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EURO-MUSCULUS/USPRM Dynamic Ultrasound Protocols for Elbow

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EURO-MUSCULUS

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ABSTRACT

In this dynamic protocol, ultrasound examination of the elbow using different maneuvers is described for several/relevant elbow problems. Scanning videos are coupled with real-time patient examination videos for better understanding. The authors believe that this practical guide - prepared by an international consensus of several experts - will help musculoskeletal physicians perform a better and uniform/standard approach.

KEY WORDS

Elbow, ultrasonography, dynamic imaging, maneuver, Physical and Rehabilitation Medicine

Among physiatrists, the utility of musculoskeletal ultrasound (US) imaging/examination has already skyrocketed in daily clinical practice. In addition to the basic scanning, dynamic assessment is perhaps one of the most important superiorities of this imaging technique when compared with other modalities. Herewith, protocols as regards how to implement this method in various elbow pathologies does not exist in the relevant literature. As such, and similar to the former/basic elbow scanning protocols in physical and rehabilitation medicine; [1] an international group of experts also prepared this protocol for dynamic assessment of elbow disorders.

ANTERIOR ASPECT

1. Radial/Coronoid Fossa Window

Technique

In supine (or sitting) position with the elbow fully extended and the forearm supinated, the longitudinal sonogram of the radial/coronoid fossa [1,2] can be done initially. During dynamic imaging, active/passive flexion and extension of the elbow can be performed **(Video 1, http://links.lww.com/PHM/B470)**. Of note, mild flexion of the elbow joint (10 - 30 degrees) is often enough to promptly reduce the tension of the volar portion of the capsule - allowing superficial displacement of the intra-capsular, extra-synovial, fat pad in the presence of joint effusion **(Figure 1A)**. [3] The authors suggest using a soft support under the patient's elbow in order to elevate it from the examination bed/table and achieve maximal elbow extension during the dynamic examination. [4] As a side note, a small-footprint linear array ('hockey-stick') transducer allows a greater degree of flexion of the elbow occupying minor space in the cubital fossa. Lastly, in the presence of moderate to severe articular effusion, the synovial fluid can be pushed also to the annular recess of the capsule during the dynamic technique.

Clinical Indications

Joint effusion: as previously mentioned, the dynamic maneuver reduces the tension of the volar capsule of the elbow and allows the joint effusion to flow in the anterior compartment displacing the intra-capsular, extra-synovial fat pad **(Figure 1A)**. [3] As such, even mild/moderate amounts of intra-articular fluid can be identified/quantified - also by evaluating the indirect sonographic sign of capsular bulging **(Video 2, http://links.lww.com/PHM/B471)**. In some patients with severe post-traumatic osteoarthritis or other rheumatic diseases, hypertrophic synovial fringes can be easily/dynamically visualized floating inside the joint cavity **(Video 3, http://links.lww.com/PHM/B472)**. Herein, it is noteworthy that the hypertrophic synovial membrane is not easily detectable during static examination since its echogenicity is similar to that of the intra-capsular fat. In this sense, the dynamic technique definitely helps to optimize the differential diagnosis.

Intra-articular loose body: active/passive movements of the elbow can be useful to mobilize/visualize an intra-articular loose body (cartilage or bone fragment) in the anterior compartment. Indeed, during static US (usually in full extension), a hyperechoic loose body may be covered/encircled by the surrounding, intra-capsular and extra-synovial fat pad - making the differential diagnosis challenging. Instead, dynamic assessment may mobilize the articular effusion around the loose body, defining its edges and size. [5] This way, real-time observation of the movements of the suspected intra-articular loose body would serve to differentiate it from other anatomical structures such as hypertrophic synovial membrane of the anterior recess or redundant intra-capsular fat. In contrast to the randomly moving loose body, synovial villi usually have a stabilizing peduncle in continuity with the capsule-synovial wall of the joint **(Video 3, http://links.lww.com/PHM/B472)**.

Radio-humeral synovial plica: under dynamic scanning, in some patients, it is possible to pump the intra-articular effusion inside a focal injury of the anterior lobe of the radio-humeral synovial plica i.e. using the synovial fluid as a sort of contrast medium **(Video 4, http://links.lww.com/PHM/B473)**. [6] Power Doppler evaluation can also be used to check for micro-vascular signals compatible with focal synovitis surrounding the radio-humeral plica. [7]

Bony fragment: in patients with post-traumatic fracture of the radial head or coronoid process of the ulna, bony fragments can be mechanically stressed to evaluate their mobility/stability. [8] The authors suggest using passive (rather than active) extension of the elbow for applying maximum tension on the fracture line - and possibly displacing the bony fragments. Of note, the degree of mechanical (in)stability of the fracture line and bony fragments can precisely guide the onward rehabilitation/management. Lastly, the dynamic maneuver can also be used to evaluate the (in)stability of the fibrous callus over time. Indeed, progressive evolution of soft callus to calcific deposition and osseous union can be closely monitored under static and dynamic US scanning. [8,9]

Anterior impingement: especially in young patients, dynamic technique can also be used in the emergency setting to promptly diagnose subluxation of the radial head and pinching of the annular ligament between the cartilagineous articular surfaces of the radio-capitellar joint. [10] Slipping of a portion of the annular ligament between the radial head and the capitulum humeri is known as the "hook sign". [11] Of note, after manual reduction, dynamic US can be performed also to rapidly confirm the correct relocation of the annular ligament out of the articular cleft [11] and the regular gliding of the articular surfaces. Lastly, in the operating theater under local/general anesthesia, the dynamic maneuver can be used to evaluate a likely compression of the neurovascular bundle between the bony surfaces in patients with elbow fracture/dislocation.

POSTERIOR ASPECT

1. Olecranon Fossa Window

Technique

In prone (or sitting) position, the patient is asked to abduct the shoulder and flex the elbow. Passive/active flexion and extension of the elbow can be performed while scanning from the posterior longitudinal acoustic window i.e. long-axis view of the triceps brachii tendon. [1,2] Gliding of the triceps brachii muscle-tendon unit, peculiar movements of the (un)locked olecranon next to the olecranon fossa and eventual displacement of the intra-capsular extra-synovial fat pad in the presence of joint effusion can be visualized **(Figure 1B)**.

Clinical Indications

Joint effusion: passive/active extension of the elbow reduces the tension of the dorsal capsule and allows the joint effusion to flow in the posterior compartment displacing the intra-capsular extra-synovial fat pad. [3] As previously mentioned, dynamic assessment helps to promptly identify even a small amount of intra-articular effusion i.e. by observing how the intra-articular fatty tissue reacts to the motions **(Video 5, http://links.lww.com/PHM/B474)**. In some patients with chronic osteoarthritis or other rheumatic disorders, hypertrophic synovial fringes can be easily visualized, floating inside the joint cavity **(Video 6, http://links.lww.com/PHM/B475)**.

