		Latissimus dorsi	0
anterior	0		
middle	0	Serratus anterior	
posterior	0	upper two digitations	4++
		lower six digitations	4++
Short rotators			
subscapularis	2	Rhomboideus major	4
supraspinatus	0		
infraspinatus	0	Rhomboideus minor	4
Pectoralis major	0	Levator scapulae	4
Pectoralis minor	0	Teres major	1

Trapezius		Teres minor	1
upper	4		
middle	4	Sternocleidomastoid	5
lower	4		

The power distribution at the elbow, forearm and hand:

Biceps	2++	Supinator brevis	0
Brachialis anterior	1	Triceps	0
Long extensor of fingers	2+	All others	0
Extensor carpi ulnaris	4		
Flexor pollicis longus	4		

On reviewing the muscle power chart it was considered that the thumb required a plastic repair to get rid of contracture of the web between the thumb and index to bring it passively in opposition and a subsequent fusion at the carpo-metacarpal joint and osteotomy to give useful mid-prone position of the forearm. Power of extensor carpi ulnaris could be used for long flexor power of the fingers, wrist being arthrodesed in optimum position. The above procedures were thought to be deferred till the shoulder was rehabilitated. The shoulder joint complex needed the upper two digitations of serratus anterior to reinforce subscapularis, levator scapulae for supraspinatus and trapezius for deltoid and active external rotation of humerus. The elbow, if it required additional power for lifting, was to be given by sternocleidomastoid transfer.

He was operated upon under general anaesthesia, the first stage upper two digitations of serratus anterior were transferred to lesser tuberosity. The levator scapulae was transferred to the anterior part of greater tuberosity and trapezius to the upper humerus below the tuberosities overlapping the levator scapulae and extending backward.

On removal of plaster after 6 weeks he was rehabilitated. The figures show his ability to lift the arm at the shoulder (Figures 46–48). It may be noted that the transfers corrected the subluxation and gave fullness to the delto-pectoral triangle and roundness to the shoulder.

The muscles of intermediate group have practically no power. There was no other alternative than to choose upper two digitations of serratus anterior, levator scapulae and trapezius though their power is a little below normal. Excellent recovery of shoulder proves that muscles may be made to develop if favourably placed even though their power is poor. It may also be noticed that the transfers corrected the subluxation and gave fullness to the delto-pectoral hollow and roundness to the shoulder. Being a retail fresh fruits shop-keeper he is waiting for a vacation to get his forearm and hand surgically rehabilitated.

Case No. 7

B.M., Male, 7 years, had residual paralysis affecting the right upper limb after an attack of acute poliomyelitis at the age of 1 year. His residual power of the muscles of the shoulder joint complex are:

Figure 45.

Figure 48.

Figure 46.

Figure 47.

Figure 45. The figure shows the helpless right upper limb (described in the text).

Figures 46–48. The figures show ability to abduct the shoulder as seen from the front and behind. The roundness of the shoulder has been restored with delto-pectoral hollow filled up. The distance between the tip of shoulder and jugular notch is somewhat reduced.

Deltoid		Latissimus dorsi	3
anterior	0		
middle	0	Serratus anterior	
posterior	0	upper two digitations	5

Figure 49.

Figure 50.

Figures 49 and 50. The figures show pre-operative status and ability to lift and maintain the shoulder vertically overhead after operation.

		lower six digitations	5
Short rotators			
subscapularis	1	Rhomboideus major	3++
supraspinatus	0		
infraspinatus	0	Rhomboideus minor	3++
Pectoralis major	2	Levator scapulae	3++
Pectoralis minor	4	Teres major	4++
Trapezius		Teres minor	1
upper	4		
middle	4	Sternocleidomastoid	5
lower	4		

Shoulder was subluxated downward and forward. Subscapularis test was positive with exaggerated posterior subluxation (Figure 15, page 46).

