JB&JS OPEN ACCESS

Computer-Assisted Surgical Anatomical Mapping of the Antebrachial Cutaneous Nerves

An Anatomical Study with a Proposition for Alternative, Cutaneous Nerve-Sparing Anterior Elbow Incisions

Lisette C. Langenberg, MD, Alexander R. Poublon, MD, PhD, Lieke Hofman, BSc, Gert-Jan Kleinrensink, MSc, PhD, and Denise Eygendaal, MD, PhD

Investigation performed at the Department of Orthopaedic Surgery and Sports Medicine and Department of Neuroscience-Anatomy, Erasmus University Medical Center, Rotterdam, The Netherlands

Background: It is common practice to assess the distance from nerves to anatomical structures in centimeters, but patients have various body compositions and anatomical variations are common. The purpose of this study was therefore to assess the relative distance from cutaneous nerves around the elbow to surrounding anatomical landmarks by providing a stacked image that displays the average position of cutaneous nerves around the elbow. The aim was to research possibilities for adjusting common skin incisions in the anterior elbow so that cutaneous nerve injury may be avoided.

Methods: The lateral antebrachial cutaneous nerve (LABCN) and medial antebrachial cutaneous nerve (MABCN) were identified in the coronal plane around the elbow joint in 10 fresh-frozen human arm specimens. Marked photographs of the specimens were analyzed using computer-assisted surgical anatomical mapping (CASAM). Common anterior surgical approaches to the elbow joint and the distal humerus were then compared with merged images, and nerve-sparing alternatives are proposed.

Results: The arm was divided longitudinally, from medial to lateral in the coronal plane, into 4 quarters. The LABCN crossed the central-lateral quarter of the interepicondylar line (i.e., was somewhat lateral to the midline at the level of the elbow crease) in 9 of 10 specimens. The MABCN ran medial to the basilic vein and crossed the most medial quarter of the interepicondylar line. Thus, 2 of the quarters were either free of cutaneous nerves (the most lateral quarter) or contained a distal cutaneous branch in only 1 of 10 specimens (the central-medial quarter).

Conclusions: The Boyd-Anderson approach, which is often used to access anteromedial structures of the elbow, should be placed slightly further medially than traditionally advised. The distal part of the Henry approach should deviate laterally, so that it runs over the mobile wad. In distal biceps tendon surgery, the risk of cutaneous nerve injury may be reduced if a single distal incision is placed slightly more laterally (in the most lateral quarter), as in the modified Henry approach. If proximal extension is required, LABCN injury may be prevented by using the modified Boyd-Anderson incision, which runs in the central-medial quarter.

Clinical Relevance: Cutaneous nerve injury may be prevented by slightly altering the commonly used skin incisions around the elbow on the basis of the safe zones that were identified by depicting the cumulative course of the MABCN and LABCN using CASAM.

The courses of the cutaneous nerves around the elbow are known to vary among individuals[1,2]. These nerves are at risk for sharp dissection or traction neurapraxia during surgical procedures. Painful neuromas may form, and elbow range of motion may even be affected[3,4].

The lateral antebrachial cutaneous nerve (LABCN) is a superficial terminal branch of the musculocutaneous nerve that emerges from underneath the lateral side of the biceps tendon. It is responsible for the sensory innervation of the lateral radial side of the forearm[5]. The medial antebrachial cutaneous nerve (MABCN) emerges from the brachialis fascia[2] and runs medial to the basilic vein at the level of the medial epicondyle[6]. These cutaneous nerves are at risk for transection or neurapraxia due to traction in several surgical procedures. It would therefore be

Disclosure: The **Disclosure of Potential Conflicts of Interest** forms are provided with the online version of the article (http://links.lww.com/JBJSOA/A522).

useful to identify a "safe zone" free of cutaneous nerve branches that can be utilized to reduce the risk of iatrogenic cutaneous nerve injury.

Several previous studies have described the distance between the nerves and anatomical landmarks in centimeters[2,7], which may not be accurate for patients with different body compositions. A cohort study of patients who underwent distal biceps tendon repair identified obesity as a risk factor for postoperative LABCN neurapraxia because anatomical exposure and protection of this delicate cutaneous nerve were complicated by the subcutaneous tissue[8]. It would therefore be very useful to provide surgeons with a map of safe zones that are based on the relative distance to anatomical landmarks, rather than the absolute distance in centimeters, and can therefore be applied to any patient.