Triceps brachii muscle-tendon unit: starting from the aforementioned position and using an active extension or passive flexion of the elbow, it is possible to stretch a focal injury at any level i.e. muscle belly, myotendinous junction and tendon. This way, dynamic assessment (widening the gap between proximal and distal ends) can make the lesion more visible. Likewise, complete vs.

incomplete lesions can also be better identified. [12,13] Finally, dynamic examination would also be contributory in differentiating the exact layer of tendinous involvement among the following three: the superficial portion originating from the lateral and the long head of the muscle, the deep portion originating from the medial head of the muscle and, the direct (muscular) insertion of the medial head of the triceps brachii over the olecranon. [12-14]

Posterior impingement: mechanical conflict that restricts complete passive or active extension of the elbow can be promptly evaluated using the aforementioned dynamic technique. Several conditions can be associated with posterior impingement of the elbow e.g. bony spur/osteophyte, [15] hypertrophic synovium **(Video 6, http://links.lww.com/PHM/B475)**, post-traumatic bony deformations and disorders of the posterior fat pad (hypertrophy, fragmentation, detachment). [16] Of note, a quite common cause of posterior impingement is the presence of an intra-articular loose body **(Figure 1C)** which easily settles inside the olecranon fossa i.e. the major recess of the joint. [5] Again, dynamic examination correctly differentiates a freely mobile loose body from the floating movements of hypertrophic synovial villi which are bound to the capsule by a stabilizing peduncle **(Video 6, http://links.lww.com/PHM/B475)**.

2. Radial Tuberosity Window

Technique

In supine (or sitting) position with the elbow flexed and the forearm supinated, a soft support can be positioned under the patient's elbow in order to elevate it from the examination bed/table and acquire more space to manage the transducer. [4,17] Active/passive pronation and supination of the forearm can be performed - using a transverse acoustic window at the level of the dorsal proximal one third of the forearm - to observe the gliding of the distal biceps brachii tendon (DBBT) in between the radial tuberosity and the supinator muscle **(Figure 1D)**. [2,17] Dynamic evaluation will clearly show the DBBT rolling up on the radius and becoming visible from the posterior/dorsal surface of the forearm **(Video 7, http://links.lww.com/PHM/B476)**. [17-19] Of note, the aforementioned maneuver can also be performed using a longitudinal acoustic window to dynamically and panoramically expose the proximal and distal facets of the radial tuberosity **(Video 8, http://links.lww.com/PHM/B477)**. Indeed, the latter technique will better show the tendon of the long head of the biceps brachii attaching to the proximal footprint and the tendon of the short head of the biceps brachii inserting to the distal footprint of the radial tuberosity. [19] Lastly, the two components of the DBBT are separated by a septum originating from the endotenon (areolar connective tissue) which simultaneously stabilizes the two tendons but also allows for their independent gliding. [20] Accordingly, the authors suggest tilting the probe - exploiting the anisotropy artifact [21] - to enhance the acoustic interfaces between the tendons and the septum **(Video 8, http://links.lww.com/PHM/B477)**.

Clinical Indications

Insertional segment of the DBBT: active/passive full pronation of the forearm puts the DBBT in tension. As such, in patients with partial/complete tear of the distal segment of the tendon, it is possible to open the gap between the proximal and distal ends dynamically. [2,19] Of note, the aforementioned technique can be also performed to better define a painful snapping DBBT. Yet, several pathological conditions like focal tendinosis, calcific tendinopathy and hypertrophic scarring (due to partial tear or surgical repair) can lead to mechanical impingement. [19,22] Biomechanically, the proximal radio-ulnar tunnel/space is reduced by 50% (at the level of the radial tuberosity) in full pronation and the DBBT occupies 85% of the tunnel during the same maneuver. [23] Normally, during pronation and supination of the forearm, the DBBT slips smoothly between radius and ulna; however, in pathological conditions, a thickened tendon can be entrapped in the proximal radio-ulnar tunnel generating an extra-articular impingement. [19,22] Lastly, bicipitoradial bursitis should be considered among the possible causes of painful impingement especially in patients with rheumatic diseases. [24]

3. Humeroradial Window

Technique

In supine (or sitting) position, with the elbow flexed and the forearm supinated; a soft support can be positioned under the patient's elbow to elevate it from the examination bed/table - as well as to acquire more space for the transducer. [4] Active/passive pronation and supination of the forearm can be performed - using a longitudinal acoustic window - to observe how the posterior lobe of radio-humeral synovial plica reacts to the joint motions **(Figure 1E)**. [6] At this level, the anconeus muscle runs superficial to the posterior capsule and - owing to the flexed position of the elbow - a large portion of the hyaline cartilage of the capitulum humeri is clearly visible **(Video 9, http://links.lww.com/PHM/B478)**. [25] Therefore, crystal depositions or focal chondral defects can be easily evaluated. Additionally, considering the pivotal role of the posterior capsule in guaranteeing the dynamic centering of the radial head; [26] this technique can also be used to promptly evaluate the (in)stability of the radiocapitellar joint during active/passive supination and pronation at different flexion angles.

Clinical Indications

Radio-humeral synovial plica: with dynamic scanning, it would be possible to i) pump the joint effusion into a focal injury of the posterior lobe of the radio-humeral plica (using the synovial fluid as a contrast medium) ii) visualize a mechanical impingement of the plica into the posterior compartment of the humeroradial joint. Of note, the posterior lobe of the plica is larger and thicker when compared with the anterior/lateral lobes. Similarly, it is more prone to develop intra-articular impingement with eventual histological changes and posterolateral elbow pain. [6] Normally, the plica is triangular in shape with two sides in contact with the synovial fluid and the base attached to the capsule **(Video 9, http://links.lww.com/PHM/B478) (Figure 1E)**. However, in patients with severe posterolateral impingement, detachment of the base of the plica from the capsular wall can be identified during dynamic imaging - with articular effusion completely surrounding it **(Video 10, http://links.lww.com/PHM/B479)**.

Radiocapitellar congruity: during active/passive pronation and supination of the forearm at different angles of elbow flexion, the radial head normally presents as a regular alignment with the capitulum humeri - with only minor anterior and posterior shifts **(Video 9, http://links.lww.com/PHM/B478)**. Instead, injury or insufficiency of the lateral complex of the elbow (i.e. common extensor tendon (CET), radial collateral ligament, lateral ulnar collateral ligament, annular ligament) can be identified as posterior translation of the radial head, also defined as dynamic radiocapitellar incongruity. [27] Herein, the authors suggest always performing a comparative dynamic assessment of the radiocapitellar joint in patients with clinical/US findings of lateral complex pathologies, since elbow pain might be of articular and extra-articular origin.

