UNIVERZITA KARLOVA

2. lékařská fakulta

Doktorský studijní program: Kineziologie a rehabilitace

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Muskuloskeletální ultrasonografie v rehabilitačním lékařství: možnosti využití u vybraných morfologických změn na horní končetině

Musculoskeletal Ultrasound in Physical and Rehabilitation medicine: possibilities in the assessment of selected morphological changes of upper limb

Disertační práce

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Praha, 2022

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V Praze, 28.10. 2022

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Poděkování

Poděkování na prvním místě patří mému školiteli, MUDr. Kamálovi Mezianovi Ph.D., za podporu a vedení v průběhu celé spolupráce a za cenné podněty při psaní této práce. Na druhém místě děkuji za konzultace prof. MUDr. Davidu Kachlíkovi Ph.D. a za podporu a dodání odvahy. Dále děkuji mým učitelům a lékařským vzorům, kteří mě provázeli studiem a životem. Na prvním místě mému tátovi doc. MUDr. Josefu Sobotovi CSc., který svůj život zasvětil radiodiagnostickým metodám a podílel se na vzdělávání mediků a lékařů v ČR i ve světě. Dále děkuji MUDr. Hassanovi Mezianovi a as. MUDr. Janu Vackovi za odborné i lidské vedení. V neposlední řadě děkuji svému manželovi za trpělivost a podporu, a mé mámě za to, že mi věří ve všem, co dělám.

Abstrakt

Disertační práce se zabývá problematikou ultrasonografické diagnostiky a navigovaných intervenčních postupů u vybraných patologických změn na horní končetině. Vyšetření ultrazvukem přímo v ordinacích lékařů specialistů, včetně rehabilitačních lékařů, je celosvětovým trendem posledních dvou desetiletí. Mezi hlavní výhody patří možnost posouzení zjištěných patologických nálezů v přímé souvislosti s klinickým vyšetřením. Přínosem je urychlení stanovení přesné diagnózy a zahájení odpovídající léčby. Nepřímo pak klesají náklady spojené s vyšetřením jinými zobrazovacími technikami a léčbou. Cílem práce je představit diagnostické a léčebné možnosti u vybraných morfologických změn na horní končetině, včetně méně častých patologií, jako jsou například kazuistiky intramuskulárních hemangiomů, k jejichž diagnostice významně přispělo ultrazvukové vyšetření. Ultrazvuk je kromě diagnostiky využíván k navigaci intervencí, což zvyšuje bezpečnost a účinnost těchto postupů. Výzkumná část práce je zaměřena na identifikaci optimálního místa obstřiku nervus medianus při syndromu karpálního tunelu. Jedná se o prospektivní, randomizovanou, zaslepenou studii se 46 pacienty se syndromem karpálního tunelu, ve které byl srovnáván účinek dvou technických modifikací sonograficky navigovaného léčebného obstřiku ke šlachám flexorů nebo technikou hydrodisekce nervus medianus. Ve sledovaných parametrech (subjektivní hodnocení pacientem, elektrofyziologické vyšetření, sonografické měření plochy příčného průřezu nervu v karpálním tunelu) nebyl mezi skupinami pozorován signifikantní rozdíl. Vzhledem ke zjištěným skutečnostem lze zejména začínajícím sonografistům doporučit techniku obstřiku mezi šlachy flexorů z důvodu nižšího rizika poranění nervus medianus. Dílčím cílem práce je představení modifikované techniky obstřiku hypertrofovaného anulárního poutka z meziprstního prostoru a formou přehledových prací také popis sonografického vyšetření a navigované léčby patologií v loketní a zápěstní krajině.

Klíčová slova: nervus medianus, intervence, intramuskulární hemangiom, stenozující tendovaginitída, syndrom karpálního tunelu, tendinopatie, ultrazvuk, nervus ulnaris

Abstract

This thesis deals with the issue of ultrasound diagnostics and ultrasound-guided interventional procedures in selected pathological changes of the upper limb. Ultrasound examination directly in specialists' offices, including rehabilitation physicians, has been a worldwide trend in the last two decades. The main advantages include the possibility of assessing the pathological findings directly related to the clinical examination. The benefit is speeding up the establishment of an accurate diagnosis and initiating adequate treatment. Indirectly, the costs associated with examination by other imaging techniques and therapy are reduced. This thesis aims to present diagnostic and therapeutic options for selected morphological changes in the upper limb, including less common pathologies, such as case reports of intramuscular haemangiomas, whose diagnosis was significantly contributed by ultrasound examination. In addition to diagnosis, ultrasound is used to navigate interventions, increasing the safety and effectiveness of these procedures. The research part of this thesis is focused on identifying the optimal site of median nerve injection in carpal tunnel syndrome. This study is a prospective, randomized, blinded study with 46 patients with carpal tunnel syndrome. We compared the effect of two technical modifications of ultrasound-navigated injections between the flexor tendons or the median nerve hydrodissection. No significant difference was observed in the parameters studied (subjective patient assessment, electrophysiological examination, sonographic measurement of cross-sectional area) between the groups. Considering the findings, the injection between flexor tendons can be recommended, especially to novice sonographers, because of the lower risk of median nerve injury. A subobjective of this paper is to present a modified injection technique of the hypertrophied annular pulley from the interdigital space and, in the form of review papers, to describe the ulrasound examination and navigated therapy of pathologies in the elbow and carpal region.

Keywords: median nerve, carpal tunnel syndrome, intervention, intramuscular hemangioma, stenosing tenosynovitis, tendinopathy, ulnar nerve, ultrasound

Seznam zkratek

AIUM	American Institute of Ultrasound in Medicine
ALARA	As Low As Reasonably Achievable
AP	anulární poutko
BCTSQ	Boston Carpal Tunnel Syndrome Questionnaire
CSA	cross-sectional area
EMG	elektromyografie
FSS	functional status scale
ESSR	European Society of Musculoskeletal Radiology
EULAR	European League Against Rheumatism
IH	intramuskulární hemangiom
KT	karpální tunel
KS	kortikosteroid
MR	magnetická rezonance
MSK	muskuloskeletální
NSA	nesteroidní antiflogistika
NU	nervus ulnaris
PRP	platelet-rich-plasma
RM	rotátorová manžeta
SKT	syndrom karpálního tunelu
SSS	symptom severity scale
UZ	ultrazvuk
WFR	wrist-to-forearm ratio

Obsah

1. Úvod

Onemocnění a bolesti pohybového aparátu jsou každodenní součástí praxe rehabilitačního lékaře. Příčiny jsou různorodé, počínaje degenerativními změnami při stoupající průměrné délce života, přetížení při nevhodné pracovní ergonomii, sedavý způsob života a na druhé straně sportovní úrazy. S tím se pojí narůstající počet zobrazovacích vyšetření a intervenčních výkonů. Z hlediska časové i ekonomické náročnosti a komfortu pro pacienta je výhodné, pokud klinické vyšetření, sonografickou diagnostiku a případnou následnou intervenci provádí stejný lékař. Vzhledem k relativně nízkým pořizovacím a provozním nákladům se muskuloskeletální (MSK) ultrazvuk (UZ) stal metodou volby jako diagnostický nástroj a nástroj pro navigaci některých intervenčních výkonů. V součinnosti s odběrem anamnézy a klinickým vyšetřením se stává důležitým článkem pro stanovení konečné diagnózy a je také proto někdy nazýván „stetoskopem" nebo „šestým prstem" rehabilitačního lékaře (Özçakar et al., 2015a).

Ultrazvukové vyšetření se celosvětově stává běžnou součástí klinické praxe a zároveň s tímto trendem vzniká potřeba zpřesňovat dosud používané diagnostické pojmy a intervenční postupy. Například nespecifické pojmy, jako je „impingement syndrom ramena" nebo „obstřik subakromiálního prostoru", jsou za pomocí diagnostického ultrazvuku konkretizovány a jsou nahrazovány termíny specifickými. Hovoříme tak například o kalcifikující tendinitídě nebo proliferativní burzitídě, která způsobuje impingement syndrom ramena. Případnou intervenci pak nazýváme podle cílové struktury a způsobu, kterým byla provedena. Například „dual-target" obstřik subakromiálněsubdeltoidní burzy a recessus bicipitalis nebo hydrodisekce nervus medianus a šlach flexorů (Özçakar et al., 2022a).

Rovněž vyvstávají nové otázky týkající se intervencí. Již se nejedná o pouhé rozhodování, zda intervenci provést, či ne, ale je potřeba uvažovat, kam je třeba obstřik zacílit, jaká látka je nejvhodnější a jaké místo vpichu je nejméně bolestivé. Například při bolesti na zevní straně lokte, při diagnostikované tendinitídě šlach extenzorů začínajících na laterálním epikondylu humeru, může být preferovanou technikou peritendinózní injekce směsi lokálního anestetika a kortikosteroidu. Pokud na zobrazovacím vyšetření odhalíme rupturu této šlachy, bude v některých případech zvolen jiný postup, např. intratendinózní aplikace PRP (platelet-rich-plasma).

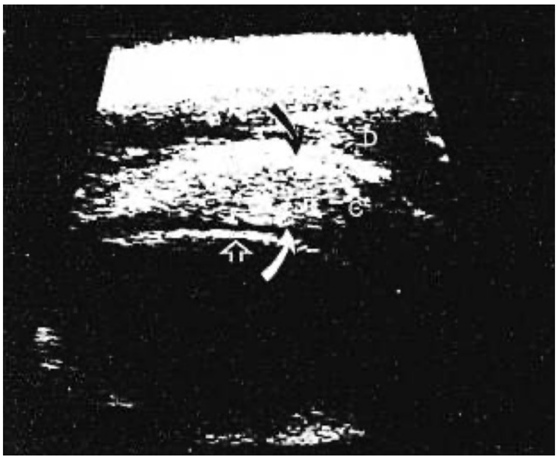
Ultrazvukově navigované intervence umožňují přesné cílení ošetřované struktury, někdy i snížení periprocedurálního diskomfortu. V souvislosti se současnými možnostmi přesného cílení aplikace léčebné látky se otevírá nová kapitola lékařského bádání v oblasti intervenční léčby onemocnění pohybového aparátu. Přímá vizualizace také umožňuje modifikaci zavedených postupů s ohledem na potřeby pacienta a lékaře v dané situaci.

Tato práce je souborem publikovaných prací, jejichž společným tématem jsou vybrané morfologické změny na horní končetině, jejich UZ diagnostika a možnosti UZ navigovaných intervencí. Součástí jsou tři přehledové články shrnující UZ diagnostiku a léčbu patologií v oblasti lokte, zápěstí a ruky, dále originální výzkum, jehož předmětem je určení optimálního místa obstřiku nervus medianus při syndromu karpálního tunelu (SKT). Dále pak kazuistiky dvou případů vzácně se vyskytujícího intramuskulárního hemangiomu na horní končetině a článek popisující méně bolestivou alternativu obstřiku hypertrofovaného anulárního poutka z interdigitálního přístupu. Cílem práce je podat přehled možností UZ diagnostiky a léčby u vybraných patologií na horní končetině a rozšířit povědomí o využití MSK UZ v klinické praxi rehabilitačního lékaře.

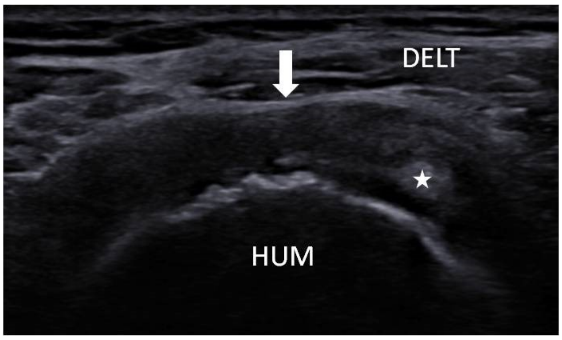
2. Ultrazvuk v praxi rehabilitačního lékaře

2.1. Historie

Muskuloskeletální ultrazvuk zažívá v posledních letech s rozvojem přístrojové techniky a vývojem ultrazvukových vysokofrekvenčních sond významný vývoj. První zprávu o využití UZ pro vyšetření muskuloskeletálního aparátu publikoval v roce 1958 Karl Theodor Dussik, který měřil akustický útlum při průchodu zvukového vlnění různými typy tkání, včetně změn detekovaných ve tkáních patologických a položil tak první základy pro diagnostický MSK UZ (Kane et al., 2004). Na počátku sedmdesátých let 20. století použili ultrazvuk američtí lékaři Daniel McDonald a George Leopold k odlišení náplně Bakerovy pseudocysty od žilní trombózy zákolenní žíly (McDonald a Leopold, 1972). První doklady o vyšetření ramenního kloubu jsou datovány do roku 1979, kdy Seltzer a jeho spolupracovníci vyšetřovali ramenní klouby u makaků po intraartikulární instilaci tekutiny a UZ sledovali její distribuci. O rok později popsali detekci volné tekutiny i u lidí (Seltzer et al., 1979; 1980). Následně byl v 80. letech 20. století popsán postup pro vyšetření rotátorové manžety (RM). Tzv. Crassova pozice, při níž je paže polohována ve vnitřní rotaci a flexi za zády vyšetřovaného, a tzv. modifikovaná Crassova pozice, při níž je dlaň vyšetřovaného uložena na hýždi, jsou dodnes součástí vyšetřovacích postupů a slouží k anteriorizaci šlach RM, a tím k jejich plné zobrazitelnosti mimo akustický stín akromia (Bretzke et al., 1985; Crass et al., 1985) (Obr. 1, 2).

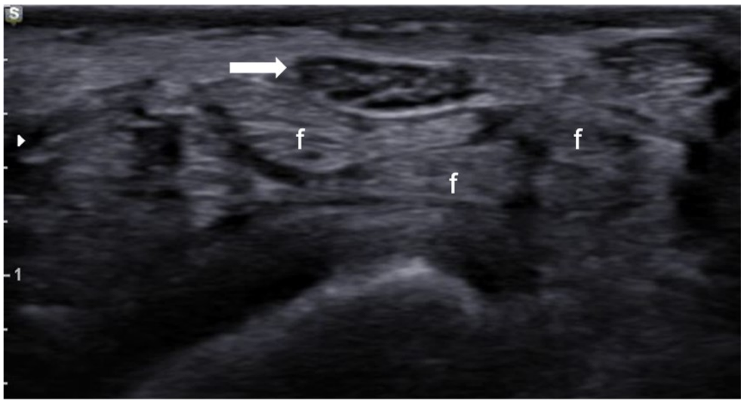


Obr. 1 UZ snímek normální rotátorové manžety publikovaný Bretzkem roku 1985 (Bretzke et al., 1985)

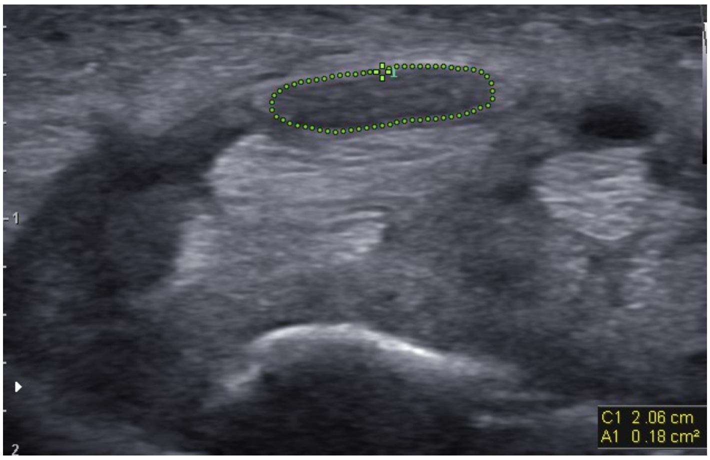


Obr. 2 Parciální ruptura RM na příčném řezu s patrným oploštěním konvexity a korespondující kostní nerovností. DELT; m. deltoideus, HUM; humerus, šipka; místo oploštění rotátorové manžety, hvězdička; šlacha dlouhé hlavy dvojhlavého pažního svalu. Snímek pořízený r. 2020 na přístroji Samsung UGEO HM70A (Jižní Korea, Seoul)

Zpočátku byl vzhledem k nízkému rozlišení UZ využíván především k detekci nitrokloubní tekutiny či náplně tihových váčků a v literatuře se začal postupně objevovat pojem „artrosonografie“. Dalším milníkem pro MSK UZ bylo vyšetření dětských kyčlí popsané v roce 1980 rakouským ortopedem Grafem. V dnešní době je UZ běžně využíván k diagnostice vrozené dysplázie kyčelních kloubů u novorozenců, u níž plně nahradil vyšetření rentgenovými paprsky (Hrazdira et al., 2003). V roce 1981 popsal B. M. Gompels UZ navigovanou aspiraci výpotku z kloubu při septické artritídě (Gompels a Darlington, 1981). První použití funkce power Doppler k detekci hyperémie v měkkých tkáních bylo zdokumentováno J. S. Newmanem v roce 1994 (Newman et al., 1994). V 90. letech 20. století se v literatuře začaly objevovat první popisy UZ vyšetření periferních nervů (Fornage, 1993; Martinoli et al., 1996). Dnes jsme již schopni díky vysokému rozlišení ultrazvukových sond zobrazit např. i tenké interdigitální nervy. Lze posoudit detailní morfologii nervu, včetně intraneurálních fasciklů, epineuria a perineuria, a kvantifikovat morfologii nervu (Obr. 3, 4). Ultrazvuk se tak stává v součinnosti s klasickou jehlovou elektromyografií a kondukčními studiemi důležitým diagnostickým nástrojem při průkazu periferních neuropatií a jejich příčin (Gasparotti et al., 2017).



Obr. 3 Příčný řez n. medianus v úrovni zápěstí za fyziologické situace (bílá šipka). Je patrná diferencovaná fascikulární struktura nervu. f; flexorové šlachy. Snímek z r. 2021 na přístroji Samsung UGEO HM70A (Jižní Korea, Seoul)



Obr. 4 Snímek n. medianus při syndromu karpálního tunelu. Zelená přerušovaná čára ohraničuje obvod nervu. Je patrný edém nervu (CSA 18mm^2) a setření typické fascikulární struktury. Snímek z r. 2020 na přístroji Samsung UGEO HM70A (Jižní Korea, Seoul)

2.2. Využití ultrazvuku v klinické praxi

V letech 2000–2008 jen v USA čtyřnásobně vzrostl počet UZ vyšetření provedených radiology i lékaři jiných odborností (Klauser et al., 2012). Právě relativně nízké provozní náklady ultrazvukových přístrojů a jejich dostupnost umožnily přesun tohoto zobrazovacího vyšetření z rukou radiologů do ordinací ambulantních lékařů. Již řadu let je UZ běžně využíván porodníky/gynekology, urology, endokrinology, stále častěji jej využívají revmatologové a v posledních letech se stává součástí praxe rehabilitačních lékařů a specialistů zabývajících se sportovní medicínou.

S rostoucími možnostmi zobrazení vznikla potřeba vytvořit ucelené a sjednocené postupy pro vyšetření jednotlivých krajin muskuloskeletálního systému ultrazvukem. Vyšetřovací protokoly pro jednotlivé klouby horní a dolní končetiny, vytvořené Evropskou společností pro muskuloskeletální radiologii (European Society of Musculoskeletal Radiology – ESSR), byly publikovány v roce 2010 a jsou volně dostupné z webových stránek essr.org. Mezi další pracovní skupiny, které zpracovaly vyšetřovací a intervenční postupy, patří Americký institut ultrazvuku v medicíně (American Institute of Ultrasound in Medicine – AIUM), Evropská liga proti Revmatismu (European League Against Rheumatism – EULAR) a v neposlední řadě mezinárodní skupina rehabilitačních lékařů s názvem EURO-MUSCULUS (Özçakar et al., 2015b). Tato skupina zaštítila v minulých letech vydání tří monografií MSK UZ, včetně učebnice intervenčních technik, nejen pro rehabilitační lékaře, a pořádá každoročně mezinárodní kurzy (Özçakar et al. 2014, 2017 a 2019).

V České republice byly vydány protokoly v českém jazyce jako podklady ke kurzu Základy sonografie pohybového aparátu (Novotný et al., 2021). V klinické praxi je UZ stále častěji využíván jako nástroj pro navigaci při aplikaci Botulotoxinu A do svalů postižených spastickou dystonií. Pro tento účel byly vypracovány skupinou EURO-MUSCULUS aplikační protokoly s popisem jednotlivých svalů a postupu aplikace (Kara et al., 2018).

Novinkou v roce 2022 je publikace protokolů k UZ vyšetření kloubů horní končetiny a kyčelní krajiny s využitím specifických dynamických testů a manévrů. V současné době pracovní skupina rehabilitačních lékařů EURO-MUSCULUS pracuje na dokončení dynamických protokolů i pro kolenní krajinu a hlezno s nohou (Özçakar et al., 2022b).

Možnosti využití ultrazvuku se stále rozšiřují a jak napovídá současný trend vývoje, bude i do budoucna představovat nedílnou součást klinické praxe i výzkumu. Relativně novou a rychle se rozvíjející metodou je tzv. sonoelastografie. Sonoelastografie je metoda, jež byla původně vyvinuta pro přesnější odlišení normální a nádorové tkáně prsu. Je založena na hodnocení tuhosti tkáně, která využívá principu deformace tlakem (Sigrist et al., 2017). Každá tkáň vykazuje specifickou odpověď na silový podnět, kterou lze měřit. Pokud dojde k patologické přeměně, lze tuto změnu detekovat (Beneš et al., 2015). Rozlišujeme dva typy elastografie – kompresivní a střižnými vlnami. V případě tzv. kompresivní elastografie (strain elastography) působíme na tkáň manuálně tlakem sondy přes kůži. Odpověď tkáně je následně měřena pomocí mechanických senzorů. Slouží jako pomocná metoda k rozlišení benigních a maligních ložisek (Hrazdira, 2013). Nevýhodou je obtížná reprodukovatelnost při potřebě opakování vyšetření. Elastografie střižnými vlnami (shear wave elastography) využívá kompresi způsobenou opakovanými impulzy vysílanými ultrazvukovou sondou. Tímto způsobem je možné získat přesnější kvantitativní informace o elasticitě tkáně (Doherty et al., 2013). Elastografii lze využít k vyšetření tkáně jater (Sigrist et al., 2017), dále tkáně prsu, prostaty a štítné žlázy (Woo et al., 2017; Winn et al., 2016). V rehabilitační medicíně nachází uplatnění při hodnocení vlastností šlach a fascií (Pirri et al., 2020), předmětem výzkumu je využití u myopatií (Mathevon et al., 2018) a jako pomocný diagnostický nástroj pro hodnocení neuropatií. Dva systematické review z roku 2019 naznačují, že nervy postižené úžinovými syndromy vykazují vyšší tuhost oproti nervům nepostiženým. Vyšší tuhost byla prokázána i u nervů postižených diabetickou neuropatií ve srovnání s jedinci, u nichž se diabetes nevyskytoval. Konkrétně u n. tibialis, u nějž byla vyšší tuhost měřena i v případě negativního elekromyografického (EMG) nálezu, a ještě před rozvojem klinických obtíží. Zdá se, že by v budoucnu tato metoda mohla vzhledem k neinvazivitě a relativně malé časové náročnosti oproti EMG sloužit jako screeningové vyšetření. Elastografie střižnými vlnami se jeví jako vhodnější oproti elastografii kompresivní. Studie jsou však provázeny řadou nejasností, například není stanoveno, zda je potřeba tuhost nervu hodnotit v rovině longitudinální nebo transverzální a zda má pozice sondy vliv na výsledky. Dalším problematickým bodem se ukázal tzv. bone proximity hardening artifact. To znamená, že pokud hodnotíme tuhost nervu v jeho průběhu v blízké vzdálenosti nad kostí, může dojít ke zkreslení a falešnému zvýšení naměřené tuhosti. To v případě syndromu karpálního tunelu, který je nejčastěji zkoumaným úžinovým syndromem, představuje významný otazník (Zakrzewski et al., 2019; Wee a Simon, 2019). Ve skupinovém konsensu publikovaném v roce 2018 radiologickou společností ESSR, vydaném na bázi provedené rešerše dostupné literatury, je elastografie metoda zatím s malou využitelností v klinické praxi, ale do budoucna představuje slibnou techniku pro rozšíření vyšetření měkkých tkání a úžinových syndromů nervů (Sconfienza et al., 2018).

Dalším předmětem výzkumů jsou možnosti využití kontrastní látky při ultrazvukovém vyšetření, zejména pro detekci pomalých toků, jejichž vyšetření je limitováno i při využití funkce power Doppler. Kontrastní látky pro ultrasonografii jsou emulze kapaliny a plynných bublin o velikosti 1–10 µm, které mohou být aplikovány do tělních dutin či cév. Tím se zvyšuje echogenita zobrazované tkáně nebo proudící krve (Hrazdira, 2011). V muskuloskeletální ultrasonografii jsou kontrastní látky využívány při detekci zánětlivých myopatií, nebo v onkologických a revmatologických indikacích (Chang et al., 2012).

Rozvoj počítačové techniky a umělé inteligence nabízí využití i v ultrazvukové diagnostice. V současné době je vyvíjen software, který umožní rozlišení a identifikaci anatomických struktur a jejich patologií v reálném čase během vyšetření (Özçakar et al., 2022c).

Oblíbené zejména v porodnictví je trojrozměrné (3D) a čtyřrozměrné (4D) zobrazení, při kterém jsou používány speciální volumetrické sondy, které na rozdíl od sond lineárních generují trojrozměrné ultrazvukové pole. V MSK UZ vyšetření však tato metoda zatím nenachází širší uplatnění. Zkušený sonografista využívá vlastní prostorové představivosti a 2D obrazu, který poskytuje ultrazvuková sonda k vytvoření komplexního 4D obrazu (Hrazdira I. et al., 2003).

3. Možnosti zobrazení ultrazvukem na horní končetině

3.1. Rameno a lopatka

Rameno patří mezi nejvyšetřovanější klouby. Je to dáno častým výskytem patologií v této krajině a dobrou dostupností pro UZ vyšetření. Pro vyšetření používáme lineární sondu o frekvenci 7,5 MHz a výše. Ultrazvukové vyšetření ramenního kloubu umožňuje hodnocení periartikulárních měkkých tkání staticky i dynamicky, což je v případě ramenního kloubu zejména výhodné při hodnocení různých typů impingementu či nestability (Özçakar a De Muynck, 2014), zároveň máme možnost porovnat nálezy s kontralaterální stranou. Doporučené polohování a vyšetřovací postup vychází ze standardizovaných vyšetřovacích protokolů pracovních skupin AIUM, EULAR, ESSR a EURO-MUSCULUS. Patologický nález, a to platí obecně pro všechny lokalizace, by měl být identifikován a potvrzen v minimálně dvou na sebe kolmých rovinách (Ozcakar et al., 2015c).

Ultrasonograficky lze v oblasti ramena zobrazit povrchově akromioklavikulární kloub a musculus (m.) deltoideus. Dále jsou to hlouběji uložené m. supraspinatus, m. infraspinatus, m. subscapularis, m. teres minor a jejich úponové šlachy, označované souborně jako rotátorová manžeta (RM). Mezi další dobře zobrazitelné struktury patří subakromiálněsubdeltoidní burza, obzvláště pokud je patologicky rozšířená, šlacha dlouhé hlavy m. biceps brachii, krátká hlava m. biceps brachii, úpon m. pectoralis major na humerus, povrchy kostních struktur, zadní okraj glenoidálního labra a stabilizující vazy. Častou patologií v oblasti ramene jsou ruptury a degenerativní léze RM. V systematickém review a metaanalýze z r. 2011, kterou provedl Smith se svými spolupracovníky, a která zahrnuje 6066 ramen vyšetřených ultrazvukem, uvádí senzitivitu u parciálních ruptur RM 84 % a specificitu 89 %. U kompletních ruptur senzitivita dosahovala až 96 % a specificita 93 % (Smith et al., 2011). Limitací UZ vyšetření ramena je nemožnost zobrazení struktur uložených za akustickým stínem kosti, jedná se především o intraartikulární struktury jako např. glenoidální labrum. Při podezření na lézi těchto struktur volíme jiné zobrazovací metody, například magnetickou rezonanci (MR). Ultrazvuk lze dále použít k diagnostice nádorových afekcí, porušení kontinuity kostního povrchu a v neposlední řadě jako vodítko k přesnému cílení intervenčních výkonů.

3.2. Loket a předloktí

Oblast loketního kloubu je další často vyšetřovanou krajinou. Například bolest na laterální straně lokte může mít řadu příčin od „klasické“ laterální epikondylitídy humeru, rupturu šlach extenzorů začínajících na laterálním epikondylu humeru, až po ganglion ze šlachové pochvy nebo iritaci n. cutaneus antebrachii lateralis. Klinické vyšetření může být v některých případech zavádějící a nepřesné a UZ metoda jej může doplnit cennou informací. Pro vyšetření se používá lineární sonda o frekvenci 10 MHz a výše a pro orientaci lze využít palpaci kostních prominencí. Je doporučeno postupovat podle standardizovaných protokolů pracovních skupin AIUM, EULAR, ESSR a EURO-MUSCULUS (Özçakar et al., 2015d). Při vyšetření pátráme po přítomnosti volné tekutiny v predilekčních místech na humeru, tj. ve fossa radialis, fossa coronoidea a fossa olecrani. Opět lze využít dynamické vyšetření, tj. pasivní extenzi v loketním kloubu se sondou přiloženou nad olekranon v podélné ose paže, při kterém můžeme hodnotit intraartikulární tekutinu, která je tímto manévrem vytlačována do fossa olecrani. Dále jsou vyšetřovány šlachy, vazy, nervy a v případě patologie lze zobrazit rozšířenou bursa olecrani. Častým příznakem bývá bolest v oblasti laterálního nebo mediálního epikondylu humeru jakožto příznak laterální, resp. mediální epikondylitídy. Sonografickým nálezem v těchto případech může být obraz setření fibrilární struktury šlachy, hypoechogenita a/nebo rozšíření v důsledku otoku začátku extenzorů/flexorů na humeru. Při chronických obtížích je možné prokázat entezofyt při úponu šlach nebo intratendinózní kalcifikace. Často je však UZ nález normální, zejména v akutních stádiích. Přehled UZ diagnostiky a léčby tendinopatií v oblasti lokte je součástí vložené přehledové publikace (P3).

Další často vyšetřovanou strukturou v oblasti lokte je n. ulnaris (NU). Ten v úrovni lokte probíhá v sulcus nervi ulnaris nad ligamentum olecranohumerale, které tvoří jeho dno. Na povrchu jej překrývá retinaculum retroepicondylare, a v některých případech akcesorní m. anconeus epitrochlearis. Distálně NU probíhá mezi hlavami m. flexor carpi ulnaris (skrz canalis cubitalis), kde je povrchově kryt pomocí ligamentum arcuatum (Osborni). V těchto anatomicky preformovaných úžinách je zvýšené riziko jeho útlaku. Byla publikována řada prací popisujících typický vzhled nervu postiženého periferní neuropatií. Nejčastěji se uvádí fokální otok s rozšířenou plochou příčného řezu (cross-sectional area – CSA), typicky proximálně od místa útlaku, zvýšení intraneurální vaskularizace (Ghasemi-Esfe et al., 2011), snížená mobilita nervu ve vztahu k okolním strukturám (Van Den Berg et al., 2013) a setření fascikulární struktury nervu (Boom a Visser, 2012). Právě nález fokálního rozšíření umožňuje odlišit periferní postižení od systémového onemocnění, jako je např. polyneuropatie typu Charcot-Marie-Tooth, při kterém lze ultrazvukem detekovat povšechné rozšíření CSA jak u distálních periferních nervů, tak u nervů plexus brachialis (Gallardo et al., 2015; Kerasnoudis, 2013). Fokální rozšíření se na podélném zobrazení jeví typicky jako obraz „bottle neck“ (hrdlo láhve), přičemž místo rozšíření se obvykle nachází proximálně od místa útlaku. K tomu dochází pravděpodobně v důsledku přímé mechanické deformace měkkých tkání nervu i poruchy axonálního transportu (Choi et al., 2015). Nejlépe jsou kritéria pro posouzení periferní neuropatie vypracována u n. medianus, jelikož syndrom karpálního tunelu (SKT) je nejčastějším úžinovým syndromem na horní končetině (viz kapitola zápěstí). U NU bylo publikováno více prací s cílem stanovit hranice normy pro hodnoty CSA v canalis cubitalis. Chang a kolektiv provedli roku 2018 metaanalýzu čtrnácti do té doby publikovaných studií, z jejíž výsledků vyplývá horní hranice CSA pro NU v canalis cubitalis 10 mm^2 u zdravých jedinců (Chang et al., 2018). Přínos stanovení horní hranice normy CSA NU pro průkaz syndromu kubitálního tunelu je však stále předmětem diskuze. Chen a kolektiv provedli v roce 2019 metaanalýzu a systematické review, do které bylo zahrnuto 663 pacientů se syndromem kubitálního tunelu a 543 zdravých jedinců. Ze studie vyplývá, že pravděpodobně nejpřesnějším parametrem pro diagnostiku syndromu kubitálního tunelu je stanovení poměru CSA v maximálním místě otoku (CSA_{max}) nebo v úrovni mediálního epikondylu humeru (CSA_{ME}), kde nejčastěji maximální otok bývá, a CSA měřeného v úrovni paže (CSA_{arm}) – v polovině vzdálenosti mezi axilou a mediálním epikondylem humeru nebo v úrovni předloktí ($CSA_{forearm}$) – v úrovni, kde se n. ulnaris odděluje od arteria ulnaris. V této metaanalýze však nebylo možno určit diagnosticky signifikantní hodnotu tohoto poměru vzhledem ke značné heterogenitě výsledků jednotlivých studií. Stanovení poměru $CSA_{max/ME}$ a CSA v oblasti zápěstí (CSA_{wrist}) – v úrovni os pisiforme – se ukázalo jako nepřesné, vzhledem k možnosti současného výskytu syndromu kubitálního tunelu a syndromu ulnárního (Gyuonova) kanálu, kde otok n. ulnaris v místě zápěstí může zapříčinit falešně negativní výsledek. Další možné parametry ke stanovení syndromu kubitálního tunelu, jako například míra oploštění n. ulnaris, poměr CSA n. ulnaris vně a uvnitř canalis cubitalis, echogenita a intraneurální vaskularizace se ve studii ukázaly jako málo přínosné. Sami autoři uvádějí v limitacích této analýzy nízký počet provedených studií a nutnost dalšího výzkumu v tomto směru (Chen et al., 2019). Problematika neuropatie n. ulnaris v oblasti je lokte je podrobně zpracována formou přehledového článku (P4).