On reviewing the power chart it was seen that there were quite a few muscles for transfer. Subscapularis required reinforcement, supraspinatus a replacement in addition to transfer of trapezius. In view of our experience with various combinations in transfer of muscle power and the best result obtained with upper two digitations of the serratus anterior, levator scapulae and trapezius transfers, it was decided to undertake the above procedures in this case.

He was operated upon under general anaesthesia. The upper two digitations of serratus anterior were transferred to lesser tuberosity, the levator scapulae to anterior part of the greater tuberosity and trapezius to upper end of humerus.

On removal of plaster after 6 weeks he was rehabilitated; the figures show his ability to lift the arm overhead (Figures 49 and 50).

Perfect recovery within four weeks of removal of plaster with no exertion shows the importance of presence of some power in the intermediate group of muscles.

Case No.8

M.M.M.,Male, 8 years, had residual paralysis of the left shoulder and elbow after an attack of poliomyelitis at the age of 4 years. He had his residual power of the left shoulder joint complex distributed as follows:

Deltoid		Latissimus dorsi	3
anterior	0		
middle	0	Serratus anterior	
posterior	0	upper two digitations	4
		lower six digitations	4
Short rotators			
subscapularis	0	Rhomboideus major	4
supraspinatus	0		
infraspinatus	0	Rhomboideus minor	4
Pectoralis major		Levator scapulae	4
clavicular head	1		
		Teres major	1+
Pectoralis major			
sternal head	2+	Teres minor	2+
Pectoralis minor	4+	Sternocleidomastoid	5
Trapezius			
upper	4+		
middle	4+		
lower	4+		

He had posterior dislocation of the shoulder while attempting protraction against resistance and anterior subluxation while rotating internally against resistance (Figure 51).

On reviewing the muscle power chart it was seen that he would require a strong elevator and replacement of the power of two short rotators. It was decided to transfer trapezius, levator scapulae and upper two digitations of serratus anterior at the usual sites. The adjoining pictures show excellent recovery within a period of 6 weeks after removal of plaster (Figures 52–54).

Though the status of the muscles transferred for replacement of power is below normal still recovery has been excellent. This shows the importance of intermediate group of muscles which have some residual power.

Case No. 9

B. Nayar, Male, 17 years, came with residual paralysis of the right upper extremity after an attack of acute anterior poliomyelitis in September 1946. His right elbow was flail. The right pectoralis major was transferred for right biceps several years ago and this has regained power since the operation to about 3+. There is a web in the anterior fold of the axilla formed by the vessels and nerves of the transferred pectoralis major (Figure 55). Residual power of the right shoulder joint complex was as follows:

Figure 51.

Figure 53.

Figure 54.

Figure 52.

Figure 51. The figure shows pre-operative status of the patient.

Figures 52–54. The figures show ability of the patient to lift the shoulder in all planes.

Deltoid		**Latissimus dorsi**	**3++**
anterior	**0**		
middle	**1**	**Serratus anterior**	
posterior	**0**	**upper two digitations**	**4**
		lower six digitations	**4**
Short rotators			
subscapularis	**0**	**Rhomboideus major**	**2+**
supraspinatus	**1+**		
infraspinatus	**0**	**Rhomboideus minor**	**2+**
Pectoralis major (transferred)	**3+**	**Levator scapulae**	**4++**
Pectoralis minor	**4**	**Teres major**	**0**
Trapezius		**Teres minor**	**0**
upper	**4++**		
middle	**4++**	**Sternocleidomastoid**	**5**
lower	**4++**		

Figure 55.

Figure 56.

Figure 57.

Figure 55. The figure shows the pre-operative status of the patient. A scar on the belly of biceps is seen, the scar on the chest is also faintly visible; (the sites of previous operation).

Figure 56. The figure shows anterior subluxation on attempting internal rotation against resistance. A skin fold is visible in the axilla (vide text).

Figure 57. The figure shows posterior subluxation on attempting abduction.

The head dislocated forwards with attempted internal rotation against resistance (Figure 56). On the other hand as there was little power in supraspinatus and flicker in middle deltoid any attempt at abduction either actively or passively dislocated the shoulder posteriorly and upwards (Figure 57).