POSTERO-MEDIAL ASPECT

1. Cubital Tunnel Window

Technique

In supine position with the shoulder abducted and externally rotated, the patient is asked to flex the elbow. This position of the patient allows stabilization of the upper limb over the examination bed in order to perform the dynamic maneuver more easily. [4] Alternatively, the patient can sit with a pillow in the axilla supporting the upper limb in shoulder abduction and internal rotation, and elbow flexion. The probe is positioned between the olecranon and the medial epicondyle to promptly identify the ulnar nerve and the surrounding soft tissues inside the cubital tunnel. [1,2,28] Then, passive/active flexion and extension of the elbow can be performed in order to dynamically visualize how the ulnar nerve and the medial head of the triceps brachii muscle react to the joint motions **(Figure 1F)**. [29] Of note, it is paramount to avoid excessive pressure i.e. not to artificially 'stabilize' the possibly snapping structures. In this sense, extra gel or gel pad can be adopted to minimize probe compression.

As a side note, the concept of 'dynamic imaging' can also encompass any scenario simulating the normal daily conditions during which subjects describe their complaints. In other words, it is not always the motions of a particular structure which need to be evaluated. For instance, secondary changes due to different positioning of the extremities can be imaged/assessed in details as well. [30]

Clinical Indications

Ulnar nerve instability: during passive/active flexion and extension of the elbow, it is possible to observe subluxation **(Video 11, http://links.lww.com/PHM/B480)** or complete dislocation **(Video 12, http://links.lww.com/PHM/B481)** of the ulnar nerve outside the tunnel. [29] Herein, the anatomical structures stabilizing the ulnar nerve at the level of the osteo-fibrous tunnel **(Figure 1F)** may be functionally insufficient due to excessive laxity, structural damage or partial absence. [29,31] Those include Osborne's ligament or retroepicondylar retinaculum, arcuate ligament and posterior-medial capsule of the elbow (the posterior bundle of the ulnar collateral ligament). In addition to dynamic scanning, the authors suggest also focusing on the comparative static images of the bony surfaces. Yet, a shallow retroepicondylar groove can well predispose to ulnar nerve instability. [32,33] Chronic frictions related to the instability may lead to inflamation and edema of the neural tissue i.e. frictional/tractional painful neuritis [29] with or without a feeling of snapping during elbow movements. Importantly, dynamic US can be used during post-operative follow up after (transposition) surgery as well **(Video 13, http://links.lww.com/PHM/B482)**. Needless to say, snapping ulnar nerve can also be seen in asymptomatic individuals [34] whereby correlating clinical and US features is once again paramount. [35]

Triceps brachii muscle instability: performing the aforementioned dynamic maneuver, in some patients, it is possible to identify the medial head of the triceps brachii muscle snapping over the medial epicondyle together with the ulnar nerve. [36] Of note, while ulnar nerve snapping (usually) occurs between 70-90 degrees of flexion; snapping of the medial component of the triceps ensues around 115 degrees. [37] Lastly, the medial antebrachial cutaneous nerve can also be involved in the snapping phenomenon (over the medial epicondyle) giving a positive sono-Tinel sign during dynamic evaluation. [38]

Posterior-medial impingement: in patients with osteoarthritis, post-traumatic dysmorphism of the elbow or heterotopic ossification **(Video 14, http://links.lww.com/PHM/B483)**; [39] several factors (e.g. bony spurs/osteophytes, intra-articular effusion, hypertrophic synovitis, loose bodies, bony fragments) can be responsible for the dynamic compression of the ulnar nerve in the tunnel **(Figure 2A)**. [40] The aforementioned dynamic technique can provide real-time visualization of the mechanical interactions between the extra-articular tissues located in the cubital tunnel.

POSTERO-LATERAL ASPECT

1. Radioulnar Window

Technique

Starting with the elbow positioned over the examination bed in 90 degrees of flexion, active/passive pronation and supination of the forearm can be performed using a transverse acoustic scan over the proximal radioulnar joint (PRUJ). In this approach, the annular ligament is clearly visible deep to the anconeus muscle, covering the radial head and attaching to the supinator crest of the ulna **(Figure 2B)**. [18,41] During dynamic scanning, it is possible to visualize (real-time) how the annular ligament stabilizes the rolling of the radial head inside the radial notch of the ulna and, if present, incongruence of the PRUJ **(Video 15, http://links.lww.com/PHM/B484)**. Of note, in some patients, posterior attachment of the annular ligament to the supinator crest of the ulna presents two different bands separated by fat. [42] As such, it can appear triangular in shape with a broad attachment to the ulna and a thin tip in continuity with the remaining segment of the ligament **(Video 15, http://links.lww.com/PHM/B484)**. Using Doppler imaging, the interosseous recurrent artery can be identified inside a small fat pad between the deep surface of the anconeus muscle and the posterior attachment of the annular ligament. Lastly, slowly pivoting the probe from a transverse to an oblique transverse scan, the distal insertion of the lateral ulnar collateral ligament can be promptly observed attaching to the supinator tubercle **(Figure 2B)**. [41,43] Further, it can be dynamically stretched and released during pronation and supination of the forearm **(Video 16, http://links.lww.com/PHM/B485)**.

Clinical Indications

Annular ligament disorders: during active/passive pronation and supination of the forearm, it is possible to visualize abnormal gliding or snapping of the annular ligament over the radial head [37] that may be related to several disorders including post-traumatic or congenital deformation of the radial head, nodular thickening of the ligament, post-traumatic hypertrophic scarring of the ligament and intra-ligamentous calcific deposition. In some patients, partial or complete avulsion of the posterior insertional segment of the annular ligament from the supinator crest of the ulna can be the cause of posterolateral elbow pain and/or click sensation. [44] As mentioned above, the posterior attachment of the annular ligament can present as a superficial band in continuity with the periosteum of the ulna and a deep band in continuity with the cartilage of the ulnar notch. [42] For sure, both parts can be involved in pathological conditions.