Ultrasonografie může být vhodnou doplňující diagnostickou metodou k elektrofyziologickému vyšetření, zejména pokud se jedná o vyloučení jiné příčiny komprese n. ulnaris, jako např. exostózy, heterotopické ossifikace (Jačisko et al., 2020), akcesorního m. anconeus epitrochlearis, lipomu a jiných nádorů měkkých tkání, ganglia, synoviální cysty či vyloučení nádorů nervové tkáně (Podnar et al., 2017; Osma-Rueda a Amaya-Mujica, 2017). Další výhodou UZ vyšetření je možnost dynamického vyšetření k vyloučení dislokace nervu ze sulcus nervi ulnaris nad nebo před mediální epikondyl humeru, a to obzvláště tam, kde je limitováno klinické vyšetření, např. při obezitě (Pisapia et al., 2017; Chuang et al., 2016). Dislokace n. ulnaris v dynamickém testu může být přítomna i u asymptomatických jedinců (Gruber et al., 2016), nález je proto třeba hodnotit ve vztahu ke klinickým obtížím. Průkaz případné nestability n. ulnaris může být relevantní v případě plánování operačního zákroku či jiných intervencí v oblasti epicondylus medialis humeri.

Ulnární nerv můžeme dále sledovat v jeho průběhu z canalis cubitalis dále do oblasti předloktí, kde pokračuje mezi dvěma hlavami m. flexor carpi ulnaris a distálněji mezi m. flexor carpi ulnaris a m. flexor digitorum profundus. V dalším průběhu se připojuje k arteria ulnaris, kterou podbíhá v oblasti zápěstí v canalis ulnaris (Guyoni). Intermuskulární svalové aponeurózy mezi svaly předloktí mohou být rovněž příčinou útlaku nervu (Won et al., 2016). Obdobně lze v oblasti předloktí zobrazit průběh n. medianus a n. radialis. Hodnotíme případné známky útlaku v predisponovaných místech a jiné strukturální nebo anatomické abnormality. V případě potřeby lze zobrazit jednotlivé svaly předloktí, což má uplatnění zejména jako navigace při aplikaci Botulotoxinu A při léčbě spastické dystonie.

Při UZ vyšetření lze odhalit i méně časté patologie, jako jsou tumory měkkých tkání. Jedním z příkladů, se kterým se lze při UZ vyšetření pohybového aparátu setkat, může být intramuskulární hemangiom (IH). Součástí práce je představení sonografické diagnostiky IH formou kazuistického sdělení (P2).

3.3. Zápěstí a ruka

Vzhledem k povrchovému uložení struktur je oblast zápěstí a ruky dobře přístupná UZ vyšetření. Je vhodné použít vysokofrekvenční lineární sondu s frekvencí 15 MHz a více, případně lze použít krátkou angulovanou sondu, tzv. hokejku, která má menší rozměry a hodí se zejména na zobrazení struktur v oblasti prstů ruky. Rovněž zde je doporučeno řídit se postupy a protokoly skupin AIUM, EULAR, ESSR a EURO-MUSCULUS. Obdobně jako u předchozích kloubů lze detekovat kolekci intraartikulární tekutiny, nejlépe z dorzální strany zápěstí v oblasti articulatio radiocarpalis. Je rovněž možné zobrazit synoviální hypertrofii při chronické iritaci. Dále lze hodnotit integritu a případnou kolekci tekutiny kolem šlach extenzorů a flexorů zápěstí a prstů (Özçakar et al., 2015e). Typickým patologickým nálezem je ganglion vycházející ze šlachové pochvy nebo synoviální výstelky kloubů. Může být zdrojem bolesti a někdy také příčinou útlaku nervových struktur v oblasti zápěstí.

Strukturou často vyšetřovanou v oblasti zápěstí je n. medianus a jeho průběh v karpálním tunelu (KT). Karpální tunel (canalis carpi) je osteofibrózní kanál, který je z dorzální strany kryt konkávním obloukem karpálních kostí a z ventrální strany jej kryje retinaculum musculorum flexorum. Proximálně jej ohraničuje os scaphoideum a os pisiforme, distálně os trapezium a hamulus ossis hamati. Karpálním tunelem prochází n. medianus povrchově, čtyři šlachy m. flexor digitorum superficialis a čtyři šlachy m. flexor digitorum profundus ve společné šlachové pochvě, šlacha m. flexor pollicis longus ve vlastní šlachové pochvě a poněkud odděleně také šlacha m. flexor carpi radialis ve vlastní šlachové pochvě. Distálně od retinaculum musculorum flexorum se n. medianus obvykle dělí na šest větví. Toto dělení vykazuje velkou anatomickou variabilitu. Zároveň i samotný n. medianus může ve svém průběhu vykazovat různé variace jako např. n. medianus bifidus, přítomnost arteria comitans nervi mediani manus / arteria mediana (Mezian et al., 2021). Z klinického hlediska je důležité mít na zřeteli ramus recurrens nervi radialis, motorickou větev, která odstupuje z nervu na laterální straně a pokračuje povrchově po krátkém flexoru palce (Standring et al., 2015). Tato větev může být poraněna při operačním výkonu, což může mít za následek dlouhodobé obtíže spojené s dysfunkcí svalů thenaru.

Syndrom karpálního tunelu je nejčastějším úžinovým syndromem a jeho diagnostice je věnováno mnoho prací. Obdobně, jako u výše zmiňovaného syndromu kubitálního tunelu jsou sledovány známky útlaku nervu, mezi něž patří: rozšíření a otok proximálně od místa útlaku, setření typické fascikulární struktury, zvýšení intraneurální vaskularizace, jeho snížená mobilita v příčné i podélné ose, tzv. gliding vůči flexorovým šlachám. Dále měříme maximální hodnotu CSA v oblasti karpálního tunelu, kdy hodnota nad 10 mm^2 je považována za suspektní pro SKT při screeningovém vyšetření. Pokud je naměřená hodnota nad 15 mm^2, považujeme tuto diagnózu za velmi pravděpodobnou (Kurca et al., 2008). Ultrazvuková diagnostika SKT pomocí měření CSA může mít senzitivitu až 77,6 % a specificitu 86,8 % (Fowler et al., 2011). Další zpřesnění lze docílit použitím tzv. delta parametru, tj. odečtením CSA v úrovni proximálního okraje m. pronator quadratus od hodnoty CSA v karpálním tunelu, kde je udávána 99% senzitivita a až 100% specificita (Klauser et al., 2009). Dále lze pro maximální výtěžnost použít tzv. wrist-to-forearm ratio (WFR). Wrist-to-forearm ration je podíl hodnoty CSA n. medianus v karpálním tunelu a hodnoty CSA naměřené ve vzdálenosti 12 cm proximálně od distální zápěstní rýhy. Za dolní hranici se považuje hodnota 1,4; pokud je poměr vyšší, lze hovořit o velmi suspektní diagnóze SKT. Hobson-Webb se spoluautory udává při použití tohoto parametru až 100% senzitivitu (Hobson-Webb et al., 2008). Ultrazvuk dále slouží k vyloučení sekundárních příčin útlaku n. medianus a k vyloučení nádorů nervové tkáně (neurom, schwanom).

Ultrazvukově navigované intervence nabývají na významu při konzervativní léčbě SKT. Z výsledků metaanalýzy provedené Babaei-Ghazanim a spoluautory vyplývá, že UZ navigované obstřiky n. medianus kortikosteroidy (KS) při SKT vykazují signifikantní zlepšení závažnosti příznaků a zároveň tato účinnost byla vyšší než u obstřiků s využitím palpační orientace (Babaei-Ghazani et al., 2018). Přesné místo zacílení obstřiku n. medianus je stále předmětem diskuze. Podle některých autorů je příčinou vzniku obtíží zvýšení tlaku v KT, které je výsledkem otoku synoviální pochvy šlach flexorů. Zastánci této teorie proto považují za dostatečnou aplikaci kortikosteroidů do okolí šlach flexorů, čím podle nich dojde k redukci otoku a dekompresi n. medianus (Podnar a Omejec, 2016; Bodor et al., 2016). Naproti tomu, jiní autoři považují u SKT za důležitou roli adhezí, které vznikají při dlouhodobě zvýšeném tlaku v KT a způsobují ischémii a sníženou mobilitu nervu, což vede ke vzniku obtíží (Orman et al., 2013; Mezian a Bruthans, 2016). Tyto adheze lze při cíleném obstřiku mechanicky rozrušit tlakem tekutiny, která je aplikována mezi nerv a šlachy flexorů a/nebo retinaculum musculorum flexorum. Tato technika se nazývá hydrodisekce (Cass, 2016; Smith et al., 2008). Během obstřiku s využitím hydrodisekce dochází k přímému mechanickému účinku a zároveň se zvyšuje plocha kontaktu nervu s léčivou látkou (Smith et al., 2008; Orman et al., 2013). Ve prospěch této teorie mluví i fakt, že UZ navigované obstřiky v blízkosti n. medianus vykazují větší účinnost ve srovnání s obstřiky s využitím palpační navigace (Ustün et al., 2013). Chen a kolektiv provedli metaanalýzu, která zahrnovala deset studií s celkem 633 pacienty ošetřenými UZ navigovaným „in-plane“ a „out-of-plane“ obstřikem. Z výsledků vyplývá signifikantně lepší efekt u „in-plane“ způsobu provedeným z ulnární strany zápěstí (Chen et al., 2015). Identifikace a popis optimálního technického provedení léčebného obstřiku při konzervativní terapii SKT je jedním z cílů této práce (P1).

Dalším úžinovým syndromem v oblasti zápěstí je útlak n. ulnaris v oblasti canalis ulnaris (Guyonově kanálu). Morfologii nervu hodnotíme analogicky jako v předchozích případech.

Ultrazvukem lze dobře hodnotit i subtilní povrchové struktury jako je např. průběh šlach povrchového a hlubokého flexoru prstů na prstech ruky, včetně chiasma tendineum a jejich poutek, dále lze hodnotit šlachy extenzorů a jejich případná poranění. Při použití vysokofrekvenčních sond lze zobrazit i digitální nervy a cévy. Pro zobrazení struktur na prstech je vhodné použít sondu typu „hokejka“, která je krátká, a lépe tak můžeme překonat nerovnosti na kloubech a kožních záhybech. Případně lze využít zobrazení ve vodním médiu, kdy sonda nemusí být v těsném kontaktu s povrchem kůže, což umožňuje vyšetření celého průběhu šlach včetně dynamického zobrazení. Častou UZ navigovanou intervencí v oblasti prstů ruky je obstřik hypertrofovaných poutek, která způsobují tzv. stenozující tendovaginitídu flexorů známou také jako „lupavý prst“. Šlachy flexorů jsou při svém průběhu na prstech fixovány systémem zesílení stěny jejich fibrózního kanálu, tzv. poutek, která za normálního stavu umožňují optimální funkci šlachy při flexi. Za patologických stavů, např. při chronickém přetěžování, dochází k jejich otoku, který způsobuje mechanický konflikt a brání tak hladkému pohybu flexorové šlachy v její pochvě. Pacient toto vnímá jako bolestivé zasekávání prstu, které lze v pokročilých stádiích překonat pouze s asistencí druhé ruky a později může dojít i ke kontraktuře. Na druhém až čtvrtém prstu se nachází pět prstencových (anulárních) poutek (AP) a tři poutka zkřížená, která jsou membranózní a flexibilní. Na palci se nacházejí dvě anulární poutka a jedno poutko šikmé (Smrčka a Dylevský, 1999). Nejčastěji postiženým poutkem bývá první anulární poutko (AP1), které se nachází v oblasti nad metakarpofalangovým kloubem. Před případným chirurgickým zákrokem se zpravidla přistupuje ke konzervativní léčbě, která zahrnuje modifikaci aktivit, případně imobilizaci, léčbu nesteroidními antiflogistiky (NSA) a obstřik postiženého poutka kortikosteroidy (Makkouk et al., 2007; Ma et al., 2019), který se považuje za metodu volby zejména u mírného postižení tzn., že zablokovaný prst lze uvolnit bez pomoci druhé ruky (Shultz et al., 2018). Novodobým trendem je využití ultrazvuku během intervence. Mezi výhody UZ navigace patří přesné zacílení ošetřované struktury a zároveň zobrazení vulnerabilních struktur, jako jsou nervově-cévní svazky. Pro navigaci jehly lze použít dva způsoby. První, více používaný, je tzv. in-plane způsob, kdy trajektorie jehly je v podélné ose se sondou. Výhodou je, že lze zobrazit hrot jehly od začátku až do konce intervence a jehla je zobrazena v reálném čase. Nevýhodou je někdy složitější manipulace v úzkých nebo drobných strukturách, jako jsou právě poutka nebo drobné ruční klouby. Druhý způsob, tzv. out-of-plane, se provádí tak, že jehla prochází kolmo na dlouhou osu sondy, přičemž se zobrazuje pouze jako bod ve středu obrazovky. Tento způsob je vhodný k ošetření povrchových a drobných struktur. Jeho hlavní nevýhodou však je, že lze zobrazit vždy jen krátký úsek jehly a je potřeba mít na zřeteli, že hrot jehly se může snadno ocitnout mimo obraz. U obou způsobů se pro intervenci v oblasti anulárních poutek běžně používá přístup z palmární strany ruky, který je však spojený s procedurálním diskomfortem, vzhledem k tloušťce kůže dlaně a přítomnosti bohaté sítě nervových zakončení. Součástí práce je popis technického postupu léčebného obstřiku tzv. lupavého prstu s menší procedurální bolestivostí (P3).

4. Cíle disertační práce

Disertační práce je tvořena souborem publikovaných prací (P1–P6), jejichž společným jmenovatelem jsou vybrané morfologické změny na horní končetině, jejich ultrazvuková diagnostika a možnosti ultrazvukově navigovaných intervencí. Cílem práce je přispět k rozvoji muskuloskeletálního ultrazvuku a využití nejnovějších poznatků v klinické praxi.

Dílčí cíle jednotlivých prací:

- Ultrasound-Guided Perineural vs. Peritendinous Corticosteroid Injections in Carpal Tunnel Syndrome: A Randomized Controlled Trial: identifikace optimálního postupu UZ navigovaného obstřiku při syndromu karpálního tunelu.
- Two Cases of Intramuscular Hemangiomas in the Upper Limbs. From Sonography to Pathology: prezentace kazuistiky dvou případů intramuskulárního hemangiomu na horní končetině, k jejichž diagnóze přispěl významně ultrazvuk.
- Interdigital Approach to Trigger Finger Injection Using Ultrasound Guidance: popis alternativního postupu při UZ navigovaném obstřiku stenozující tendovaginitídy.
- Ultrasound-Guided Procedures in Common Tendinopathies at the Elbow: From Image to Needle, Ulnar Neuropathy at the Elbow: From Ultrasound Scanning to Treatment, Ultrasound Imaging and Guidance in Common Wrist/Hand Pathologies: přehledové články, jejichž cílem je rozšířit povědomí o možnostech UZ diagnostiky v praxi rehabilitačního lékaře.

5. Materiál a metodika

Autorské snímky byly pořízeny na přístroji Samsung UGEO HM70A (Soul, Jižní Korea) s lineární sondou o frekvenci 3–16 MHz. Nastavení ostrosti, hloubky a frekvence sondy bylo vyšetřujícím upraveno pro získání optimálního obrazu. Osoby se syndromem karpálního tunelu účastnící se randomizované studie musely splňovat kritéria pro zařazení do studie a podepsaly informovaný souhlas. Výzkumná část byla provedena na výše zmíněném přístroji. Kondukční studie prováděl lékař elektrodiagnostik na přístroji Medelec Synergy (Oxford Instruments, Velká Británie). Vyšetření bylo prováděno dle „American Association of Neuromuscular and Electrodiagnostic Medicine guidelines“ (Jablecki et al., 1996). Sonografista s více než osmiletou praxí v MSK UZ provádějící vyšetření n. medianus a intervence byl zaslepený výsledkům klinického a elektrodiagnostického vyšetření. Pacienti byli zároveň zaslepeni typu technického provedení intervence. Všechny léčebné obstřiky byly provedeny z ulnární strany zápěstí „in-plane“ technikou. Byla použita směs 1 ml 1% trimecain chloridu (Mesocain) a 1 ml (40 mg) methylprednisolon acetátu (Depo-Medrol) a jehla kalibru 25 gauge a délky 25 mm. Statistické zpracování dat bylo provedeno pomocí statistického softwaru MedCalc verze 14.

Snímky pro kazuistická sdělení byly publikovány se souhlasem vyšetřovaných osob. Snímky použité v přehledových pracích byly použity s ohledem na ochranu práv pacienta, z obrazové dokumentace byly odstraněny všechny údaje, které by mohly vést k jeho identifikaci. Obrazová dokumentace kadáverů v přehledových pracích byla připravena a publikována se souhlasem Anatomického ústavu 1. LF UK.

Metodika je podrobně uvedena v jednotlivých publikacích, které jsou součástí disertační práce.

6. Výsledky

6.1. Ultrasound-Guided Perineural vs. Peritendinous Corticosteroid Injections in Carpal Tunnel Syndrome: A Randomized Controlled Trial (P1)

Z původních 52 jedinců bylo vyloučeno šest pacientů, kteří nesplňovali kritéria pro zařazení do studie. Zbývajících 46 účastníků bylo rozděleno náhodně, obálkovou metodou, do dvou skupin po 23. Celkem šest pacientů studii nedokončilo, čtyři z důvodu uzávěru při pandemii Covid-19, jeden podstoupil operační řešení před 12. týdnem od intervence a jeden z blíže nespecifikovaných důvodů. Z těchto šesti jeden účastník odstoupil bezprostředně po intervenci, zbývajících pět se neúčastnilo pouze výstupní kontroly ve 12. týdnu. Co se týká demografických dat, klinických, elektrodiagnostických a ultrasonografických nálezů, bylo jejich rozložení v obou skupinách při vstupní kontrole rovnoměrné (Tabulka 1). V průběhu studie nebyly pozorovány žádné nežádoucí účinky léčivé látky nebo komplikace spojené s intervencí. V obou skupinách došlo ke statisticky významnému zlepšení vizuální analogové škály bolesti (VAS), která byla sledována jako primární ukazatel, a které přetrvávalo 12 týdnů od provedení zákroku. Zlepšení bylo zaznamenáno i u sekundárního ukazatele, jímž byla část bostonského dotazníku hodnotící subjektivní vnímání závažnosti symptomů (Symptom Severity Scale – SSS). U ostatních parametrů, kterými byla část bostonského dotazníku hodnotící stupeň funkčního postižení (Functional Status Scale – FSS), síla stisku měřená ručním dynamometrem a dvoubodové diskriminační čití, nebyl prokázán statisticky signifikantní rozdíl (Tabulka 2). U obou skupin došlo ke zlepšení objektivních parametrů, jimiž byla distální motorická latence (dml) a CSA n. medianus v karpálním tunelu (Tabulka 3). Zároveň mezi skupinami nebyl prokázán statisticky signifikantní rozdíl v účinnosti léčby.

Tab. 1 Vstupní charakteristika účastníků

	Skupina A (N=23)	**Skupina B (N=23)**
Věk (roky)	50,0 ± 15,9	54,3 ± 15,0
Pohlaví (Ž/M)	18/5	19/4
BMI (kg/m^2)	30,6 ± 6,1	30,2 ± 4,3
Oboustranný SKT (N)	14	13
Dominantní končetina (P/L)	23/0	22/1
Trvání obtíží (měsíce)	5,9 ± 3,3	5,9 ± 4,7
Strana intervence (P/L)	18/5	15/8
VAS (cm)	5,2 ± 2,4	4,7 ± 2,3
Síla úchopu (kg)	22,7 ± 11,9	20,5 ± 9,5
Pozitivní Tinelův příznak	10	12
Pozitivní Phalenův příznak	11	14
Dvoubodové diskriminační čití (mm)	4,6 ± 2,7	4,7 ± 3,8
Bostonský dotazník		
SSS	31,3 ± 8,6	28,6 ± 6,7
FSS	18,0 ± 6,7	17,0 ± 6,1
Kondukční studie n. medianus		
Stupeň závažnosti (mírný/střední/vážný/velmi vážný)	2/17/4/0	4/14/4/1
DML (ms)	5,5 ± 1,4	5,4 ± 1,9
Sonografické hodnocení		
CSA (mm^2)	18,0 ± 5,0	16,6 ± 5,1
Delta CSA (mm^2)	9,8 ± 4,5	9,2 ± 5,0
WFR	2,6 ± 0.8	2,4 ± 0,9

Data jsou průměrnou hodnotou ± směrodatná odchylka

BMI; body mass index, SKT; syndrom karpálního tunelu, P; pravá, L; levá, N; number (počet), VAS; vizuální analogová škála bolesti, SSS; Symptom Severity Scale (stupeň závažnosti subjektivních příznaků), FSS; Functional Status Scale (stupeň funkčního postižení), DML; distální motorická latence, CSA; cross-sectional area (plocha příčného řezu), WFR; wrist-to-forearm ratio

Tab. 2 Klinické výstupy (vstupně, 2., 6. a 12. týden)

		Skupina A (N=23)	Rozdíl od vstupního vyšetření	Skupina B (N=23)	Rozdíl od vstupního vyšetření
VAS	Vstupně	5,2 ± 2,4		4,7 ± 2,3	
	2. týden	2,7 ± 2,6	-2,4 ± 2,8	1,9 ± 1,9	-2,6 ± 2,6
	6. týden	2,1 ± 2,6	-3,1 ± 3,1	2,0 ± 2,0	-2,6 ± 2,6
	12. týden	2,3 ± 2,9	-2,7 ± 2,4	2,4 ± 2,4	-2,1 ± 2,7
BCTQ-SSS	Vstupně	31,3 ± 8,6		28,6 ± 6,7	
	2. týden	21,2 ± 9,3	-10,0 ± 8,4	18,4 ± 6,5	-10,4 ± 7,5
	6. týden	19,6 ± 0,6	-11,7 ± 9,8	18,8 ± 7,4	-9,6 ± 7,3
	12. týden	21,7 ±10,4	-9,1 ±5,2	20,2 ± 8,1	-7,6 ± 9,5
BCTQ-FSS	Vstupně	18,0 ± 6,7		17,0 ± 6,1	
	2. týden	14,0 ± 6,5	-4,0 ± 5,6	13,5 ± 5,5	-3,5 ± 4,1
	6. týden	13,0 ± 7,4	-5,0 ± 6,8	12,9 ± 6,1	-4,2 ± 5,3
	12. týden	14,3 ± 8,0	-3,3 ± 5,2	13,0 ± 5,2	-4,0 ± 5,1
Dvoubodové diskriminační čití (mm)	Vstupně	4,6 ± 2,7		4,7 ± 3,8	
	2. týden	3,6 ± 1,9	-1,0 ± 1,6	4,1 ± 3,8	-0,8 ± 1,4
	6. týden	3,4 ± 2,2	-1,2 ± 2,1	3,9 ± 3,9	-0,9 ± 1,4
	12. týden	3,4 ± 2,9	-1,0 ± 2,2	3,6 ± 4,0	-1,1 ± 2,0
Síla úchopu (kg)	Vstupně	22,7 ± 1,9		20,5 ± 9,5	
	2. týden	24,4 ±12,0	1,6 ± 3,7	22,6 ±11,0	2,9 ± 5,2
	6. týden	25,1 ±11,4	2,3 ± 5,2	23,9 ± 1,6	3,6 ± 6,1
	12. týden	25,2 ±10,7	0,7 ± 7,2	24,4 ±11,8	3,1 ± 7,3
Závažné nežádoucí události		0		0	

Data jsou průměrnou hodnotou ± směrodatná odchylka

VAS; vizuální analogová škála bolesti, BCTQ; Boston Carpal Tunnel Questionnaire (Bostonský dotazník), SSS; Symptom Severity Scale (stupeň závažnosti subjektivních příznaků), FSS; Functional Status Scale (stupeň funkčního postižení), N; number (počet)

Tab. 3 Srovnání ultrasonografických a elektrodiagnostických parametrů

		Skupina A (N=23)	Rozdíl od vstupního vyšetření	Skupina B (N=23)	Rozdíl od vstupního vyšetření
CSA (mm^2)	Vstupně	18,0 ± 5,0		16,6 ± 5,1	
	12. týden	15,7 ± 3,1	-2,0 ± 2,0	14,3 ± 3,3	-1,7 ± 1,3
DML (ms)	Vstupně	5,5 ± 1,4		5,4 ± 1,9	
	12. týden	5,1 ± 1,2	-0,5 ± 0,6	5,0 ± 1,5	-0,5 ± 0,7

Data jsou průměrnou hodnotou ± směrodatná odchylka

CSA; cross-sectional area (plocha příčného řezu), DML; distální motorická latence, N; number (počet)

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European Journal of Physical and Rehabilitation Medicine 2021 October;57(5):775-82
DOI: 10.23736/S1973-9087.21.06682-X

ORIGINAL ARTICLE

Ultrasound-guided perineural *vs.* peritendinous corticosteroid injections in carpal tunnel syndrome: a randomized controlled trial

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ABSTRACT

BACKGROUND: Corticosteroid injections are proven to be effective in the management of carpal tunnel syndrome (CTS); however, the optimal injection site still remains unclear.
AIM: The aim of this study is to compare the efficacy of perineural *vs.* peritendinous target sites for corticosteroid injection in CTS.
DESIGN: A randomized, single-blind, controlled trial.
SETTING: Outpatients, tertiary care center.
POPULATION: Forty-six patients were equally randomized into two intervention groups as group A (18 female and five male patients; mean age: 50.0±15.9 years; mean symptom duration: 5.9±3.3 months) and group B (19 female, four male patients; mean age: 54.3±15.0 years; mean symptom duration: 5.9±4.7 months).
METHODS: Methylprednisolone acetate (40 mg) and 1 mL of 1% trimecaine hydrochloride was injected next to the median nerve (group A) or among flexor tendons away from the nerve (group B) under ultrasound (US) guidance. The visual analogue scale was used as the primary outcome measure, and the symptom severity scale and functional status scale of the Boston Carpal Tunnel Questionnaire were used as the secondary subjective outcome measures. Two-point discrimination, grip strength, cross-sectional area, and distal motor latency were assessed as objective outcome measures. The data were collected at baseline and at 2, 6 and 12 weeks after the injection.
RESULTS: Both groups showed improvement in subjective and objective measures at 2 weeks following the injection - also maintained up to 12 weeks during the follow-up ($P<0.05$). However, no difference was observed between the two groups ($P<0.05$). No serious adverse effects were observed in either group.
CONCLUSIONS: Both intervention techniques seem to be effective and safe in the conservative treatment of CTS.
CLINICAL REHABILITATION IMPACT: Based on this study results, it might be noteworthy that physicians can opt for perineural or peritendinous injections without compromising the treatment efficacy and safety. Herewith, US guidance is, for sure, necessary for performing safe and accurate injections.

(*Cite this article as:* Mezian K, Sobotová K, Kuliha M, Chang KV, Ceé J, Angerová Y, *et al.* Ultrasound-guided perineural *vs.* peritendinous corticosteroid injections in carpal tunnel syndrome: a randomized controlled trial. Eur J Phys Rehabil Med 2021;57:775-82. DOI: 10.23736/S1973-9087.21.06682-X)

KEY WORDS: Median nerve; Ultrasonography; Nerve compression syndromes; Adrenal cortex hormones; Carpal tunnel syndrome; Intra-articular injections.

Carpal tunnel syndrome (CTS) is the most common peripheral nerve entrapment syndrome worldwide whereby the symptoms usually result from compression of the median nerve at the wrist.[1] Its diagnosis is based

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on clinical evaluation, nerve conduction studies, and ultrasonographic (US) examination. Actually, in the last two decades, the popularity of US has increased among musculoskeletal physicians.[2] It is commonly being used to morphologically show the compression (i.e. median nerve enlargement), to uncover the possible causes for nerve entrapment (*e.g.* aberrant soft tissue), and also to guide for interventional procedures (injections or minor surgery) in the management.[3-6] Among conservative treatment alternatives, corticosteroid injections have been proven to be effective in CTS patients;[7] however, the optimal target site for corticosteroid delivery still remains debatable.[8-10]

The pathophysiology of CTS has still not been fully unmasked. One of the presumed mechanisms of increased intracarpal pressure[11] is due to swelling of the flexor tendon sheaths under mechanical strain.[12] This ′theory of tendinopathy′ is actually in line with the higher prevalence of CTS in manual laborers. Likewise, the favorable effects of corticosteroid injections in CTS would presumably be linked to the thinning of those tenosynovia (owing to the reduction of cellular activity and collagen production),[13] decompressing the median nerve. Some authors also described fibrosis of the subsynovial connective tissues as a common finding in CTS patients. Normally, those tissues form a multilayer gliding unit (between the flexor tendons and the median nerve) which is compromised in CTS patients.[14] In line with the ′theory of tendinopathy′, it would be reasonable to inject corticosteroids among the flexor tendons inside the carpal tunnel *i.e.* away from the median nerve.[15]

Another mechanism as regards functional impairment of the median nerve would be the perineural adhesions. Theoretically, they may develop due to increased intratunnel pressure and impaired circulation. Further, the nerve's decreased mobility could also result in shear stress from the surrounding tissues, causing damage to the epineurium.[16] Considering this ′theory of adhesions′, injecting next to the median nerve — with the aim to mechanically disrupt the perineural adhesions — can be anticipated. The subsequent restoration of the normal nerve mobility might contribute to better improvement of the median nerve function in CTS patients.[17] Likewise, in this study, our hypothesis was that the perineural injection technique might provide an additional benefit compared to the peritendinous injection away from the median nerve. As such, the objective of this study was to compare the efficacy of two particular US-guided corticosteroid injections in CTS, *i.e.* perineural *versus* peritendinous.

Materials and methods

Study design

This study was conducted as a prospective randomized clinical trial (with a 12-week follow-up) between June 2016 and July 2020 (ClinicalTrials.gov identifier NCT02907671). The study protocol was approved by the Ethics Committee of the General University Hospital in Prague (number 1860/19 S-IV) and it was conducted/reported in accordance with the CONSORT guidelines. All subjects volunteered to participate, gave written informed consent before enrollment, and were allowed to leave the study at any time.

Subjects

Patients who presented to our physical and rehabilitation medicine outpatient clinic with the symptoms of numbness, tingling, or pain in the median nerve innervated area of the hand were initially treated with a wrist splint during the night. The patients were also given tailored instructions for activity (*e.g.* to avoid repetitive use of hands and holding vibrating tools) and ergonomics (*e.g.* mouse and keyboard) modifications. Patients who did not improve with splint therapy and activity/ergonomics modifications were informed about other treatment options, i.e. operative carpal tunnel decompression, physiotherapy, and US-guided corticosteroid injection. Those patients (aged 18-80 years) who opted for injection therapy were assessed for eligibility. They were recruited in the study if they met the electrodiagnostic criteria for at least mild CTS[18] and the ultrasonographic criteria based on the nerve cross-sectional area.[19] Exclusion criteria were the presence of any secondary/underlying cause of compression (*e.g.* ganglion cyst, bursitis), diabetes mellitus, uncontrolled thyroid or inflammatory disease, cervical radiculopathy, brachial plexopathy, polyneuropathy, severe illness, psychiatric disease, prior CTS surgery, wrist fracture, pregnancy. Subjects were also excluded if they had a previous corticosteroid injection for CTS within the last six months, or if they had allergy to methylprednisolone acetate or trimecaine hydrochloride. Anatomic variations (*e.g.*, persistent median artery/vein, bifid median nerve) were not considered an exclusion criteria. In patients with bilateral CTS, the worse side of the patient — according to the Symptom Severity Scale (SSS) of the Boston Carpal Tunnel Questionnaire (BCTQ) — was included in the analyses.

Patient assignment and randomization

Participants (N.=46) who met the above-mentioned criteria were randomly assigned into two intervention groups

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— 1:1 with an emphasis on the balanced distribution of important covariates. To generate the random allocation sequence, we used a computerized random-number generator. For the randomization, opaque envelopes containing notes for each of the two US-guided injection techniques, *i.e.* "next to the median nerve" and "between the flexor tendons" were used. Subjects were allocated to group A (perineural injection, N.=23 patients/wrists) and group B (peritendinous injection, N.=23 patients/wrists) accordingly. All participants, the outcome assessor and the physician who performed the electrodiagnostic tests were kept blinded to the allocation during the whole study period. Due to the nature of the study, it was not possible to keep the physician (K.M.) — who performed the US examination and the US-guided injections — blinded to the groups. Herewith, he was unaware of the electrophysiological and other clinical data of the subjects.

Outcome measures

All patients completed the Visual Analogue Scale (VAS), and self-administered BCTQ which has good responsiveness and serves as a valid/reliable tool to measure symptom severity and functional status in CTS.[20] The BCTQ comprises two subscales, namely the SSS (11 items) and the Functional Status Scale (FSS, eight items), where the higher scores indicate greater symptom severity and disability, respectively.[21] Changes in VAS were considered the primary outcome to assess the efficacy of the two injection techniques. The secondary outcomes were BCTQ-SSS, BCTQ-FSS, 100-mm VAS, and clinical examination (grip strength and 2-point discrimination).