The case was peculiar as the shoulder could not be elevated passively beyond 140° and that too with the head in the dislocated position. This set up a problem of stabilisation of the head in the fossa of the glenoid during elevation in all planes. Postero-superior dislocation prevented the use of a posterior glider acting from behind to replace subscapularis by latissimus dorsi. This if done would aggravate the dislocation of the head backwards. The other alternative of using upper two digitations of serratus anterior and/or pectoralis minor to replace the subscapularis power and to prevent posterior subluxation seemed rational. The usual trapezius and levator scapulae to replace deltoid and reinforce supraspinatus respectively had to be done.

He was operated upon under general anaesthesia. The upper two digitations of serratus anterior were found to be of enough bulk to replace the subscapularis power and prevent posterior dislocation. At the operation table when this was rerouted, the head became stable while passively raising the arm at the shoulder. No further reinforcement by pectoralis minor was thought necessary. Trapezius and levator scapulae were transferred in the usual way. The limb was immobilised in such position as to avoid stretching of the nerve to the pectoralis major. Post-operatively,

Figure 58.

Figure 59.

Figure 60.

Figures 58–60. The figures show post-operative status and his ability to raise the shoulder overhead with a small weight in hand (½ kg). Shoulder stability has been regained. The elbow flexes on raising the arm overhead due to complete absence of power in triceps.

plaster was removed after eight weeks and rehabilitation was carried out by only active exercises (Figures 58–60).

Two-directional instability of the shoulder posed a challenge that has been adequately met by transfer of upper two digitations of serratus anterior. Functionally shoulder has regained almost full range of movement and power sufficient for normal activities. He has only one active muscle belonging to the intermediate group having power 3+.

Case No. 10

Baby Dam, Female, 3 years, came with residual paralysis of right upper extremity after an attack of acute poliomyelitis at the age of 6 months. Residual power of the limb was as follows:

Deltoid		Latissimus dorsi	0
anterior	0		
middle	0	Serratus anterior	
posterior	0	upper two digitations	4
		lower six digitations	4
Short rotators			
subscapularis	0	Rhomboideus major	3+
supraspinatus	0		
infraspinatus	0	Rhomboideus minor	3+
Pectoralis major	0	Levator scapulae	3++
Pectoralis minor	0	Teres major	0
Trapezius		Teres minor	0
upper	4		
lower	4	Sternocleidomastoid	5
middle	4		

Figure 61.

Figure 62.

Figures 61 and 62. The figures show post-operative status and her ability to lift the shoulder in coronal plane. The elbow being almost flail is seen flexed by gravity.

The head of the humerus had forward and downward subluxation, her right elbow was flail except for slight power in the flexors (2++). The forearm was fixed in pronation with diminished power of all the muscles. She had partial paralysis of muscles of thenar eminence and diminished power in the intrinsics of the right hand.

There was very little to choose to give active movements to the shoulder joint; the trapezius, upper two digitations of serratus anterior and the levator scapulae were the only muscles that could be spared.

She was operated upon under general anaesthesia on 1.9.64. There being no power in any of the external rotators of the limb special care was taken during rerouting of trapezius to provide for active external rotation. She was rehabilitated after removal of plaster at the end of eight weeks (Figures 61 and 62).

She is the youngest of the patients in our series. External rotation is now possible with the help of the rerouted trapezius. As expected she is unable to bring the limb to the side from the vertical overhead position in the coronal plane when lying on her side or back. Lately she is developing a trick by which she flexes the shoulder with the help of the rerouted serratus to such a position when gravity helps to bring the arm to the side.