Computer-assisted surgical anatomical mapping (CASAM) merges multiple 2-dimensional photographs into a single image and takes 3-dimensional structures into account[9,10]. It has proven to be a reliable technique for depicting the course of small cutaneous nerves around the wrist[11], knee[12], and lower leg[9]. Warping marked pictures of anatomical specimens allows the relative distance from anatomical structures to landmarks to be assessed, and safe zones with the least likelihood of containing superficial nerves may be identified.

The present study used CASAM to depict the variable courses of the LABCN and MABCN in the coronal plane around the elbow joint. The goal was to merge several images of human specimens and depict the relative distances from the nerves to several landmarks around the elbow joint in a heat map that may be applied to any individual patient, and then identify potential safe zones for surgical approaches to the elbow joint and the distal humerus. Two optimizations of traditional approaches to the anterior distal humerus will be proposed, and options for incisions used in distal biceps tendon surgery will be discussed.

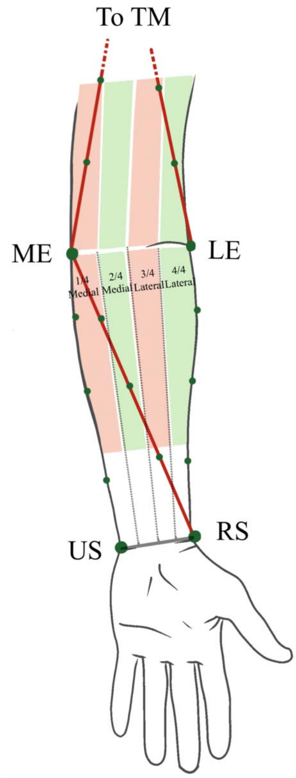

Fig. 1
Schematic view of a specimen. Each specimen was photographed in the coronal plane in full supination. The arm was then divided into 4 quarters (red and green areas) by dividing the line between the radial styloid (RS) and ulnar styloid (US), the interepicondylar line (between the medial epicondyle [ME] and the lateral epicondyle [LE]), and the proximal end of the specimen into quarters. Dark green dots and red lines indicate markers that were placed to enable grid formation in Magic Morph. TM = tuberculum minus.

Materials and Methods

Ten human arm specimens that included the hand and the humeral bone were fixed using AnubiFiX. Anatomical preparation was performed by 2 authors (A.R.P. and L.H.), and 2 authors (A.R.P. and L.C.L.) then marked nerves, veins, the biceps tendon, and landmarks for CASAM analysis.

We chose to use landmarks that are visible to the surgeon while preparing the patient for surgery. Markers were placed on the lateral epicondyle (LE), radial styloid (RS), and lesser tuberosity of the humerus (tuberculum minus, TM). The elbows were extended with the lower arm supinated, as the patient would be positioned for reconstruction of the distal biceps tendon (Fig. 1). Lines were drawn between the osseous landmarks and divided into equal proportions (green dots in Fig. 1) to allow creation of a grid during processing of the photographs in CASAM. The grid allows the program to respect curves and relief when building a 3-dimensional surface model[9].

A reproducible setup was used for photographing all arms. A digital camera (Nikon D with Sigma 50 mm 1:2.8 DG MACRO lens) was fixed on a tripod at a distance of 100 cm from the specimen. Test photographs of a checkered surface were made prior to specimen photography to confirm that there was no distortion effect.

Three-dimensional warping was performed using Magic Morph (version 1.95; EffectMatrix), and image analysis was performed in Photoshop CS4 (Adobe). First, the courses of the LABCN, MABCN, nearby veins such as the medial antebrachial vein and the cubital vein, and the distal biceps tendon in each image were drawn onto the image in a separate layer using a digital stylus pen (Figs. 2-A and 2-B). The 10 individual images containing an exact copy of the nerves were then stacked, and these layers were combined into a single heat map presenting an overview of anatomical structures (Fig. 3-A). The arm was divided longitudinally, from medial to lateral in the coronal plane, into 4 quarters as shown in Figure 1, and the positions of the nerves were assessed at the level of the elbow crease (as they crossed the interepicondylar line, a line connecting the medial and lateral epicondyles).