Electrodiagnostic testing

Nerve conduction studies were performed by a single electrophysiologist (JC), using a Medelec Synergy device (Oxford Instruments, Abingdon-on-Thames, UK). The examination was carried out following the American Association of Neuromuscular and Electrodiagnostic Medicine Guidelines.[22] We used the median nerve distal motor latency (DML) as an objective secondary outcome measure. It was obtained by placing surface electrodes over the abductor pollicis brevis (APB) muscle with stimulation at the wrist.

Ultrasound examination

Ultrasonographic evaluation was performed according to EURO-MUSCULUS/USPRM wrist and hand scanning protocol,[23] using a 3-16 MHz linear array transducer (Samsung UGEO HM70A, Seoul, South Korea). Settings for focus, gain, depth and probe frequency were adjusted by the examiner to obtain the optimal image of the median nerve and adjacent structures (flexor retinaculum, flexor tendons, ulnar artery, and ulnar nerve). After the median nerve was identified in the carpal tunnel inlet; its cross-sectional area (CSA) was measured by digital caliper, tracing the internal border of the epineurium (hyperechoic rim). In addition, to increase the diagnostic specificity, the median nerve CSA was also measured at the level of the proximal third of the pronator quadratus muscle (PQM) to obtain the so-called delta CSA (CSA-inlet — CSA-PQM).[24] Further, we have also measured the median nerve CSA in the forearm, 12 cm proximal to the distal wrist crease.[25] Each image was measured three times and the mean value was used for analyses.

Ultrasound-guided injections

Like all the US examinations, US-guided injections were performed by the same physiatrist with more than eight years of experience in the musculoskeletal US (K.M.). Patients were seated facing the sonographer with their affected wrist in slight dorsiflexion resting on a rolled towel in a palm up position, the forearm supinated and elbow semiflexed at 90°. The skin over the injection site was prepped with an alcohol-based disinfection solution, while the US probe was covered with a sterile glove with non-sterile US gel inside, using a sterile US gel between the probe and the skin. The US probe was positioned transversely at the level of the distal wrist crease. All injections were performed (using a freehand ulnar side in-plane approach keeping the median nerve in the short-axis) with a 2 mL syringe containing 1 mL trimecaine hydrochloride and 1 mL (40 mg/mL) methylprednisolone acetate. Under direct US visualization; 25-gauge, 25-mm needle was advanced subcutaneously, slightly obliquely, superficial to the ulnar nerve and artery. Figure 1 illustrates the schematic drawing with respect to the anatomical targets during the injections. In group A, the needle was advanced until the tip of the needle was adjacent to the median nerve with subsequent slow administration of the injectate between the median nerve and the superficial flexor tendons. In group B, the injectate was slowly administered between the middle and ring finger flexor tendons in the horizontal plane, and between the superficial and deep flexor tendons in the vertical plane, away from the median nerve. In some cases, passive flexion/extension of the fingers was necessary to elucidate the cleft between the flexor tendons.[26] After withdrawal of the nee-

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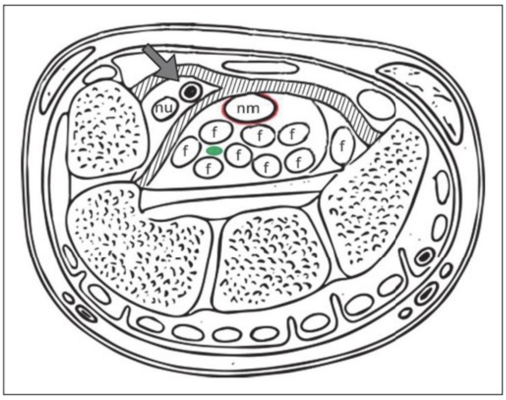

Figure 1.—Schematic drawing of the injection techniques. The green oval in the online version shows the injection site among the flexor tendons (f) away from the nerve. The red line encircling the median nerve (nm) in the online version designates the zone for perineural injection. The arrow points at the ulnar artery. The hatched lines mark the flexor retinaculum. nm; median nerve; f: flexor tendons; nu: ulnar nerve.

dle, repetitive wrist flexion and extension was passively done five times to enhance the injectate delivery distally along the carpal tunnel.

Follow-up

The patients were instructed to wear the wrist splints all day and night (as tolerated and with hygiene exception) and to limit their activities associated with the handloading for three days following the injection. No other treatments were given. If present, adverse reactions (*e.g.* post-injection flare, facial flushing and skin/fat atrophy) after the injections were noted. While BCTQ, VAS and clinical evaluations were performed at baseline, 2, 6 and 12 weeks after the injection; US and electrodiagnostic examinations were conducted at baseline and 12 weeks following the interventions.

Statistical analysis

Statistical analyses were performed using MedCalc version 14 statistical software. The level of statistical significance was set at $P<0.05$. The sample size was calculated assuming an alpha level 0.05, and 80% power to recognize the minimal clinically important difference (MCID) between-groups of 25% on the VAS, eight points in SSS, and five points in FSS at the baseline and follow-up periods.[27] Accounting for 10% dropout rate, a sample size of 23 patients was required for each group (46 subjects in total). Mann-Whitney U-test was used for comparisons of continuous variables, whereas the categorical data were compared using the χ^2 test. Effects of the intervention on the primary outcome was analyzed using a 4×2 repeated-measures analysis of variance. The difference in time (baseline and post-injection 2, 6 and 12 weeks) served as the within-subjects factor, whereas the types of injections were considered as the among-subjects factor.

Results

Out of 52 patients assessed for their eligibility, six were excluded for not having met the inclusion criteria. Figure 2 shows how the 46 participants were equally randomized into the intervention groups. Six patients could have not completed the study due to COVID-19 pandemic lockdown (N.=4), surgical referral (N.=1) and non-specified reason (N.=1). Out of those six patients, one left the study after the baseline visit, and the rest (N.=5) completed all but not the last 12th-week visit. As such, we applied an intention-to-treat analysis of the study data.

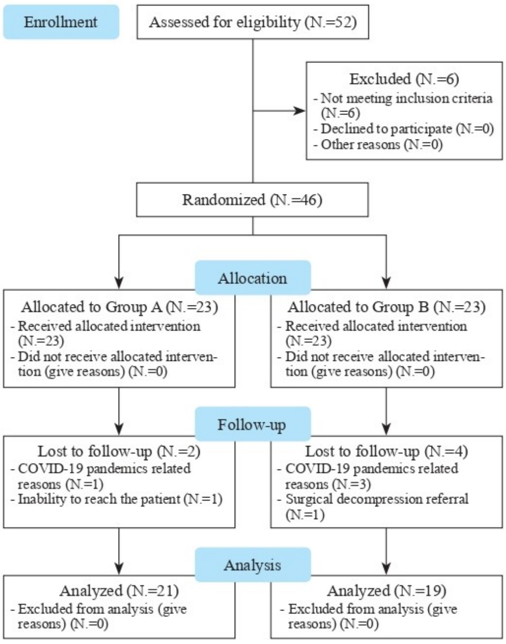

Figure 2.—Flow diagram of the study.

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TABLE I.—*Patient baseline characteristics.*

Characteristics	Group A (N.=23)	Group B (N.=23)
Age, years	50.0±15.9	54.3±15.0
Gender, F/M	18/5	19/4
BMI, kg/m²	30.6±6.1	30.2±4.3
Bilateral CTS, N.	14	13
Dominant side, R/L	23/0	22/1
Duration of symptoms, months	5.9±3.3	5.9±4.7
Injection side, R/L	18/5	15/8
VAS, cm	5.2±2.4	4.7±2.3
Grip strength, kg	22.7±11.9	20.5±9.5
Tinel positivity	10	12
Phalen positivity	11	14
2-point discrimination, mm	4.6±2.7	4.7±3.8
Boston Carpal Tunnel Questionnaire		
SSS	31.3±8.6	28.6±6.7
FSS	18.0±6.7	17.0±6.1
Nerve conduction study		
Severity grading (mild/moderate/severe/extreme)	2/17/4/0	4/14/4/1
DML, ms	5.5±1.4	5.4±1.9
Ultrasonographic evaluation		
CSA, mm²	18.0±5.0	16.6±5.1
Delta CSA, mm²	9.8±4.5	9.2±5.0
WFR	2.6±0.8	2.4±0.9

Data are given as mean±SD.
BMI: Body Mass Index; CTS: carpal tunnel syndrome; R: right; L: left; VAS: Visual Analogue Scale; SSS: Symptom Severity Scale; FSS: Functional Status Scale; DML: distal motor latency; CSA: cross sectional area; WFR: wrist-to-forearm ratio.

Both groups were similar as regards demographic, clinical, ultrasonographical and electrophysiological data at baseline (Table I). None of the patients reported intolerance for the diagnostic/interventional procedures and no serious adverse events were observed in the groups.

Table II demonstrates the treatment outcome of the participants, using the intention-to-treat analysis. The two groups were similar regarding each and every parameter at any time point. Compared to the baseline scores, both in groups A and B, VAS scores (the primary outcome) reached the minimal important difference (MCID) at two weeks (-2.4±2.8, -2.6±2.6 respectively), while the effect was maintained at 12 weeks (-2.7±2.4, -2.1±2.7 respectively) after the injection. A similar observation was also present for the SSS (secondary outcome) of the BCTQ at two weeks (-10.0±8.4, -10.4±7.5 respectively), and at 12 weeks (-9.1±5.2, -7.6±9.5 respectively) after the injection. Additionally, there were no significant differences between follow-up improvements in both groups in the remaining measured parameters (BCTQ-FSS, 2-point discrimination, and grip strength).

Table III summarizes the changes in ultrasonographic and electrodiagnostic measurements. In both groups, the carpal tunnel inlet CSA and DML were significantly improved at the 12-week follow-up (all $P<0.05$). Meanwhile,

TABLE II.—*Clinical outcomes at baseline, 2, 6 and 12 weeks.*

Scale	Timepoint	Group A (N.=23)	Difference from baseline	Group B (N.=23)	Difference from baseline
VAS	Baseline	5.2±2.4		4.7±2.3	
	2 weeks	2.7±2.6	-2.4±2.8	1.9±1.9	-2.6±2.6
	6 weeks	2.1±2.6	-3.1±3.1	2.0±2.0	-2.6±2.6
	12 weeks	2.3±2.9	-2.7±2.4	2.4±2.4	-2.1±2.7
BCTQ-SSS	Baseline	31.3±8.6		28.6±6.7	
	2 weeks	21.2±9.3	-10.0±8.4	18.4±6.5	-10.4±7.5
	6 weeks	19.6±10.6	-11.7±9.8	18.8±7.4	-9.6±7.3
	12 weeks	21.7±10.4	-9.1±5.2	20.2±8.1	-7.6±9.5
BCTQ-FSS	Baseline	18.0±6.7		17.0±6.1	
	2 weeks	14.0±6.5	-4.0±5.6	13.5±5.5	-3.5±4.1
	6 weeks	13.0±7.4	-5.0±6.8	12.9±6.1	-4.2±5.3
	12 weeks	14.3±8.0	-3.3±5.2	13.0±5.2	-4.0±5.1
2-point discrimination, mm	Baseline	4.6±2.7		4.7±3.8	
	2 weeks	3.6±1.9	-1.0±1.6	4.1±3.8	-0.8±1.4
	6 weeks	3.4±2.2	-1.2±2.1	3.9±3.9	-0.9±1.4
	12 weeks	3.4±2.9	-1.0±2.2	3.6±4.0	-1.1±2.0
Grip strength, kg	Baseline	22.7±11.9		20.5±9.5	
	2 weeks	24.4±12.0	1.6±3.7	22.6±11.0	2.9±5.2
	6 weeks	25.1±11.4	2.3±5.2	23.9±11.6	3.6±6.1
	12 weeks	25.2±10.7	0.7±7.2	24.4±11.8	3.1±7.3
Serious adverse events		0		0	

Data are given as mean±SD.
VAS: Visual Analogue Scale; BCTQ: Boston Carpal Tunnel Questionnaire; SSS: Symptom Severity Scale; FSS: Functional Status Scale.

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TABLE III.—*Comparison of ultrasonographical and electrodiagnostic parameters.*

Parameter	Timepoint	Group A (N.=23)	Difference from baseline	Group B (N.=23)	Difference from baseline
CSA, mm^2	Baseline	18.0±5.0		16.6±5.1	
	12 weeks	15.7±3.1	-2.0±2.0	14.3±3.3	-1.7±1.3
DML, ms	Baseline	5.5±1.4		5.4±1.9	
	12 weeks	5.1±1.2	-0.5±0.6	5.0±1.5	-0.5±0.7

Data are given as mean±SD.
CSA: cross sectional area; DML: distal motor latency.

there was no significant difference for any parameter (either at baseline or 12-week follow-up) between the groups (all $P>0.05$).

Discussion

This randomized controlled trial aimed to compare the treatment efficacy of US-guided perineural *versus* peritendinous corticosteroid injections in CTS. According to our results, the two interventions yield similar clinical, electrophysiological and ultrasonographical findings in the 2-12 week post-injection period. The intervention led to significant clinical improvement in both groups, concordant with previous reports.[28, 29]

As our understanding of neuropathic pain is largely based on animal models involving acute and severe injuries, its extrapolation to mild and chronic scenarios in humans is limited.[30] Increased pressure within the space-limited osteofibrous carpal tunnel, nerve swelling due to compromised endoneural blood flow and blockage of axoplasmic transport are possible mechanisms for the development of CTS.[31] Long lasting swelling may eventually cause intra- and extra-neural fibrotic changes as well.[32] Additionally, the premise of extraneural fibrotic changes in the connective tissues inside the carpal tunnel is another possible explanation for the compromised kinematic behavior of the median nerve in CTS.[33]

With respect to the injectates used during interventional treatments; various substances have been reported in the literature, such as platelet-rich plasma, 5% dextrose, hyalase, local ozone (O_2-O_3) and corticosteroids.[34-36] The injectable corticosteroid used in our study was methylprednisolone acetate — a long-lasting, crystalline suspension with an average duration of action of 7-84 days.[37] Symptom relief mediated from the injectable depot corticosteroids is believed to be *via* decreasing inflammation in the synovial tissues. Its anti-inflammatory effect is also coupled with a decrease in the number of mast cells, lymphocytes and macrophages, thus reducing edema.[38] However, the effects of injectable corticosteroids in extraarticular sites are not fully understood. Although less than oral or intravenous formulations, local corticosteroid injections may elicit dose-related systemic effects.[39] A single methylprednisolone acetate injection into the carpal tunnel was found to be superior when compared to oral prednisolone for 10 days.[40] Evidence from several studies supports that the use of corticosteroid injection should improve patient reported outcomes.[41] Herein, as the injections performed in majority of the studies were palpation-guided, the exact injection site was often unclear. Although some studies which compared palpation *versus* US-guided CTS injections have reported superiority of the latter, the optimal site of injection has not been ascertained until now.[28, 29] As regards the solutions used for hydrodissecting the median nerve, several drugs have been studied. In 2018, Wu *et al.*[42] randomized 34 patients with CTS to receive either US-guided hydrodissection with 5-mL saline or injection into the subcutaneous tissue. Significant symptom improvement was observed in the hydrodissection group as compared to the control group at 6 months after the treatment. On the other hand, Schrier and colleagues[43] have reported similar results of US-guided injections using 1 mL betamethasone + 1% lidocaine either applied by hydrodissection or a single delivery medial to the median nerve.

Based on our preliminary results, injecting the corticosteroid immediately next to the median nerve does not make any difference in the treatment outcome when compared with injecting away from the median nerve, inside the carpal tunnel. The favorable clinical outcome of the intervention, regardless of the injection site, can possibly be attributed to the anti-inflammatory effects of corticosteroids. Therefore, this study cannot demonstrate the potential/additional effects of hydrodissection at the median nerve/flexor tendon interface. As such, the optimal injection approach could feasibly be defined/chosen in accordance with the local anatomy and/or the physician's preference.

Limitations of the study

However, the findings of this study must be interpreted in light of some important limitations, *i.e.* the short duration

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of follow-up and low study power. Further, the strict inclusion/exclusion criteria might be limiting the generalizability of its results. Accordingly, caution should be taken when extrapolating our findings to different populations (*e.g.* postoperative conditions and diabetic patients). In this sense, future studies also including cases with failed carpal tunnel decompression would be contributory.

Conclusions

This randomized controlled trial showed that targeting the median nerve or injection among the flexor tendons away from the nerve (during US-guided corticosteroid injections in CTS) is equally effective in terms of pain relief, functional/electrophysiological improvement and decreased nerve swelling at 2-12 weeks of follow-up.

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Conflicts of interest.—The authors certify that there is no conflict of interest with any financial organization regarding the material discussed in the manuscript.

Authors' contributions.—Kamal Mezian and Karolina Sobotová have contributed equally to this study and share first authorship. Kamal Mezian, Karolína Sobotová, Martin Kuliha, Ke-Vin Chang, and Jiří Ceé carried out the data collection. Kamal Mezian wrote the manuscript with support from Karolína Sobotová and Levent Özçakar. Levent Özçakar and Yvona Angerová supervised the project.

Congresses.—An earlier version with preliminary results was presented as a poster at the 2019 National Neurology Congress, which was held on Nov 27th-30th, 2019 in Prague, Czech Republic.

History.—Article first published online: March 18, 2021. - Manuscript accepted: March 15, 2021. - Manuscript revised: March 12, 2021. - Manuscript received: October 31, 2020.

6.2. Two Cases of Intramuscular Hemangiomas in the Upper Limbs. From Sonography to Pathology (P2)

Tato publikace popisuje dvě kazuistiky intramuskulárního hemangiomu na horní končetině. V prvním případě se jednalo o 13letého chlapce, který byl odeslán na naše pracoviště z chirurgické ambulance pro podezření na tendinitídu šlach flexorů na předloktí. Udával bolesti zejména při fyzické aktivitě, věnoval se profesionálně tenisu. Při klinickém vyšetření bylo patrné nebolestivé, pohmatově měkké prosáknutí v oblasti přední strany předloktí o délce přibližně 10 cm. Na kůži nebyly patrné barevné změny. Ultrazvukové vyšetření odhalilo dobře ohraničené ložisko lobulárního charakteru, vyplněné kompresibilními kavernami s ojediněle pozitivním signálem power Doppler. Ložisko bylo uložené ve svalovém bříšku povrchového flexoru prstů a vyplňovalo téměř celý sval. Pacient byl odeslán ve zrychleném režimu na vyšetření magnetickou rezonancí, jímž bylo potvrzeno podezření na intramuskulární hemangiom. Dále byl řešen na dětském oddělení ortopedie, kde byla provedena embolizace cév hemangiomu.

V druhém případě se jednalo o 38letou ženu s bolestmi v oblasti thenaru trvajících více než 10 let. Bolesti se zhoršovaly prací na počítači a v posledních letech se stupňovaly. V klinickém vyšetření dominoval nález pohmatově bolestivého prosáknutí v oblasti thenaru. Iniciálně byla léčena pro tendinitídu dlouhého flexoru palce ruky. Ortéza však zhoršovala klinické obtíže a UZ vyšetření odhalilo dobře ohraničené ložisko vyplněné kompresibilními kavernami s ojedinělými kalcifikacemi, uložené v bříšku povrchové hlavy krátkého flexoru palce ruky. Magnetická rezonance potvrdila diagnózu intramuskulárního hemangiomu a na oddělení plastické chirurgie bylo indikováno operační řešení (P2).

Two Cases of Intramuscular Hemangiomas in the Upper Limbs

From Sonography to Pathology

Karolína Sobotová, MD, Kamal Mezian, MD, PhD, Ahmad Jasem Abdulsalam, MD, Jan Galko, MD, and Levent Özçakar, MD

Abstract: Intramuscular hemangiomas are benign soft tissue tumors that are rarely found in the upper limbs. Diagnosing these tumors may be challenging owing to their pertinent nonspecific symptoms—often leading to misdiagnoses like tendinitis or muscle strain. In this article, two cases of intramuscular hemangiomas are presented—one in flexor pollicis brevis muscle and the other one in flexor digitorum superficialis muscle. Both subjects had nonspecific clinical symptoms whereby ultrasound imaging led to prompt diagnosis. To this end, the authors strongly advocate sonographic examination as an extension of physical examination in the daily clinical practice of musculoskeletal physicians.

Key Words: Ultrasonography, Doppler, Upper Limb, Muscle, Hemangioma

(*Am J Phys Med Rehabil* 2021;100:e82–e84)

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Intramuscular hemangiomas (IHs) are abnormal benign proliferations of blood vessels within the muscles, presenting at any age and comprising a spectrum from capillary subtypes to vascular malformations.[1] Wierzbicki and colleagues[2] estimate the incidence of hemangiomas as 7% among all soft tissue tumors, and IHs comprise less than 0.8% of them.[3] Skeletal muscle involvement usually occurs in the lower limbs, and patients generally present with symptoms like chronic pain, swelling, and loss of function (at later stages).[2,4,5] The symptom of pain, which is reported by 60% of the patients, is often exacerbated with physical activity of the involved muscle secondary to vascular dilation and increased regional blood flow—leading to swelling.[2] Hence, because of these nonspecific clinical findings, the diagnosis of IHs is often challenging.

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The patients consented to be presented in this case report.

An earlier version with some ultrasound images was presented as a poster at the 2020 14th ISPRM World Congress and 53rd AAP Annual Meeting March 4–9, 2020, Orlando, FL.

Karolína Sobotová and Ahmad Jasem Abdulsalam are in training.

Financial disclosure statements have been obtained, and no conflicts of interest have been reported by the authors or by any individuals in control of the content of this article.

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ISSN: 0894-9115

DOI: 10.1097/PHM.0000000000001561

Although plain radiographs are often noncontributory, ultrasonography (US) and magnetic resonance imaging are frequently used to investigate the vague musculoskeletal complaints.[6] Herein, two cases of upper limb IHs are reported, with their contributory US characteristics.

CASE PRESENTATION

This study conforms to all CARE guidelines and reports the required information accordingly (see Supplemental Checklist, Supplemental Digital Content 1, http://links.lww.com/PHM/B102).

Case 1

A 13-yr-old boy, a tennis player, presented with a mass on the volar aspect of his right forearm for the last year. He described pain only during physical activities. He denied any neurologic symptoms (e.g., dysesthesia, paresthesia, and weakness) in the upper limbs. His current neuromusculoskeletal examination was normal except an approximately 10-cm-long palpable and painless mass/swelling on the volar aspect of the forearm. US evaluation showed a well-marginated heterogenous cavernosal echotexture and moderately positive power Doppler signals inside the midbelly of the flexor digitorum superficialis muscle, involving almost the entire muscle (Fig. 1*A* and *B*). The suspected diagnosis of an IH was

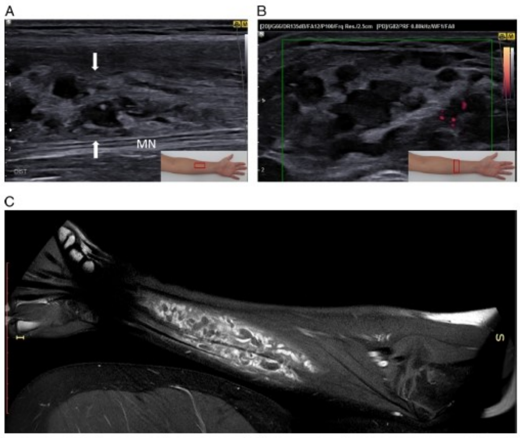

FIGURE 1. Ultrasound imaging of the anterior forearm in Case 1 (*A*, *B*). Insets show the transducer positions (*red rectangles*) during longitudinal (*A*) and axial (*B*) scanning. A well-marginated cavernosal mass (*white arrows*) is seen in the flexor digitorum superficialis muscle belly adjacent to the median nerve (MN) (*A*). Power Doppler imaging shows mild signals (*B*). Magnetic resonance image of the hemangioma (*C*).

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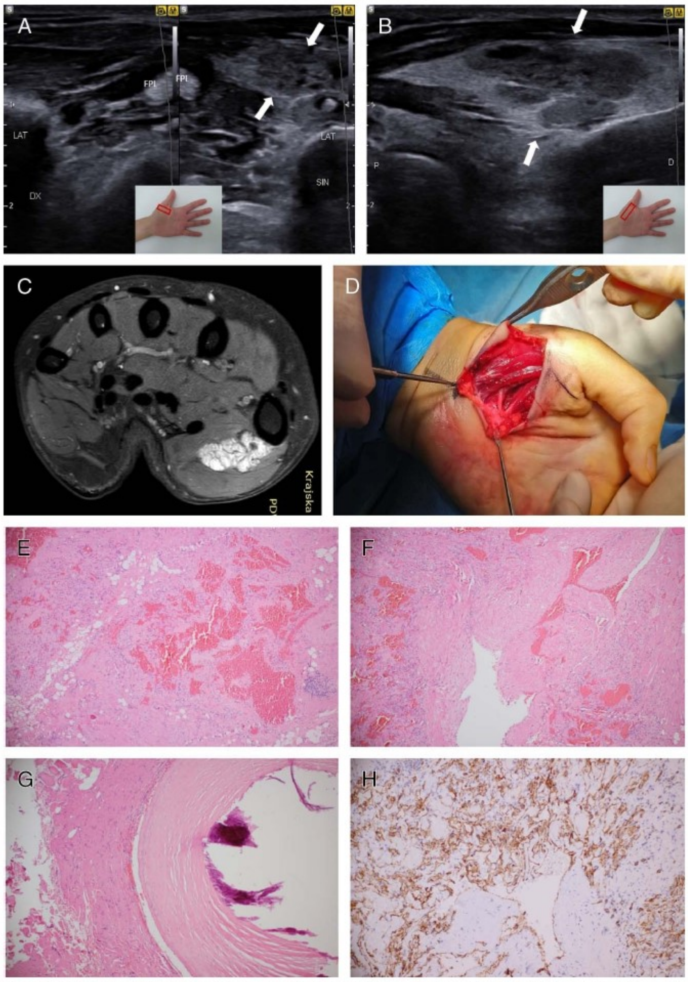

FIGURE 2. Ultrasound imaging of the thenar region in Case 2 (*A*, *B*). Insets show the transducer positions (*red rectangles*) during axial (*A*) and longitudinal (*B*) scanning. Side-to-side comparison shows a well-marginated cavernosal mass (*white arrows*) in the flexor pollicis brevis superficial muscle belly close to the flexor pollicis longus tendon (FPL) (*A*). Corresponding longitudinal image (*B*). Magnetic resonance (*C*) and intraoperative (*D*) images of the hemangioma. Histopathologic evaluations were performed from formalin-fixed, paraffin-embedded tissue blocks stained with hematoxylin-eosin (*E–H*). Selected section was analyzed immunohistochemically using antibodies against CD31 (clone JC70A, 1:50; Dako, Glostrup, Denmark) and CD34 (clone QBEND 10, 1:100; Dako). Poorly defined vascular proliferations consisting of blood vessels of various sizes, lined by bland endothelium, are present. Thin-walled blood vessels, partly growing in a cavernous pattern, with areas of adipose tissue (magnification, 100×) (*E*). Less frequent thick-walled veins and arteries (magnification, 100×) (*F*). Sporadic, organized thrombi with calcified centers (phleboliths) (magnification, 100×) (*G*). Endothelial cells expressing CD31 and CD34 (magnification, 200×) (*H*).

also confirmed with magnetic resonance imaging (Fig. 1*C*). The patient was referred to the pediatric orthopedic surgery department where arterial embolization was performed. The procedure seemed to have provided satisfactory results on the third month follow-up, and he returned to play with no limitation.

Case 2

A 38-yr-old woman presented with chronic pain in her left thenar area for more than 10 yrs, worse during computer work. Initially, she was managed as flexor pollicis longus tenosynovitis with a wrist/thumb splint. However, 3 mos later during her follow-up, she reported that the pain in the left thenar area had got worse especially while wearing the orthosis. As compared with the initial clinical examination, mild swelling and tenderness were observed in the left thenar area. US evaluation showed a well-marginated heterogenous echotexture with calcifications, involving the superficial head of the flexor pollicis brevis muscle (Fig. 2*A* and *B*). The suspected diagnosis of an IH in the flexor pollicis brevis muscle was confirmed by

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magnetic resonance imaging (Fig. 2*C*). She was referred to plastic surgery, where excision of the mass was performed (Fig. 2*D*). Grossly, the excision material consisted of muscle tissue with a poorly defined tumor measuring 8 × 7 × 6 mm. The center of the tumor was grayish white, whereas the periphery was highly vascular with firm white pellets in some of the lumina. Subsequently, microscopic examination showed vascular proliferations—consistent with the diagnosis of IH (Fig. 2*E–H*). On the follow-up visit (1 yr after surgery), the patient was pain-free, with no functional limitation.

DISCUSSION

Despite the fact that IHs are rarely seen in the upper limbs; in this report, two relevant cases (involving the flexor pollicis brevis and flexor digitorum superficialis muscles) are discussed and their ultrasonographical/histologic features, as well as their management, are highlighted. The diagnosis of IHs is actually quite challenging because of vague clinical symptoms and normal appearing radiographs. In addition, different studies have reported that such noncontributory symptoms (eg, vague pain and dysfunction) might subsequently lead to a delay in the diagnosis—also resulting in complications like flexion contracture and eventually causing extra cost and morbidity.[7,8]

In clinical examination, these tumors might appear as localized masses, with little or no compressibility. Typically, there are no skin color changes that are usually specific for superficial hemangiomas.[4] Confirmation of the diagnosis is best made by histopathologic examination. Similarly, ultrasonographic diagnosis of IHs can also be difficult because of their diffuse infiltrations in vascular and nonvascular (e.g., fat and fibrous) tissues.[9,10] These infiltrations cause pressure on blood vessels and prevent hemorrhage, also limiting the blood circulation inside the hemangioma. Consequently, during Doppler imaging, the poor blood flow may (not) be weakly detected.[4] Herewith, despite the difficulties, the high specificity of US has been reported in the diagnosis—especially for estimating the extent of tissue infiltration.[11] Last but not the least, physiatrists fortunately/increasingly use US examination in their routine practice (i.e., as the extension of physical examination), and they can efficiently/conveniently scan to catch these IHs and tailor the management of their patients accordingly.[1] For sure, the imaging method otherwise needs to be magnetic resonance imaging in the diagnostic algorithm.[2]

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6.3. Interdigital Approach to Trigger Finger Injection Using Ultrasound Guidance (P3)

Článek představuje popis alternativního způsobu obstřiku hypertrofovaného anulárního poutka při tzv. lupavém prstu. Díky UZ navigaci lze využít přístup z meziprstního prostoru, který je spojen s menším periprocedurálním diskomfortem.

Pain Medicine, 0(0), 2019, 1–3
doi: 10.1093/pm/pnz109
Letter to the Editor

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Interdigital Approach to Trigger Finger Injection Using Ultrasound Guidance

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Conflicts of interest: The authors declare that there are no conflicts of interest regarding this article and nothing further to disclose.

Dear Editor,

Stenosing tenosynovitis, or trigger finger, is an inflammation and swelling of the retinacular sheath that progressively restricts the motion of the flexor tendons [1]. This sheath normally forms a pulley system in each digit that functions to maximize the flexor tendon's force and efficiency [2]. The first annular pulley (A1) at the metacarpal head is by far the most frequently affected pulley in trigger finger; it causes pain, clicking, catching, and loss of motion of the affected finger [3]. Before surgery, initial management of trigger finger is conservative and involves activity modification, nonsteroidal anti-inflammatory drugs, joint immobilization, and corticosteroid injections [3]. The injections of corticosteroid for the stenosing tenosynovitis of the finger seem to be the most reasonable treatment option for mild triggering [3].

In the past decade, these injections have been performed under ultrasound (US) guidance, whereby intratendinous steroid injections can be avoided [3, 4]. Moreover, in the literature, reduced thickness of the A1 pulley and the volume of the flexor tendons following cortico-anesthetic mixture injections have been reported [5]. This suggests a valuable role of US also in the follow-up phase. On the other hand, several sonographic findings of trigger finger may also be visualized before the intervention, such as diffuse hypoechoic thickening of the A1 pulley, swelling of the tendons, synovial sheath effusion, and dynamic changes in the shape of the synovial sheath during flexion and extension (dynamic US examination) [6].

Ultrasound (US) guidance aids in disposing the corticosteroids successfully into the tendon sheath in 70% of all cases, as opposed to only 15% when the injection is performed blind, and it provides a higher and long-lasting positive outcome when compared with injecting blindly [7]. The US-guided technique involves positioning a US linear probe on the volar aspect of the hand and using a needle to inject corticosteroids into the sheath of the flexor tendons, distally to the first annular pulley [8]. Two approaches may be used for these injections: the in-plane approach or the out-of-plane approach, depending on the insertion of the needle. Despite the viability of both options, the out-of-plane approach provides poorer visualization of the needle, because only one short segment of it is visible in this approach. Herewith, due to the highly innervated and sensitive palmar skin and the pain associated with injecting this anatomical region, some authors in the literature have highlighted "the cruelty" of this procedure, recommending the insertion of the needle blindly in the midpoint of the web skin [9]. Injecting in this space alternatively provides a much less painful procedure due to the poor innervation of the skin in this area [10]. The use of real-time US guidance in the injection of trigger finger through the interweb space (a less painful procedure) would be considered noteworthy.