CONCLUSION

Owing to lack of precise knowledge of the mechanism of the shoulder and the uncertainty of the available limited methods the results of our surgical rehabilitation of paralysed shoulder had been meagre. We mainly confined our attention to the harnessing of the lifting power. The trapezius was considered to be the best replacement. Its insertion had to be extended to the deltoid impression of the humerus. Leo Mayer's technique of sandwiching the belly and the freed margin of the trapezius between the two layers of fascia lata and extending it to the deltoid impression was tried in several cases. The results of this transfer have been poor. Patients treated by this method hardly developed enough power to lift the shoulder to 90°. With the passage of time even this range gradually diminished. On re-exploration the fascia elongated and was found to be anchored to the surrounding tissues by fibrous, lacy strands extending from both the surfaces. These caused loss of lifting power.

We later tried isolated Bateman's procedure. This also failed to give the expected results in 75 per cent of our cases. The genuine flail shoulder with loss of short rotators gave uniformly poor results. Besides, rerouting the trapezius to the tuberosity gives less leverage and, consequently, enormous power is required to give adequate lifting force.

In some of our cases where the girdle muscles were strong we did arthrodesis generally by Brittain's technique. We experienced difficulty in obtaining a rigid fusion. The overall results were far from satisfactory. The arm could not be raised to more than about 120° in the most successful cases. In successful arthrodesis we found that the girdle muscles developed to a remarkable extent almost like those of an athlete, and in most cases more than those on the sound side. The muscles that developed were trapezius, serratus anterior and rhomboids. Our experience with the paralysed shoulder has been mostly between the ages of three and eighteen years. In the very young group in my earlier practice I used to postpone the arthrodesis owing to its possibility of failure till such time that the patient attained adolescence. That was also considered a great handicap particularly in right-handed children.

The uncertain results of all these procedures led us to the enquiry of the causes of failure. With better knowledge of the shoulder mechanism and the action of the various muscles of the shoulder joint complex we arrived at a conclusion that besides the lifting power provided by what has been termed in the preceding chapters prime mover, power to effect the gliding of the head of the humerus in two planes and its phasic fixation on the glenoid at each instant of elevation is required.

The three steering muscles, subscapularis, supraspinatus and infraspinatus instead of acting as three isolated units behave as a hood over the head of the humerus gaining continuous attachment to the lesser and greater tuberosities of the humerus (musculo-tendinous cuff of Codman). The particular muscle fibres of this musculotendinous cuff falling in the plane of movement, contract to help the prime mover from the initial stages of elevation. The power of the coplaner contracting muscle fibres initiates and maintains the elevation to 120° when the action potential reaches its maximum. The inevitable gliding of humeral head (*vide infra*) takes place in this plane as the elevation progresses. The other fibres anterior and posterior to these take over the steering function of gliding the head in the glenoid at a little later stage of elevation to bring the arm overhead. This has been proved electromyographically. We find that during elevation in the scapular plane, supraspinatus helps the lifting force of the prime mover in the earlier and subscapularis at a later phase. Likewise, in flexion the supraspinatus helps steering action as shown by its later development of power while the subscapularis develops its power at an earlier phase.

The mechanical advantage of the steering action in two planes is enhanced if the muscles act close to the bend of the axes of the head and neck and of the shaft. This has been corroborated mathematically.

The intermediate group of four muscles have their role in lifting by the gliding and depressor action. The peculiarity of the tendons near their insertions helps the above actions.

Besides these, the scapular blade requires fixation in the setting phase of the scapula and a force couple to rotate particularly during the later stages of elevation of the shoulder. The fixation and rotation of the scapula were analysed and found to be mainly affected by rhomboids, levator scapulae, pectoralis minor, serratus anterior and trapezius. In other words, we have quite a lot of reserve in case the lifting force required is heavy. The scapula would have a tendency to roll over the shoulder in their absence. The question arose how far we could draw from this reserve without affecting the fixation and rotation of the scapula. The levator scapulae, upper two digitations of serratus anterior, pectoralis minor and trapezius were thought to be dispensable maximum in the above respect. The rhomboids and the lower six digitations of the serratus anterior would both act as fixator and rotator of the scapula. The inevitable upward and forward movement of the scapula over the chest wall is carried out by the force transmitted through the rotation of the scapula by this spare rotator couple.