Source of Funding
No external funding was received for this study.

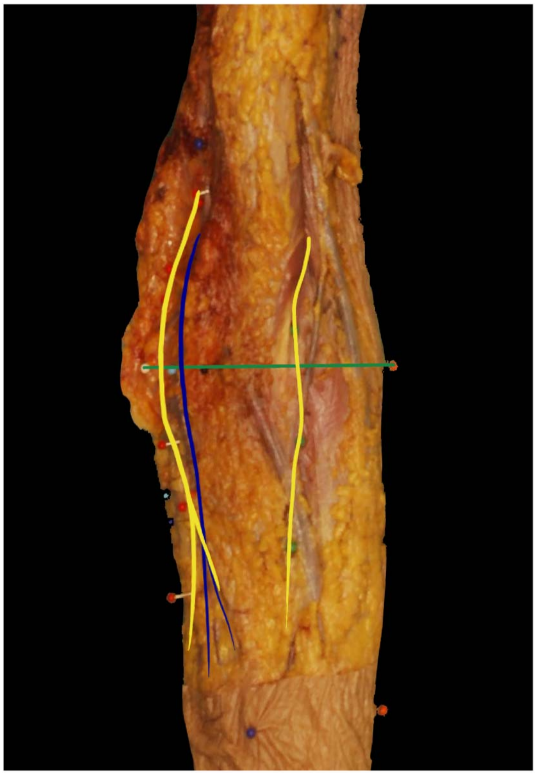

Fig. 2-A

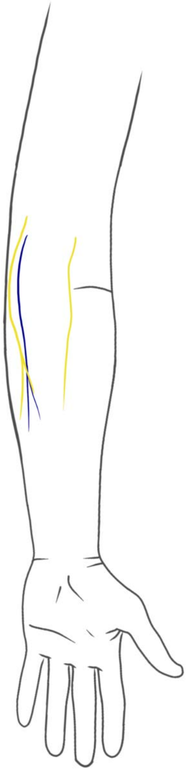

Fig. 2-B

Fig. 2-A Photograph showing a representative specimen. The MABCN is indicated with red pins, and the LABCN is indicated with green pins. The green line is the interepicondylar line. The yellow lines indicate the LABCN and MABCN, and the blue line indicates the basilic vein. **Fig. 2-B** Digital depiction of the LABCN and MABCN of the same specimen after the image has been warped using Magic Morph. The MABCN was found to run medial to the basilic vein in all specimens.

Results

The LABCN and MABCN could be identified in all 10 specimens (Figs. 3-A and 3-B).

The LABCN originated from underneath the lateral distal biceps tendon in all specimens, and it bifurcated distal to the elbow crease in 2 specimens. A pattern could be seen in which the course of the LABCN was lateral to the medial cubital vein proximally and medial to the cephalic vein distally. The LABCN crossed lateral to the midpoint of the interepicondylar line in 9 of the 10 specimens.

The MABCN ran medial to the basilic vein and crossed the most medial quarter of the interepicondylar line in all specimens.

Figure 3-A shows the merging of all specimens into a single file using CASAM. A safe zone can be seen in the most lateral quarter at the level of the elbow crease, and a relatively safe zone can be seen in the central-medial quarter, as shown in Figure 3-B.

Discussion

This study focused on the small cutaneous nerves around the elbow and used CASAM to analyze their courses in 10 human specimens. The results indicate that subtly shifting the commonly used skin incisions by several millimeters may reduce the risk of damaging the small cutaneous nerves surrounding the elbow. Deeper dissection, below the subcutaneous fat, remains unaltered.