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P3

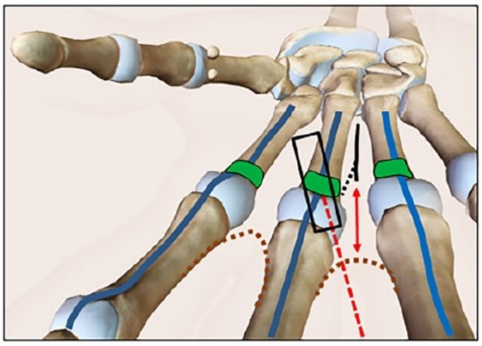

Figure 1. The rectangle illustrates the probe positioning in the longitudinal oblique plane over the third metacarpal bone on the palmar side of the hand. The straight dotted line indicates the needle's route, from distal to proximal, through the skin of the interdigital space (curved dotted lines) until the intrasheath space of the flexor tendons beneath the affected A1 pulley (box structures). The double arrow represents the neurovascular bundle, which bifurcates more proximal to the needle's route. Of note, the dorsal branch (straight dotted line) of the proper digital nerve (black line) is seen rising proximal to the needle entry point.

A high-frequency linear array (preferably hockey stick) probe can be used during imaging. While the patient sits facing the sonographer, transverse and longitudinal scanning over the flexor tendons on the palm and digits can be easily performed. After static imaging, dynamic maneuvers (i.e., flexion/extension) that may reveal locking and snapping can/must be used to better understand the functional impact of the structural abnormalities. Flexion against resistance of the finger can either demonstrate tear of the tendon (tissue discontinuity) or annular pulley rupture (increased distance between the tendon and bone/bowstringing effect). In the case of fibrillar pattern discontinuity, flexion/extension motions under US real-time visualization can be used to clearly distinguish the deep and superficial tendon [6]. The power Doppler modality, with a precise location of the region of interest in the intermetacarpal space, provides a clear identification of the neurovascular bundle (proper digital nerves and vessels) in order to avoid it during the interventional procedure. In the presence of sonographic features compatible with trigger finger (e.g., annular pulley hypertrophy, synovial sheath effusion, tendon swelling), the injection can be planned.

With the probe positioned in a longitudinal oblique plane on the palmar side of the hand, the needle can be

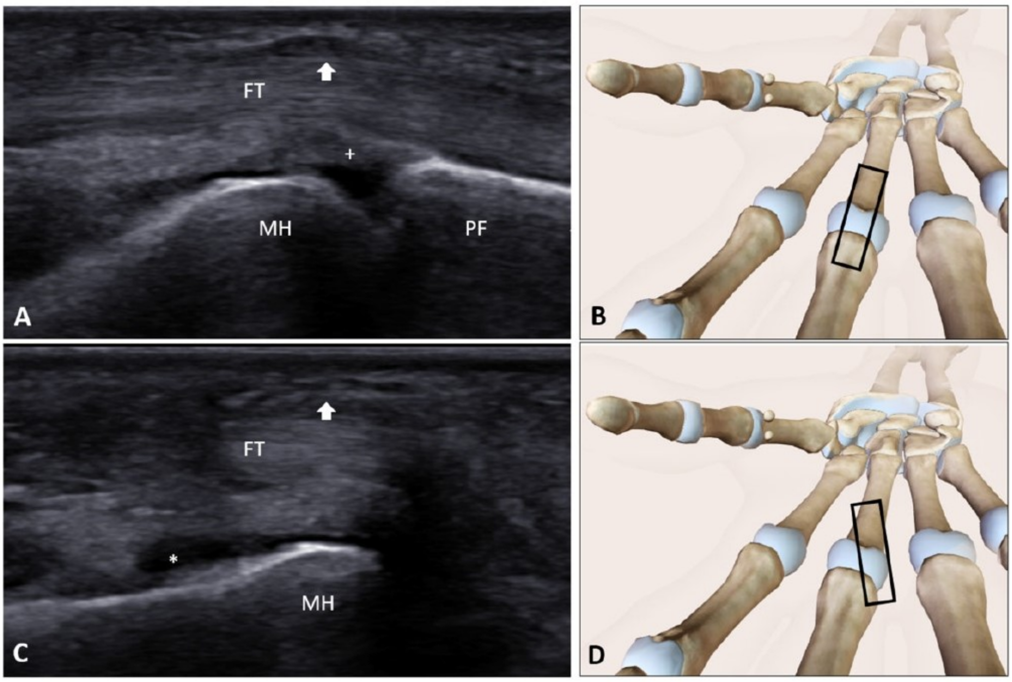

Figure 2. Ultrasound image highlighting the anatomical structures in longitudinal and oblique view with the corresponding schematic drawing of the position of the probe (rectangle). Arrow: swollen A1 pulley. *Volar synovial recess of the joint. +Volar plate. FT = flexor tendons; MH = metacarpal head; PF = proximal phalanx.

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inserted via the interdigital wing skin (Figure 1). The injection may be performed using a direct in-plane approach (real-time visualization of the long axis of the needle), and the drugs are administered into the intrasheath space beneath the affected pulley (Figure 2). We recommend using a thin needle (e.g., 25–27 G), to reduce the procedure-related pain, with a mixture of corticosteroid and local anesthetics (based on personal/institutional preference). Of note, the detachment of the annular pulley (A1) from the flexor tendon(s) during the injection is the proof/confirmation of the correct location of the needle's tip. Additionally, the intrasheath distribution of the drugs is confirmed by the dilatation of the superior and inferior recesses of the synovial sheath of the flexor tendon complex (Supplementary Data).

In short, we strongly advocate the use of US imaging not only in the diagnostic phase but also/especially in the interventional treatment of trigger finger for two main reasons. The first is the possibility of clearly identifying the neurovascular bundle located in the palmar side of the hand (interindividual variability) in order to perform a safe injection. The second is the possibility of planning a painless needle route (in our case, a longitudinal oblique plane) not simply based on anatomical landmarks (metacarpal head by palpation) but on visualizing in real time the needle's progression through the tissue planes until the synovial sheath of the flexor tendons under the A1 pulley, avoiding the neurovascular structures.

Supplementary Data

Supplementary data are available at *Pain Medicine* online.

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6.4. Ultrasound-Guided Procedures in Common Tendinopathies at the Elbow: From Image to Needle (P4)

Ulnar Neuropathy at the Elbow: From Ultrasound Scanning to Treatment (P5)

Ultrasound Imaging and Guidance in Common Wrist/Hand Pathologies (P6)

Jedná se o tři přehledové články popisující problematiku sonografického vyšetření a UZ navigovaných intervencí struktur v oblasti lokte, průběhu n. ulnaris v oblasti lokte a anatomicky predisponovaných úžinách na paži a předloktí v blízkosti loketního kloubu a struktur v oblasti zápěstí a ruky. V každém z nich je představeno anatomické pozadí, včetně fotografií jednotlivých krajin na kadáverózních preparátech a odpovídající ultrazvukové zobrazení. Dále jsou představeny základní možnosti léčby a UZ navigovaných intervencí včetně obrazové dokumentace.

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Review

Ultrasound-Guided Procedures in Common Tendinopathies at the Elbow: From Image to Needle

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Abstract: Elbow pain is a prevalent condition in musculoskeletal physicians' settings. The majority of cases present with periarticular pathologies (varying from tendinopathy to nerve entrapment syndrome). Nevertheless, in some cases, the underlying cause can be intra-articular, e.g., loose bodies or rheumatic disease. Progress in ultrasound (US) technology has yielded high-resolution assessment of the elbow and, importantly, allows real-time, radiation-free guidance for interventions. Particularly in ambiguous cases, US imaging is necessary to arrive at the correct diagnosis. The following four clinical conditions are covered: tennis elbow, golfer's elbow, distal biceps, and distal triceps tendinopathy. The present review illustrates cadaveric elbow anatomy, corresponding US images, and exemplary pathologies. Additionally, the authors also discuss the existing evidence on ultrasound-guided procedures in the conditions mentioned above.

Keywords: tendinopathy; golfer's elbow; tennis elbow; distal biceps; distal triceps; ultrasonography; steroid; injection

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Citation: Mezian, K.; Jačisko, J.; Novotný, T.; Hrehová, L.; Angerová, Y.; Sobotová, K.; Naňka, O. Ultrasound-Guided Procedures in Common Tendinopathies at the Elbow: From Image to Needle. *Appl. Sci.* **2021**, *11*, 3431. https://doi.org/10.3390/app11083431

Academic Editor: Marco Invernizzi

Received: 31 March 2021
Accepted: 9 April 2021
Published: 12 April 2021

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1. Introduction

Pain at the elbow is a relatively common condition, particularly among athletes, manual laborers, and office workers [1]. The broad spectrum of elbow pain etiologies ranges from tendinopathy to soft tissue neoplasms. Mainly, tendinopathies are frequent in daily clinical practice. Repetitive microtrauma resulting from overload or overuse can cause collagen fibril rupture and the innate immune system's activation [2,3]. However, histopathological studies have shown an absence of inflammatory cells in chronic tennis elbow biopsies [4,5]. Accumulating evidence identifies it as tendinosis, an asymptomatic degenerative process characterized by an abundance of fibroblasts, vascular hyperplasia, and unstructured collagen. These findings were termed "angiofibroblastic hyperplasia" by Nirschl and Alvarado [6]. In situations of repetitive stretching, multiple microtears of the tendon potentially cause an irreversible denaturing of matrix proteins and proliferation of fibrous tissue [7]. Over time, these scar tissues are vulnerable to repetitive forces, with subsequent further tears and worsening symptoms [8]. Histopathological studies have shown defects and necrosis inside the tendon fibers within tendons in patients with chronic tennis elbow, which is ascribed to a strong association with the underuse of the affected limb due to the fact of pain-related immobilization [9]. In addition, inadequate tendon angiogenesis and continuous muscle contraction can lead to tendon ischemia, further aggravating tendinosis development [10]. The elbow joint is a complex hinge joint between the humerus and the radius and ulna, providing pronation/supination of the forearm and flexion/extension of the elbow.

Due to the elbow's complex anatomy, the underlying etiology's determination is sometimes far from straightforward. Understanding the elbow's anatomy, pathophysiology, and biomechanics is essential for managing pertinent pathologies [11]. The role of physical examination is essential; however, it is also limited as physical signs are often nonspecific [12,13]. Ultrasound (US) imaging has proven to be a valuable method to provide a specific diagnosis and a convenient tool to guide interventions [14–17]. Numerous interventional procedures (e.g., injections of corticosteroids and local anesthetics, dry needling, or regenerative medicines) are commonly performed to treat painful conditions at the elbow [18].

This review aims to describe the anatomy, US imaging/guidance, and the literature evidence about the most common interventional procedures targeting tendons in the elbow region, i.e., tennis elbow, golfer's elbow, distal biceps, and distal triceps tendinopathy.

2. Materials and Methods

Representative pictures of the anatomic regions were elaborated using donated bodies with the approval of the Institute of Anatomy, First Faculty of Medicine, Charles University, Prague. Normal ultrasound images were obtained in a 32 year old asymptomatic female volunteer using the ultrasound system, UGEO HM70A, with a 3–16 Mhz linear phased array transducer (Samsung, Seoul, Korea). For elbow scanning, we recommend a comfortable semi-supine positioning of the patient [19,20]. As an alternative, the patient may also sit facing the physician with his or her elbow being supported on the examination bed/table [21]. Since most elbow structures are superficially situated, a high-frequency (8–18 MHz or higher) linear array would be preferred during all the procedures described below.

3. Common Elbow Pathologies

3.1. Tennis Elbow

Tennis elbow (i.e., lateral epicondylitis) is a painful condition of the common extensor tendon (CET) in the proximal dorsal forearm. The problem was first described by Runge [22] in 1873. The "Lawn Tennis Arm" was labeled and published in *The Lancet* by Morris in 1882. Patients usually complain of pain and tenderness at the lateral elbow. In most cases, the etiology is overuse due to the fact of repetitive strain from excessive grip or wrist extension, radial deviation, and/or forearm supination causing microtrauma [23]. In addition to mechanical forces, the unique origin of the extensor carpi radialis brevis muscle (ECRB) in the lateral part of the capitellum could influence repeated undersurface abrasion during repetitive flexion and extension [24]. Following the tendon's repetitive stretching, multiple microtears can cause irreversible denaturing of matrix proteins and fibrous tissue proliferation [7]. The annual incidence of tennis elbow was reported as 2.4 per 1000 people [25], the prevalence was estimated as 1–3% [26], and the peak incidence is between 40 and 50 years of age [27]. It seems to be independent of sex or ethnic background [28]. It is also a socioeconomic problem, because workers are absent from work [29]. The diagnosis is based on clinical evaluation, US examination, and eventually an X-ray.

3.1.1. Essential Anatomy

A conjoint tendon, called the CET, represents the forearm's extensor muscles' proximal insertion, which is located in the ventral and lateral aspects of the lateral humeral epicondyle (LE) (Figures 1 and 2). Its course is more distally and deeper to the brachioradialis and extensor carpi radialis longus (ECRL) muscles, which originate more proximally. The CET consists of fibers derived from the extensor carpi radialis brevis (ECRB), extensor digitorum communis (EDC), extensor digiti minimi (EDM), extensor carpi ulnaris (ECU) tendons, and receives fiber from the ECRL. The ECRB represents the anterior and deep

P4

portion, and the EDC makes up the anterior and superficial parts. The ECU forms the posterior part. The ECRB, the prime dorsiflexor of the wrist and the key tendon in tennis elbow development, originates from the LE of the humerus, from the lateral collateral ligament (LCL), and the adjacent intermuscular septum [30]. Greenbaum with coauthors [31] in a cadaveric study described no clear margins between the ECRB and EDC; thus, the authors considered those two tendons mentioned above as one common tendon. Furthermore, interconnecting tendons between the ECRB and ECRL were found in 35% of limbs [32]. Distally, the ECRB inserts onto the base of the third metacarpal. These muscles' action extends the wrist and fingers while also supinating the forearm and abducting the wrist. The radial nerve innervates all of the muscles mentioned above. The brachioradialis, ECRL, and ECRB are supplied by direct branches from the radial nerve. Other extensors are innervated via the deep branch of the radial nerve (posterior interosseous nerve) [33]. Deep to the CET, the LCL bridges from the LE down to the radial head.

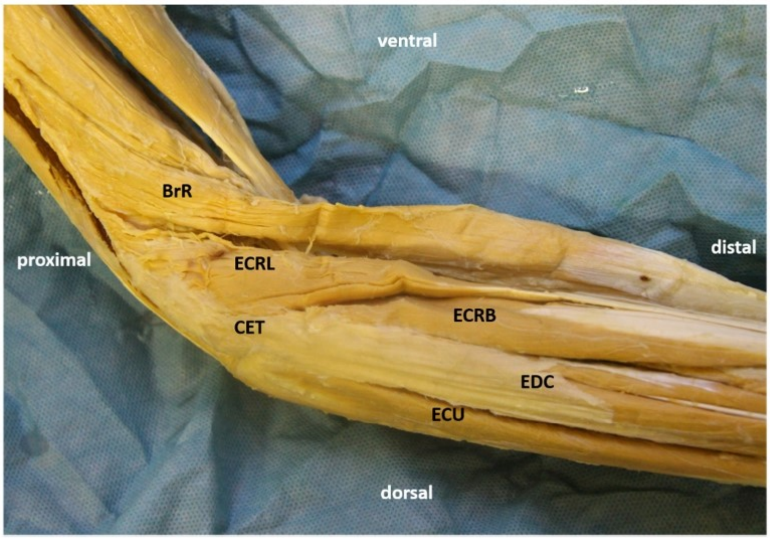

Figure 1. Common extensor origin. The cadaveric specimen shows the location of muscular origin on the posterolateral aspect of the right elbow joint. BrR: brachioradialis muscle, CET: common extensor tendon, ECRB: extensor carpi radialis brevis muscle, ECRL: extensor carpi radialis longus muscle, ECU: extensor carpi ulnaris muscle, EDC: extensor digitorum communis muscle.

3.1.2. US scanning and Guided Injection

For US scanning of the CET, the patient may be positioned supine on the examination bed while the patient's forearm rests on the stomach in mild supination. For the contralateral elbow, the US practitioner can easily scan the lateral compartment from his seat. Alternatively, the patient may sit opposite to the sonographer with the elbow flexed and with the shoulder internally rotated and the forearm semi-supinated. The probe is placed at the LE along the forearm's long axis to visualize the CET in the long axis (Figure 3). The underlying bony landmarks are the LE and the radial head. The hyperechoic fibrillar layer between bone and subcutaneous tissue represents the CET (superficial) and the lateral collateral ligament (deep), which is difficult to distinguish from the CET due to the similar fibrillar echotexture. Similarly, distinguishing between individual tendons of the CET can also be challenging. To identify an individual tendon, one can use distal to proximal muscle tracking. The ECRB and EDC tendons are predominantly affected [34]. Notably, identifying the specific tendon affected by inflammation might help tailor the rehabilitation

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program [35] and determine a convenient target for interventions (e.g., dry-needling or regenerative medicine injections).

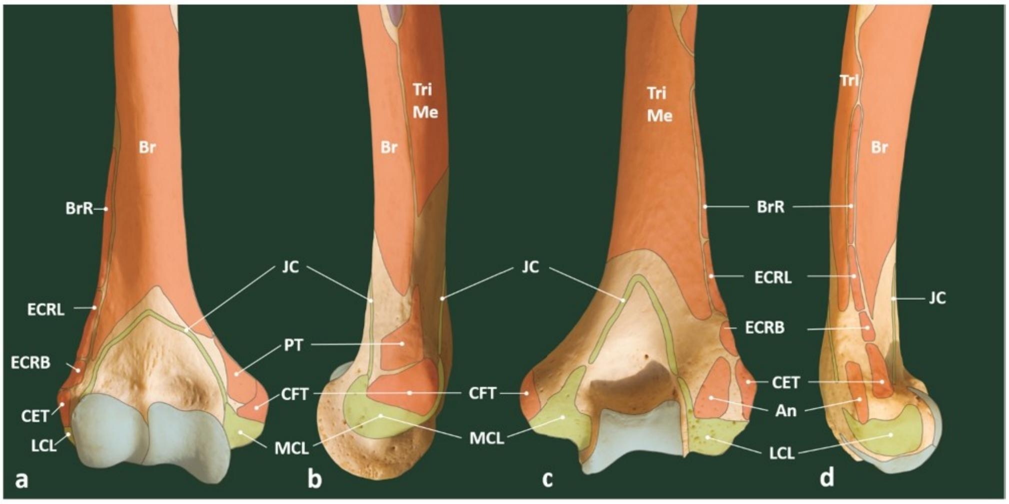

Figure 2. Location of muscular and ligamentous attachments on distal humerus: (**a**) anterior, (**b**) medial, (**c**) posterior, and (**d**) lateral aspect of the right distal humerus. Light blue: articular surfaces. An: anconeus, Br: brachialis, BrR: brachioradialis muscle, CET: common extensor tendon, CFT: common flexor tendon, ECRB: extensor carpi radialis brevis muscle, ECRL: extensor carpi radialis longus muscle, JC: joint capsule, LCL: lateral collateral ligament, MCL: medial collateral ligament, PT: pronator teres, Tri: triceps brachii, TriMe: triceps brachii, medial head.

Figure 3. Ultrasound-guided injection for tennis elbow: (**a**) position of the patient (supine, elbow flexed to 90°, internal rotation of the shoulder, thumb extension); (**b**) position of the probe on the lateral epicondyle perpendicular to the long axis of the forearm.

When intact, the CET is noncompressible, homogenous, and hyperechoic with a fibrillar tendinous pattern (Figure 4a). In pathologic cases, the examiner can observe cortical irregularities (e.g., bony spurs or erosions), tendon thickening with a loss of normal fibrillar pattern, focal or diffuse hypoechogenicity, calcifications, tears, and hypervascularity (Figure 4b–e) [36]. Furthermore, the examiner can use sonopalpation to correlate the abnormal findings with local tenderness [37].

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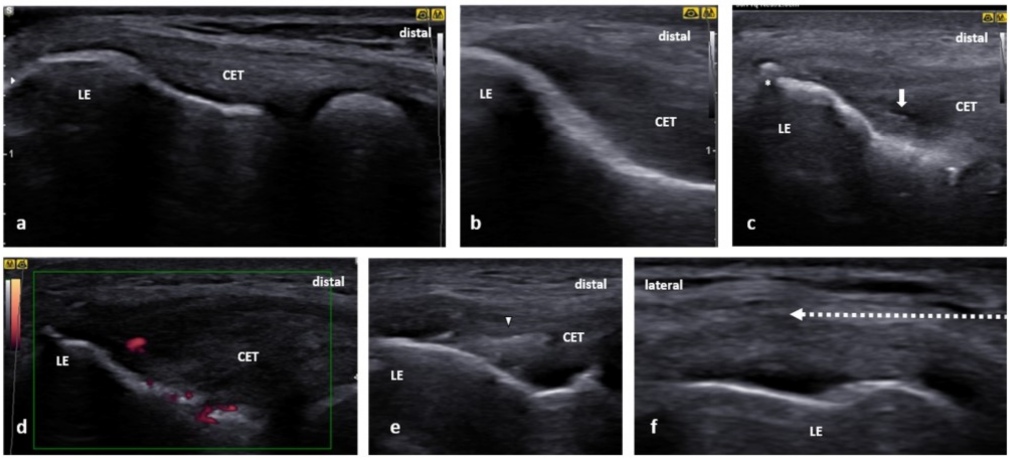

Figure 4. Ultrasound (US) images of the CET: (**a**) normal image, (**b**) a simple thickening and hypoechogenicity of the CET, (**c**) US image demonstrating a prominent spur (white asterisk) on the tip of the lateral epicondyle (LE) and focal hypoechogenicity in the tendon (white arrow), (**d**) a severe swelling of the CET with increased vascularity on power Doppler, (**e**) a mild swelling of the CET with intrasubstance hyperechogenicity indicating an immature calcification (white arrowhead) without acoustic shadowing, and (**f**) a US-guided peritendinous CET injection showing the needle (white, dotted arrow) being inserted from medial to lateral in a short axis of the CET.

Even though tennis elbow is, to a certain point, a self-limited disease, approximately 80% of patients get better after a year. Notably, some methods can enhance the healing process [38]. Sayegh et al. [39] reported a lack of clinical benefit comparing nonsurgical treatment to observation/placebo in intermediate to long-term clinical benefits. Nevertheless, in some patients who suffered from recalcitrant pain, despite the initial conservative therapy (physiotherapy, local/oral nonsteroidal anti-inflammatory drugs, orthotics), injection therapy can be considered. One promising option is dry-needling therapy, which, compared to ibuprofen, showed a better effect at six months follow up [40]. In clinical trials, various injectates are commonly compared to placebo, which is typically represented by saline solution (SS). A recent meta-analysis reported that SS might have some therapeutic effect itself. Acosta-Olivo et al. [41] reported a significant reduction in (visual analogue scale) VAS pain after SS injection, even after one year following administration. The authors also reported a substantial improvement in functional scores. The outcomes in the SS injection group were better than in the noninvasive group. Gao et al. [42] in their meta-analysis reported that 9 out of 10 (randomized controlled trial) RCTs showed no statistically significant difference between SS application and other solution injections such as platelet-rich plasma (PRP), autologous blood (AB), corticosteroids (CS), and botulinum toxin (BT). The most common agents to treat lateral epicondylitis are corticosteroids. Xiong et al. [43] reported a better effect from shockwave therapy with CS injection regarding VAS and grip strength after 12 weeks follow up. Another option for the treatment of the tennis elbow would be PRP injection. Platelet-rich plasma is an autologous preparation from patients' blood that can enhance the healing process. Simental-Mendía et al. [44] found no difference in improvement in pain and joint functionality comparing PRP with placebo (SS). Several meta-analyses compared PRP and CS injection effects. Corticosteroids injection provided better outcomes regarding pain and joint function in the short term (4 to 8 weeks after application), while PRP injection improved pain and function in the long-term (6 months to one year) more effectively [45–48]. As an alternative, AB collected from the patient's peripheral veins can also be administered into the tendon. Application of AB might enhance tissue healing. A meta-analysis by Chou et al. [49] suggested that AB is more effective at decreasing pain than CS injection, but there was no significant difference between AB and

PRP. According to Arirachakaran et al.'s [50] meta-analysis, AB can improve pain disability scores but has a higher risk of complications than PRP. Kalichman et al. [51] accessed the use of botulotoxin as a possible method of treating tennis elbow in their meta-analysis. They reported a decrease in pain at 3 months follow up. The authors concluded that BT injection in the forearm might be a suitable treatment method for chronic recalcitrant tennis elbow.

One of the technical variants to perform the tennis elbow injection is the same as for the examination in the supine position. The transducer is positioned on the lateral epicondyle perpendicular to the long axis of the forearm. The needle is inserted from lateral to medial (Figure 4f). Depending on the particular procedure plan, the needle tip can reach the peritendinous space or the tendon itself to perform intralesional (e.g., PRP) injection. The approach mentioned above allows the needle course to be parallel to the probe thus providing excellent needle visibility. Alternatively, the needle can be administered from distal to proximal (Supplementary Materials Video S1) or vice versa. When injecting the tennis elbow, potentially vulnerable structures include the anterior branch of the deep brachial artery and the deep branch of the radial nerve. Using US guidance can reduce the risk of iatrogenic injury to the structures mentioned above.

3.2. Golfer's Elbow

Golfer's elbow (i.e., medial epicondylitis) usually presents as pain at the medial elbow. It is three- or six-fold less frequent than tendinopathy of the lateral elbow (i.e., tennis elbow). It is often associated with sports activities (particularly overhead throwing) and manual labor, e.g., carpenters and plumbers [52]. Medial epicondylitis reaches nearly 10% of all cases of epicondylitis [53]. Its prevalence is approximately 0.3–0.6% in men and 0.3–1.1% in women [28]. Repetitious wrist flexion or forearm pronation at least two hours every day, smoking, diabetes mellitus, and obesity were identified as risk factors of medial epicondylitis [54]. The pain manifests itself especially when the fingers and wrist are bent. Overhead throwers are at risk due to the elbow's valgus torque during the acceleration phase of throwing, causing significant strain on the common flexor tendon. Some throwers may have other pathologies, including medial collateral ligament insufficiency, and some of them also show chronic signs of impingement known as "chronic valgus overload syndrome" [55]. Medial elbow tendinopathy diagnosis is usually not as easy as a lateral one [38]. In the differential diagnosis, one must also think of pain caused by ulnar or medial antebrachial cutaneous nerve entrapments [56,57]. Cervical radiculopathy of C6 and C7 could be associated with weakness and dysfunction of pronator teres (PT), flexor carpi ulnaris (FCR), palmaris longus (PL), flexor digitorum superficialis (FDS), and flexor carpi ulnaris (FCU) muscles. Their imbalance can lead to the onset of medial epicondylitis [58]. For diagnosis, US imaging and an MRI are beneficial, mainly when history and physical examination are noncontributory [59]. In adolescent pitchers, a common cause of medial elbow pain is due to the fact of repetitive valgus overload. This condition is known as "Little League elbow". In severe cases, the medial epicondyle fracture may occur [60].

3.2.1. Essential Anatomy

The common flexor tendon (CFT), also known as the caput commune ulnare, is a conjoint tendon of the flexor–pronator musculature on the medial humeral epicondyle (ME) (Figure 5). The CFT attaches proximally to the anterior bundle of the medial collateral ligament (MCL). The part of the CFT that is the ulnar head of the pronator teres muscle (PT) is confluent with the anteromedial joint capsule [61]. The CFT is on average 3 cm long and crosses the humeroulnar joint medially [62]. Flexor–pronator musculature is a group of four muscles of the superficial layer of the anterior forearm compartment. These muscles are the PT, FCR, PL, and FCU. The PT and FCR originate from the most proximal and anterior part of the medial humeral epicondyle. They are the most susceptible to tendinopathy development from the CFT [38]. Repetitive eccentric loading of muscles, conducting wrist flexion, and forearm pronation combined with valgus overload at the

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elbow is considered the leading cause of golfer's elbow [63]. The PT is inserted on the lateral border of the radius in the middle of the radial diaphysis. Other tendons of the flexor–pronator musculature undergo the flexor retinaculum of the wrist joint. The FCR tendons are inserted in the ventral part of the base of the second and third metacarpals. The PL inserts into the palmar aponeurosis. FCU is inserted onto the pisiform bone. PT, FCR, and PL are innervated by the median nerve. The FCU is innervated by the ulnar nerve. The ulnar nerve at the elbow level runs posterior to the medial epicondyle within the cubital tunnel.

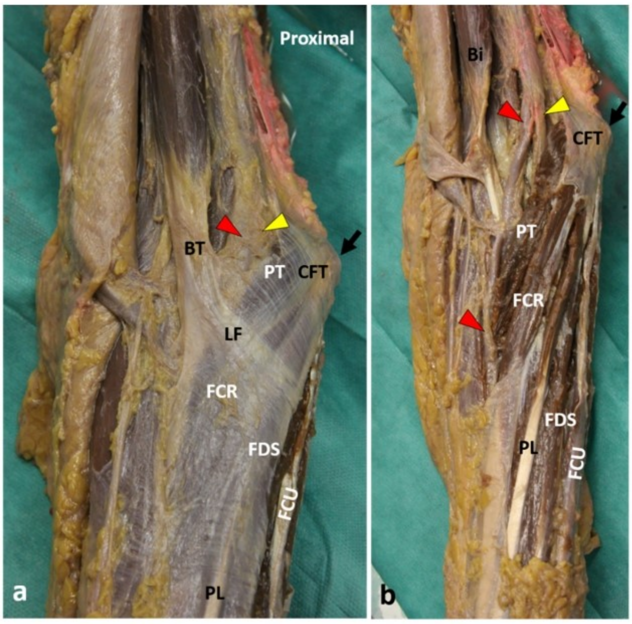

Figure 5. Common origin of flexors from the medial epicondyle. (**a**) Common flexor tendon originating from the medial epicondyle. Muscles are covered by antebrachial fascia. (**b**) The same specimen without fascial covering; the lacertus fibrosus was removed. Black arrow: medial epicondyle, yellow arrowhead: median nerve, red arrowhead: brachial artery, black arrowhead: distal biceps tendon, CFT: common flexor tendon, FCR: flexor carpi radialis muscle, FDS: flexor digitorum superficialis, FCU: flexor carpi ulnaris muscle, LF: lacertus fibrosus (aponeurosis of the biceps brachii), PL: palmaris longus muscle, and PT: pronator teres muscle.

3.2.2. US scanning and Guided Injection

For US scanning of the CFT, the patient may be positioned semi-supine on the examination bed while the patient's arm is resting on the bed with the forearm hanging over the bed's edge. As an alternative, the patient may sit facing the examiner, leaning to the ipsilateral side with the supinated forearm resting on an examination bed. To obtain the longitudinal view of the CFT, the transducer is placed at the medial humeral epicondyle (ME) along the forearm's long axis. The important bony landmarks would be the ME and coronoid process of the ulna. Superficial to these bony structures, the anterior bundle of the MCL and CFT can be identified (Figure 6a). Compared to CET, the CFT is broader and shorter. Normally, the CFT is proximally noncompressible and compressible distally while the softer muscle tissue prevails the stiffer tendon. A sensitivity and specificity of 95% and 92%, respectively, have been reported for the detection of clinical golfer's elbow. Characteristic US images of medial epicondylitis show focal areas of hypoechogenicity [59]. Typically, the swelling in a golfer's elbow is located very proximally (Figure 6b) [15]. Fur-

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ther signs, such as tendon thickening, cortical irregularities, intratendinous calcifications, and hypervascularity, are also common (Figure 6c,d). Notably, lesions of the anterior bundle of MCL can mimic or be concurrent with medial epicondylitis. In such a scenario, US imaging would reveal MCL structural abnormalities, e.g., thickening and discontinuity. Notably, the dynamic US valgus stress test might be beneficial to demask MCL rupture, coupled with elbow instability [19].

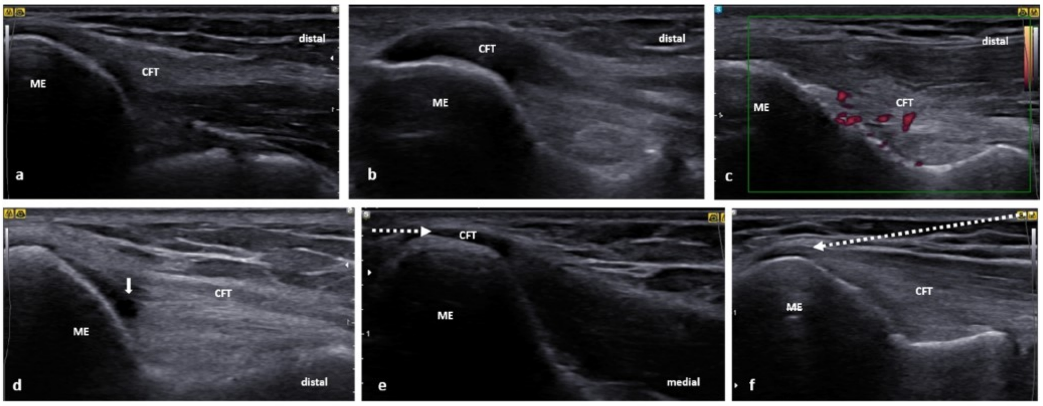

Figure 6. Ultrasound images of the CFT: (**a**) normal image of the CFT, (**b**) a severe thickening and hypoechogenicity of the CFT, (**c**) US image demonstrating degenerative changes and hypervascularity in the CFT, (**d**) small ganglion (white arrow) in the CFT, (**e**) US-guided peritendinous CET injection showing the needle (white, dotted arrow) being inserted from medial to lateral in a short axis of the CFT, (**f**) the needle (white, dotted arrow) can also be inserted from distal to proximal along the long axis of the CFT.

There is a lack of evidence for injections in medial epicondylitis. To the best of our knowledge, no meta-analysis was performed, and there are only a few RCTs. Stahl et Kaufman [64] performed RCT on 60 elbows comparing CS injection with placebo and concluded that CS injection has only short-term (6 weeks after the injection) benefit in pain reduction. The long-term effect was the same for CS and placebo. Suresh et al. [65] performed a prospective study on 20 subjects assessing pain reduction after dry-needling and autologous blood injection under US control. They found this combined method effective in reducing pain ten months after the procedure. Bohlen et al. [66] found in their cohort study (level of evidence 3) that PRP injection had a similar clinical effect as surgical treatment.