Postero-lateral impingement: in patients with post-traumatic radial head fracture, or in young patients with congenital abnormalities; morphological deformity of the bony surfaces may lead to articular block with mechanical impingement between the radial head and the radial notch of the ulna during pronation and supination movements (i.e. forearm rotation blockage). [45] The authors suggest performing a comparative dynamic scanning to better assess different excursions of the PRUJ (pathological vs. contralateral/normal). For sure, in the presence of dynamic sonographic findings suspicious for PRUJ mechanical block, panoramic imaging might add extra value as regards prompt management. [45] Lastly, dynamic imaging can also be performed after surgical fixation of the radial head fracture (with plates, screws, etc.) to evaluate impingement of the orthopedic implants on the surrounding anatomical structures. [46]

Proximal radioulnar joint instability: repetitive low-energy stresses can progressively lead to micro-elongation of the radial collateral ligament, lateral ulnar collateral ligament and annular ligament complex whereby hypermobility of the radial head and extra frictions at the level of the sigmoid notch might ensue. [47] Normally, rolling of the radial head must be smooth and strictly adherent to the radial notch of the ulna during different elbow movements **(Video 15, http://links.lww.com/PHM/B484)**. [48] In case of PRUJ instability, intermittent diastasis of the proximal radioulnar joint, posterior/anterior shift of the radial head and transient pinching of the capsule-synovial complex between the bony surfaces can be seen under dynamic imaging. For sure, the diagnosis can be confirmed in light of comparative dynamic scanning, medical history and clinical findings. Herein, early detection of this instability is paramount to avoid long-term complications such as local synovitis, focal chondropathy, and capsular injuries. [47] Finally, dynamic incongruence of the PRUJ due to insufficiency of the above quoted ligament complex can progressively lead to compensatory overload of the dynamic stabilizers with eventual sono-histological changes of the CET [47] or intermittent compression of the radial nerve between the musculo-fascial planes near the radiohumeral joint [49] - i.e. secondary radial tunnel syndrome.

2. Humeroulnar Window

Technique

With the elbow positioned over the examination bed in flexion and the forearm in pronation, the examiner can use one hand to supinate the wrist and the other one to simultaneously keep the probe between the lateral epicondyle and the olecranon. [50] This maneuver - also called the sonographic posterolateral rotatory stress test - allows the examiner to evaluate widening of the posterolateral humeroulnar joint **(Figure 2B)**. [50] Normally, stable congruence of the articular surfaces can be observed during the stress test. Additionally, a small intra-capsular and extra-synovial fat pad can be recognized deep to the anconeus muscle, while gently moving in and out from the articular line, exerting a shock absorber effect **(Video 17, http://links.lww.com/PHM/B486)**.

Clinical Indications

Posterolateral rotatory instability: unlike the proximal radioulnar joint instability, the radial head and ulna concomitantly roll off the distal humerus in posterolateral rotatory instability (PLRI). [50] Intermittent widening of the humeroulnar joint, transient displacement of the articular effusion in the posterolateral recess and abnormal intrusion of the intracapsular fat pad inside the articular cleft are the most common dynamic US findings in patients with PLRI. Similar to other joint instabilities; comparative dynamic scanning, medical history and clinical findings need to be melted in a pot. As a side note, the posterolateral rotatory instability can often be coupled with insufficiency/injury of the lateral elbow complex i.e. CET, radial collateral ligament, lateral ulnar collateral ligament (LUCL) and annular ligament. [50] In this regard, especially in patients with chronic lateral elbow pain, the authors suggest not to focus only on the sono-histological changes of the lateral complex but also to consider possible radiocapitellar, radioulnar and humeroulnar instability.

LATERAL ASPECT

1. Lateral Complex Window

Technique

Starting with the elbow positioned over the examination bed in flexion, passive/active pronation and supination of the forearm can be performed using a longitudinal acoustic window for the CET. [1,51] Additionally, other structures of the lateral elbow i.e. radial collateral ligament (RCL), annular ligament (AL) and the radio-humeral synovial plica also react during joint movements **(Figure 2C)**. [18] In physiological conditions, the CET-RCL/LUCL-AL complex of the elbow stabilizes the radio-humeral joint allowing only minor shifts of the radial head **(Video 18, http://links.lww.com/PHM/B487)**. Using the same sonographic approach, we can ask the patient to actively extend the wrist with or without distal resistance i.e. US-guided Cozen's test. This way, it could be possible to put the CET in tension and promptly evaluate damage to its fibers **(Video 19, http://links.lww.com/PHM/B488)**. [35] Like elsewhere, focal injury of the CET can be diagnosed by observing a gap between the proximal and distal stumps during stretching. Moreover, tensioning the CET can also help to optimize evaluation of the anatomical interface between the CET and the underlying RCL **(Video 19, http://links.lww.com/PHM/B488)**. [52]

The aforementioned dynamic techniques can also be performed in full extension of the elbow shifting the extensor carpi radialis longus muscle over the CET-RCL/LUCL-AL complex. As such, the lateral complex can be evaluated panoramically, avoiding excessive compression of the superficial tissues **(Video 20, http://links.lww.com/PHM/B489)**. [4] Medially, the flat bony surface of the distal humerus represents the attachment site of the anterior portion of the RCL. Slowly shifting the probe laterally, the CET and the posterior portion of the RCL will be seen as attaching to a more irregular cortical bone **(Video 21, http://links.lww.com/PHM/B490)**. [53] Rotating the probe 90 degrees and centering the radial head, it is possible to dynamically evaluate rotations under the anterior component of the annular ligament during active/passive pronation and supination of the forearm **(Video 22, http://links.lww.com/PHM/B491)**.

Clinical Indications

The lateral complex: during active/passive pronation and supination of the forearm, it is possible to push the intra-articular effusion towards the lateral recess of the elbow - better defining an injury of the radio-humeral synovial plica **(Video 23, http://links.lww.com/PHM/B492)** or of the RCL **(Video 24, http://links.lww.com/PHM/B493)**. Herein, the synovial fluid can serve as a native contrast agent whereby active/passive movements of the elbow will shift the contrast agent into the area to be evaluated. Further, injuries of the RCL/LUCL-AL complex are often related with mild, multi-directional, dynamic subluxation of the radial head during elbow movements **(Video 24, http://links.lww.com/PHM/B493)** which can lead to progressive damage of the cartilaginous surfaces. [47]

The dynamic technique can also be used to promptly evaluate an abnormal protrusion of the RCL/LUCL-AL-synovial plica complex between the bony surfaces of the radio-humeral joint **(Video 25, http://links.lww.com/PHM/B494)** i.e. intra-articular impingement with possible snapping or blocking. [7,37] In patients with high-energy trauma of the elbow, the authors suggest evaluating the lateral compartment in full extension. Yet, the extensor carpi radialis longus muscle acts as a “shock absorber” between the probe and the lateral structures - reducing the maneuver-related pain and improving the visualization of different acoustic interfaces **(Video 26, 27, http://links.lww.com/PHM/B495, http://links.lww.com/PHM/B496)**. Finally, the US-guided Cozen’s test should always be performed during dynamic assessment of the lateral elbow. This is because active contraction of the extensor muscles stretches the CET and allows the synovial fluid to flow in the lateral recess of the joint - helping better evaluation of the RCL/LUCL-AL-synovial plica complex **(Video 28, http://links.lww.com/PHM/B497)**.