Henry Anterior Distal Humeral Approach

The Henry approach uses the "mobile wad" (MW in Fig. 4-A) as a landmark. The mobile wad is a palpable mobile muscle mass, formed by the extensor muscles of the wrist and hand, on the proximal lateral side of the lower arm. The skin incision then progresses proximally along the lateral border of the biceps tendon and muscle—"a slender fingerbreadth lateral to the edge of the biceps," as Henry stated. There is a high risk of incising or placing traction on the LABCN[13] (Fig. 4-A). In a retrospective study, numbness, tingling, or pain around the scar was reported by 62% of 40 patients following surgery using an anterolateral Henry approach to the humerus[14]. Henry, too, acknowledged that "surgeons will take a pride in rescuing the lateral cutaneous twig of musculocutaneous which runs in surface fat."[13]

The Henry approach may be modified to prevent LABCN injury by deviating the distal part of the skin incision laterally, over the mobile wad. After starting proximally and running lateral to the lateral border of the biceps muscle, it should deviate laterally when crossing the elbow crease (Fig. 4-A). The

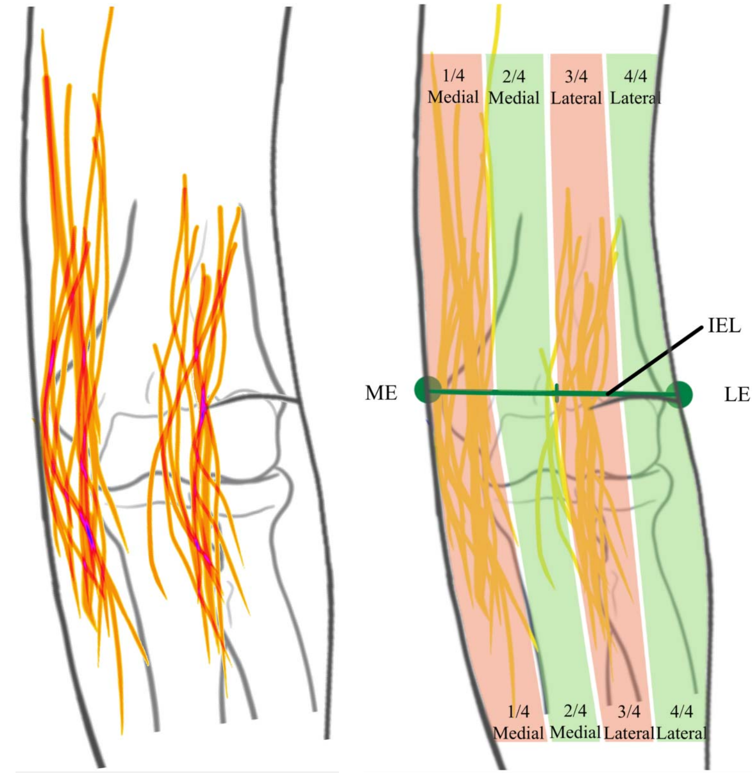

Fig. 3-A Fig. 3-B

Fig. 3-A Heat map showing the LABCN and MABCN positions in a coronal view of a right elbow. Yellow indicates 1 nerve; orange, 2 overlapping nerves; red, 3 overlapping nerves; and blue, 4 overlapping nerves. Nine of the 10 LABCNs can be seen to cross the elbow crease lateral to the midline. **Fig. 3-B** Coronal view showing a right elbow divided into 4 quarters. Relative safe zones can be seen in the central-medial (2/4) quarter and in the most lateral (4/4) quarter. As in Figure 1, the green line is the interepicondylar line (IEL) connecting the lateral epicondyle (LE) and medial epicondyle (ME).

internervous plane between the brachialis and brachioradialis muscles should still be reachable if the lateral deviation is not commenced too proximally. This incision may be advantageous in approaching complex fractures of the capitellum or trochlea of the distal humerus[15].

Boyd-Anderson Anterior Distal Humeral Approach

The LABCN is encountered between the brachialis muscle and the distal biceps tendon[16] in the traditional anterior Boyd-Anderson approach to the distal humerus[17]. The s-shaped skin incision that is made to access the anterior aspect of the humerus may be extended distally and medially to approach the coronoid, lacertus fibrosus, and median nerve (Fig. 4-B). The risk of encountering a cutaneous nerve is high, especially around the elbow crease.