For the golfer's elbow injection, the patient may be positioned in the prone while his or her forearm also rests pronated on the examination bed (Figure 7). The probe is positioned on the medial epicondyle perpendicular to the long axis of the forearm. The needle is inserted from lateral to medial. Again, depending on the particular procedure plan, the injection can be performed peri- or intratendinous. The parallel course of the needle to the probe provides excellent needle visibility along its whole path (Figure 6e). Alternatively, the needle can be inserted from distal to proximal (Figure 6f). When injecting a golfer's elbow, one should take caution not to pierce the ulnar nerve, particularly in cases of ulnar nerve anterior dislocation [67] or in patients who underwent ulnar nerve anterior transposition surgery. Using US imaging, the safe needle route can be determined proceeding with the intervention.

Figure 7. Prone position for the ultrasound-guided golfer's elbow injection with the elbow flexed and forearm pronated while supported on the examination bed.

3.3. Distal Biceps Tendinopathy

Overuse injury and tearing of the distal biceps tendon (DBT) typically presents as a sudden onset of pain at the antecubital region, usually following an acute event, e.g., lifting or catching a heavy object [68]. Distal biceps tendinopathy is rare compared to tennis or golfer's elbow. It is believed that tendinopathy and tearing of the distal biceps tendon represent a mutual pathological process [38]. Cases of a complete tear of the distal biceps tendon are reported to account for 3% of the total cases of biceps tendon rupture, and the prevalence of this disease is estimated to be 2.55 per 100.000 [69] There is a 7.5 fold increased risk of rupture in patients who smoke [70]. Most distal biceps tendinopathy cases without the complete tear of the biceps tendon are generally associated with minor trauma or repeated activity without accompanying trauma [71].

3.3.1. Essential Anatomy

Biceps brachii muscles originate in two heads. The short head originates in the coracoid process of the scapula. The long head originates from the supraglenoid tubercle and partly from the superior part of the glenoid labrum. A DBT is a conjoint tendon of two heads. The long head inserts into a radial tuberosity proximal aspect, whereas the short head inserts into the radial tuberosity's distal aspect (Figure 8). Attachment of the DBT to the radial tuberosity has a spreading area of approximately 3 cm^2 [72]. Bifurcation of the distal biceps tendon allows functional independence and isolated pathological processes of each portion [73]. The fibers of the tendon form a spiral formation [74]. Proximal radioulnar joint was identified as a potential site of impingement of the DBT, potentially influencing the DBT vascular zone alterations [75]. The bicipitoradial bursa is located in between the DBT and the anterior part of the radial tuberosity. Enthesopathy of DBT could be an accompanying factor in the evolution of DBT tears [72]. At the elbow joint, the bicep muscle forms the biceps aponeurosis, known as the lacertus fibrosus (LF). The LF originates from the short head of the DBT and transverses medially over the CFT [38]. The biceps brachii muscle is innervated by the musculocutaneous nerve.

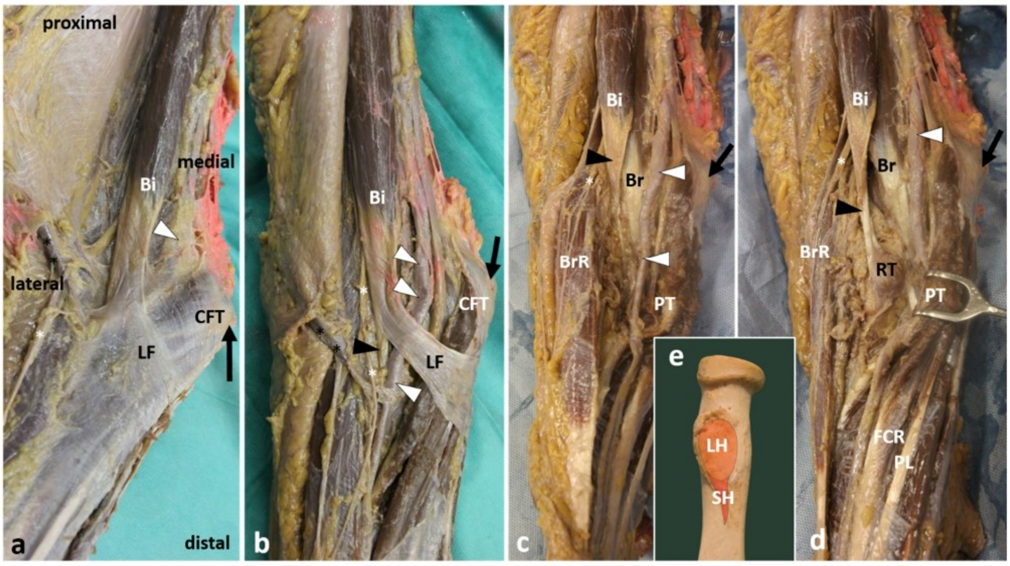

Figure 8. Insertion of biceps brachii. The cadaveric specimen shows an anteromedial aspect of the right elbow joint (all specimens were in the same position). (**a**,**b**) Lacertus fibrosus (bicipital aponeurosis) fans out in the forearm's fascia and covers the brachial artery. (**c**,**d**) The proper tendon of the biceps continues to the radial tuberosity. Its position is changing during pronation (**c**) and supination (**d**). Notably, during the supination, the bicipital tendon is moving anteriorly and superficially. (**e**) Area of insertion of the biceps tendon on radial tuberosity—proximally is situated tendon springs off from the long head (LH) and more distally inserting tendon from the short head (SH). Black arrow: medial epicondyle, black arrowhead: bicipital tendon, white asterisk: lateral cutaneous nerve of forearm, black asterisk: median cubital vein, white arrowhead: brachial artery, Bi: biceps brachii muscle, Br: brachialis muscle, BrR: brachioradialis muscle, CFT: common flexor tendon, LF: lacertus fibrosus (aponeurosis of the biceps brachii), PT: pronator teres muscle, RT: radial tuberosity.

3.3.2. US Scanning and Guided Injection

The assessment of the DBT using US imaging can be technically challenging given its oblique course. There are different ultrasound approaches to assess the DBT. It is beneficial to examine the patient lying supine with his or her upper limb extended along the trunk. The patient is asked to actively supinate the forearm while the examination bed provides a suitable resistance. The transducer is first placed in the transverse plane. When the DBT is identified lateral to the brachial artery, the probe is turned 90° to visualize the tendon in its long axis (Figures 9a,b and 10a). To reduce the unsolicited anisotropic artifact given by the tendon's oblique course, the examiner should perform a "heel–toe" maneuver with the probe to obtain the optimal image to assess the DBT. Rotating the transducer towards the pronator teres muscle, the lacertus fibrosus insertion will appear, attaching to the superficial fascia of the muscle mentioned before. To visualize the insertion of the DBT on the radial tuberosity, the elbow is flexed, the forearm is fully pronated, and the wrist flexed to "cobra position" (Figure 9c). The transducer is placed in the transverse aspect of the forearm, at the radial head. The "cobra position" is convenient for injection at the tendon insertion. The normal DBT image demonstrates homogenous fibrillar hyperechoic echostructure. The DBT tendinopathy goes along with tendon hypoechogenicity, thickening and sometimes also calcifications and increased vascularity. When the tendon is torn and retracted, the recoiled stump may demonstrate the shadowing artifact (Figure 10b) [76]. Furthermore, bicipitoradial bursitis can also be revealed in some patients presenting with anterior elbow pain.

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Figure 9. Ultrasound imaging and injection of distal bicep tendinopathy. (**a**) The physician sits adjacent to the examination bed while the patient is lying supine. The patient's actively supinated forearm rests along the body. (**b**) The same position as described before in detail. (**c**) Ultrasound-guided injection of the distal bicep tendinopathy from the "cobra position". The elbow and wrist are flexed, while the forearm is fully pronated. The probe is placed in the transverse aspect of the forearm at the radial head. The needle is inserted from lateral to medial.

Figure 10. Ultrasound images of the DBT: (**a**) normal longitudinal image of the DBT; (**b**) DBT is torn and retracted, and the recoiled stump demonstrates the shadowing artifact (white arrow); (**c**) US-guided peritendinous injection of the DBT at its footprint (white asterisk) showing the needle (white, dotted arrow) being inserted from the "cobra position" of the patient's forearm.

There is very little evidence regarding distal bicipital tendinopathy interventions and injections. Sanli et al. [77] performed a prospective cohort study on 12 patients injecting PRP with US guidance. The study showed significant improvement in pain and functional outcome at 47 months follow up. Barker et al. [78] concluded on a cohort of six patients that a US-guided PRP injection was an effective (regarding improving pain and performance scores) and a safe procedure, but further investigation involving RCT is needed. For the DBT injection, the patient can be positioned supine with the forearm in the "cobra position" to access the tendon footprint avoiding the vulnerable adjacent neurovascular structures (Figure 10c) [79]. Potentially vulnerable structures when injecting the DBT are the brachial artery and median nerve, which follow the LF. The course of the lateral cutaneous nerve of the forearm [80] and the median cubital vein should be taken into account laterally from the DBT. As such, the "cobra position" provides a potentially safer alternative to injection in the anterior side of the elbow. Ultrasound guidance aids in visualizing structures that should not be unintentionally injured.

3.4. Distal Triceps Tendinopathy

Distal triceps tendinopathy is the rarest of the tendinopathies around the elbow with little evidence in the literature. Nirschl (1988) [81] described it as a "posterior tennis elbow". Triceps rupture represents the terminal phase of tendinopathy, again, similarly to distal biceps tendinopathy. Tendinopathies may arise from both the medial and the lateral part of the tendon [38]. An eccentric force on the contracting muscle has been proposed as a possible injury mechanism [82].

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Several medical comorbidities have been described as potential predisposing risk factors for this problem, including anabolic steroid use, local steroid injections for bursitis, oral steroids, renal disease, diabetes, and familiar tendinopathy [83].

3.4.1. Essential Anatomy

The triceps brachii muscle (TBM) is formed from three heads. The long head originates in the infraglenoid tubercle of the scapula. The lateral head originates in the posterolateral aspect of the humeral shaft, proximally to the radial sulcus. The medial head originates in the posteromedial aspect of the humeral shaft, distally from the radial sulcus. The TBM tendon inserts into the olecranon (Figure 11). The attachment is approximately 12–14 mm distal to the olecranon tip with an average width of 40 mm [84]. The lateral and long heads of the TBM converge distally and form the superficial part of the triceps tendon attachment. This part attaches to the olecranon's medial aspect, where it may converge with the anconeus muscle's fascia [38]. The medial head forms the deep portion of the triceps inserted into the olecranon [85] and is mainly muscular at its insertion [86]. Some authors describe the space filled with fatty tissue between these attachments like "distal pretricipital space" on MRI sections and cadaver specimens [87]. The triceps muscle is innervated by the radial nerve.

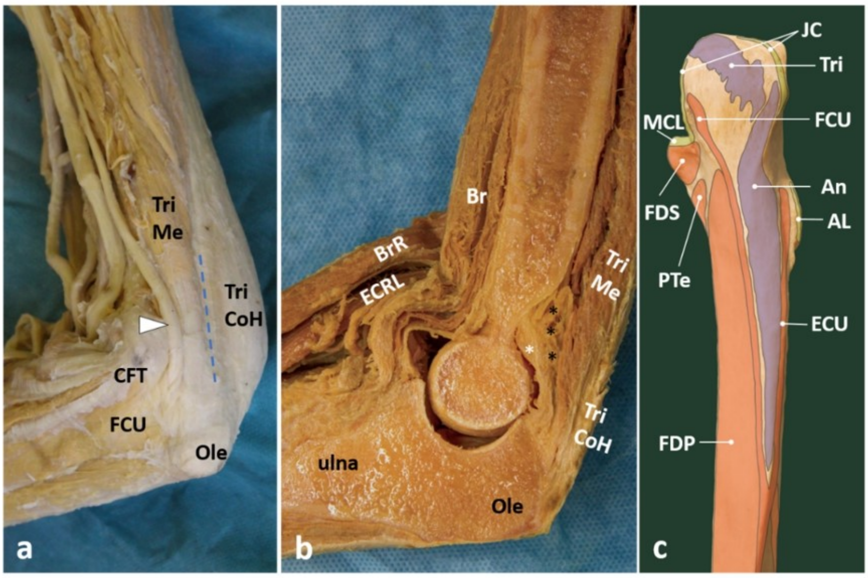

Figure 11. The tricipital tendon (right elbow). (**a**) The tricipital tendon is attached to the olecranon. The tendon has a bipartite arrangement. The medial head has separate insertion from the common tendon of lateral and long heads. The dashed line indicates the border between them. (**b**) Attachment of the common and medial heads on the sagittal section. The medial head's insertion is more muscular and more profound than the common head insertion. (**c**) Location of muscular and ligamentous attachments on proximal ulna from the posterior aspect. Black asterisks: distal pretricipital space filled with fat and connective tissue, white asterisk: the posterior fat pad inside the joint, white arrowhead: ulnar nerve, AL: annular ligament, An: anconeus muscle, Br: brachialis muscle, BrR: brachioradialis muscle, CFT: common flexor tendon, ECRL: extensor carpi radialis longus muscle, ECRB: extensor carpi radialis brevis muscle, EDig: extensor digitorum muscle, ECU: extensor carpi ulnaris muscle, FCU: flexor carpi ulnaris muscle, FDS: flexor digitorum superficialis muscle, FDP: flexor digitorum profundus muscle, JC: joint capsule, ME: medial epicondyle, Ole: olecranon, Pte: pronator teres TriMe: triceps brachii—medial head, Tri–CoH: triceps brachii–common head (lateral and long head).

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3.4.2. US Scanning and Guided Injection

The triceps tendon (TT) evaluation can be performed with the patient positioned semi-supine on the examination bed. Using this positioning technique, the elbow rests on the patient's stomach, while the elbow is free for flexion/extension dynamic assessment. The dynamic evaluation is useful to assess for the TT continuity but also to rule out the presence of fluid/loose bodies in the olecranon fossa. For the TT assessment—the longitudinal view—the examiner can see the myotendinous junction and the TT insertion footprint on the olecranon (Figure 12a). The US features of TT tendinopathy comprise local hypoechogenicity, tendon thickening, hypervascularity, calcifications, and bony irregularities/spur (Figure 12b). Triceps tendon tendinopathy is rare; however, inflammation of the overlaying olecranon bursa is more common, particularly following trauma or in patients with inflammatory diseases. The way to aspirate olecranon bursitis should be decided with respect to local anatomy (e.g., septa, adjacent structures). Notably, US guidance provides clinicians freedom in all interventional procedures [88]. There is little evidence using US-guided injections in triceps tendinopathy. Cheatham et al. [89] reported a case report of a patient with distal triceps partial tear treated with PRP injection and rehabilitation, resulting in pain-free activities of daily living and return to preinjury sports activity after four months. When injecting TT, a potentially vulnerable structure would be the ulnar nerve, which passes medially along the tendon. Using the lateral approach and the US guidance can reduce the risk of iatrogenic injury to the nerve (Figure 13).

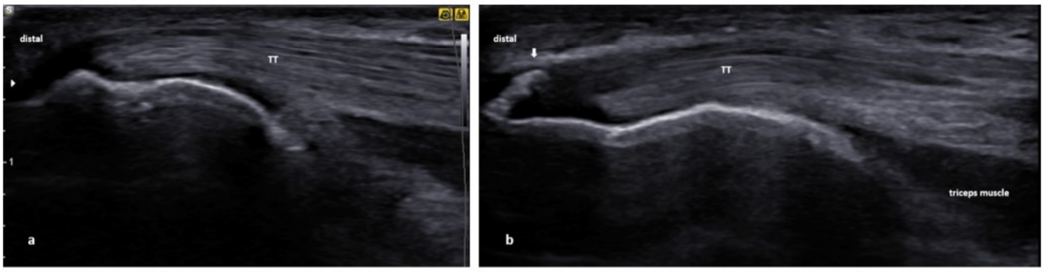

Figure 12. Ultrasound images of the distal triceps tendon (TT): (**a**) normal longitudinal image of the TT; (**b**) US image that demonstrates a prominent spur (white arrow) at the olecranon's TT insertion site.

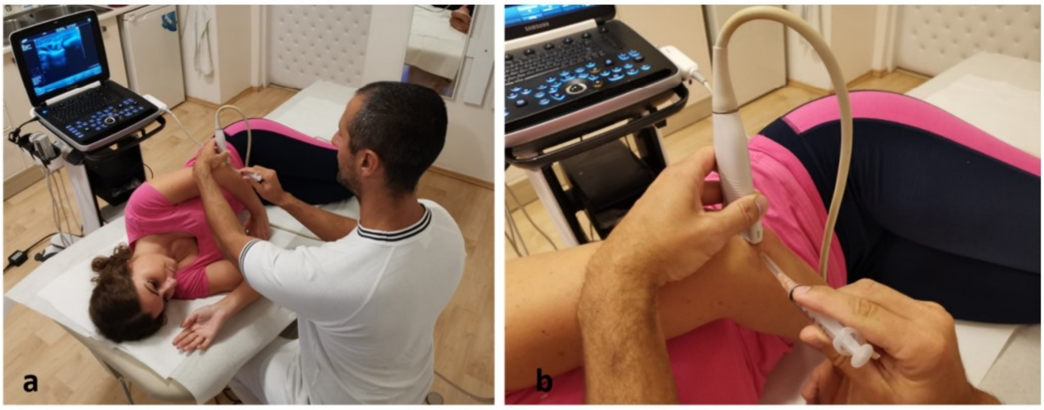

Figure 13. Ultrasound imaging and injection of the distal triceps tendinopathy: (**a**) the patient in the decubitus position with the shoulder internally rotated; (**b**) the same procedure as described before in detail—the needle is inserted from lateral to medial.

4. Conclusions

Elbow pain resulting from overuse or trauma is a common cause of patients' visits to physicians' practice. This review describes four common musculoskeletal pathologies and their interventional treatment. A clinical examination often brings only incomplete information and, therefore, using US imaging daily helps us set the final diagnosis. Moreover, it can guide interventions to target a precisely treated structure and avoid vulnerable structures such as nerves or vessels. An emerging and promising tool in tendon imaging is ultrasound elastography to assess tissue properties by measuring their stiffness. Nevertheless, ultrasound elastography still requires validation to become a reliable method for tendon pathology assessment [90,91]. Future research in ultrasound imaging can be directed towards further image quality improvement. One option would be a fuzzy pre-processing operation to pretreat the images before proceeding with the clinical evaluation [92,93].

Supplementary Materials: The following are available online at https://www.mdpi.com/article/10.3390/app11083431/s1, Video S1: Ultrasound-guided tennis elbow injection: distal to proximal approach.

Author Contributions: Conceptualization, K.M. and J.J.; methodology, K.M.; data curation, K.M. and K.S.; writing—original draft preparation, K.M., J.J. and T.N.; writing—review and editing, Y.A., K.S., L.H. and O.N.; visualization, L.H., K.M. and J.J. supervision, O.N. and Y.A.; funding acquisition, Y.A. and K.M. All authors have read and agreed to the published version of the manuscript.

Funding: Open-access publication fees were supported by the Open Access Fund of the General University Hospital in Prague.

Institutional Review Board Statement: Not applicable.

Informed Consent Statement: Not applicable.

Data Availability Statement: No data sets were generated or analyzed.

Acknowledgments: We would like to express our sincere gratitude to Jan Kacvinský, an academic painter from the Institute of Anatomy, First Faculty of Medicine, Charles University in Prague, for schematic drawings of certain anatomic regions in this manuscript.

Conflicts of Interest: The authors declare no conflict of interest.

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frontiers in Neurology

REVIEW
published: 14 May 2021
doi: 10.3389/fneur.2021.661441

Ulnar Neuropathy at the Elbow: From Ultrasound Scanning to Treatment

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Ulnar neuropathy at the elbow (UNE) is commonly encountered in clinical practice. It results from either static or dynamic compression of the ulnar nerve. While the retroepicondylar groove and its surrounding structures are quite superficial, the use of ultrasound (US) imaging is associated with the following advantages: (1) an excellent spatial resolution allows a detailed morphological assessment of the ulnar nerve and adjacent structures, (2) dynamic imaging represents the gold standard for assessing the ulnar nerve stability in the retroepicondylar groove during flexion/extension, and (3) US guidance bears the capability of increasing the accuracy and safety of injections. This review aims to illustrate the ulnar nerve's detailed anatomy at the elbow using cadaveric images to understand better both static and dynamic imaging of the ulnar nerve around the elbow. Pathologies covering ulnar nerve instability, idiopathic cubital tunnel syndrome, space-occupying lesions (e.g., ganglion, heterotopic ossification, aberrant veins, and anconeus epitrochlearis muscle) are presented. Additionally, the authors also exemplify the scientific evidence from the literature supporting the proposition that US guidance is beneficial in injection therapy of UNE. The non-surgical management description covers activity modifications, splinting, neuromobilization/gliding exercise, and physical agents. In the operative treatment description, an emphasis is put on two commonly used approaches—*in situ* decompression and anterior transpositions.

Keywords: ulnar nerve (MeSH), ultrasound, musculoskeletal, US-guidance, entrapment neuropathy, cubital tunnel syndrome, peripheral nerve, elbow

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Edited by:
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Specialty section:
This article was submitted to Applied Neuroimaging, a section of the journal Frontiers in Neurology

Received: *30 January 2021*
Accepted: *23 March 2021*
Published: *14 May 2021*

Citation:
Mezian K, Jačisko J, Kaiser R, Machač S, Steyerová P, Sobotová K, Angerová Y and Naňka O (2021) Ulnar Neuropathy at the Elbow: From Ultrasound Scanning to Treatment. Front. Neurol. 12:661441. doi: 10.3389/fneur.2021.661441

INTRODUCTION

Ulnar neuropathy at the elbow (UNE) represents the second most common entrapment neuropathy in the upper extremity encountered in clinical practice. The features suggesting a lesion of the ulnar nerve (UN) are based upon knowledge of the UN and its sensory and motor branch distribution. However, due to anatomic variations, a broad spectrum of differential diagnoses, and miscellaneous clinical presentations, the clinical diagnosis is often far from straightforward. If not treated timely and adequately, UNE can progress to persistent impairment of sensation, pareses, and joint contracture (1). Ultrasound (US) imaging might provide better insight into the UN morphology, mainly if the diagnosis is in doubt. The UN can be depicted using high-end

US equipment with a high resolution in its course from the axilla to palm level (2). US imaging is an emerging tool in physicians' clinical practice across different specialties (3), as it allows an immediate correlation between imaging and clinical findings. It also provides a sort of "US-assisted physical examination," e.g., "sono-Tinel" and "sono-palpation" (4). A better understanding of the relevant (sono)anatomy might help optimize clinical reasoning in patients presenting with UNE symptoms (5).

ANATOMY

In practice, there are mainly two locations where the UN can be compressed: the retroepicondylar groove and under the humeroulnar aponeurotic arcade (HUA). However, the UN can be entrapped at various sites across the elbow: the medial intermuscular septum (MIS) of the arm, the thickened proximal edge of the arcade of Struthers and the entire arcade of Struthers, cubital tunnel, connective tissue between the flexor carpi ulnaris (FCU), and flexor digitorum superficialis (FDS) muscles (**Figure 1**). The UN is the terminal branch of the brachial plexus's medial cord and originates mainly from C8 and T1 and sometimes also receives fibers from C7 roots. At the arm level, the UN descends toward the medial bicipital sulcus along with the MIS. Approximately 10 cm above the elbow (6), the UN penetrates the MIS from the arm's anterior to the posterior compartment (**Figure 2**) (7). Struthers' arcade is a non-constant, morphologically variable tendinous or muscular tissue situated 6–10 cm proximal to the medial epicondyle (ME), between the medial head of the triceps brachii muscle and MIS (1). Mizia et al. (8) estimated its prevalence as 53%. Tubbs et al. (9) described three types of Struthers' arcade. Type I was described as the most common, where thickening of the brachial fascia formed the arcade. In type II, the arcade is related to the internal brachial ligament (aponeurotic continuation of the brachialis muscle), and type III arcade is due to thickened MIS (9).

In some cases, the arcade can be formed by the superficial muscle fibers of the medial head of the triceps brachii muscle as they attach the MIS (10).

Then they pass through the retroepicondylar groove (RTC, groove for the UN in formal anatomical terminology), which a floor is formed by the posterior bundle of the medial collateral ligament, and the roof is represented by a superficial fascia or non-constant retroepicondylar retinaculum. In the relaxed condition (when the elbow is extended), the retinaculum is shorter, whereas it stretches during the elbow flexion. This retinaculum was described as a structure under which UN entrapment may occur (11). O'Driscoll et al. (12) divided the retinaculum into four groups, considering its morphology and function. In type 0, the retinaculum was absent. In type Ia, the retinaculum was lax in extension and taut in full flexion not compressing the UN. Type Ib stands for the retinaculum that tights at 90–120° of flexion, with evidence of UN compression. In type II, the ligament was replaced by the anconeus epitrochlearis muscle (12).

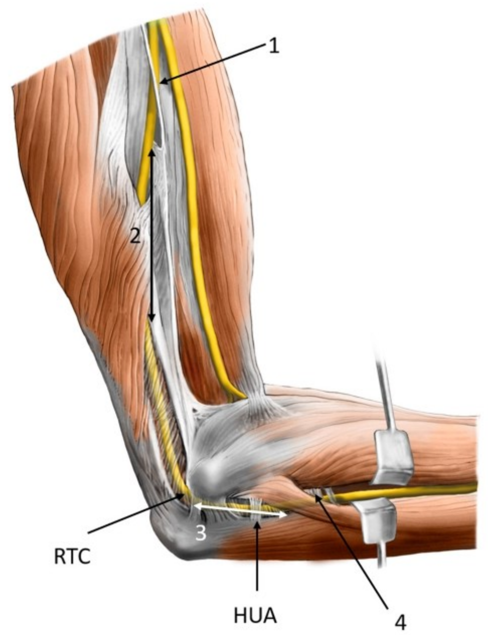

FIGURE 1 | Possible sites of compression of the ulnar nerve at and around the elbow: (1) the medial intermuscular septum of the arm, (2) arcade of Struthers, (3) cubital tunnel, and (4) connective tissue between flexor carpi ulnaris and flexor digitorum superficialis muscles. RTC, retroepicondylar groove; HUA, humeroulnar aponeurotic arcade.

The nerve continues distally behind (ME) the elbow. It enters the forearm through the true cubital tunnel (**Figure 3**), a space between the ulna and the ulnar and humeral heads of FCU, and a thickened fascial tissue connecting the two heads of FCU, known as the HUA (**Figure 4**) (13). HUA represents a thickened fascial tissue layer derived from the fusion of the antebrachial fascia and the deep fascia of the FCU (14).

After exiting the cubital tunnel, the nerve runs inside the FCU muscle and distally between the FCU and the flexor digitorum profundus (FDP) muscle. In the proximal forearm, the nerve runs at a certain distance from the ulnar artery, while more distally, the ulnar artery and nerve become adjacent. Won et al. (15) described the aponeurosis of flexor muscles of the forearm, such as intermuscular aponeuroses between the FCU and flexor digitorum superficialis, and between the FCU and the FDP as a potential site of entrapment of the UN (15).

EPIDEMIOLOGY AND RISK FACTORS

The prevalence of UNE reaches up to 5.9% in the general population (16). An increased risk for developing UNE has been reported in association with smoking (17). Another retrospective study identified increasing age and male sex as risk factors

Abbreviations: CSA, cross-sectional area; FCU, flexor carpi ulnaris; ME, medial epicondyle of the humerus; MIS, medial intermuscular septum; RCT, randomized controlled trial; UN, ulnar nerve; US, ultrasound.

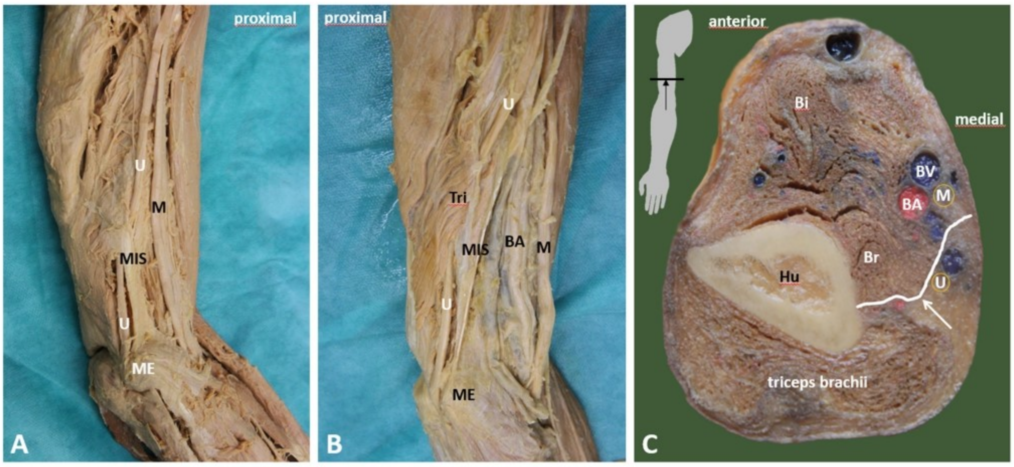

FIGURE 2 | Course of the ulnar nerve in the arm. **(A)** Relationship of the ulnar nerve (*U*) and the medial septum (*MIS*). Ulnar nerve penetrates the medial septum—the penetration is demarcated by a ligamentous thickening (Struther's arcade). **(B)** Penetration of the septum and further course of the ulnar nerve is covered by muscular fibers of medial head of triceps brachii muscle, which begins on the medial intermuscular septum. **(C)** Transverse section of midarm depicting the relationship between ulnar nerve (*U*) and medial intermuscular septum (white arrow). BA, brachial artery; Bi, biceps brachii muscle; Br, brachialis muscle; BV, brachial vein; Hu, humerus; M, median nerve; ME, medial epicondyle; MIS, medial intermuscular septum; U, ulnar nerve; white arrow, medial intermuscular septum.

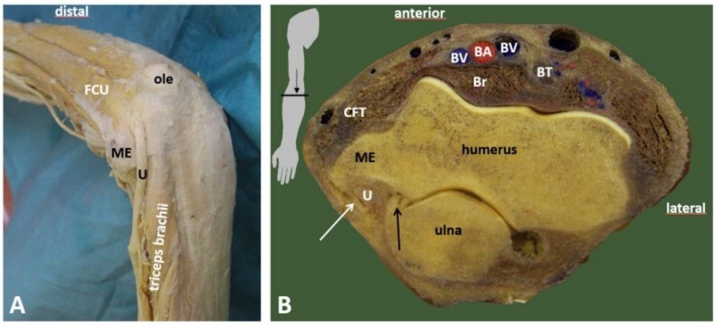

FIGURE 3 | Retroepicondylar groove and the entrance to the cubital tunnel. **(A)** Entrance of the ulnar nerve to the cubital tunnel. **(B)** Demarcation of the cubital tunnel. BA, brachial artery; Br, brachialis muscle; BT, biceps brachii muscle tendon; BV, brachial vein; CFT, common flexor tendon; FCU, flexor carpi ulnaris muscle; ME, medial epicondyle; ole, olecranon; U, ulnar nerve; black arrow, medial collateral ligament, posterior bundle; white arrow, retroepicondylar retinaculum.

for UNE development (18). UNE development is also possible in relation to occupational hand-arm-vibration exposure (19). Interestingly, UNE was reported on the left side more frequently than on the right, regardless of the patient's handedness (20). Although recurrent subluxation or dislocation of the UN and its contribution to UNE is widely debated, some authors consider the UN instability as one of the risk factors for UNE (21). The reported prevalence of UN instability varies depending on the method of measurement. In asymptomatic arms, Van Den Berg et al. (22) reported the occurrence of UN subluxation and dislocation as 5.7 and 5.7%, respectively. According to Omejec and Podnar, the incidence rate of UN subluxation and dislocation may reach up to 27 and 20%, respectively. According to their data, the UN dislocation may cause mild damage to the UN (23).