Annular ligament disorders: as previously mentioned for dynamic assessment of the posterolateral portion of the annular ligament via the radioulnar window, it is possible to evaluate the more anterior portion of the AL starting from the CET window [51] and rotating the probe 90 degrees **(Video 22, http://links.lww.com/PHM/B491)**. During active/passive pronation and supination of the forearm, abnormal gliding or painful snapping of the AL over the radial head may be observed due to several disorders like post-traumatic or congenital deformation of the radial head, nodular thickening or hypertrophic scarring of the ligament and its calcifications or, rheumatic disorders **(Video 29, http://links.lww.com/PHM/B498)**. [37]

2. Brachioradialis Muscle Window

Technique

With the elbow positioned over the examination bed in flexion and the forearm in full supination, proximal to distal or distal to proximal sono-tracking of the extensor muscles is performed until the DBBT is visualized deep to the brachioradialis muscle. [2,17,54] Of note, using the lateral approach, the insertional segment of the DBBT attaching to the radial tuberosity is not visible as it is located on the medial side of radius **(Figure 2D)**. Active/passive pronation and supination of the forearm will allow the examiner to dynamically evaluate the anatomical integrity and the gliding of the DBBT - coupled with rotational movements of the radius **(Video 30, http://links.lww.com/PHM/B499)**.

If the dynamic maneuver is performed using active forearm movements, contraction and relaxation of the supinator muscle - which wraps the radius - can also be evaluated. There is a small fibrofatty pad normally located between the supinator and brachioradialis muscles (inside the inter-fascial planes) and, during dynamic imaging, it generates an acoustic shadow over the DBBT. [54] Although this hypoechoic zone is easily observed to be not moving with tendon gliding, it should still not be misinterpreted as focal tendinosis **(Video 30, http://links.lww.com/PHM/B499)**.

The DBBT appears thicker with regular fibrillar pattern during supination, but thinner and hypoechoic during pronation **(Video 30, http://links.lww.com/PHM/B499)**. These sonographic features are related with the variation of the spatial orientation of the tendon during dynamic assessment as well as with the variable exposure to the US beam arriving from the lateral elbow. In this zone, small branches of the radial recurrent artery are also/normally located in the triangular space bounded by the brachioradialis muscle, the DBBT and the supinator muscle. Lastly, slowly shifting the probe more cranially, dynamic assessment of the distal myotendinous junction of the biceps brachii can be performed during active/passive forearm pronation and supination **(Video 31, http://links.lww.com/PHM/B500)**.

Clinical Indications

The DBBT: active/passive pronation and supination of the forearm can be used to stretch the DBBT - observing how a specific segment of the tendon reacts to the motions. In this sense, the dynamic maneuver opens the gap between the proximal and distal stumps in case of a complete pre-insertional tear or retracts the tendon proximally in case of distal avulsion from the radial tuberosity. [54] Herein, in some patients, the presence of lacertus fibrosus may prevent proximal retraction of the stump/tendon - making the diagnosis of complete pre-insertional tear or distal avulsion quite challenging without dynamic assessment. [55] Moreover, focal thickening of the DBBT can be seen due to focal tendinosis, calcification, fibrous scar and surgical repair. Painful snapping of the tendon within the surrounding muscles, fasciae and bones may also accompany the clinical scenario. Likewise, the aforementioned dynamic technique can also be used to evaluate a possible mechanical impingement. Of note, the authors suggest coupling the brachioradialis muscle window with the flexor-pronator muscles window in each and every patient to fully and dynamically evaluate the DBBT until the insertional segment over the radial tuberosity. Lastly, since the dynamic technique can squeeze the bicipitoradial bursa between the radius and the DBBT; in patients with bursal effusion, the ventral portion of the bursal cavity protruding behind the bony surface can also be observed **(Figure 2D)**. [54]

MEDIAL ASPECT

1. Humeroulnar Window

Technique

In supine (or sitting) position, with the upper limb in external rotation, shoulder in abduction, elbow in flexion and forearm in full supination; [56] the UCL can be visualized with well-defined margins, optimal echogenicity, internal fibrillar echotexture and taut position. [57] After positioning the proximal edge of the probe over the medial epicondyle, gentle pivoting of the distal edge ('windshield wiper' technique) is necessary to obtain clear visualization of the anterior bundle of UCL which is located deep to the flexor/pronator muscles and inserts on the sublime tubercle of the proximal ulna. [56,57] Using the same technique, the humeroulnar joint and its synovial recess can be promptly identified under the ligamentous plane **(Figure 2E)**. [1,2] Moreover, a small intra-articular fat pad can be observed between the ligament and the joint cleft. [58]

The authors suggest performing the dynamic evaluation in three different phases firmly maintaining the probe over the anterior bundle of the UCL as follows **(Video 32, http://links.lww.com/PHM/B501)**:

i) during the first phase, the physician supports the forearm of the patient to evaluate the joint and peri-articular soft tissues in static view

ii) during the second phase, the examiner removes the support to evaluate how the anterior bundle of the UCL and the humeroulnar joint react to gravity. In some patients, the second phase is enough to evoke pain and observe pathological US findings **(Video 33, http://links.lww.com/PHM/B502)**

iii) during the third phase, the sonographer may apply valgus stress **(Video 34, http://links.lww.com/PHM/B503)** to stretch the UCL and open the humeroulnar joint gap **(Figure 2E)**. [56,59]

All the three phases can be performed by a single operator since the patient's shoulder and proximal arm lie over the examination bed stabilizing the entire upper limb. Herein, while one hand of the operator is used to manage the probe, the other one is used to handle the patient. Lastly, 70 degrees of elbow flexion can be considered as an optimal angle to visualize the anterior bundle of the UCL in static view [57] and as a starting position for dynamic view. However, the authors suggest performing the valgus stress at different angles (30 - 90 degrees) of elbow flexion to unlock the olecranon from the fossa and to dynamically evaluate the anatomical structures of the medial elbow. [56]

Clinical Indications

Instability of the medial elbow: during different phases of dynamic assessment, peculiar sonographic findings may be visualized in patients with medial elbow pain and clinical findings of medial instability. Partial/complete injury of the anterior bundle of the UCL, diastasis of the humeroulnar joint, [56,60] leakage of the intra-articular effusion into the medial capsular recess **(Video 35, http://links.lww.com/PHM/B504)** and herniation inside the articular cleft of the intra-capsular fat pad are some of the most common findings. Leakage of fluid between the distal insertion of the UCL and the cortex of ulna (T-sign) may be visualized in patients with partial insertional injury of the UCL as well as in asymptomatic athletes (i.e. adaptive change). [61] Finally, medial elbow instability can be associated with transient vacuum phenomenon generating hyperechoic microfoci (gas bubbles) moving from the deep portion of the humeroulnar joint towards the superficial side. [62]

2. Flexor-Pronator Muscles Window

Technique

With the elbow flexed to 90 degrees and the forearm fully supinated, a medial approach can be used to visualize the DBBT in long-axis view i.e. flexor-pronator musculature acoustic window. [2,63] Unlike the lateral side (brachioradialis muscle window), the medial approach allows complete visualization of the insertional segment of the DBBT over the radial tuberosity **(Figure 2F)**. [17,22,63]

The authors suggest performing the dynamic evaluation in two different phases firmly maintaining the probe over the DBBT as previously mentioned: [55]

i) during the first phase, active/passive pronation and supination of the forearm can be performed to evaluate the rolling movements of the radius coupled with the tensioning movements of the tendon **(Video 36, http://links.lww.com/PHM/B505)**
ii) during the second phase, the examiner blocks the distal third of the forearm and the patient tries to flex the elbow - putting the biceps brachii muscle-tendon unit in tension.

