기능적 해부학 및 정상생역학
Functional Anatomy and Biomechanics

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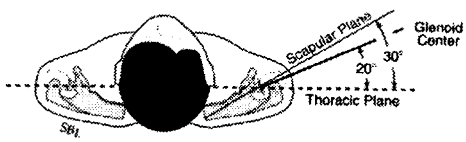
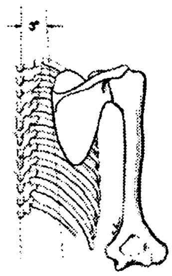
〈STABILITY-RELATED〉

A. STATIC FACTORS

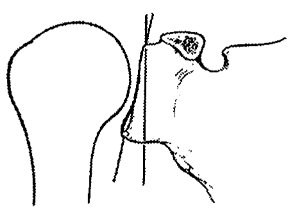
1. Glenoid version

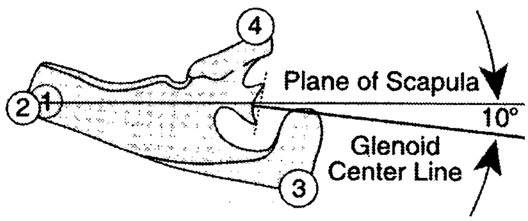
1) Scapula
- face 30° anteriorly on the chest wall
- tilt 3° upward relative to transverse plane
- tilt 20° forward relative to sagittal plane





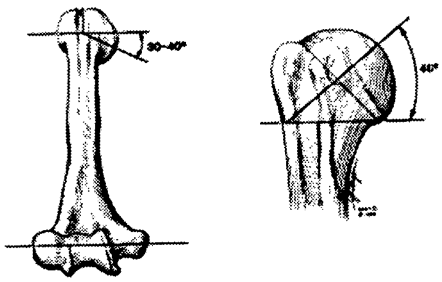
2) Glenoid
- superior tilt of 5°
- 7° retroversion~10° anteversion





3) Excessive glenoid version, glenoid dysplasia, malunion

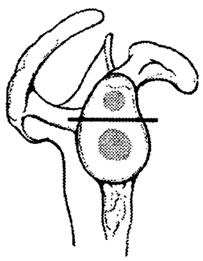
2. Humeral version

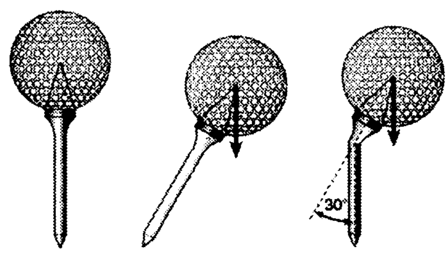


1) Neck-shaft angle 130 to 140°
2) Retrotorsion 30° relative to transepicondylar axis of distal humerus
3) Congenital small retroversion, dysplasia, malunion

3. Articular conformity

1) Glenoid surface: "inverted comma"-narrow superior & broader inferior area
2) Size mismatch: golf ball sitting on a tee
   glenohumeral index (GHI) = Max. glenoid diameter/Max. humeral head diameter (sagittal 0.75, transverse 0.76)

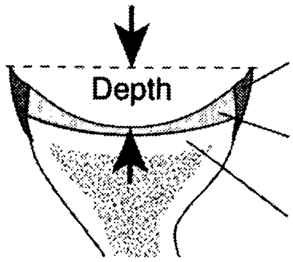




3) Excellent congruency (<3 mm) & uniform contact: due to articular cartilage
4) Ball-in-socket motion with coupled translation in articular surface
5) Hill-Sach's lesion

4. Labrum

1) Three mechanism of stability
   - It acts as a fibrocartilaginous ring around the glenoid to which the capsule-ligamentous structures are anchored.
   - It deepens the concavity of the glenoid socket to 9 mm in the superior-inferior and 5 mm anterior-posterior plane.



: Bankart lesion can decrease the glenoid socket depth by up to 50%.
- It can increase the surface area of contact for the humeral head (GHI).

2) Bankart lesion: most common pathology affecting the labrum
   cf. It should not be confused with sublabral sulcus underneath a cord-like MGHL or a loosely attached labrum superiorly.
3) Virtually all labral lesions are associated with glenohumeral instability.