We have seen that powerful girdle muscles are necessary to obtain good results in arthrodesis. This is due to elongated leverage from fixation of the joint and movement of the girdle with the humerus in one piece round the scapulo-thoracic joint. The fulcrum is thus shifted from the gleno-humeral joint to the scapulo-thoracic. The very fact that strong girdle muscles are required for fixation of the shoulder defeats the aim of the principles of rehabilitation. When we have good power in girdle muscles, we can spare some of these muscles for lifting, gliding and fixation at the gleno-humeral joint level while retaining the minimum for rotation and fixation of the scapula. Therefore, it may be assumed that there cannot be any indication for arthrodesis in a flail shoulder. A mobile shoulder using part of the girdle muscles can be made to function more efficiently than an arthrodesed shoulder.

In other words, past workers confined themselves to the development of techniques of the operations rather than to the principles of rehabilitation of a post-polio paralysed shoulder. Therefore, cases having good residual power in short rotators and/or intermediate group had good results with classical trapezius transfer. Cases where these muscles were more severely affected the results were poor and a total failure when these muscles were completely paralysed.

Lack of appreciation of the multiaxial nature of the gleno-humeral joint, change of contact surface with elevation and, therefore, of the fulcrum, bent anatomical axis, role of different forces at different levels in such a system, role of steering and depressor group of muscles besides the prime movers, zero-position of the shoulder joint, essential movements at the proximal end (fulcrum) and its equivalent at the distal end probably stood in the way of evolution of surgery of rehabilitation of a post-polio paralysed shoulder.

A modification of Bateman's trapezius transfer is used to give the lifting power at a greater mechanical advantage. Extensive mobilisation from the whole of the spine of the scapula keeping the implanting area as wide as possible facilitates more distal rerouting on the shaft of the humerus and gives a wider angle of pull. The multiple crushing of acromion in continuity helps to take the curve of the narrow shaft during rerouting.

For reinforcement or replacement of the subscapularis power upper two digitations of serratus anterior, pectoralis minor, part or whole of pectoralis major with bundled tendon of insertion and levator scapulae or a substitute acting from above *(vide supra)* may be used either singly or in combination. The direction of the fibres of the first three replacements conforms more to the normal direction of the fibres of subscapularis and, therefore, these replacements are more suitable than the last transfer where the direction of the fibres is from above and does not fully satisfy the criteria of subscapularis replacement. All these transfers act as posterior glider acting from the front.

The posterior glider can also be reconstructed with the help of the muscles from the posterior aspect of the shoulder rerouting immediately below the lower limit of the greater tuberosity. The muscles that can be used as posterior glider acting from behind are latissimus dorsi and teres major either singly or in combination. Infraspinatus when paralysed does not require replacement *(vide supra)*.

The vertical glider supraspinatus commences its action from the beginning of the elevation in the scapular plane. Its replacement or reinforcement can be obtained by levator scapulae, sternocleidomastoid, scalenus anterior and scalenus medius. Of these the first two gave good results. The others may also be tried as their direction of fibres is more or less identical with the first two transfers and, therefore, the results are expected to be good.

The muscles can be used in various combinations. There are always one or two muscles available provided the girdle has a fair control of movement.

The procedures are best carried out with the sabre-cut incision and erasion of the deltoid from its origin without any subsequent repair. One or more counter-incisions in the axilla to deliver the transposed muscles before rerouting are used. Post-operative immobilisation in zero-position for six to eight weeks is carried out as a routine measure. Subsequent rehabilitation showed recovery in all the cases though complications and difficulties of fixation of the trapezius with the shaft of the humerus were encountered.

The procedures almost invariably give near-normal control of the shoulder, fill the hollow between the humerus and chest wall anteriorly, roll back the head of the humerus in its position, prevent subluxation and give reasonable function even in the most desparate cases.

The negative attitude of management of flail shoulder needs revision by a positive approach. Indications for arthrodesis have now been shown to be the ideal indications for giving an actively mobile shoulder. Arthrodesis is losing its ground in the rehabilitation programme of the postpolio flail shoulder.

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