Repositioning the probe from an oblique longitudinal view to a transverse scan of the proximal third of the forearm, it is possible to assess dynamically the proximal radio-ulnar tunnel at the level of the radial tuberosity **(Video 37, http://links.lww.com/PHM/B506)**. [22]

Clinical Indications

The insertional segment of the DBBT: due to the deep location and curved course of the DBBT, the differential diagnosis between focal tendinosis vs. tear may often be tricky, especially for the more distal segment of the tendon. In this sense, stress test of the DBBT may be performed under real-time US guidance while combining the two aforementioned phases of the dynamic technique. [55] Dynamic assessment of the DBBT using this window is useful to evaluate partial or complete avulsions of the tendon from the radial tuberosity **(Video 38, http://links.lww.com/PHM/B507)**. [55] For instance, the dynamic examination can show an unstable bony fragment originating from the radial tuberosity and surgery might be needed. On the other hand, patients with detached fibers from the radial footprint would be eligible for conservative treatment. [55]

Peri-tendinous structures: especially during the first phase of the dynamic maneuver, the bicipitoradial bursa is squeezed and released between the DBBT and the surrounding tissues. [24] As such, dynamic assessment can be useful to characterize the sono-histological pattern of the bursal pathology e.g. hypertrophic bursitis with synovial proliferations floating inside the cavity, exudative bursitis with a thin wall and intra-bursal loose body. [64] Of note, the brachial artery normally runs superficial to the DBBT [63] and should not be misinterpreted as a pathological, peri-tendinous fluid collection. Therefore, the authors suggest routine use of Doppler imaging to better characterize the effusions surrounding the DBBT. [64]

Proximal radio-ulnar tunnel: active/passive pronation and supination of the forearm **(Video 37, http://links.lww.com/PHM/B506)** can be performed to evaluate impingement at the level of the proximal radio-ulnar space. [22] As previously mentioned for the radial tuberosity window, several pathological conditions of the DBBT can lead to irregular passage of the tendon between the radius and ulna. [19] In addition, post-traumatic or congenital dysmorphism of the radius/ulna can result in mechanical block at the level of the proximal radio-ulnar space. Accordingly, the authors suggest combining the dorsal and medial approaches for prompt dynamic examination of this (complex) anatomical compartment of the elbow i.e. proximal radioulnar tunnel.

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Figure Legends

Figure 1

Schematic drawings show dynamic assessment of the radial/coronoid fossa anteriorly **(A)**, and the olecranon fossa posteriorly **(B)**. Flexion and extension are paramount to fully evaluate the interactions between the intra-articular effusion *(black arrow)*, synovial cavity *(light blue)* and the extra-synovial intra-capsular fat pad *(yellow)*. For instance, an intra-articular cartilaginous loose body *(white asterisk)* - located at the level of the olecranon fossa, in the proximal pouch of the dorsal capsule *(red arrowhead)* - can be dynamically evaluated during elbow extension to check for an eventual impingement with the olecranon and/or the intra-capsular fat pad *(yellow dotted line)* **(C)**. Three-dimensional renderings show the dynamic evaluations of the distal biceps brachii tendon *(white)* **(D)** and radiocapitellar joint **(E)** during active/passive pronation and supination *(red arrow)* of the forearm, and of the cubital tunnel **(F)** during flexion of the elbow triggering dynamic slipping of the ulnar nerve (UN) *(red)* over the bony surface of the medial epicondyle *(yellow)*.

AL: annular ligament, black asterisks: annular recess, white arrowheads: proximal radio-ulnar tunnel/space, orange: radio-humeral synovial plica, blue: Osborne's ligament/retroepicondylar retinaculum, green: arcuate ligament, FCU: flexor carpi ulnaris muscle

Figure 2

A three-dimensional rendering shows possible locations for an intra-articular loose body *(white)*, a post-traumatic bony fragment *(black dotted line)* and an extra-articular heterotopic ossification *(grey)* causing posteromedial impingement of the elbow **(A)**. Schematic drawings show dynamic assessment of the proximal radioulnar joint and posterolateral humeroulnar joint during pronation/supination *(curved double arrow)* or application of stress forces *(red arrows)* **(B)**, of the common extensor tendon *(grey)*, radial collateral ligament/lateral ulnar collateral ligament *(red)* and radio-humeral synovial plica *(yellow)* **(C)**, of the pre-insertional segment of the DBBT *(white)* **(D)**, of the ulnar collateral ligament *(green)* **(E)** and of the insertional portion of the DBBT *(white)* **(F)**.

Light blue: synovial cavity, UN: ulnar nerve, SC: supinator crest, st: supinator tubercle, orange: lateral ulnar collateral ligament, AL: annular ligament, BRb; bicipitoradial bursa

Video Legends

Video 1

A small amount of intra-articular effusion is pushed inside the coronoid fossa during passive flexion/extension of the elbow.

Video 2

Dynamic assessment shows the articular effusion which displaces the intra-capsular, extra-synovial fat pad at the level of the coronoid fossa. Additionally, progressive accumulation of fluid inside the anterior compartment also induces bulging of the articular capsule deep to the brachialis muscle.

Video 3

In patients with chronic osteoarthritis of the elbow, the dynamic maneuver allows visualization of the hypertrophic synovial villi floating inside the joint cavity. Note the stabilizing peduncle in continuity with the capsule-synovial wall of the joint.

Video 4

Dynamic evaluation shows the synovial fluid slipping inside the focal defect of the anterior lobe of the radio-humeral synovial plica. Note the multiple hyperechoic gas bubbles in the effusion.

Video 5

During passive elbow extension, the olecranon rolls into the corresponding fossa and the articular effusion bulges the posterior capsule – superficially displacing the intracapsular extra-synovial fat pad.