5. Negative intra-articular pressure (NIP)

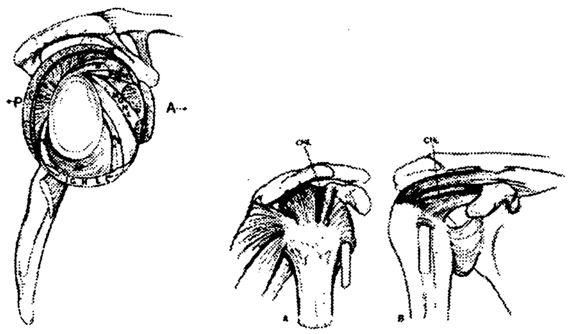
1) NIP plays an important role in limiting inferior translation of the humeral head when arm is hanging at side (when muscles are relaxed and there are no tensions of superior capsulo-ligamentous structures)
2) Biomechanics of NIP
   - shoulder joint: closed compartment surrounded by joint capsule (=elastic diaphragm)
   - If articular surfaces are pulled apart, negative pressure or suction effect develops to resist further displacement.
   - -42 cm water in adducted & relaxed shoulder (due to high osmotic pressure in the interstitial tissues that causes water to be drawn out of the joint)
   - -82 cm water with 25N of inferior force
3) Vented capsule or increased joint volume (capsular tear or rotator interval defect) eliminate the vacuum effect of NIP.
4) The magnitude of the NIP effect on LOM depends on arm position & muscle activity. (adduction>abduction (due to IGHL effect in abducted position))

6. Capsulo-ligamentous structures

1) Superior glenohumeral (SGHL) and Coracohumeral ligament (CHL)
   A. parallel
   B. structural components of the rotator interval region: triangular-shaped

space between the anterior border of the supraspinatus tendon and upper border of the subscapularis tendon.

C. CH ligament
  - extra-articular structure
  - origin: lateral surface of the coracoid process
  - insertion: greater and lesser tuberosities on either side of bicipital groove



  - major structural component of the anterior-superior capsule (x4 than SGHL) vs. just a capsular fold
  - possess the stiffness and load bearing capacity to statically stabilize humeral head (only 15% of ACL in knee joint)
  - In chronic retracted cuff tear, CH ligament is scarred & contracted. CHL release is necessary in that case.

D. SGHL
  - origin: superior glenoid rim, just inferior to the biceps tendon
  - insertion: lesser tuberosity just medial to the bicipital groove
  - most consistent glenohumeral ligament (>90%)

E. Functions
  - constrain the humeral head on the glenoid
  - limiting inferior translation and ER when arm is adducted
  - limiting posterior translation when shoulder is FF, Add, IR position

2) Middle glenohumeral ligament (MGHL)

A. most variable ligament: absent in up to 30%, poorly defined in 10%

B. Morphological variations
  sheetlike (confluent with AIGHL) or cordlike (foraminal separation with AIGHL)

C. origin: superior glenoid just below SGHL & above the AIGHL, slight medial to glenoid labrum

D. Function:
- limiting ant. translation when abducted in the range from 60 to 90°, in ER
- limiting inf. translation when adducted at the side

3) Inferior glenohumeral ligament (IGHL) complex
A. triangular shaped structure
B. runs from labrum to the humeral head btw. subscapularis & triceps
C. 3 component: anterior band (2.8 mm), posterior band (1.7 mm), axillary pouch
D. thicker near the glenoid than humerus
E. Viscoelastic response of IGHL complex: stronger & stiffer at the higher strain
F. Central portion of ligament: more elastic behavior
Insertion area: more viscoelastic & less oriented collagen & high proteoglycan
G. Hammock-like anatomy: with abduction, it moves underneath the head & become taught
- IR cause limiting posterior translation
- ER cause limiting anterior translation
- Horizontal flexion of abducted shoulder limiting posteroanterior translation
- Horizontal extension limiting anteroposterior translation
- Statically limiting inferior translation of abducted shoulder (secondary role)
H. complex structures suggest a functional adaptability of different regions of IGHL to restrain the humeral head at various loading rate.

4) Posterior capsule
A. posterior & superior to the posterior band of IGHL complex
B. thinnest portion of the joint capsule
C. primary static stabilizer to posterior translation of ADD/FF/IR shoulder.

5) Biomaterial properties of joint capsule
A. Stress at failure of IGHL was far lower (5.5 Mpa) than knee joint.
B. Thus, in the shoulder, the ligaments must share load with the muscles and other stabilizing mechanisms.
C. Plastic deformation of capsule by submaximal repetitive or single trauma

7. Proprioception

1) Proprioceptive mechanoreceptors transduce electric signals about joint position and motion.
2) Capsule and ligaments not only act to statically control motion of the joint, but also provide afferent feedback for reflexive muscular control of the rotator cuff and biceps tendon.