PATHOPHYSIOLOGY AND CAUSES

The UN at the elbow level can be harmed statically in entrapment neuropathies (usually below the HUA). UNE at the HUA level was reported to be associated with hard manual labor. By contrast, episodic damage to the UN may occur during specific

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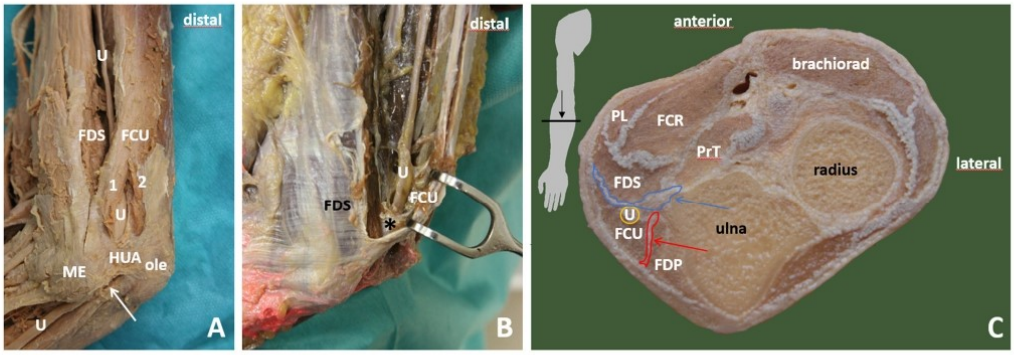

FIGURE 4 | Cubital tunnel. **(A)** View on proximal part of the cubital tunnel with humeroulnar aponeurotic arcade (*HUA*) and ulnar nerve (*U*) going between humeral (1) and ulnar (2) head of flexor carpi ulnaris muscle (*FCU*). The course of ulnar nerve between FCU and flexor digitorum superficialis muscle (*FDS*). Humeral head is moved away, and the retroepicondylar retinaculum is transsected (*white arrow*). **(B)** Ulnar nerve exiting the cubital tunnel to forearm. The nerve is in close relationship to intermuscular connective tissue between FCU and FDS (*black asterisk*). **(C)** Cross section of the forearm depicting the relationship between the ulnar nerve and surrounding muscles and connective tissues (*red and blue arrows*). (1) flexor carpi ulnaris muscle, humeral head; (2) flexor carpi ulnaris muscle, ulnar head; HUA, humeroulnar aponeurotic arcade; Brachiorad, brachioradialis muscle; FCU, flexor carpi ulnaris muscle; FDP, flexor digitorum profundus muscle; FDS, flexor digitorum superficialis muscle; ole, olecranon; PrT, pronator teres; U, ulnar nerve; blue arrow, intermuscular connective tissue between FCU and FDS, deep flexor pronator aponeurosis; red arrow, intermuscular connective tissue between FCU and FDP.

movements (typically elbow flexion) or external compression around the retroepicondylar groove, e.g., when the forearm is lying pronated on the desk during working on the computer (a possible explanation of the more common occurrence of UNE on the left) (23). The pathophysiology of dynamic UN compression is not yet fully understood. Nevertheless, some factors associated with elbow flexion seem to play a crucial role, e.g., tightening of the retroepicondylar groove retinaculum. Furthermore, a decrease in the canal's volume, increase of intracanal pressure, and the strain of the UN accompanied by its flattening were also documented during the elbow flexion (24, 25). A congenital absence of the retroepicondylar groove retinaculum forming its roof is one of the possible explanations for the increased mobility of the UN outside the retroepicondylar groove during elbow flexion (11). Another factor possibly contributing to the UN instability would be a shallow bony retroepicondylar groove (26). However, as UN instability was reported to be common in asymptomatic volunteers, the causative relationship between symptoms and UN instability remains unclear (27). Although asymptomatic in most cases, UN instability is considered as a possible cause of pain syndrome due to friction and increased pressure applied to the UN across the ME.

Furthermore, as the hypermobile UN becomes more vulnerable during flexion, a direct trauma or pressure forces might contribute to its damage. According to Bordes et al. (28) review, the UN instability can also contribute to frictional and tractional neuritis. The concept of "frictional neuritis" assumes the subluxating/dislocating UN being irritated during the movement against bony irregularities around an arthritic or post-traumatic joint. Interestingly, Leis et al. (29) proposed complete UN dislocation as a protective factor toward the nerve strain. In entrapment neuropathy, an impaired intraneural blood flow and axoplasmic transport inside the nerve might trigger swelling. If the flow inside the nerve remains impaired, long-term intra- and extraneural fibrotic alternation with irreversible nerve damage may occur (30).

In contrast, Omejec and Podnar reported the nerve constriction as typical for UN entrapment distal to the ME by using US imaging. Simultaneously, lesions at or proximal to the ME did not show the UN's characteristic hourglass appearance, indicating its swelling in the longitudinal view (31). Other underlying causes of UNE at the elbow would comprise nerve tumors or space-occupying lesions (ganglia, accessory muscles, bony irregularities/osteophytes, or traumatic bone abruption) (32). Regarding the accessory anconeus epitrochlearis muscle, its causative role in UNE development is controversial. Wilson et al. (33) reported the occurrence of accessory anconeus epitrochlearis muscle significantly lower in patients with cubital tunnel syndrome than in asymptomatic controls. They hypothesized that anconeus epitrochlearis might be a protective factor against UNE development (33).

DIAGNOSIS AND ULTRASOUND SCANNING TECHNIQUES

Diagnosis is based on history, physical examination, electrophysiological assessment, and US examination. Symptoms suggesting the UNE at the elbow are medial elbow pain, tingling, and numbness in the UN supplied area (usually the fourth and fifth digits). These symptoms are commonly aggravated with elbow flexion, e.g., when talking on the phone or leaning on the elbow at the table, or sleeping with the elbow bent more than 90°. Due to neuropathic pain, sleep disturbance is common

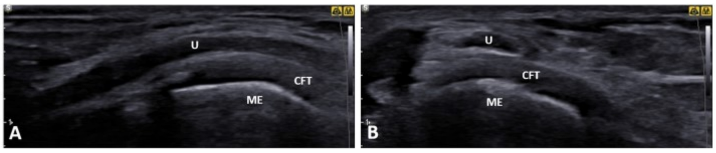

FIGURE 5 | Ultrasound (*US*) imaging of the ulnar nerve (*U*) at the level of the medial epicondyle (*ME*) in a patient with symptomatic ulnar nerve dislocation. Both longitudinal **(A)** and short-axis **(B)** views clearly demonstrate a close contact between the ulnar nerve and common flexor tendon origin. U, ulnar nerve; CFT, common flexor tendon; ME, medial epicondyle.

in patients presenting with cubital tunnel syndrome (34, 35). Patients sometimes describe having difficulties with typing on a keyboard, buttoning buttons, and opening bottles. However, more contributory (motor) findings suggesting UN damage are often absent initially (e.g., atrophy and weakness of the intrinsic hand muscles). The broad differential diagnosis even mounts diagnostic challenges, covering Guyon canal syndrome, carpal tunnel syndrome, C7 or C8 radiculopathy (sometimes coexisting with UNE), brachial plexopathy, or Pancoast's tumor invading its medial cord, generalized polyneuropathy, and tendinopathy (36). The UNE is often misdiagnosed as a golfer's elbow due to an intimate relationship between UN and the common flexor tendon (CFT) origin. Notably, in a case of UN instability, the nerve can be directly overlying the CFT during elbow flexion (**Figure 5**). In more severe cases, weakness and the UN's innervated muscle wasting can be apparent (the first dorsal interosseous muscle in particular).

Further characteristic findings of severe UNE are clawing of the ring and small fingers (also known as Duchenne's sign), Wartenberg's sign (involuntary abduction of the little finger), and a positive Froment's sign (weakening of the pinch grip between the thumb and index finger). Several diagnostic provocative tests aid in diagnosing UNE, e.g., the Tinel test at the retroepicondylar groove and the elbow flexion test with wrist extension. Additional shoulder internal rotation has been reported to increase sensitivity and specificity (24). Furthermore, impairment of two-point discrimination of the ring/small fingers can also be present. For assessing of the dislocating UN, sometimes, the nerve snapping beneath the fingertips anterior to the ME during elbow flexion can be perceived. The clinical severity is widely evaluated using McGowan's classification: Grade 1, intermittent subjective symptoms with or without mild hypoesthesia; Grade 2, remarkable sensory loss and measurable motor weakness of ulnar intrinsic hand muscles (both lumbrical and interosseous muscles); and Grade 3, persistent severe sensorimotor deficits with muscle wasting (37).

Electrodiagnosis represents a useful tool for diagnosing UNE, determining the site of entrapment and disease severity (from mild to demyelinating or axonal), aiding in prognosis, and ruling out alternative diagnoses (e.g., carpal tunnel syndrome or radiculopathy) (38). The following techniques can be used: motor nerve conduction studies (MNCSs), short segment motor studies (SSMSs), sensory nerve conduction studies (SNCSs), and needle examination. UN MNCS is a commonly performed method. As the length of the standard MNCS measured segment is 10 cm, a small lesion typical for UNE can be missed because of the dilution of the short abnormal segment in a much longer unaffected measured segment. Therefore, another method called SSMS (inching) technique is used to reveal the UN's focal damage more precisely. The elbow should be flexed to 90°, to prevent slack of the UN, which occurs when the elbow is fully extended and leads to an apparent slow conduction velocity across the elbow (39). The inching method evaluates short segments (most often 2 cm blocks) of the UN from under the elbow to above the elbow. This method's advantage is the precise localization of the nerve damage, which is important because it can influence decision making on whether conservative or surgical treatment is more beneficial (40). On the other hand, this method is technically more difficult, and despite the higher sensitivity, this method is rarely used in clinical practice. Some studies presented normative and reference values for SSMS UN evaluation (31, 41). As sensory nerves are more sensitive to compression than motor nerves, SNCS reveals pathology earlier than MNCS, but it has low significance in the diagnostic process because of its low specificity. Needle examination is important for ruling out other nerve damage sites such as wrist, brachial plexus lesion, or C8 radiculopathy. However, electrodiagnostic studies are not contributory in assessing the morphology of the UN and its surrounding tissues. A secondary cause of UN compression (e.g., ganglion and heterotopic ossification) can be missed if an imaging examination is not carried out.

Additionally, the clinical (and electrophysiological) examination can lead to an erroneous diagnosis if an anomalous innervation is present, e.g., Martin–Gruber or Marinacci anastomosis (42, 43). These forearm interconnections between the motor branches of the ulnar and median nerves account for a prevalence of up to 39% of healthy individuals (44) and can be sometimes identified with US imaging (45). To this end, US or magnetic resonance imaging should be considered, mainly if the diagnosis is in doubt. Conventional radiographs can be beneficial in assessing for the cubitus valgus, bony deformities, and space-occupying lesions (e.g., heterotopic ossification).

ULTRASOUND SCANNING TECHNIQUES

Device Settings and Patient Positioning

The images and videos in this section (except for the images of exemplary pathology) were obtained using the Samsung UGEO HM70A machine (Samsung, Seoul, South Korea) with a 3–16 MHz linear transducer. Settings for the depth, gain, and frequency were adjusted by the examiner to obtain the optimal image of the UN. The focus was positioned at the same depth or just below the UN. For the comfortable UN visualization in the retroepicondylar groove, the patient is positioned supine on the examination bed. The patient's arm is resting on the examination bed with the forearm hanging over the edge of the bed, so the examiner can comfortably reach the retroepicondylar groove. The described position is comfortable for both the patient and the examiner (46). The UN evaluation and dynamic dislocation test can be easily performed, while the examination bed provides excellent probe stability. For the UN assessment at the elbow, both static and dynamic scans need to be performed (47).

Static Evaluation

First, the transducer is positioned between the olecranon and the medial humeral epicondyle. The UN can be seen adjacent to the ME's bony surface as a uni- or multifascicular hypoechoic, round, oval, or triangle-like structure surrounded by a hyperechoic rim (**Figure 6A**). Due to the arching course, the UN appears hypoechoic at the retroepicondylar groove as a result of anisotropy (48). A hypoechoic band extended from the medial humeral condyle to the olecranon represents the retroepicondylar retinaculum. Rotation of US transducer 90° will change the short-axis view into a long-axis view of the UN (**Figure 6B**). In the authors' opinion, this is a convenient site from which the UN can be easily tracked either proximally or distally. For the proximal tracking, the UN is followed from the retroepicondylar groove further proximally. It ascends along the anterior aspect of the medial head of the triceps brachii muscle, posterior to the MIS (**Figure 7A**). Further proximally, at the midarm level, it inclines laterally while piercing the MIS to reach the anterior compartment, where it accompanies on the posteromedial side the proximal part of the brachial artery and brachial veins (**Figure 7B**). More proximally, the UN runs beside the axillary artery. For the UN distal tracking from the retroepicondylar groove level, the examiner follows the UN while entering the cubital tunnel between the humeral and ulnar heads of the FCU (**Figure 7C**). More distally, the UN runs inside the FCU and further between the FCU and FDP muscles (**Figure 7D**). In the proximal mid-forearm, the UN starts to be accompanied by the ulnar artery (**Figures 4**, **7E**). At the wrist, the UN enters its cross-sectional triangular-shaped Guyon canal, which is superficially bounded by the palmar carpal ligament. The transverse carpal ligament forms the floor, and the pisiform represents the medial border (**Figure 7F**).

In general, characteristic US findings suggest nerve function impairment and swelling (usually) proximal to the compression site, loss of the normal nerve fascicular pattern, and reduced nerve mobility (47). In addition, the Doppler sonography can reveal hypervascularity to evaluate the severity of UNE (49).

An essential method to evaluate the UN statically is the measurement of its cross-sectional area (CSA) along the inner hypoechoic border (**Figure 8**). At the same time, the examiner can use digital tracing methods to obtain its numeric values. According to Chang et al. (50) meta-analysis, UN CSA's upper cutoff value of 10 mm^2 at the ME level should be considered for diagnosing UNE. Mean values of 18.3 mm^2 in CSA were reported in severe cases with axonal loss (51). As an alternative, a swelling ratio of the UN $CSA_{ME}/CSA_{forearm}$ has also been proven as a good indicator to diagnose UNE, particularly in patients with polyneuropathy (52, 53). Besides, a focal change of the UN diameter or hourglass-shaped appearance suggests of the location of the nerve lesion in case of mechanical compression or torsion (54).

Dynamic Evaluation

While the hand of the examiner is supported on the examination bed, the patient's supine position for the UN dynamic assessment provides excellent probe stability during passive movement from extension to full flexion (usually 135°) of the elbow. Notably, the examiner should avoid too much pressure on the transducer, as this may cause deformation of the UN and prevent its dislocation. Dynamic US evaluation of the UN allows real-time visualization of the UN in high resolution throughout elbow flexion and extension. Thus, it is considered the gold standard method to assess its stability within the retroepicondylar groove. In a part of the population, the UN moves anteromedially, out of the retroepicondylar groove upon elbow flexion either onto the tip (**Supplementary Video 1**) or snapping entirely anterior to the ME (**Supplementary Video 2**). At the same time, it relocates back to its groove during extension (22). For increased mobility of the UN, Childress, in 1975, proposed a classification to type A (incomplete dislocation) and type B (complete dislocation) during elbow flexion (55). The UN hypermobility was identified in 37% and of those bilaterally in 30% as reported by Calfee et al. (56). Besides increased mobility, the UN during elbow flexion also shows a change in its shape in terms of flattening (25).

Exemplary Pathologies

Theoretically, the UN can be compressed at any site along its course in the upper extremity (32). Besides idiopathic entrapment neuropathy, other relevant causes of UNE are space-occupying lesions, e.g., ganglion (**Figure 9A**), heterotopic ossification (**Figure 9B**), anconeus epitrochlearis accessory muscle (**Figure 9C**), peripheral nerve tumors, elbow fractures associated with cubitus valgus or post-traumatic degenerative joint disease (**Figure 9D**), the nerve compression from scar tissue (**Figure 9E**), aberrant veins (**Figure 9F**) (57), and systemic diseases, e.g., diabetes or leprosy. Importantly, dynamic nerve irritation associated with repeated subluxation/dislocation outside the retroepicondylar groove during flexion of the elbow is also possible (**Supplementary Videos 1, 2**) (58).

NON-SURGICAL TREATMENT

Conservative treatment of UNE region mainly consists of approaches based on empirical experience more than on a significant level of quantified evidence. A key component of the treatment is to instruct the patient concerning risky arm positions, along with situations and movements that should be avoided. Furthermore, non-operative treatment often includes anti-inflammatory medications, manual therapy, splinting,

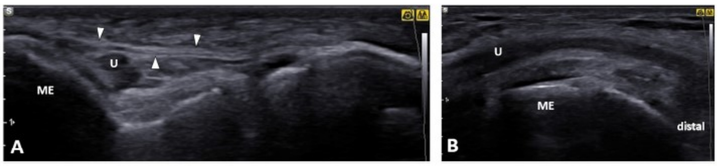

FIGURE 6 | Normal ultrasound images of the ulnar nerve. **(A)** Short axis. **(B)** Long axis. U, ulnar nerve; ME, medial epicondyle; arrowheads, retroepicondylar retinaculum.

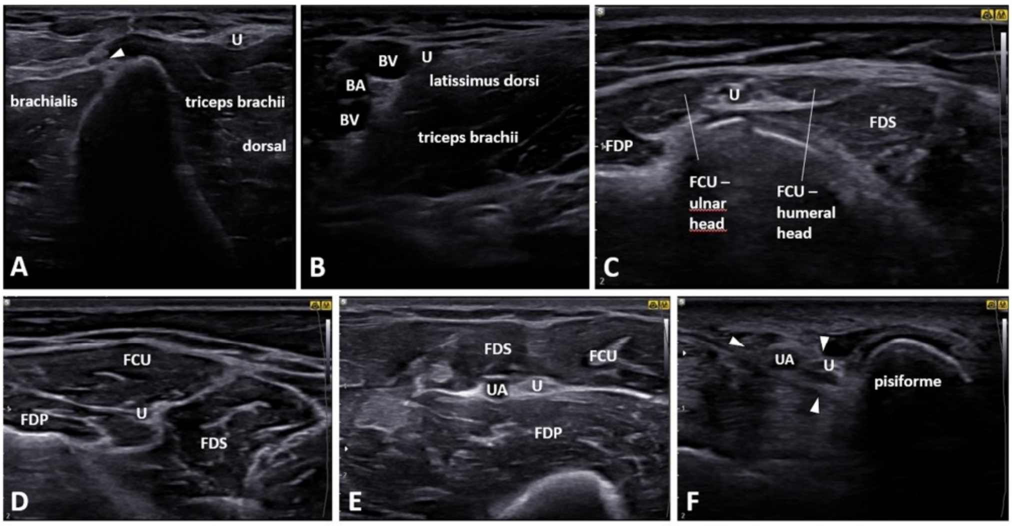

FIGURE 7 | Proximal and distal tracking of the ulnar nerve starting from the retroepicondylar groove. **(A)** Midarm, arrowhead: medial intermuscular septum. **(B)** Proximal midarm. **(C)** Flexor carpi ulnaris muscle (FCU) level. **(D)** Proximal forearm. **(E)** Proximal mid-forearm, the ulnar nerve accompanied by the ulnar artery. **(F)** Ulnar nerve in Guyon canal (*arrowheads*). FDP, flexor digitorum profundus muscle; FDS, flexor digitorum superficialis muscle; U, ulnar nerve; BA, brachial artery; BV, brachial vein.

kinesiotaping, exercise and neurodynamic mobilization, electrotherapy, shock wave therapy, dry needling, and injections. In general, the non-surgical treatment seems to be less suitable for patients with persistent post-traumatic cubital tunnel symptoms (59). Omejec and Podnar reported a study on 96 patients where the treatment was tailored based on the presumed mechanism of the UN's compression. The patients with external compression were instructed to avoid risky positioning, and those with entrapment under the HUA were offered surgical release. They reported an improvement in 83% of HUA and 84% of RTC patients. In line with this strategy, another 11 patients who were treated contrary to their recommendations showed less favorable outcomes (60).

The majority of studies on conservative treatment of UNE consists of case reports or case series with a low number of patients. Nearly all studies demonstrated clinical improvement in patient symptoms over time. However, the absence of adequate controls made it difficult to distinguish the natural amelioration of cubital tunnel syndrome from the effects of therapy (61).

The latest Cochrane review on the treatment of UNE identified only two studies on the treatment of UNE using conservative approaches (62). Besides, it was not very clear when to treat a person with this condition conservatively or surgically (62). Another recent systematic review confirms the paucity of literature and high-quality studies regarding the conservative management of cubital tunnel syndrome. The following treatment modalities were identified: education and activity modification, splinting, steroid/lidocaine injection, nerve mobilization/gliding, pulsed US, laser therapy, non-steroidal anti-inflammatory drugs, and physiotherapy. Kooner et al. (61) systematic review suggested that activity modification/education and splinting may be effective for mild or moderate disease.

Svernlöv et al. (63) published one of the few clinical trials evaluating the conservative treatment of cubital tunnel

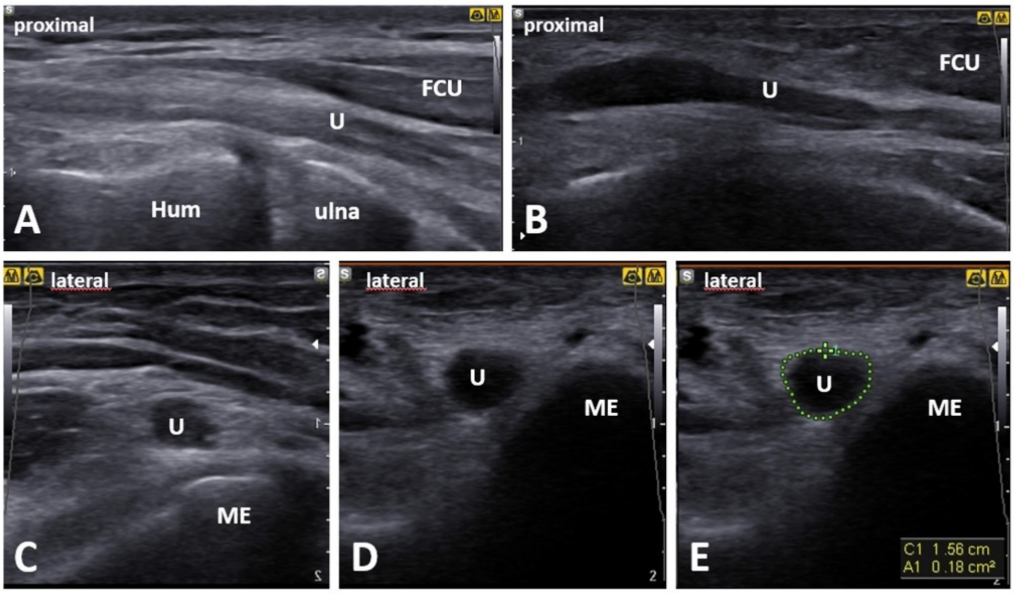

FIGURE 8 | Comparative ultrasound (*US*) imaging of the ulnar nerve (*U*) at the level of the medial epicondyle (*ME*) in a patient with cubital tunnel syndrome. When compared with the normal side. **(A)** The asymptomatic side in a long axis of the ulnar nerve. **(B)** The symptomatic side ulnar nerve shows swelling ("bottle neck appearance") proximal to the cubital tunnel inlet in long-axis. **(D,E)** In short axis, compared with the normal side **(C)**, the ulnar nerve on the symptomatic side shows enlargement in its cross-sectional area of 18 mm^2 outlined using the direct US tracing method (*green dotted line*). Hum, humerus; FCU, flexor carpi ulnaris muscle.

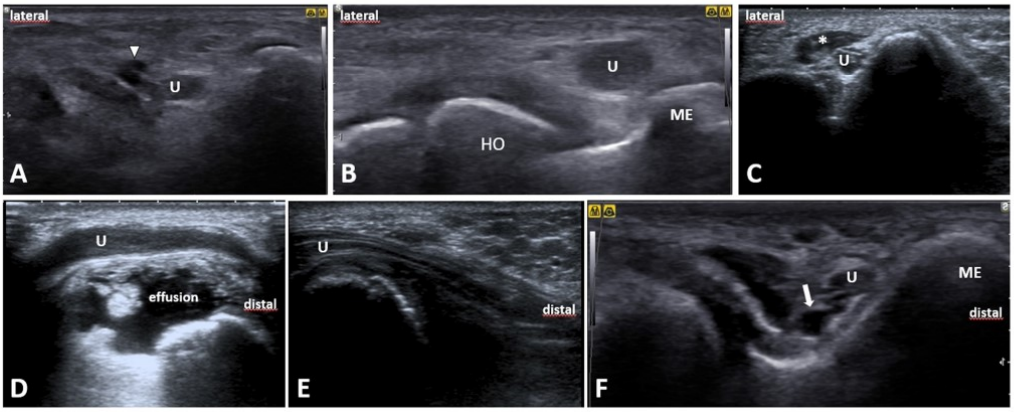

FIGURE 9 | Ultrasound images of the ulnar nerve exemplary pathologies. **(A)** Short-axis image at the level of the humeral medial epicondyle (*ME*) shows the ulnar nerve (*U*) in an intimate contact with a ganglion (*white arrowhead*), likely derived from the triceps tendon. **(B)** A short-axis US image of the ulnar nerve situated just next to the heterotopic ossification (*HO*). **(C)** The ulnar nerve short-axis image shows an accessory anconeus epitrochlearis muscle (*asterisk*). **(D)** A longitudinal US image of the post-traumatic degenerative joint disease with effusion compressing the ulnar nerve. **(E)** A longitudinal image of the ulnar nerve depicts the nerve compression from scar tissue after olecranon surgery. **(F)** A short-axis view at the ulnar nerve (*U*) shows an aberrant vein (*white arrow*) next to it. ME, medial epicondyle of humerus; U, ulnar nerve.

syndrome. This study of 3 months' duration enrolled 70 subjects with mild-to-moderate discomfort, while 51 subjects completed the study. All patients were employed as manual laborers. The subjects were randomly divided into three groups. One group was instructed to use a prefabricated elbow brace each night for 3 months. The brace prevented flexion of more than 45°. The second group was instructed to perform nerve gliding exercises. The third group did not perform exercises or apply any night braces. All three groups received the same written information on the anatomy of the UN, an explanation of the probable pathomechanics, and a regimen regarding the avoidance of movements and positions provoking the symptoms. Surprisingly, after 6 months, there was no significant difference in hand function, pain, strength, and neurophysiological examination. Ninety percent of patients with mild-to-moderate cubital tunnel symptoms (most patients had normal electrodiagnostic testing) improved with non-surgical treatment. In that study, 10% of patients had proceeded to surgical intervention at 6 months. Information on the causes of the condition and how to avoid provocation appeared sufficient, while night splints and nerve gliding exercises did not add favorably in this patient group (63).

Instructions to the Patients

It is supposed that traction is one of the key mechanisms causing harm to the UN, while an elevated level of strain is strongly associated with elbow flexion. Furthermore, the duration of abnormal postures or repetitive motion probably plays a significant role in the UNE development. The strain in UN is particularly increased when nerve gliding is limited. As Vinitpairot et al. (64) described on a cadaveric model, the strain on the UN can increase if nerve gliding is restricted by 154% while working on a computer. The long-term static activity of the FCU muscle, e.g., when using a cell phone or working on a computer, or in relation to some occupations (e.g., glassmakers), probably also plays an important role. If repetitive external pressure and traction occur, often concerning activities that provoke pain and paresthesia, these symptom-causing activities should be avoided or modified. The importance of modification of movement regime was demonstrated in the above-mentioned study by Svernlöv et al. (63), where night splints and nerve gliding exercises did not add any benefit in addition to the simple instruction to avoid provocative moments (63). Arm position control may be difficult during sleep when the arm may move into a sharp flexion of the elbow beyond conscious control; hence, the use of a night brace may be appropriate in some cases.

Splinting

The main principle of splinting is the reduction of compressive and tensile pressure on the UN by limiting elbow flexion (65). A nightly fixation of the elbow with a splint made of plastic material with good padding from the middle of the upper arm all way to the hand (30–35° flexion of the elbow, forearm at 10–20° pronation, and the wrist in a neutral position) for 6 months led to a significant amelioration of symptoms (66, 67). Nocturnal splinting can be shorter in clinical practice than the 6 months mentioned above, depending on symptom relief. Other splint options range from rolled towels placed in the antecubital fossa and secured with an elastic bandage using a neoprene brace with aluminum reinforcement to rigid thermoplastic custom-fit orthoses.

Neuromobilization/Gliding Exercise

Therapeutic approaches based on neurodynamics have become a popular model for manual therapeutic techniques in peripheral nerve neuropathy. In particular, Butler's description of these techniques has become the norm (68). A fundamental premise of this concept is that intraneural swelling at the affected peripheral nerve site restricts intraneural blood flow (69). Simultaneously, correctly applied dynamic changes in intraneural pressure can act in a "pumping action" or "milking effect" and thus reduce this intraneural swelling together with a reduction of the symptoms (70, 71). Another assumption is that neurodynamic techniques may limit fibroblastic activity and minimize scar formation via normal and early use of mesoneurial gliding tissues (72).

The basis of this therapeutic concept is two different techniques—a sliding technique and a tensioning technique. Generally speaking, sliding is achieved by increasing the tension on the peripheral nerve by correctly applying changes in joint position at one end and releasing the tension of the nerve at its opposite end—in the UN, this is elbow flexion and simultaneous shoulder abduction or vice versa. Tensioning is achieved by increasing the tension of the nerve at both ends at one time. Indeed, in cadavers, it has been shown that a typical UN sliding technique does cause nerve movements of 8.3 mm proximal to the elbow with almost no impact on the nerve strain while tensioning causes a nerve displacement of only 3.8 mm and stretches the nerve by 9.8%. From these data, it seems that the sliding technique is less aggressive and may be more appropriate for acute injury, postoperative management, and situations leading to nerve irritation and entrapment such as bleeding and inflammation around the nerve (73). However, while in the case of carpal tunnel syndrome, neural mobilization showed some positive neurophysiological effects (e.g., reduced intraneural edema), the effect on cubital tunnel syndrome remains uncertain (74). However, it should be emphasized that the successful use of neurodynamic techniques depends, of course, on the experience and skills of the physiotherapist or physician and their ability to correctly implement these techniques in patients and to combine these approaches with manual soft tissue release (fascias in particular), forearm muscle relaxation (especially FCU muscle), and other manual techniques.

Electrotherapy, Shock Wave Therapy, and Laser Therapy

As in the case of electrotherapy, shock wave therapy, or laser therapy in the treatment of UNE, there is insufficient evidence for a clear choice of an effective approach. Bilgin Badur et al. (75) published one of the few double-blind, randomized controlled clinical trials. In this study, the authors evaluated the therapeutic effect of shortwave diathermy in the treatment of UNE. Sixty-one patients completed the study, while approximately half of them ($n = 31$), randomly selected, were treated using shortwave diathermy 10 times over 2 weeks. The control group was given a placebo shortwave diathermy. Both groups were given elbow splints and instructed to avoid activities likely to provoke symptoms. Three months after the intervention, there was no significant difference between the groups regarding health status as measured by SF-36 (short form) questionnaires, pain, or hand function (75).

In clinical practice, the use of shock waves is widespread across the world in patients with different diagnoses. The presumed effect of the shock wave on the peripheral nerves is based on animal studies using a rat model (76, 77). The shock wave's effectiveness in patients with other types of entrapment syndromes, especially carpal tunnel syndrome, has previously been studied. Compared with the application of therapeutic US, patients with carpal tunnel syndrome who received extracorporeal shock wave therapy showed a more significant improvement in pain and hand function parameters at 12-week follow-up (78). In another randomized clinical trial, Raissi et al. (79) showed a comparable clinical outcome in patients with carpal tunnel syndrome treated with (1) wrist splints alone and (2) wrist splints + extracorporeal shock wave therapy. However, in the group with added shock wave therapy, a more favorable effect was demonstrated in median nerve distal sensory latency in nerve conduction studies (79). These results were in line with a recently published study by Gesselbauer et al., (80) who found promising clinical and electromyography (EMG) improvement after three sessions of focused extracorporeal shock wave therapy in patients with mild-to-moderate carpal tunnel syndrome and no improvement in the control group. Notably, a pilot study evaluating the effect of extracorporeal shock wave therapy for cubital tunnel syndrome has also been presented (81). Seven patients (10 elbows) received three radial extracorporeal shock wave sessions (2.000 shots, 4 bar, 5 Hz) in a total period of 3 weeks. As assessed by the Quick DASH questionnaire, the upper limb function showed significant improvement at all follow-up points evaluated within 12 weeks after therapy. According to the visual analog scale (VAS), the pain assessed was also significantly reduced (mean decrease from 4.7 ± 0.3 to 2.2 ± 0.2). The most significant improvement was in the first month after treatment. No placebo group was included in this pilot study. Nevertheless, the mean symptom duration in this study was 27.9 months, and spontaneous remission of symptoms in this patient group was not very likely. Other potential treatment options for UNE include low-laser therapy. Ozkan et al. (82) showed promising results of this therapy on functional, clinical, and electrophysiological outcomes. All beneficial effects lasted, in contrast to the US-treated group, until the third month of follow-up. Nevertheless, there was no control group in this study (82).

Priessnitz's Wrap

To the best of our knowledge, there is no study evaluating the effect of Priessnitz's wrap on the effectiveness of UNE therapy. However, our clinical experience with this treatment is favorable. Priessnitz's wrap consists of applying two layers to the elbow area: (1) a wet squeezed cloth is applied directly to the skin, and (2) the second layer is a dry cloth serving as thermal isolation. In approximately the first 15 min, application of this wrap causes tissue cooling, followed by local hyperemia. The duration of the described wrap can range from several dozens of minutes to several hours. The assumed effect is mainly against swelling along with anti-inflammatory action. The CSA of the UN, as measured sonographically, is expected to be reduced after several applications. However, there is no published evidence for this assumption at this time, and this is only an expert opinion of the authors of this paper.

Dry Needling

Anandkumar and Manivasagam reported three cases of patients with confirmed cubital tunnel syndrome. All patients had previously undergone unsuccessful treatments, including medication, massage, exercise therapy, US therapy, neurodynamic mobilization, and taping. The patients were treated four times over 2 weeks with dry needling, targeting the FCU muscle in two patients. In one patient, the needle was superficially inserted between the ME and the olecranon process. At discharge at 6-month follow-up, all three patients were pain-free and fully functional (83). Of note, to minimize possible adverse effects of nerve damage during the dry needling procedure, sonographic monitoring is advantageous.

Ultrasound-Guided Injection Techniques and Exemplary Evidence

The patient's position is either lying supine with the elbow flexed and hand over the head (**Figures 10C,D**) or lying prone with the elbow bent and hand hanging over the examination bed (**Figures 10A,B**). As the UN at the elbow is close to the skin surface, a high-frequency linear transducer can be effectively used. Vascular structures and local abnormalities should be clarified in advance when planning the needle trajectory (84). Rules of the standard aseptic technique should be followed. Before the injection itself, a basic evaluation of the nerve and surrounding structures should be performed. A thin, e.g., 25-gauge, needle is usually preferred. The injected volume varies from 2 to 5 ml. A combination of steroids and a local anesthetic is commonly administered (85).