Video 6

In the first phase of the maneuver, active extension of the elbow pushes the articular effusion towards the posterior compartment (bulging the capsule). In the second phase, active flexion increases the pressure and enhances the floating movements of the hypertrophic synovial villi.

Video 7

Dynamic imaging shows normal gliding of the distal biceps brachii tendon through the proximal radioulnar tunnel during passive forearm pronation/supination.

Video 8

During passive pronation and supination of the forearm (using the longitudinal acoustic window), proximal and distal facets of the radial tuberosity as well as the overlying tendons of the long and shorts head of the biceps brachii muscle are visualized. Note the thin hyperechoic septum in the two bundles.

Video 9

Passive pronation and supination of the forearm show physiological movements of the posterior lobe of the radio-humeral synovial plica which shifts in and out of the articular cleft gently touching the cartilaginous surfaces. The radial head remains strictly aligned with the capitulum humeri during the dynamic assessment without any sign of instability e.g. anterior or posterior translations.

Video 10

Deformation of the radial head, severe hypertrophic synovitis of the radiocapitellar joint and complete disruption of the posterior lobe of the radio-humeral synovial plica can be observed in this patient with rheumatoid arthritis.

Video 11

Dynamic maneuver shows shifting of the ulnar nerve from the cubital tunnel over the apex of the medial epicondyle (transient subluxation or 'purched' ulnar nerve).

Video 12

During dynamic assessment of the posteromedial elbow, the ulnar nerve fully shifts in and out of the cubital tunnel (complete luxation or 'snapping' ulnar nerve).

Video 13

Dynamic assessment by moving/tilting the probe medial to lateral without any elbow flexion/extension shows persistent snapping of the ulnar nerve within the muscle flap after an anterior transposition surgery for cubital tunnel syndrome. This particular sonographic finding provides better understanding of the scenario - further guiding the clinical/surgical approach.

Video 14

From distal to proximal sono-tracking of the ulnar nerve shows a peri-articular irregular heterotopic ossification (contacting the ulnar nerve) as a possible cause of posteromedial impingement.

Video 15

Dynamic scanning of the proximal radioulnar joint shows regular rolling of the radial head inside the radial notch of the ulna without mechanical impingements, normal gliding of the annular ligament over the radial head without snapping phenomenon and physiological alignment of the two bones without abnormal (anterior or posterior) shifts of the radial head with respect to ulna.

Video 16

Passive pronation and supination of the forearm are performed to (de)tension the lateral ulnar collateral ligament that is located between the anconeus muscle and the proximal radioulnar space - also surrounded by the peri-ligamentous fat tissue. Note the histological continuum between the lateral ulnar collateral ligament and the annular ligament in proximity of the radial head.

Video 17

Normally, the sonographic posterolateral rotatory stress test shows a stable humeroulnar joint without diastasis of the articular cleft or abnormal protrusion of the intracapsular fat pad between the articular surfaces.

Video 18

Normally, the lateral stabilizing structures of the elbow (common extensor tendon, radial collateral ligament/lateral ulnar collateral ligament and annular ligament) allow minor movements of the radial head with respect to humerus during dynamic imaging. The synovial fluid is also confined inside the articular cleft without leakage.

Video 19

During sonographic Cozen's test (active extension of the wrist against distal resistance) the CET becomes tense allowing better evaluation of its anatomical integrity. While resting, it presents a concave superior margin and during resistance it shows a convex superior edge. Also note the spur at the proximal attachment (asymptomatic in this case) which can be commonly painful in lateral epicondylitis.

Video 20

Extending the elbow, muscle belly of the extensor carpi radialis longus can be used as an acoustic window to optimize the dynamic evaluation of the lateral stabilizing structures during active/passive pronation and supination of the forearm.

Video 21

Shifting the probe medial to lateral and vice versa; different components of the lateral complex and the corresponding insertional facets can be panoramically evaluated.

Video 22

The regular rolling of the radial head deep to the anterior portion of the annular ligament can be evaluated during active/passive pronation and supination of the forearm. Extensor carpi radialis longus and brachioradialis are the two muscles visible at this level.

Video 23

During active pronation and supination of the forearm, the synovial fluid is pumped into the lateral recess of the elbow - suggesting injury of the radio-humeral synovial plica and the deep fibers of the radial collateral ligament.

Video 24

During pronation and supination of the forearm, the intra-articular effusion is moving towards the deep surface of the lateral complex - suggesting proximal avulsion of the radial collateral ligament from the bony footprint. Of note, this condition can be associated with instability of the radio-humeral joint whereby the floating lateral complex can transiently be pinched between the bony surfaces - causing painful snapping of the lateral elbow.

Video 25

The dynamic technique takes advantage of the articular effusion as a natural contrast agent to show abnormal location of the annular ligament floating between the bony surfaces of the radio-humeral joint. This condition might ensue secondary to an injury of the distal portion of the lateral complex - possibly leading to intra-articular impingement of the elbow with painful snapping.

Video 26

After high-energy trauma, dynamic imaging in full elbow extension with passive pronation and supination of the forearm shows severe disruption of the anterior portion of the lateral complex. Note the presence of only some fibers of the anterior bundle of the RCL deep to the extensor carpi radialis longus muscle - suggesting a subtotal injury. Irregular shape of the radial head may be related with a fracture - necessitating further imaging.

Video 27

Different layers of the lateral complex and its attachment site over the lateral epicondyle are no longer recognizable due to severe hypertrophic synovitis of the lateral compartment of the radiocapitellar joint in a patient with psoriatic arthritis.

Video 28

The synovial fluid moving from the deep compartment of the radio-humeral joint to the deep surface of the lateral complex (during sonographic Cozen's test) suggests severe injury of the lateral complex. Of note, static ultrasound assessment is not always sufficient to fully identify injuries of the deep layers of the lateral complex.

Video 29

Irregularities of the radial head and severe distension of the annular ligament-annular recess complex is dynamically evaluated in a patient with rheumatoid arthritis. Of note, the surrounding muscles (extensor carpi radialis longus and brachioradialis) present advanced fibrotic involution.

Video 30

The gliding of the DBBT (during active/passive pronation and supination of the forearm) can be dynamically evaluated using a lateral approach through the brachioradialis muscle. Tensioning the tendon fibers and stretching the pathological segment, this can be particularly useful to better discriminate focal tendinosis vs. tear.

Video 31

Using the lateral approach, dynamic evaluation of the distal myotendinous junction of the biceps brachii muscle can be performed during active pronation/supination of the forearm.

Video 32

The three different phases of the dynamic technique using the humeroulnar window.

Video 33

Simply applying gravity to the elbow, it is possible to stretch the anterior bundle of the UCL, opening the humeroulnar joint and evoking medial elbow pain in a young patient with congenital laxity. No articular effusion is visible in the medial recess during the dynamic assessment.