A modified Boyd-Anderson approach should ideally be placed slightly further medially (Fig. 4-B). Medial structures such as the coronoid, lacertus fibrosus, median nerve, and medial side of the distal humerus may be reached by an incision that starts proximally over the biceps muscle and deviates medially when crossing the elbow crease. Distally, the incision should not cross the basilic vein, to prevent injury to the MABCN. This advice is in agreement with the findings of King and Johnston[14], who stated that the anterior approach to the distal humerus should use an incision located slightly more medially than in the traditional Henry approach.

Distal Biceps Tendon Repair

The most common complication in distal biceps tendon repair is injury to the LABCN, with reported rates of 9.2% to 30%[1,18,19]. Several options for approaching the footprint of the distal biceps on the radial tuberosity have been described. A single distal incision may start 2 fingerbreadths distal to the elbow crease[18], and it may be transverse or run longitudinally along the medial border of the mobile wad[20].

In a recent review, the rate of LABCN injury was significantly higher with an extensive approach that crossed the elbow crease proximally than with a limited anterior approach that only involved a distal incision. Transient neurapraxia was frequent, which may be attributed to traction on the nerve[1].

Based on the CASAM analysis of the LABCN in the present study, we propose slightly modified approaches. If there is no need to extend the exposure proximally, a single distal incision should be placed slightly further laterally, as in the modified Henry approach described above. The traditional interval