The UN should be visualized in the short axis, while the in-plane approach can be used. This technique allows constant visualization of the nerve's margins and the needle tip during the procedure. This technique showed a lower risk of intraneural application of the injectate (86). According to Kim and Choi, the needle should be inserted into the cubital tunnel at the ME level penetrating the retroepicondylar retinaculum (87, 88). The needle tip should be placed tightly adjacent to the nerve between the ME and the UN. To prevent compartment syndrome with persistent paresthesia, the UN injection may be performed proximal to the retroepicondylar groove (**Supplementary Video 3**). To confirm the needle tip's epineural position, a test injection with lidocaine can be performed to see the injectant's epineural flow. To provide total coverage of the injectate around the nerve, it is sometimes necessary to reposition the needle to the other side of the nerve. This hydrodissection separating the UN from the ME end might be followed by US during the injection (85). According to a recent randomized controlled trial (RCT), the effect of dextrose injection was superior to that of steroid injection (89). vanVeen et al. (90) in their study used visualization in the long axis, which,

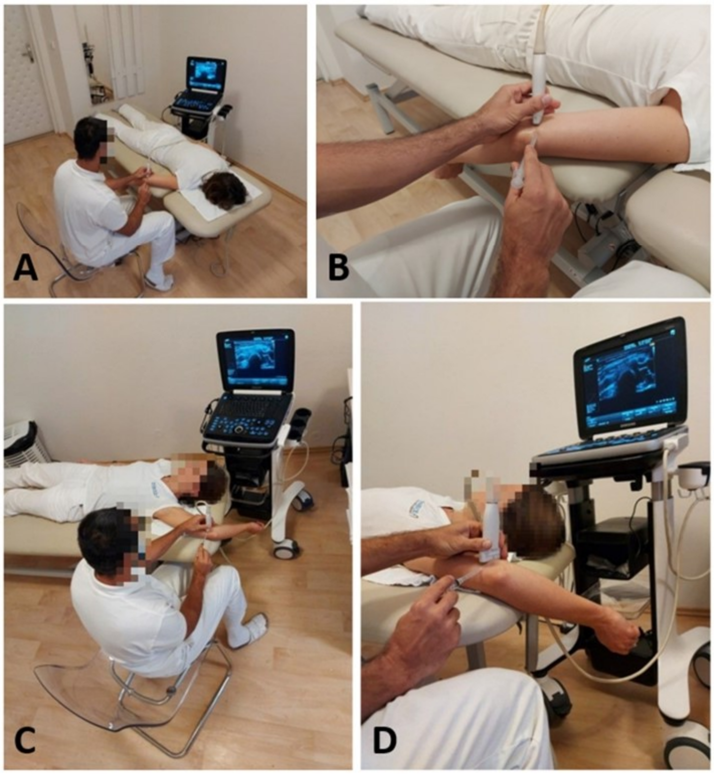

FIGURE 10 | (A) Prone position for the ultrasound-guided ulnar nerve in-plane injection with the elbow flexed and hanging over the examination bed. **(B)** The same procedure as described before in detail. **(C)** Supine position for the ultrasound-guided ulnar nerve in-plane injection; the patient is positioned on the examination bed with the elbow flexed and hand over the head. **(D)** The same procedure as described before in details.

according to other authors, is less convenient because the nerve can be confused with other structures (91). In a case report, Stoddard suggested that hydrodissection with a higher injected volume might also be beneficial (92).

A recent systematic review evaluating conservative treatment of cubital tunnel syndrome proposed that steroid injection decreased nerve CSA. The review's limitation was the paucity and heterogeneity of the studies concerning steroid or local anesthetic injection (61). Hong et al. (66) compared two conservative treatment approaches—splinting vs. splinting plus injection with corticosteroids and local anesthetic. A total of 10 patients (12 nerves) were assessed. Clinical evaluation and nerve conduction studies were performed 1 and 6 months after the intervention. Their results showed significant improvement in both groups' symptoms, and there were no significant differences between the two intervention groups. Therefore, splinting alone was concluded to be sufficient with no need for an additional steroid injection. However, the injections in this study were landmark-guided (66). vanVeen et al. (90) conducted a randomized, double-blinded trial to compare the effect of steroid injection with that of placebo injection. In total, 55 patients were involved in this study. The primary outcome was a subjective change in symptoms after 3 months from intervention. Secondary outcomes were CSA of the nerve and electrodiagnostic studies. The results showed that 30% of steroid group participants reported a favorable outcome, compared with 28% in the placebo control group. There was a significant decrease of CSA in the steroid injection group and no significant improvement in electrodiagnostic studies. The study concluded that the positive effect of US-guided steroid injection compared with placebo was not demonstrated (90). Rampen et al. (93) published a case series of seven patients with UNE, treated with steroid injection. Four out of seven patients reported clinical improvement (in terms of symptom relief and neurologic improvement) and CSA reduction 6 weeks following the intervention. Symptoms were unchanged in two of the patients and worsened in one patient. This study, however, lacked a control group, and the patients opted for injection because they disapproved of surgical treatment after initial conservative therapy failed (93). Alblas et al. (94) conducted a feasibility study with eight patients (nine UNEs) regarding US-guided steroid injection. During 3 months of follow-up, five patients reported improved symptoms, whereas three patients had no change in symptoms, and one patient reported worsening of the symptoms. The study concluded that US-guided steroid injection was as safe and easy (94).

Another feasibility study was conducted by Choi et al., (88) who assessed the in-plane approach of US-guided steroid injection for cubital tunnel syndrome in 10 patients. Their results showed a statistically significant decrease in the severity of the symptoms as evaluated by the VAS and CSA decrease in the first and fourth week of follow-up. No side effects were reported (88). A recent RCT by Chen compared the effect of steroid injection with that of dextrose injection in patients with UNE. In total, 33 patients completed the study. The primary outcome was digital pain/paresthesia evaluated with VAS. Secondary outcomes were disability questionnaires, nerve conduction studies, and CSA of the UN. There was a more considerable decrease in symptom severity in the dextrose group from the third month of follow-up and onward. The study concluded dextrose to be more suitable for perineural injection in patients with UNE (89).

SURGICAL TREATMENT

In 1957, Osborne described the first series of surgically treated patients with spontaneous UNE (95). Surgical treatment of cubital tunnel syndrome remains controversial. Although many techniques may be used for decompressing the UN, there are no clear consensus for one approach over another. This uncertainty was not resolved even by several systematic reviews published during the last decade. Therefore, the choice of approach is often based on personal experience and subjective preference for specific clinical findings. Almost 90% of surgeons use more than one procedure in the treatment of cubital tunnel syndrome (96). However, up to 30% of the patients do not improve after surgery and require revision procedures, which is even more controversial and rarely curative (97, 98).

In situ Decompression

Simple decompression is a basic and probably the most commonly used technique, particularly beneficial when nerve entrapment is the underlying cause of UNE. It is easy to perform and generally free of complications. It is performed from a small incision above the ME parallel to the course of the UN. Care must be taken to protect the posterior branches of the medial antebrachial cutaneous nerve. The surgery aims to release the nerve by cutting the superficial fascia of the FCU muscle, retroepicondylar groove retinaculum, and the HUA. However, it is always necessary to explore the nerve proximally toward the MIS of the arm to check for any compression by the arcade of Struthers or by the septum itself. Similarly, the nerve is explored distally to the proximal forearm to release possible compression within the FCU by the thicker parts of the intermuscular connective tissue (**Figure 11A**). After sufficient decompression of the nerve, flexion and extension of the elbow are examined to rule out subluxation over the ME (99).

In such cases, the decompression can be facilitated by the medial epicondylectomy, which allows a mini-anterior transposition without excessive dissection and devascularization of the nerve. It is recommended to remove less than 4 mm of the ME's width in the coronal plane to prevent damage of the anterior part of the medial collateral ligament, which may result in elbow instability or medial elbow pain (100). Some authors, however, prefer to perform an anterior transposition of the nerve to preclude chronic injury to the nerve by its repetitive subluxation (101).

Anterior Transposition

Transpositional surgical treatment may be performed by subcutaneous, intramuscular, and submuscular techniques. The transposition aims to reduce the tension on the nerve and prevent further compression in the cubital tunnel by bony spurs, synovial swelling, or chronic subluxation (102).

All other techniques than *in situ* decompression require a longer incision (~6 cm). The nerve is transposed anteriorly under the skin flap (or intra or under the forearm flexors' common head) after its wide release from the original bed. The easiest and most commonly performed technique is subcutaneous transposition (**Figure 11B**). Submuscular or intramuscular transpositions are much more invasive and, therefore, carried out less frequently, especially in patients with minimal amounts of subcutaneous fat or in some revision cases. The argument for higher invasiveness is to create a healthy vascular bed protected by soft tissue. Nevertheless, Liu et al. (101) found in their meta-analysis that subcutaneous and submuscular transpositions are equally effective.

Said et al. (103) demonstrated in their meta-analysis no difference in outcome or revision rate between simple decompression and anterior transpositions in primary cubital tunnel syndrome. Similarly, Chen et al. (102) found the same effect of both methods and a significantly lower incidence of complications in cases operated by simple decompression. Anterior transposition is often used in revision release after failed primary decompression. Moreover, some authors recommend submuscular transposition after failed subcutaneous transposition (104). However, there is no robust evidence supporting the need for anterior transposition in recurrent cubital tunnel syndrome (105).

Moreover, an excessive release of the nerve before its transposition is associated with decreased regional blood flow to the nerve for at least 3 days. Those mentioned above may increase the complication rate after surgery (102).

Endoscopic Decompression

The endoscopic technique was introduced as a minimally invasive alternative for open decompression, aiming to minimize

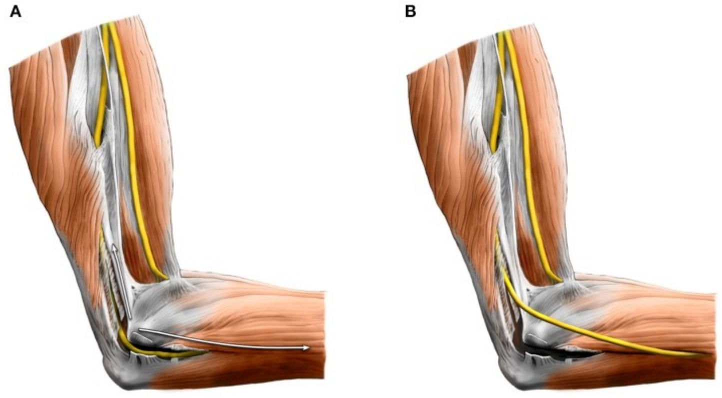

FIGURE 11 | (A) *In situ* decompression of the ulnar nerve in the cubital tunnel. **(B)** Anterior subcutaneous transposition—after wide decompression, the ulnar nerve is transposed anteriorly under the cutaneous flap.

trauma to the tissues and improve postoperative recovery. Its theoretical advantages are the patient's faster recovery, decreased invasiveness, minimal adverse events, and less scar discomfort. However, it should be applied only in selected cases without evidence of nerve subluxation, traumatic etiology of cubital tunnel syndrome, or significant structural pathology (106).

Schmidt et al. (107) and Krejčí et al. (99) performed RCTs comparing open and endoscopic decompression. In both studies, the authors failed to show any additional benefit of the endoscopic technique, and they concluded that both techniques are equally effective. These results were in line with several systematic reviews and meta-analyses (106, 108, 109).

However, it has been proven that endoscopic technique is associated with a lower incidence of scar tenderness or elbow pain (106). Moreover, it is performed with a smaller skin incision (1.5–2 cm) compared with open decompression (∼4 cm). On the other hand, it is significantly longer than open surgery. Although the difference in the median duration of decompression (i.e., incision to suture time) was only 6 min in a study of Krejčí et al. (99) (30 min for open and 36 min for endoscopic techniques, respectively), the setup time was almost three times longer in the endoscopic procedure (6 and 18 min, respectively). Another disadvantage is that it is necessary to have an assistant holding the arm in place and changing the flexion degree as needed (99).

Summary of the Techniques

Wade et al., (98) in 2020, performed a comprehensive review and meta-analysis of all possible open or endoscopic methods for treating cubital tunnel syndrome. They found that open *in situ* decompression (with or without medial epicondylectomy) appears to be the safest and most effective method for primary cubital tunnel syndrome patients. It was associated with the greatest response to treatment and the lowest risk of complications, reoperation, and recurrence. They also showed that *in situ* decompression (open, minimally invasive, or endoscopic) was associated with a lower risk of complications than any form of transposition. Moreover, the addition of epicondylectomy led to a higher success rate without increasing the risk of complications. Another advantage of *in situ* decompression is the reduced operative time and its simplicity. Of note also is that it is 18–55% cheaper than the transposition procedure (98). Therefore, open *in situ* decompression should be considered a first choice in treating patients with primary cubital tunnel syndrome. In recurrent cases, the surgeon should consider the extent of primary decompression, previous elbow trauma, and possible chronic subluxation to decide whether to perform more extensive decompression only or an anterior transposition. To this end, one should plan the surgery concerning local anatomy (e.g., anatomic variations and space-occupying lesions), where US can provide valuable information preceding the surgery, e.g., aberrant vein (**Figure 9F**).

CONCLUSIONS AND FUTURE DIRECTIONS

Cubital tunnel syndrome is commonly encountered in daily clinical practice. If correctly diagnosed, the treatment outcome can be promising. In the light of the broad differential diagnosis, a convenient imaging tool may be necessary in some cases. Hence, high-resolution US can be an inexpensive, safe, and accessible modality for visualizing and guiding the treatment of UN neuropathy around the elbow. US imaging in such indications can be expected to increase its awareness among physicians worldwide in the near future.

AUTHOR CONTRIBUTIONS

KM devised the project and the main conceptual ideas. ON supervised this work. Five authors wrote the first drafts of the

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manuscript sections (KM—introduction and US assessment. JJ—US-guided procedures and anatomy. RK—surgical techniques. SM—non-operative treatment. ON—anatomy). JJ formatted the figures and their legends. ON and KM dissected the cadaveric specimen and obtained the corresponding photographs. PS provided exemplary US images together with figure legends. KS, YA, and PS (together with other co-authors) provided critical feedback, helped shape the manuscript, and obtained figures and videos. All authors approved the final manuscript.

FUNDING

Open-access publication fees are supported by the Open Access Fund of the General University Hospital in Prague.

ACKNOWLEDGMENTS

The pictures of the anatomic specimens were elaborated using donated bodies with the approval of Institute of Anatomy, First Faculty of Medicine, Charles University, Prague. We are grateful for the assistance of Ivan Helekal, an academic painter from the Institute of Anatomy, First Faculty of Medicine, Charles University in Prague, for schematic drawings of certain anatomic regions in this manuscript.

SUPPLEMENTARY MATERIAL

The Supplementary Material for this article can be found online at: https://www.frontiersin.org/articles/10.3389/fneur.2021.661441/full#supplementary-material

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Conflict of Interest: The authors declare that the research was conducted in the absence of any commercial or financial relationships that could be construed as a potential conflict of interest.

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Ultrasound Imaging and Guidance in Common Wrist/Hand Pathologies

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Abstract: Wrist/hand pain is a prevalent musculoskeletal condition with a great spectrum of etiologies (varying from overuse injuries to soft tissue tumors). Although most of the anatomical structures are quite superficial and easily evaluated during physical examination, for several reasons, the use of ultrasound imaging and guidance has gained an intriguing and paramount concern in the prompt management of relevant patients. In this aspect, the present review aims to illustrate detailed cadaveric wrist/hand anatomy to shed light into better understanding the corresponding ultrasonographic examinations/interventions in carpal tunnel syndrome, trigger finger, de Quervain tenosynovitis, rhizarthrosis, and the radiocarpal joint arthritis. In addition, evidence from the literature supporting the rationale why ultrasound guidance is henceforth unconditional in musculoskeletal practice is also exemplified.

Key Words: Carpal Tunnel, Trigger Finger, de Quervain, Rhizarthrosis, Ultrasonography, Steroid, Injection

(*Am J Phys Med Rehabil* 2021;100:599–609)

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The prevalence of disabling wrist/hand pain among the working population reaches up to 36.2%.[1] The spectrum of chronic wrist/hand pain is quite broad, ranging from overuse injuries to soft tissue tumors.[2] Aside from several conservative alternatives (rest, physical therapy etc.); various interventional treatments (e.g., corticosteroid, local anesthetic, or regenerative injections) are frequently applied to treat these painful conditions affecting the hand and wrist. Herein, it is noteworthy that—in contrast to previous blind approaches—the role of ultrasound (US) imaging and guidance has essentially been established in recent years.[3] Of note, US guides these procedures initially by providing prompt clinical decision making—for the diagnosis and optimal/technical planning of the intervention alike.[4,5] Needless to say, it also provides precise targeting during the intervention (avoiding collateral damage) as well as convenient/close follow-up thereafter.[6]

In this aspect, this article aims to describe the anatomy, US imaging/guidance, and the literature evidence pertaining to the most commonplace interventional procedures in daily clinical practice, that is, carpal tunnel syndrome, trigger finger (TF), de Quervain tenosynovitis, rhizarthrosis, and radiocarpal joint arthritis.

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Financial disclosure statements have been obtained, and no conflicts of interest have been reported by the authors or by any individuals in control of the content of this article.

Supplemental digital content is available for this article. Direct URL citations appear in the printed text and are provided in the HTML and PDF versions of this article on the journal's Web site (www.ajpmr.com).

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ISSN: 0894-9115

DOI: 10.1097/PHM.0000000000001683

CARPAL TUNNEL SYNDROME

Carpal tunnel syndrome (CTS) is the most common peripheral nerve entrapment syndrome worldwide, resulting from compression of the median nerve at the wrist. Its diagnosis is based on clinical evaluation, nerve conduction studies, and US examination.

Anatomy

The carpal tunnel is a fibro-osseous space situated between the carpal bones' concave arch from the dorsal and the flexor retinaculum from the volar side. The bony landmarks for the carpal tunnel are the scaphoid and the pisiform proximally and the hook of hamate and the trapezium distally. Structures that pass through the carpal tunnel comprise the median nerve, four flexor digitorum superficialis and four flexor digitorum profundus tendons, and the flexor pollicis longus tendon inside their synovial sheaths. Distal to the retinaculum, the median nerve usually divides into five or six branches, showing a miscellaneous anatomic variability. Understanding variations of the median nerve's recurrent motor branch is essential[7] because its inadvertent resection during surgery would be associated with thenar function loss. The recurrent branch arises from the nerve's lateral side with a slight recurrent curve and continues superficial to or traverses the flexor pollicis brevis muscle, which is usually supplied by this nerve (Fig. 1A).[8] Notably, the median nerve also shows variations within the carpal tunnel, for example, bifid median nerve and persistent median artery.[9–11] Furthermore, space-occupying lesions/structures such as ganglion cysts, flexor tenosynovitis, and accessory muscles may also be present.[12] To this end, it is paramount to use a convenient imaging modality (e.g., US) to understand the pertinent anatomy before the injection.

US Imaging and Guided Injection Technique

Patients are usually seated facing the sonographer with their affected wrist in slight dorsiflexion resting on a rolled towel in a palm-up position, the forearm supinated, and elbow semiflexed at 90 degrees. As most of the wrist and hand structures are superficially localized, a high-frequency (8–18 MHz or higher) linear or hockey-stick probe would be preferred[13] during all the below-described procedures. The transducer is

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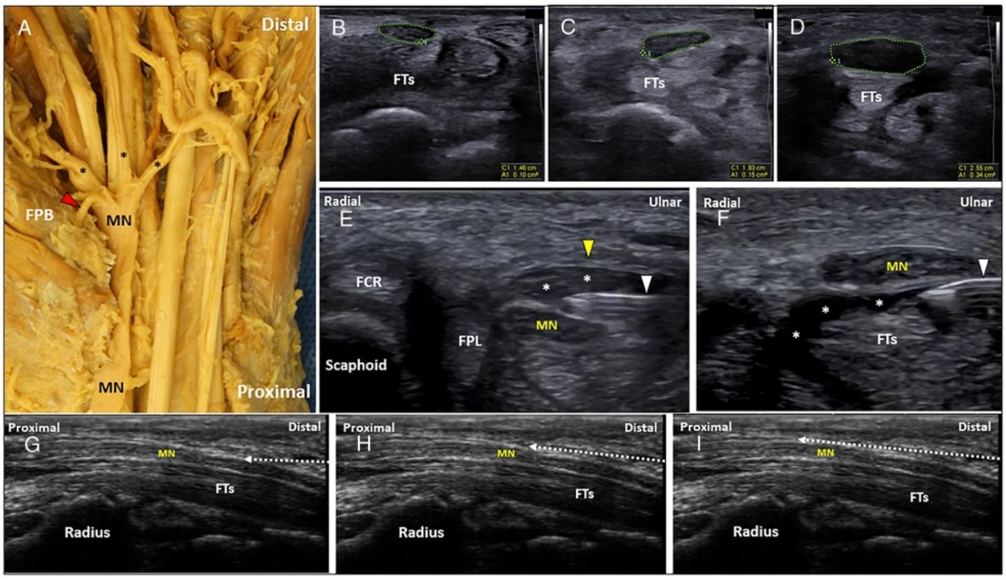

FIGURE 1. The cadaveric specimen shows the recurrent branch (red arrowhead) of the median nerve (MN) piercing the flexor pollicis brevis (FPB) muscle and the terminal branches–common digital palmar nerves (black asterisks) coursing distally (A). The short-axis sonogram promptly allows a detailed measurement of the cross-sectional area of the median nerve to evaluate the pathology/entrapment at mild (B), moderate (C), and severe (D) stages. US-guided hydrodissection (in-plane, ulnar to radial approach) guarantees a dual-target intervention releasing the median nerve–flexor retinaculum (yellow arrowhead) interface (E) and the median nerve–flexor tendon (FT) interface (F) during the same procedure. Although the longitudinal acoustic window allows an extensive hydrodissection (of the MN–flexor retinaculum interface) as the needle (white dotted arrow) is advanced from distal to proximal, it is not suitable if the nerve-FT interface is planned to be injected (G, H, I). White asterisks: mixture of the injectate; white arrowhead: needle. FCR indicates flexor carpis radialis tendon; FPL, flexor pollicis longus tendon.

placed along the short-axis of the wrist, slightly proximal to the scaphoid-pisiform level. The median nerve can be visualized as a honeycomb-appearing oval structure just beneath the flexor retinaculum. In CTS, the nerve typically shows flattening (at the entrapment site), loss of its normal fascicular pattern, and swelling (usually proximal to the entrapment site). Using US-measured cross-sectional nerve area, the severity can be classified as mild (<11.64 mm^2) (Fig. 1B), moderate (>13.74 mm^2) (Fig. 1C), and severe (>16.80 mm^2) (Fig. 1D).[14] In 2008, Hobson-Webb et al.[15] proposed a novel parameter for CTS's ultrasonographic diagnosis, named the wrist-to-forearm ratio, which was obtained 12 cm proximal in the forearm, measured from the distal wrist crease. In their preliminary results, the authors reported 100% sensitivity using a wrist-to-forearm ratio of greater than 1.4 to diagnose CTS. To increase the diagnostic specificity, apart from the carpal tunnel inlet, the median nerve cross-sectional area (CSA) can also be measured at the level of the proximal third of the pronator quadratus muscle to obtain the "ΔCSA" (CSA-inlet—CSA–pronator quadratus muscle). Klauser et al.[16] obtained the best diagnostic discrimination by using a ΔCSA threshold of 2 mm^2. According to a meta-analysis by Chen et al.,[17] the wrist-level CSA can also be used in diabetic patients, with a possible nonsignificant preexisting enlargement of the median nerve. Because the median nerve is considered stiffer in CTS patients, US elastography can also increase the diagnostic accuracy.[18] Furthermore, radial and ulnar arteries must be accurately identified/avoided during the procedure and color/power Doppler imaging can readily be used in this sense. A proximal-to-distal and distal-to-proximal sonotracking of the region should also be performed to rule out space-occupying lesions or to evaluate likely anatomical variants.

According to the aseptic technique, the skin should be disinfected, and to minimize the risk of infection, the probe should be covered with a sterile cover and sterile gel should be used as well. A freehand ulnar side in-plane approach visualizing the median nerve in the short-axis is usually performed. Under direct US visualization, a thin (e.g., 25-gauge, 25-mm) needle is advanced subcutaneously, slightly obliquely, superficial to the ulnar nerve and artery. The needle tip can be advanced next to the median nerve with subsequent slow administration of the injectate either between the median nerve and the superficial flexor tendons (Video 1, Supplemental Digital Content 1, http://links.lww.com/PHM/B224) or between the flexor tendons away from the median nerve.[19] A hydrodissection technique can also be used (especially in "failed-carpal tunnel release" patients) whereby a circumferential fluid plane should be formed around the epineurium of the median nerve, that is, in the median nerve–flexor retinaculum (Video 2, Supplemental Digital Content 2, http://links.lww.com/PHM/B225) and median nerve–flexor tendon interfaces (Fig. 1E–I). Delivering the injectate both deep and superficial to the median nerve allows

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separation of the nerve from the (potentially constricting) surrounding connective tissues, restoring the normal nerve mobility.[20] After the procedure, repetitive wrist flexion/extension is recommended to enhance the injectate delivery along the carpal tunnel.

Exemplary Evidence

Among conservative treatment options, US-guided corticosteroid injections have been proven effective (and superior to those landmark-guided) for symptom severity improvement in CTS patients.[21] Apart from corticosteroids and local anesthetics, different substances such as platelet-rich plasma, hyalase, local ozone (O_2-O_3), and 5% dextrose have been used in the literature as well.[22–24] Moreover, several studies comparing different injection sites have also been reported. Babaei-Ghazani et al.[25] compared US-guided corticosteroid injections "above" *vs.* "below" the median nerve in patients with mild to moderate CTS and found that both techniques effectively reduced the symptoms and improved function as well as the US and electrodiagnostic findings. Nair et al.[26] published a double-blind noninferiority trial comparing corticosteroid injections 2 cm proximal and 2–3 cm distal to the wrist crease whereby patient-reported outcomes were found to be similar. Hsu et al.[27] reported greater symptom relief and patient satisfaction for intraepineurial (*vs.* extraepineurial) corticosteroid injections. In the same study, patient-reported outcomes and nerve conduction studies at the 12-wk follow-up were similar between subjects injected with 40 *vs.* 10 mg of triamcinolone acetonide.

A relatively novel technique that is currently studied in the management of nerve entrapment syndromes is described as "nerve hydrodissection."[28] This method usually involves delivering the injectate (e.g., local anesthetic, saline, dextrose, corticosteroids) to separate the nerve from the surrounding tissues. Some authors believe that hydrodissection, coupled with mechanical disruption of the adhesions around the nerve, may restore normal nerve mobility.[29] Wu et al.[30] conducted a placebo-controlled study where hydrodissection of the median nerve (in contrast to subcutaneous 5 mL saline injection) yielded symptom improvement 6 mos after the procedure. On the other hand, Schrier et al.[31] reported comparable results of US-guided injections applied by either hydrodissection or single delivery medial to the median nerve.

Another option for CTS treatment is US-guided release of the transverse carpal ligament. This mini-invasive percutaneous technique has been shown as a safe, quick, effective, and reproducible procedure to transect the transverse carpal ligament on cadavers.[32,33] Compared with open surgery, US-guided release has shown better outcomes in scar tenderness, grip strength, superficial pain, and return to daily activities.[34] Further investigation of this method is certainly warranted.

TRIGGER FINGER

TF, also known as stenosing tenovaginitis, results from inflammation of the finger flexor tendons and/or their synovial sheaths. The conflict at the intersection of the tendon with its pulley is most commonly related to the thickening of the first annular pulley (A1). However, other pulleys can also be affected, and therefore, clinical findings without imaging can indeed cause misdiagnosis. In such clinical scenarios, the use of static/dynamic US examination would be crucial for detecting the triggering and the possible underlying mechanism.

Anatomy

The digital flexor fibrous sheath-pulley system keeps the tendons adjacent to the bone when bending the fingers. In other words, these fibro-osseous bands (most importantly A2 and A4) prevent bowstringing of the flexor tendons during finger flexion.[35] Those pulleys are five annular (A1–A5) and three cruciform (C1–C3) ligaments for the second to fifth digits and

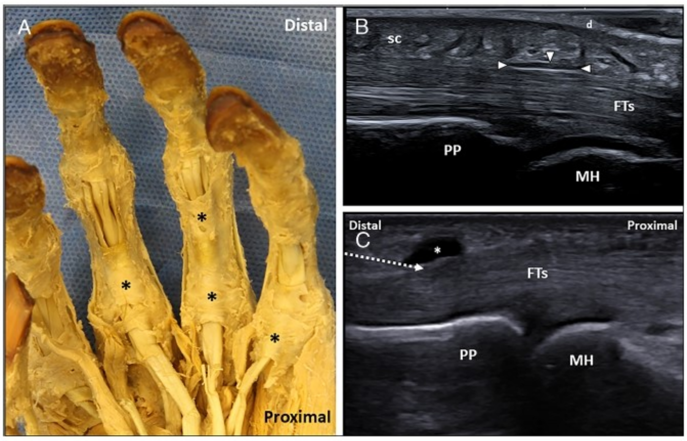

FIGURE 2. The cadaveric specimen shows the pulleys of fibrous sheaths (black asterisks) stabilizing the flexor tendons of the fingers (A). Using a high-frequency linear probe, a normal pulley (white arrowheads) may be visualized as a thin and hypoechoic structure located between the subcutaneous tissue and the flexor tendons (FTs) (B). In some patients, a focal collection (white asterisk) of fluid in proximity of the flexor tendons (FTs) —related to pathological changes of the pulley and/or synovial cyst of the tendon sheath—can be targeted using an in-plane (distal to proximal) approach while advancing the needle (white dotted arrow) until the intrasheath compartment (C). MH indicates metacarpal head; PP, proximal phalanx; d, dermis.

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two annular (A1–A2) and one oblique pulley for the thumb. A1 pulley is located anterior to the metacarpal head. The A2 overlies the middle third of the proximal phalanx but may extend more proximal or distal. It is the strongest pulley and arises from the longitudinal ridges on the phalanx's palmar aspect (Fig. 2A).[8] A3 is a narrow pulley lying palmar to the proximal interphalangeal joint, and A4 and A5 overlie the middle phalanx and the distal interphalangeal joint, respectively. Variations occur frequently, though. A1, A3, and A5 pulleys insert onto the volar plate, whereas A2 and A4 insert directly on the bone.[36] Histologically, the pulley system consists of a deep synovial component and a superficial retinacular component. Flexors digitorum superficialis and profundus and flexor pollicis longus tendons are enveloped in two synovial sheaths at the flexor retinaculum level and distally reach about halfway along the metacarpal bones, where they end as blind diverticula. In the little finger and the thumb, the sheaths are usually more extended.[8]

US Imaging and Guided Injection Technique

The patient is seated face to face to the examiner with the affected hand in a palm-up position. The transducer is placed along the finger's long-axis to visualize the flexor tendons as a hyperechoic fibrillar structure superficial to the metacarpals/phalanges. Annular pulleys are seen as hypoechoic thickening of the volar aspect of the tendon sheath (Fig. 2B). Subsequently, transverse scanning should also be performed to rule out other pathologies potentially mimicking TF (Video 3, Supplemental Digital Content 3, http://links.lww.com/PHM/B226). After static imaging, (passive) dynamic examination during flexion/extension of the finger should be performed (Videos 4 and 5, Supplemental Digital Content 4 and 5, http://links.lww.com/PHM/B227, http://links.lww.com/PHM/B228) to complete the functional assessment. In TF, pulley swelling/thickening or effusion inside the synovial sheath may be present. In addition, tendon thickening and abnormal tendon motion associated with friction patterns are typical US findings.[37]

Various injection techniques have been reported in the literature. Owing to the highly innervated and sensitive palmar skin, some authors even recommend using the interdigital web skin for the needle entry point as a less painful alternative.[38] While planning for the intervention, power Doppler imaging would again provide clear identification of the neurovascular bundle (proper digital nerves and vessels) to be avoided. During the injection, a thin (e.g., 27-gauge, 19-mm) needle is preferred to reduce the procedure-related pain. With the transducer placed in a longitudinal, oblique plane on the palmar side, the needle can be inserted via the interdigital wing skin (Fig. 2C). The

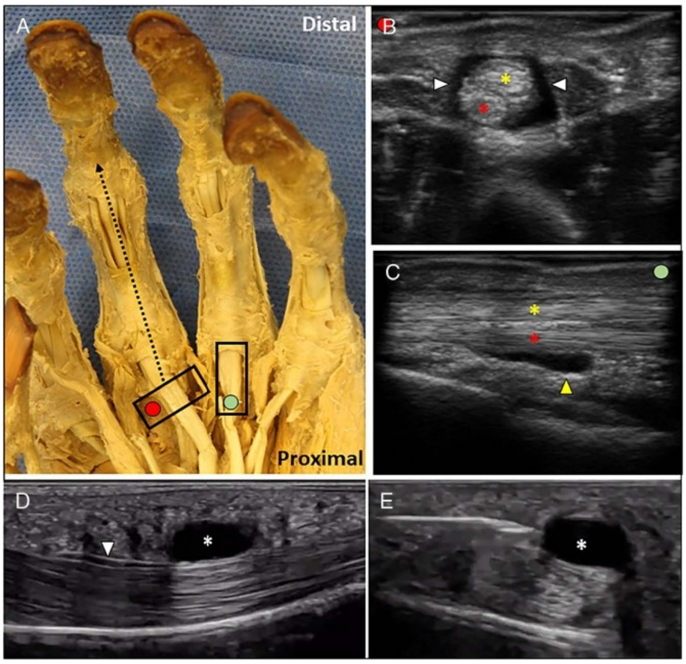

FIGURE 3. After the US-guided intervention for the trigger finger, a postprocedure check is recommended in two orthogonal planes and using the elevator technique (black dotted arrow) (A). A circumferential, anechoic ring (white arrowheads) surrounding the superficial (yellow asterisk) and deep (red asterisk) flexor tendons in short-axis view (B) and a cul-de-sac collection (yellow arrowhead) below the deep (red asterisk) flexor tendons in long-axis view (C) are usually considered to be confirmatory for a correct intrasheath injection. For sure, the US-guided procedure for a trigger finger must be planned in relation to the specific clinical and ultrasonographic findings for each and every patient. In this particular case, a cyst-like lesion (white asterisk) originating from the pulley (white arrowhead) (D) has been approached using an in-plane technique in short-axis view to better perform needling of the mass (E). Black rectangle: probe.