Video 34

Normally, no diastasis of the articular cleft between the humerus and the ulna is visible during the third phase of the dynamic maneuver applying valgus stress to the elbow.

Video 35

Under valgus stress, the humeroulnar joint is stable but there is small leakage of the articular effusion inside the medial recess - displacing the intra-capsular fat pad.

Video 36

Dynamic assessment of the insertional segment of the DBBT - using a medial approach - shows structural continuity of the tendon (without any injury, retraction or fluid) until the distal attachment over the radial tuberosity.

Video 37

During passive pronation and supination of the forearm, regular rolling of the radius can be observed with no pathological findings at the level of the proximal radio-ulnar tunnel.

Video 38

Dynamic assessment of the DBBT - using the flexor-pronator muscles window - shows complete avulsion of the tendon from the radial tuberosity. Note that some tendon fibers are still anchored to the radial tuberosity but they do not result in mechanical impingement inside the proximal radio-ulnar tunnel during pronation and supination.

Figure 1

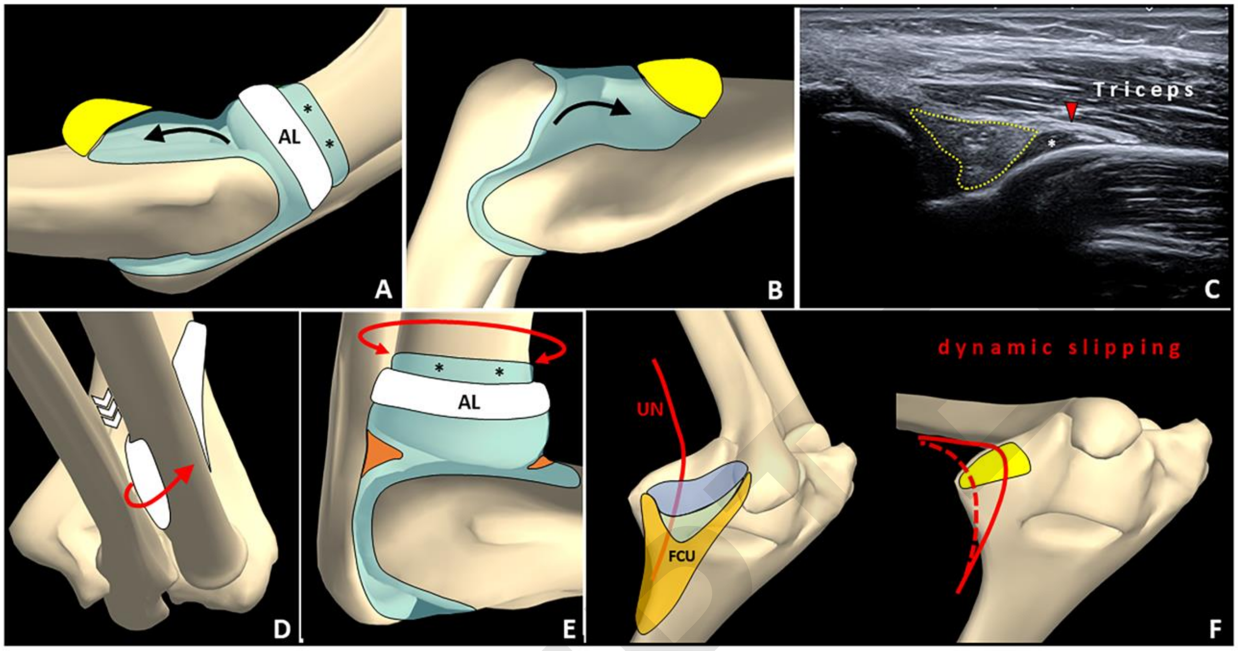
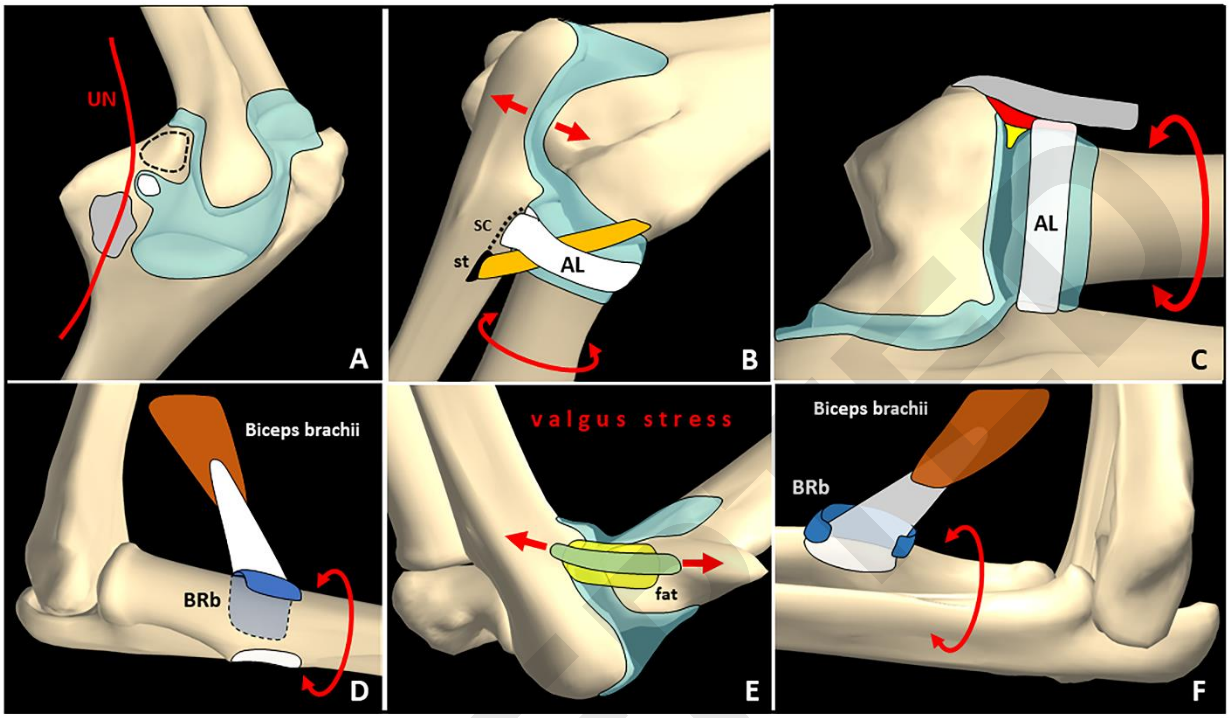


Figure 2


UN
A
sc
st
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C
Biceps brachii
BRb
D
valgus stress
fat
E
Biceps brachii
BRb
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