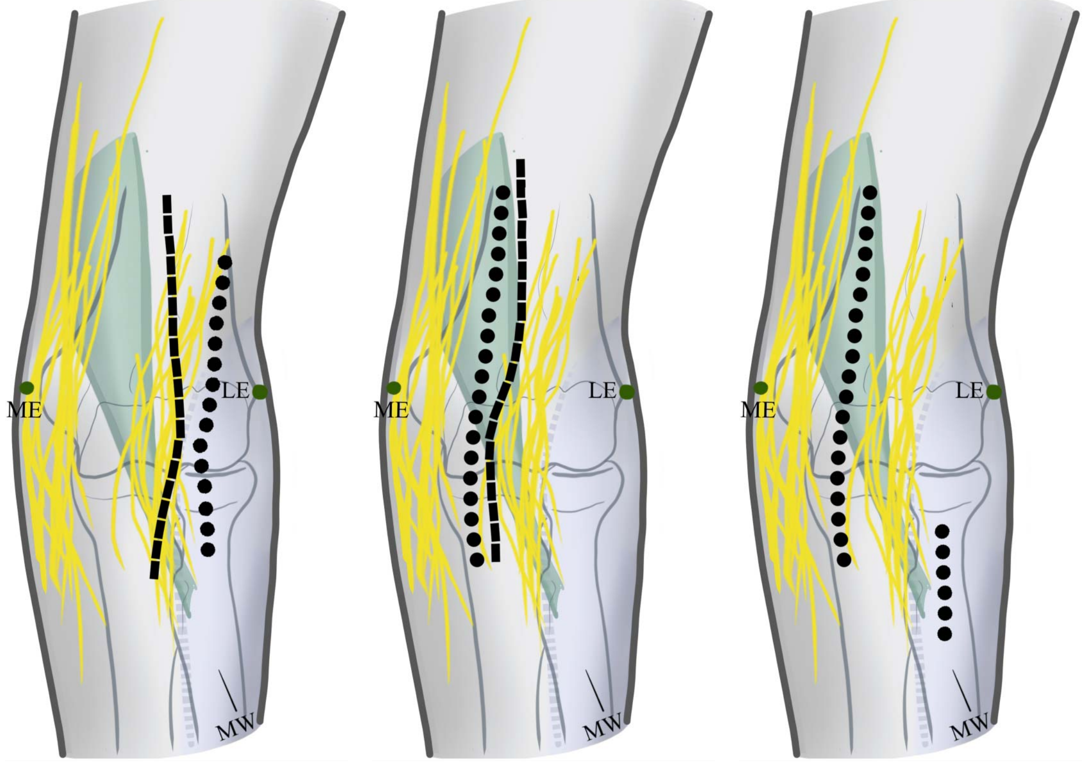

Fig. 4-A Fig. 4-B Fig. 4-C

Figs. 4-A, 4-B, and 4-C Approaches to the anterior aspects of the distal humerus and elbow joint. The cutaneous nerves in all 10 specimens (yellow) have been merged into 1 image. Traditional approaches are shown by dashed lines, and proposed nerve-sparing alternative skin incisions are shown by dotted lines. LE = lateral epicondyle, ME = medial epicondyle, and MW (gray dashed line) = mobile wad. **Fig. 4-A** The Henry approach runs between the MW and the lateral border of the distal biceps (green)[13,21]. The alternative runs slightly further laterally and curves laterally, over the mobile wad. **Fig. 4-B** The Boyd-Anderson approach[17] starts proximal and lateral to the biceps muscle, crosses the elbow crease at a non-perpendicular angle, and extends to the medial border of the biceps tendon. The alternative runs slightly further medially, but lateral to the basilic vein distally. **Fig. 4-C** Alternative incisions for distal biceps repair. If an extensive incision is needed, it should follow the same course as in Figure 4-B. If only a distal incision is used, it should lie further laterally.

between the brachioradialis and pronator teres muscles may be accessed through this modified incision. We advise against a transverse incision, as the risk of cutaneous nerve damage is high and there is no option to extend the incision if visualization of anatomical structures is insufficient.

If the exposure needs to be extended proximally, as may be the case if the tendon is retracted in a chronic injury, a single extensive Boyd-Anderson incision may be placed slightly further medially (Fig. 4-B), taking caution not to cross the basilic vein.

Conclusions

The cutaneous nerves around the elbow are at risk in several surgical procedures that involve exposure of the anterior humerus, elbow joint, or distal biceps tendon. CASAM analysis of the courses of these nerves illustrated that the LABCN ran somewhat lateral to the midline of the lower arm at the level of the elbow crease in 9 of 10 specimens. The central-medial quarter and the most lateral quarter of the arm in the coronal plane were both relatively safe, with no or almost no cutaneous nerve branches in the specimens.

We propose slight modifications to the skin incisions that are traditionally used to expose the elbow joint and distal humerus, in order to decrease the risk of cutaneous nerve injury. Deeper dissection can then proceed in the same manner as following the traditional incisions. The incision for the Boyd-Anderson approach should be placed slightly further medially than traditionally advised. The distal part of the incision for the Henry approach should deviate laterally, so that it runs over the mobile wad. The distal part of the incision for distal biceps tendon surgery should be longitudinal and slightly lateral to the border of the mobile wad. ■

Note: The authors thank Yvonne Steinvoort and Lucas Verdonschot for their technical assistance during the preparation of the elbow specimens.

Lisette C. Langenberg, MD[1]
Alexander R. Poublon, MD, PhD[1]
Lieke Hofman, BSc[2]
Gert-Jan Kleinrensink, MSc, PhD[3]
Denise Eygendaal, MD, PhD[1]

[1]Department of Orthopaedic Surgery and Sports Medicine, Erasmus University Medical Center, Rotterdam, The Netherlands

[2]Utrecht University Medical Center, Utrecht, The Netherlands

[3]Department of Neuroscience-Anatomy, Erasmus Medical Center, Rotterdam, The Netherlands

Email for corresponding author: lc.langenberg@nwz.nl

References

1. Amarasooriya M, Bain GI, Roper T, Bryant K, Iqbal K, Phadnis J. Complications After Distal Biceps Tendon Repair: A Systematic Review. Am J Sports Med. 2020 Oct;48(12):3103-11.

2. Damwan A, Agthong S, Amarase C, Yotnuengnit P, Huanmanop T, Chentanez V. Medial Antebrachial Cutaneous Nerve: Anatomical Relationship with the Medial Epicondyle, Basilic Vein and Brachial Artery. Int J Morphol. 2014;32(2):481-7.

3. Dellon AL, MacKinnon SE. Injury to the medial antebrachial cutaneous nerve during cubital tunnel surgery. J Hand Surg Br. 1985 Feb;10(1):33-6.

4. Sarris I, Göbel F, Gainer M, Vardakas DG, Vogt MT, Sotereanos DG. Medial brachial and antebrachial cutaneous nerve injuries: effect on outcome in revision cubital tunnel surgery. J Reconstr Microsurg. 2002 Nov;18(8):665-70.