B. DYNAMIC FACTORS

1. Joint compression effect

1) provided by contraction of the rotator cuff and long head of biceps
2) increase joint stability by conforming fit of the humeral head into the glenoid
   : containment concept/ concavity compression
3) importance of labrum
4) weak or ineffective rotator cuff action allows greater degrees of translation of the humeral head during active shoulder motion

2. Coordinated rotator cuff contraction

1) complex & interdependent role of the rotator cuff muscles in controlling shoulder motion and stability
2) Posterior cuff and biceps tendon reduce anterior translation in the abducted, externally rotated shoulder.
3) Fatigue in rotator cuff of throwing athlete might place the anterior capsulo-ligamentous structure at risk for injury.
4) Patients with voluntary instability cause dislocation by asynchronous contraction of rotator cuff muscles.

3. Ligament dynamization

1) Glenohumeral ligaments and capsule relatively lax in the midrange and limit excessive translation and rotation at the end ranges.
2) Rotator cuff tendons attach directly to portions of the capsule-ligamentous apparatus. Therefore, during active shoulder motion, capsule and ligaments may be dynamized (placed under tension) by contraction of cuffs.

4. Kinematics: Effect of scapulothoracic motion

1) 2° of glenohumeral rotation for 1° of scapulothoracic rotation during scapular plane abduction
2) Fatigue of serratus anterior and trapezius may occur with repetitive overhead activities and may lead to poor scapulothoracic motion.

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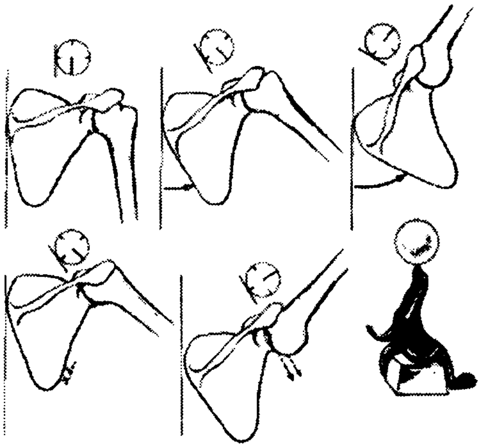


- Scapula winging (coracoacromial arch descend relative to advancing GT) could result in impingement.

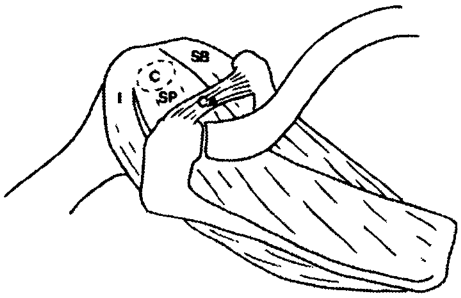
⟨CUFF RELATED⟩

A. ANATOMY

1. Muscle and tendon anatomy

1) 4 muscles: subscapularis, supraspinatus, infraspinatus, teres minor
2) Rotator interval: thin collagenous tissue between subscapularis and supraspinatus, under which lies long head of biceps tendon and reinforced by coracohumeral ligament
3) Cuff are inserting into greater tuberosity fuse into a tendinous aponeurosis. This interconnected arrangement of cuff insertions influence the configuration & complexity of tears.
4) Five layer structure: insertion complex of subscapularis and supraspinatus
   - layer 1: superficial fibers of CHL (coracohumeral ligament)
   - layer 2: primary portion of cuff tendon
   - layer 3: thick tendinous structure with tendon fascicle (small & less uniform)
   - layer 4: deep extension of CHL, perpendicular to layer two, distribute the forces between different tendons
   - layer 5: true capsular layer, randomly oriented fiber
5) Due to the various fiber orientations & distinct layers, significant shear stress exist that may play a role in cuff tear & tear pattern.
6) This complex woven pattern provides better purchase for suture materials during repair.
7) vascular anatomy

- posterior circumflex a. & suprascapular a.
  : forming interlacing arcade over the posterior cuffs
  : major blood supply to teres minor and infraspinatus
- anterior circumflex a. & thoracoacromial a. & suprahumeral branch from axillary a. : anterosuperior cuff
- acromial branch of thoracoacromial a.
  : supraspinatus m.
- hypovascular zone (="critical zone" by Codman)
  # within tendinous portion of supraspinatus
  # diminished vascularity from older individuals
  # age-related tendon degeneration
  # relative hypovascularity on articular side than bursal side
  # transient hypovascularity according to arm position & activity

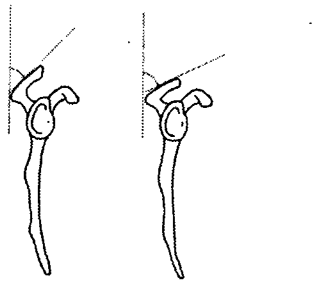


- hypervascularity (neovascularization) in the area of impingement

2. Coracoacromial arch anatomy

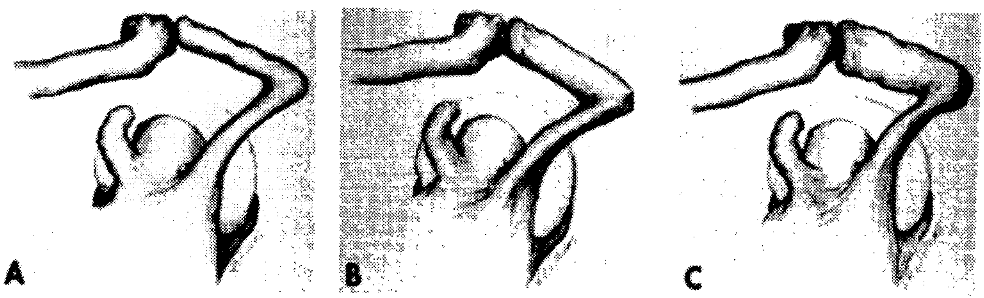
1) bony acromion / coracoacromial ligament / coracoid process
2) forming the supraspinatus outlet, through which supraspinatus passes
3) implicated in rotator cuff pathology
4) Coracoacromial (CA) ligament
   - triangular shape, thickening of claviculopectoral fascia
   - lateral aspect & anterior half of coracoid-anteromedio-inferior acromion
   - three types: quadrangular, Y-shape, one broad band
   - anteroinferior acromial spurs: ossification of CA ligament
5) Os acromiale
   - failure of fusion of the ossification centers (2~3) by age 22 years
   - 1.4%, 62% in bilateral
   - incidence of os acromiale in cuff disease: 6%
   - pre_, meso_, meta_, basiacromion
6) Acromion anatomy-just primary anatomic characteristics: only risk factor

- Bigliani classification of acromial morphology
  : lateral radiograph tilted 10' cephalad (supraspinatus outlet view)

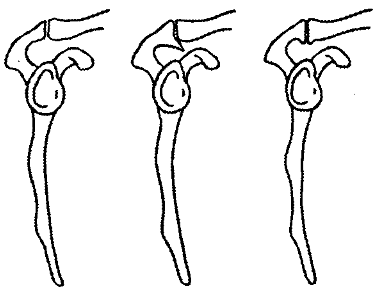


Type I: flat (17%) / Type II: curved (43%) / Type III: hooked (40%)
full thickness cuff tear: type III acromial shape, anterior spur of acromion, greater angle of anterior slope (<30°)

- Modified Bigliani classification
  : acromial thickness at the junction of anterior to mid 1/3 of acromion
  Type A<8 mm Type B 8-12 mm Type C>12 mm



- Subacromial spur



anterior third of acromion at the insertion of the CA ligament
further decrease volume for supraspinatus excursion
associated with flatter slope of acromion by cadaver study

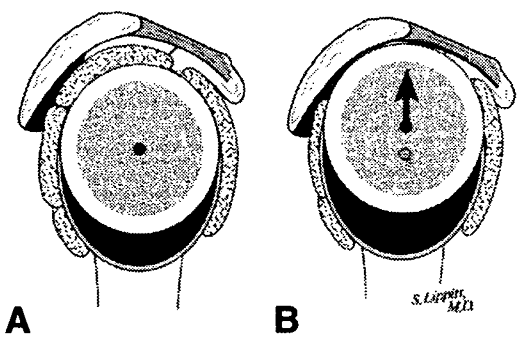
- Cadaver study: subacromial contact by anterior tip of acromion on supraspinatus tendon & greater tuberosity: greatest in the middle range elevation (60° ~120°)
- Optical stereophotogrammetric study: subacromial contact btw. 60° ~120°, more contact in 20° IR, type III acromion
- Finite element model of stress environment
  : high stress on bursal side, articular side, or within the tendon
  : error of only bursal side
- Computer simulation of acromioplasty: flattening of anterior 1/3 remove impingement in 100%

7) Coracoacromial arch
- important passive stabilizer against superior humeral subluxation
- last restraint when the cuff is no longer function
- Subacromial contact may cause tendon wear, but is also part of a normal stabilizing mechanism.