5. Chang KV, Mezian K, Naňka O, Wu WT, Lou YM, Wang JC, Martinoli C, Özçakar L. Ultrasound Imaging for the Cutaneous Nerves of the Extremities and Relevant Entrapment Syndromes: From Anatomy to Clinical Implications. J Clin Med. 2018 Nov 21;7(11):457.

6. Kwon S, Bin Z, Deslivia MF, Lee HJ, Rhyu IJ, Jeon IH. Curved skin incision for Ulnar nerve transposition in Cubital Tunnel Syndrome: Cadaveric and clinical study to avoid injury of medial cutaneous nerve. Orthop Traumatol Surg Res. 2020 Jun; 106(4):757-63.

7. Wongkerdsook W, Agthong S, Amarase C, Yotnuengnit P, Huanmanop T, Chentanez V. Anatomy of the lateral antebrachial cutaneous nerve in relation to the lateral epicondyle and cephalic vein. Clin Anat. 2011 Jan;24(1):56-61.

8. Beks RB, Claessen FMAP, Oh LS, Ring D, Chen NC. Factors associated with adverse events after distal biceps tendon repair or reconstruction. J Shoulder Elbow Surg. 2016 Aug;25(8):1229-34.

9. Kerver ALA, van der Ham AC, Theeuwes HP, Eilers PH, Poublon AR, Kerver AJ, Kleinrensink GJ. The surgical anatomy of the small saphenous vein and adjacent nerves in relation to endovenous thermal ablation. J Vasc Surg. 2012 Jul;56(1): 181-8.

10. Kerver ALA, Carati L, Eilers PHC, Langezaal AC, Kleinrensink GJ, Walbeehm ET. An anatomical study of the ECRL and ECRB: feasibility of developing a preoperative test for evaluating the strength of the individual wrist extensors. J Plast Reconstr Aesthet Surg. 2013 Apr;66(4):543-50.

11. Poublon AR, Walbeehm ET, Duraku LS, Eilers PH, Kerver AL, Kleinrensink GJ, Coert JH. The anatomical relationship of the superficial radial nerve and the lateral antebrachial cutaneous nerve: A possible factor in persistent neuropathic pain. J Plast Reconstr Aesthet Surg. 2015 Feb;68(2):237-42.

12. Kerver AL, Leliveld MS, den Hartog D, Verhofstad MH, Kleinrensink GJ. The surgical anatomy of the infrapatellar branch of the saphenous nerve in relation to incisions for anteromedial knee surgery. J Bone Joint Surg Am. 2013 Dec 4;95(23): 2119-25.

13. Henry AK. Extensile Exposure. 3rd ed. Pearson Professional; 1995.

14. King A, Johnston GH. A modification of Henry's anterior approach to the humerus. J Shoulder Elbow Surg. 1998 May-Jun;7(3):210-2.

15. Yu T, Tao H, Xu F, Hu Y, Zhang C, Zhou G. Comparison of lateral approach versus anterolateral approach with Herbert screw fixation for isolated coronal shear fractures of humeral capitellum. J Orthop Surg Res. 2019 Jul 22;14(1):230.

16. Capo JT, Criner KT, Shamian B. Exposures of the humerus for fracture fixation [v.]. Hand Clin. 2014 Nov;30(4):401-14

17. Boyd HB, Anderson LD. A Method for Reinsertion of the Distal Biceps Brachii Tendon. J Bone Joint Surg Am. 1961;43(7):1041-3.

18. Savin DD, Watson J, Youderian AR, Lee S, Hammarstedt JE, Hutchinson MR, Goldberg BA. Surgical management of acute distal biceps tendon ruptures. J Bone Joint Surg Am. 2017 May 3;99(9):785-96.

19. Recordon JA, Misur PN, Isaksson F, Poon PC. Endobutton versus transosseous suture repair of distal biceps rupture using the two-incision technique: a comparison series. J Shoulder Elbow Surg. 2015 Jun;24(6):928-33.

20. Dillon MT, King JC. Treatment of chronic biceps tendon ruptures. Hand (N Y). 2013 Dec;8(4):401-9.

21. Bain GI, Mehta JA. Anatomy of the Elbow Joint and Surgical Approaches. In: Baker CL, Plancher KD, editors. Operative Treatment of Elbow Injuries. Springer New York; 2002. p 1 -27.