B. Kinematics

1. Rotator cuff kinematics

1) primary function of rotator cuff
- humeral head depressor against upward shear forces by deltoid during active elevation, particularly first 60° of elevation.
- dynamic stabilizer of glenohumeral joint: maintain center of rotation within 2 mm of its geometric center



- creating a fulcrum for deltoid motion
- infraspinatus and teres minor

    # primary external rotators
    # 80% of external rotational force
  - subscapularis
    # internal rotator and dynamic barrier to anterior displacement
  - supraspinatus
    # 50% of torque output in shoulder elevation in scapular plane
    # 50% of total torque of forward elevation in sagittal plane

2) changes in moment arms of the rotator cuff by cadaver study
  - abductor moment arm of supraspinatus
    : anterior portion-decreased with internal rotation
    : posterior portion-decreased with external rotation
  - infraspinatus
    : internal rotation- enhanced effectiveness of superior portion as Abd.
    : abduction- reduced effectiveness of superior portion as ER.
  - subscapularis
    : internal rotator with abductor moment arm greatest for superior portion
    : external rotation increased ability of superior portion to elevate arm

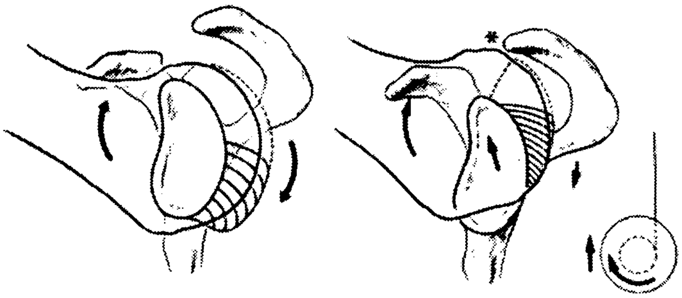
3) biomechanical model by Bukhart
  - A massive tear model in which a balance of forces anteriorly & posteriorly might preserve stability & appears to have normal kinematics.
  - Thick free edge of the cuff might transmit stress around tear (cable in a suspension bridge)

4) simulated supraspinatus tear cadaver model
  - increase deltoid force needed to lift arm
  - no alteration of kinematics

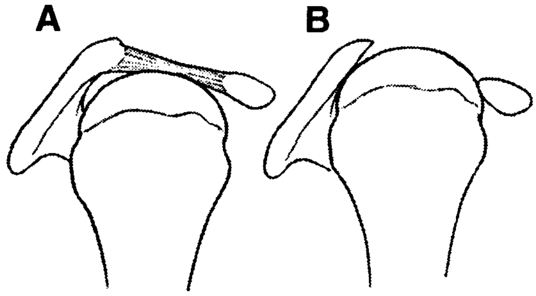
5) spacer effect of cuff
  - full-thickness defect of SST-impaired head centering, some of arms could not be elevated
  - pain model with intact cuff but applying no force to SST-lesser degree of superior translation, full active elevation
  - to restrain superior humeral translation
  - to provide smooth surface continuous with greater tuberosity, which can glide below the acromion.
  - increase superior translation with increasing tear size, reversed by repair

6) Obligate translation of center of humeral head rotation
  - tightness of posterior capsule cause dynamic cephalad migration & impingement under CA arch

- importance of capsular stretching



7) biceps long head function to stabilize humeral head with massive cuff tear
   - active or just due to passive musce-tendon stretch
   - spacer effect of tendon
   - Biceps tenotomy at cuff repair may impair the fulcrum for arm elevation.
8) function of coracoacromial ligament in stabilizing shoulder
   - transsection of CA ligament in massive cuff tears



two mechanism of superior translation
  a. loss of buffering contact by the under surface of CA ligament
  b. loss of tethering between coracoid and anterior acromial tip
     : allowing the acromion to deform upward & increased CA gap
- important passive stabilizer and final restraint to anterosuperior humeral migration when dynamic head centering function of rotator cuff was compromised by tears.

9) nutritional function of cuff to the articular cartilage: cuff arthropathy
10) scapulothoracic kinematics: scapula lag (by cervical spondylosis, muscle paralysis, chronic fatigue) causes mechanical impingement under CA arch.

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