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injection may be performed using a direct in-plane technique, and the injectate is delivered into the intrasheath space underneath the affected pulley (Fig. 3A–E).

Exemplary Evidence

Corticosteroid injections improve TF by reducing flexor tendon and A1 pulley inflammation, with the documented response rates being between 45% and 80%.[39] A meta-analysis on treatment success showed better short-term effects of corticosteroid injections combined with lidocaine than lidocaine alone.[40] Shultz et al.[41] reported better success of corticosteroid injections (1 mo after the procedure) in patients with mild triggering than those with severe findings. Furthermore, the success rate was lower in cases with multiple digit involvement. The outcome was reported to be poorer in patients with coexisting diabetes and inflammatory conditions.[42] The long-term effectiveness of corticosteroid injections is possibly not as favorable as surgery; however, 37%–56% symptom relief has been reported in patients presenting with TF for as long as 10 yrs.[43,44]

In a study that included 124 trigger digits (119 patients), Rozental et al.[45] found a symptom recurrence rate of 56% at a median of 5.6 mos after the injection as well as higher rate of treatment failure in diabetic patients. According to one study, US guidance showed an accuracy of 70% with regard to intrasheath placement of steroids when compared with the rate of 15% for landmark-guided injections.[37] Concerning the corticosteroid preparation, Roberts et al.[46] reported a higher need for additional injections when triamcinolone was administered in contrast to dexamethasone or methylprednisolone. US-guided A1 pulley release is another procedure that can be performed. Significant pain reduction and functional improvement were reported in 98% of patients, with no recurrence of catching/locking in the first year of follow-up.[47] Compared with open surgery, US-guided treatment resulted in shorter sick leave and better cosmetic results, without any major complications.[48]

DE QUERVAIN TENOSYNOVITIS

de Quervain disease (DQD) was first described in 1895 by Fritz de Quervain (1868–1940) as a common cause of radial-sided wrist pain.[8] It is an inflammation of the abductor policis longus (APL) and/or extensor policis brevis (EPB) tendons, and their tendon sheaths confined within the first dorsal compartment at the level of the radial styloid. Several anatomic variations (e.g., subcompartmentalization or accessory abductor pollicis longus) are commonly seen in this extensor compartment (Fig. 4C). As such, (US) imaging is necessary to understand the local anatomy/relevance of the findings and to plan the likely intervention accordingly.

Anatomy

In general, the normal anatomy of the first extensor compartment describes the APL and EPB as a single tendon enveloped in a common extensor sheath running through a single fibro-osseous tunnel deep to the extensor retinaculum. However, this compartment shows a high anatomic variability with significant implications for DQD and the pertinent injections. One possible variation to be considered before the injection would be the presence of multiple compartments divided by septae, which was actually reported to be more prevalent in patients with DQD when compared with healthy individuals.[49] The septum usually creates a separate narrow compartment for the EPB tendon.[50] Regarding the tendinous anatomy, EPB is usually described as a single tendon inserting on the thumb's proximal phalanx. However, multiple EPB tendon slips with

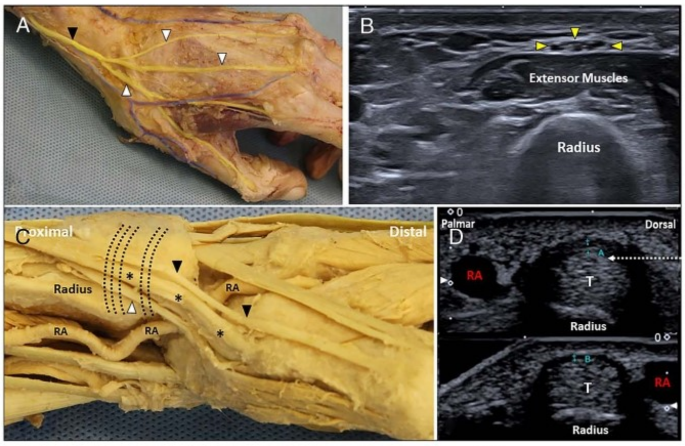

FIGURE 4. The cadaveric specimen shows the superficial branch (black arrowhead) of the radial nerve and its terminal branches (white arrowheads) coursing superficial to the fascia (A). Before any intervention at the level of the radial side of the forearm, sonotracking of the sensory components of the radial nerve (yellow arrowheads) should be performed for a safer planning of the procedure avoiding iatrogenic injuries (B). The extensor pollicis brevis (black arrowheads), abductor pollicis longus (black asterisks), and, in some patients, the accessory abductor pollicis longus (white arrowhead) tendons course proximally between the cortical surface of the radius and the retinaculum (black dotted lines), whereas, distally, they cross over the radial artery (RA) to reach the insertional sites (C). Comparative scanning may promptly identify pathological thickening of the first extensor retinaculum, and if clinically indicated, a US-guided injection, using an in-plane technique (dorsal to palmar approach) may be performed releasing the mixture at the retinaculum-tendon (T) interface (D). White dotted arrow: needle.

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several different attachment points have also been described.[51] Moreover, EPB tendon was reported to be absent or replaced by an accessory tendon of APL in 6.2% of the cases, and EPB was also considered to be the most variable muscle in the forearm.[52] At least one slip of the APL is inserted on the first metacarpal base in almost all cases. However, the presence of multiple distal tendinous slips is ubiquitous, and they might insert into the trapezium or the carpometacarpal joint or can be merged with adjacent tendons.

US Imaging and Guided Injection Technique

The patient sits face to face with the physician, with a table in between. US imaging starts with the elbow flexed and the forearm in pronated position lying on the table/examination bed. The probe is placed axially over the Lister tubercle (at the distal radius), which can also/easily be palpated. However, forming a boundary between the second and third compartments, it serves as an anatomical landmark. Thereafter, the probe can be moved further radial to depict the first extensor compartment in the short-axis. Common sonographic findings of DQD comprise hypoechoic thickening of the extensor retinaculum and/or thickening of the first extensor compartment tendons (Fig. 4D; Video 6, Supplemental Digital Content 6, http://links.lww.com/PHM/B229). When performing dynamic scanning, gliding of the tendon(s) beneath the retinaculum can be compromised. Enhanced intratendinous vascular flow on power Doppler and a variable volume of inflammatory fluid in the synovial sheath can also be present. In general, a thin needle (e.g., 27 gauge, 19 mm) is inserted from either side of the probe using an in-plane approach to reach the tendon sheath (Video 7, Supplemental Digital Content 7, http://links.lww.com/PHM/B230). According to the US and clinical findings, DQD injections can be performed proximally at the common tendon sheath or distally after their division in the individual compartments. However, as the distal separate tendon sheaths are tighter, injection at this level may be more painful. Alternatively, an out-of-plane approach can be used as well. In case of aforementioned aberrations, the affected tendon sheath or subcompartment needs to be selectively injected under real-time guidance (Fig. 5A–E). Caution should be taken to avoid the radial artery (running on the volar side) and the superficial radial nerve, which courses from volar to dorsal just proximal to the radial styloid—with variable branching pattern (Fig. 4A, B; Video 8, Supplemental Digital Content 8, http://links.lww.com/PHM/B231).[53]

Exemplary Evidence

Corticosteroid injection into the first dorsal compartment sheath is a commonly used treatment approach for DQD patients. A systematic review and meta-analysis investigating the effectiveness of corticosteroid injection in DQD reported a significant increase in the resolution of symptoms, pain relief, and increased function. In the analyzed studies, the most commonly used steroids were methylprednisolone, dexamethasone, and triamcinolone.[54] In 2007, Sawaizumi et al.[55] compared a landmark-guided single injection (above the tender induration) and two-point injection (over the EPB and APL tendons), and the latter technique provided better outcomes—with the efficacy reaching 89%. In 2017, another systematic review proposed that if a single injection technique is to be administered, a proximal (rather than distal) injection should be preferred because it would be more likely to infiltrate multiple compartments in case of septations.[49] Importantly, with the use of US guidance, new techniques are being widely reported in the recent literature.[56] McDermott et al.[57] reported at least partial

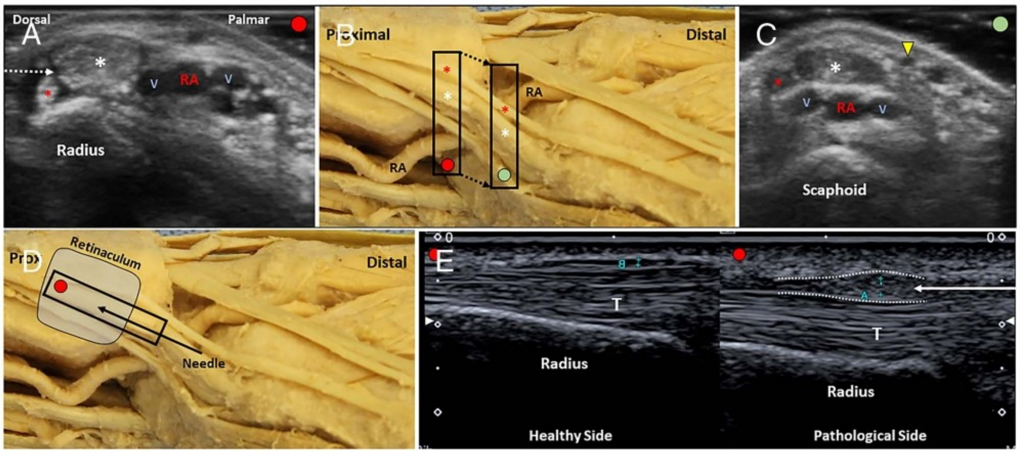

FIGURE 5. In selective pathologies of the extensor pollicis brevis tendon (red asterisk), a US-guided injection targeting its synovial sheath may be performed. Avoiding the abductor pollicis longus tendon (white asterisk) is possible with the use of an in-plane (dorsal to palmar approach) at the distal end of the radius (A). Of note, shifting the probe (black rectangle) more distally (B), the injection may be more challenging because of the "criss-cross" between the tendons, the radial artery (RA), and the distal branch (yellow arrowhead) of the sensory component of the radial nerve (C). If clinically indicated, a US-guided needling/release of the first extensor retinaculum can also be performed using an oblique longitudinal acoustic window (D). Targeting the thickened retinaculum (white dotted lines) and avoiding the underlying tendons (T) are possible with back-and-forward movements of the needle (white arrow) (E). White dotted arrow: needle. V indicates vein.

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resolution of symptoms in 97% of the patients 6 wks after the US-guided injection. In their retrospective study, Hajder et al.[58] reported good long-term (7.3 mos) results in 91% of patients who received two US-guided corticosteroid injections. US was shown to be important in the visualization of an intercompartmental septum, and US-guided injections were proven to be accurate—providing good outcomes.[59] In short, the efficacy and safety of corticosteroid injections are linked to prompt imaging and guidance.[60–63] Although studied in a small group of cadavers/patients, US-guided release in patients with DQD has been reported as a safe and reliable procedure, without any specific morbidity.[64]

RHIZARTHROSIS

The first carpometacarpal (CMC) or the trapeziometacarpal joint is the second most commonly affected site by primary idiopathic arthritis in the hand, only after the distal interphalangeal joints.[65] *Rhizarthrosis* and *thumb CMC osteoarthritis* are commonly used terms to describe morphologic alterations due to degenerative process of the CMC joint. The thumb is the key contributor to hand function. As such, symptomatic rhizarthrosis can interfere with work and normal daily activities, potentially resulting in significant functional disability coupled with decreased quality of life. Moreover, pain in the thumb and the radial side of the wrist is associated with rhizarthrosis.[66] It is more prevalent in postmenopausal women and in elderly patients.[67] Its diagnosis is based on clinical evaluation, radiographic, and US examination.

Anatomy

The first CMC joint is a biconcave saddle-type joint between the first metacarpal base and the trapezium bone. Its shape with extensive articular surfaces allows motion in three planes, providing wide mobility and active opposition.[68] The great range of motion is associated with a need for stability, which is provided by a system of ligamentous structures that stabilize the joint while performing a pinch movement. Lateral, anterior, and posterior ligaments, together with a fibrous capsule, bind the first metacarpal and trapezium bones together (Fig. 6A). The joint's stability is important because clinical studies have correlated joint laxity with the development of CMC osteoarthritis. The forces affecting the first CMC are great. Biomechanic studies have shown that while performing grasp and pinch, the forces increase exponentially from the tip to the CMC joint.[68] Some muscles (e.g., APL and extensor pollicis brevis) and arteries (e.g., radial artery) are situated in the proximity of the first CMC.

US Imaging and Guided Injection Technique

The patient is seated face to face with the physician. The arm is flexed to 90% in the elbow, and the hand is resting on a table or bed with the thumb facing upward.[66] The probe is attached to the radial side of the first metacarpal and translated proximally until the base of the first metacarpal and trapezium bones is identified (Fig. 6B). If the joint is not clearly visible, passive thumb motion can reveal the joint margins.[69] Identification of APL and EPB tendons crossing the joint, as well as the radial artery, is important to avoid collateral damage (Fig. 6C).[66]

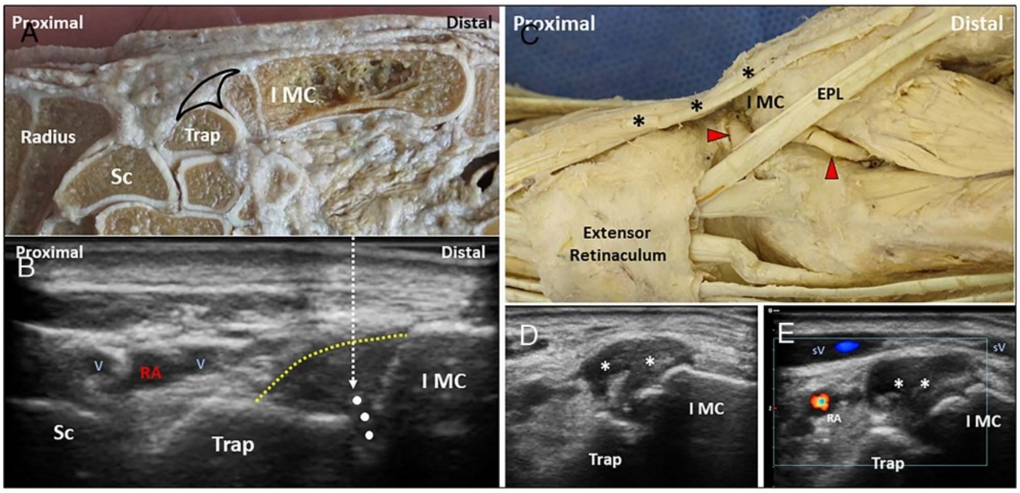

FIGURE 6. The cadaveric specimen—with an internal view—shows the triangular-shaped joint (black line) between the trapezium (Trap) and the proximal end of the first metacarpal bone (I MC) (A). Using an out-of-plane (radial to ulnar) approach, the needle tip (white dotted arrow) can be clearly visualized passing the capsule (yellow dotted line) and releasing the mixture (white dots) into the joint cavity avoiding the radial artery (RA) and veins (V) (B). The cadaveric specimen—with an external view—shows the tendons of the first extensor compartment (black asterisks) and the radial artery (red arrowheads) partially "covering" the trapezium–I MC joint (C). The US-guided injection should be modified in relation to the anatomical variability of each and every patient. In this particular case, detailed planning of the procedure was necessary to target the articular ganglion (white asterisks) originating from the trapezium (Trap)–I MC joint (D). Color Doppler imaging clearly shows the radial artery (RA) and superficial vein (sV) surrounding the mass (E). Sc indicates scaphoid bone; EPL, extensor pollicis longus tendon.

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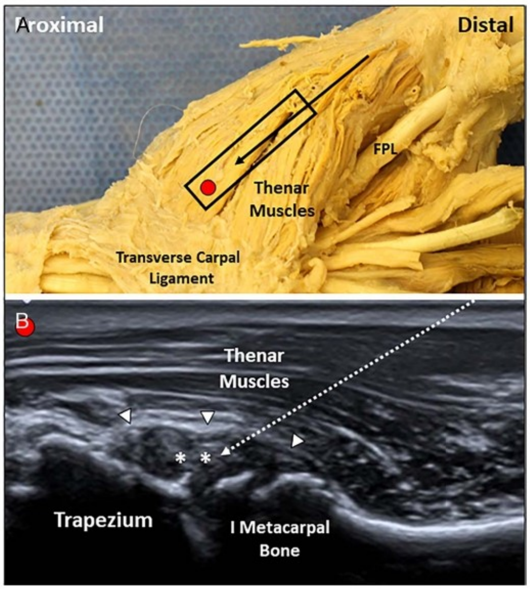

FIGURE 7. In selected cases, an in-plane (distal to proximal) approach may be used to target the trapezium–first metacarpal joint from the palmar side (A). Of note, using this technique, the needle (white dotted arrow) is advanced through the thenar muscles to pass the capsule (white arrowheads) and target the synovial cavity (white asterisks) (B). As such, a palmar approach may be more painful compared with the dorsal one. Black rectangle: probe; black arrow: needle. FPL indicates flexor pollicis longus tendon.

Findings that might be present in patients with rhizarthrosis include joint effusion, articular space narrowing, cortical irregularities, and osteophyte formation (Fig. 6D, E). The injection is performed with a short 25- to 27-G needle. There are several techniques to perform the injection: in-plane or out-of-plane, lateral to medial, proximal to distal, or distal to proximal (Fig. 7A, B; Video 9, Supplemental Digital Content 9, http://links.lww.com/PHM/B232). The selection of the technique should be adapted to the individual anatomical variability and the physician's expertise.[69] Of note, because the joint space is very small, only a small amount of volume (max. 0.5 to 1 ml) should be injected to avoid pain caused by overdistension of the joint capsule.[66,70]

Exemplary Evidence

Despite the fact that rhizarthrosis is quite common, there are only poor-quality studies with inconsistent results in the literature.[71] Corticosteroid and hyaluronic acid injections are commonly used in the conservative treatment of rhizarthrosis. In a recent meta-analysis, hyaluronic acid was reported to be efficient on the function and corticosteroids on pain control in the long-term.[72] Herewith, the limitation in that meta-analysis was that there was high heterogeneity between studies with regard to different dosages/types of the drugs used. With regard to thumb OA, Riley et al.,[73] in their meta-analysis, stated that there is a lack of evidence on which injection-based therapy is the most effective. According to the RCT of Monfort et al.[74] with 88 patients using hyaluronic acid and betamethasone, both were effective in the management of rhizarthrosis, whereas the effectivity of HA was higher over time. The accuracy of US-guided CMC injections was found to be better than injections without US guidance.[75]

RADIOCARPAL JOINT ARTHRITIS

Because of inflammatory or noninflammatory causes (with a common eventuality of radiocarpal joint degeneration), patients usually present with pain and limited motion. The history should be focused on flagging previous injuries (e.g., distal radius/scaphoid fracture, scapholunate ligament injury) as well as an existing/early inflammatory condition (e.g., rheumatoid arthritis).[66,76] US examination of the radiocarpal joint can reveal pathologic findings such as joint effusion, synovial thickening, cortical irregularities, or formation of osteophytes.[69] Conservative treatment is usually initiated with anti-inflammatory medications and rest (e.g., wrist splints). Corticosteroid injection would perhaps be the next option to preserve function and to control pain. Aside from its therapeutic effect, the injection might diagnostically serve to distinguish between intra-articular pathologies, tendinopathies, or compressive neuropathies.[76] In patients who are not responsive to conservative alternatives, surgical treatment might be considered.

Anatomy

The radiocarpal joint is a biaxial and ellipsoid-type synovial joint, comprising the articulation of distal radius and triangular fibrocartilage with the scaphoid, lunate, and triquetrum bones (Fig. 8A). Together with the ligaments, triangular fibrocartilage (2–5 mm thick disc), composes a part of the triangular fibrocartilaginous complex. Triangular fibrocartilaginous

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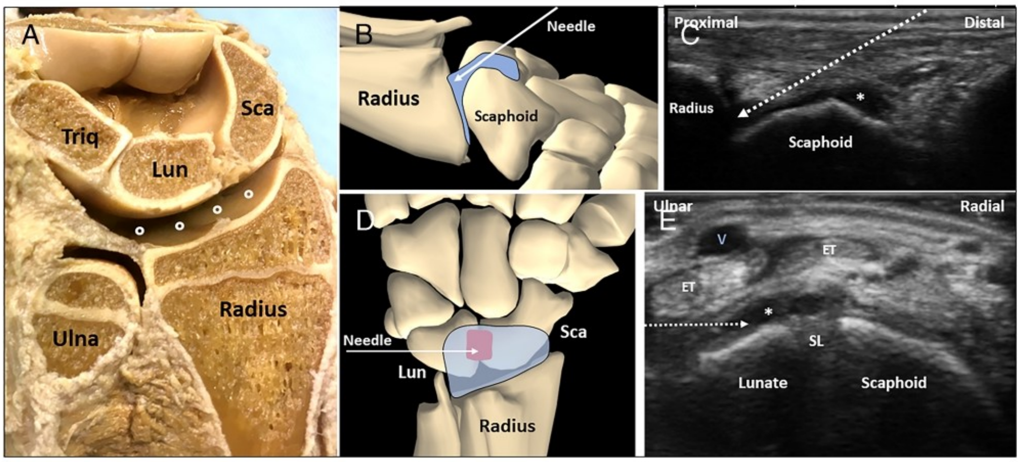

FIGURE 8. The cadaveric specimen—with an internal view—shows the radiocarpal joint (white dots) between the distal end of the radius and the scaphoid (Sca), lunate (Lun), and triquetrum (Triq) bones (A). Using an in-plane (distal to proximal) approach, the needle (white dotted arrow) can be advanced inside the dorsal, radioscaphoid recess (white asterisk) to perform a radiocarpal injection (B, C). Likewise, using an in-plane (ulnar to radial) approach, the dorsal recess of the radiocarpal joint (white asterisk), which is located between the dorsal scapholunate ligament (SL) and the extensor tendons (ET), may be easily targeted, keeping the needle more parallel to the US beam and optimizing its visualization (D, E). Blue: articular cavity; red: dorsal scapholunate ligament. V indicates vein.

complex suspends the ulnar carpus and distal radius from distal ulna. The fibrous capsule of the joint is lined by synovial membrane and is strengthened by palmar and dorsal radiocarpal, palmar ulnocarpal, and radial and ulnar collateral ligaments. When the wrist is in neutral position, only scaphoid and lunate are in contact with radius and the triangular fibrocartilaginous complex. Triquetrum comes to contact only when the wrist is fully adducted. Radiocarpal movements are evaluated together with the intercarpal bones, since they are both involved in wrist movements whereby same muscles perform the action. Active wrist joint movements are flexion, extension, abduction (radial deviation), adduction (ulnar deviation), and circumduction (all four movements together).

US Imaging and Intervention Technique

The patient can either be sitting in front of the examiner or lying supine. The supine position is more comfortable for the patient, lowering the risk of vasovagal syncope.[69] The forearm of the patient is in maximal pronation. A small towel is put under the wrist, which is in slight flexion, and the radiocarpal joint opens on the dorsal side.[77] For injection, radioscaphoid joint is a preferred place because it is easily accessible and there are no overlying tendinous or vascular structures.[69] The injection into the tendon sheath or the small vessels can easily be prevented with US guidance.[77] For localizing the radioscaphoid joint, the transducer is initially/axially put over the radial styloid and wrist. After visualizing the Lister's tubercle in the middle of the image, the probe is rotated 90 degrees to the sagittal plane, so the probe becomes longitudinal across the radioscaphoid joint. Pathologic US findings would be joint effusion, thickening of the synovium, articular space narrowing, bony irregularities, and osteophyte formation.[66,69] A 25-G needle loaded with 2–3 ml of injectate (e.g., corticosteroids, viscosupplementation, and platelet-rich plasma) volume is typically used.[66,78] The needle is inserted using the in-plane technique following a distal to proximal trajectory (Fig. 8B, C). Another possibility can be the out-of-plane approach following a radial-to-ulnar or ulnar-to-radial trajectory.[69] When the injection is correctly administered into the joint, no resistance should be encountered.[66] An alternative would be the in-plane technique and ulnar to radial approach, releasing the drug over the dorsal scapholunate ligament inside the dorsal radiocarpal recess (Fig. 8D, E).

Exemplary Evidence

According to a recent meta-analysis, US examination is a valid and reproducible technique for detecting synovitis in the wrist and it may be considered as a part of the standard diagnostic algorithm in RA.[79] Intraarticular injections are commonly used to treat (non)inflammatory conditions in the radiocarpal joint.[80] These injections have been traditionally given blindly, using palpation for landmarks to identify the joint. US-guided injections have better accuracy[78] and clinical efficacy.[80] Likewise, another RCT reported that US guidance improved the performance, cost-effectiveness, and clinical outcomes of intraarticular wrist injections in rheumatoid arthritis.[81] Concerning the comparison of operative *vs.* nonoperative treatments of wrist osteoarthritis, one recent meta-analysis has reported the paucity of prospective studies on the topic.[82]

CONCLUSION

As most of the wrist/hand structures are superficial, US imaging/guidance would be noteworthy for the management of pertinent disorders in the daily practice of musculoskeletal physicians. Accordingly, in this article, the authors tried to exemplify certain anatomical and technical issues that—they believe—excel such diagnostic and therapeutic procedures

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performed by using US. Last but not least, it is necessary to keep in mind that US is an invaluable tool to guide the holistic clinical approach to patients.

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7. Diskuse

Z výsledků námi provedené studie vyplývá, že ve sledovaných parametrech není signifikantní rozdíl mezi aplikací kortikosteroidů (KS) ke šlachám flexorů a hydrodisekcí od šlach flexorů, což nepotvrdilo počáteční hypotézu, že hydrodisekce by mohla být účinnější, vzhledem k přídatnému mechanickému faktoru rozrušení adhezí. Ve prospěch této hypotézy vypovídala řada studií, ve kterých byla provedena hydrodisekce za použití jiných látek, jako například roztok 5% dextrózy, fyziologický roztok nebo hyaluronidáza, s prokazatelným zlepšením v subjektivních i objektivních sledovaných parametrech (Alsaeid, 2019; Wu et al., 2019; Elawamy et al., 2020). Wu a kolektiv provedli prospektivní, randomizovanou, dvojitě zaslepenou a placebem kontrolovanou studii, kdy v jedné skupině byla provedena hydrodisekce n. medianus od šlach flexorů roztokem chloridu sodného (NaCl) a ve skupině kontrolní byl NaCl aplikován do podkoží. Skupina s provedenou hydrodisekcí vykazovala přetrvávající účinek ve zlepšení příznaků až 6 měsíců od intervence (Wu et al., 2019). Evers a spolupracovníci publikovali studii na 12 kadáverech, ze které vyplývá, že hydrodisekce roztokem NaCl n. medianus od šlach flexorů i retinaculum musculorum flexorum jednoznačně snížila index tření n. medianus při pohybech horní končetiny (Evers et al., 2018). V další studii se 40 účastníky byl sledován účinek hydrodisekce n. medianus od šlach flexorů i retinaculum musculorum flexorum za použití hyaluronidázy (adheziolytický efekt) vs. dexamethasonu. Účinek hyaluronidázy se ukázal jako významnější ve sledovaných parametrech i po 6 měsících od intervence (Alsaeid, 2019). Zdá se, že v případě kortikosteroidů hydrodisekce nepřináší významný adjuvantní efekt k samotnému účinku KS. V souladu s tímto tvrzením je studie s 64 účastníky z roku 2021, ve které Wang a kolektiv zkoumali účinek aplikace triamcinolon acetátu hydrodisekcí a pouze laterálně od n. medianus. Výsledky se shodují se závěry námi provedené studie, tzn. došlo ke zlepšení sledovaných parametrů v obou skupinách bez rozdílu mezi těmito skupinami (Wang et al., 2021). Babaei-Ghazani a spolupracovníci publikovali výsledky randomizované studie, ve které srovnávali účinek obstřiku kortikosteroidy nad a pod n. medianus u 44 pacientů s mírným až středním SKT. V této studii neprokázali statisticky signifikantní rozdíl mezi jednotlivými skupinami. Nicméně obě skupiny prokazovaly zlepšení subjektivních příznaků, funkce i výsledků elektrodiagnostického vyšetření (Babaei-Ghazani et al., 2018b). Pilotní studie s 20 účastníky z roku 2020, zkoumala účinek obstřiku n. medianus při SKT betamethasonem s hydrodisekcí a bez ní. Ze závěru vyplývá, že po čtyřech a 24 týdnech došlo ke zlepšení v obou skupinách bez statisticky významného rozdílu mezi nimi. Kontrola ve 24. týdnu však probíhala pouze telefonicky, nebyly tak posuzovány objektivní parametry (Schrier et al., 2020).

Patofyziologie vzniku SKT ještě není zcela objasněna. Pravděpodobně dochází ke zvýšení tlaku v omezeném prostoru KT v důsledku otoku synoviální vrstvy šlach flexorů a měkkých tkání. To má za následek lokální zánětlivou odpověď, poruchu cévního zásobení a axonálního transportu nervu a jeho otok (Dilley a Bove, 2008; Mackinnon, 2002). Histologické nálezy odhalily fibrózu subsynoviální pojivové tkáně, která je uložena pod retinaculum musculorum flexorum a nad šlachovými pochvami povrchového flexoru prstů (Ettema, 2004). Tato tkáň by měla umožňovat snadný pohyb n. medianus oproti okolním strukturám, což v důsledku fibrózy není možné. Není ještě přesně objasněn vztah mezi omezením pohyblivosti n. medianus a neuropatií, pravděpodobným mechanizmem je zamezení pohybu nervu laterálně při silovém úchopu rukou. To má za následek jeho další traumatizaci (Sucher, 2009). Pravděpodobně je příčinou vzniku obtíží kombinace obou mechanizmů (Mackinnon, 2002). Jedním z nejčastějších neoperačních postupů při léčbě mírného až středně závažného SKT je aplikace kortikosteroidů do oblasti zápěstí. Účinek spočívá pravděpodobně v jejich protizánětlivém a antiedematózním účinku (Bland, 2007; Armstrong et al., 2004). Zároveň bylo prokázáno, že UZ navigované obstřiky mají větší účinnost oproti obstřikům provedených na základě pohmatové orientace (Babaei-Ghazani, 2018; Ustün et al., 2013). Přesné místo a technické provedení obstřiku je stále předmětem diskuze. Je potřeba dalšího výzkumu k objasnění účinků hydrodisekce za použití KS a jejich přetrvávání v čase. Dalším směrem by mohlo být studium hydrodisekce u pacientů s přetrvávajícími či recidivujícími potížemi po operační dekompresi, tzv. failed carpal tunnel surgery.

Intramuskulární hemangiom se na UZ zobrazuje jako dobře ohraničené, někdy lobulární ložisko, vyplněné heterogenními cévními strukturami, v nichž mohou být přítomné kalcifikace (Griffin et al., 2007). Zobrazení power Doppler může být nápomocné, ale vzhledem k pomalému toku krve v malformovaných cévách nemusí být vždy pozitivní. K potvrzení diagnózy a vyloučení malignity se doporučuje zobrazení MR a případně i histologické vyšetření (Pirri et al., 2022). Hemangiomy obecně jsou benigní nádory z krevních cév, které tvoří asi 7 % nádorů měkkých tkání, IH jsou zastoupeny méně než v 0,8 % případů. Nejčastěji jsou uloženy ve stehnu a lýtku a objevují se s vyšší prevalencí do 30 let věku. Jejich diagnostika může být svízelná právě proto, že se pro jejich vzácnost na tuto diagnózu nepomýšlí a klinické projevy mohou být nespecifické. Na rozdíl od povrchově uložených hemangiomů se neobjevují barevné změny na kožním povrchu. Nejčastěji se v klinickém nálezu popisuje chronická bolest, může být patrná pohmatově měkká rezistence. Může být provázena dysfunkcí postižených svalů, 60 % postižených udává zhoršení při aktivitách, v důsledku zvýšení krevního průtoku cévami (Wierzbicki et al., 2013). Publikace z poslední doby uvádí, že UZ je často prvním zobrazovacím vyšetřením vedoucím ke stanovení diagnózy (Pirri et al., 2022).

Popsaná technika pro obstřik hypertrofovaných anulárních poutek představuje alternativu ke konvenčním obstřikům z dlaňového přístupu. V kůži dlaňové části prstů a dlaně se nachází vysoká koncentrace hmatových receptorů (100–140/cm^2) a směrem k zápěstí se tato koncentrace snižuje (Johansson a Vallbo, 1979). Tato bohatá inervace je příčinou značné bolestivosti tohoto výkonu. Ultrazvuková navigace zvyšuje účinnost obstřiku, neboť dle kadaverické studie vyplývá, že při injekci s pohmatovou orientací je pouze 15 % účinné látky skutečně aplikováno do šlachové pochvy (Lee et al., 2011). Díky UZ navigaci můžeme jehlu zavést z meziprstního prostoru bez poranění nervově-cévního svazku. Kůže v meziprstí nevykazuje takovou citlivost jako kůže dlaně a procedura je pacienty relativně dobře tolerována.

Ultrazvukové přístroje se cenově významně liší. Nicméně všeobecně platí, že pořizovací a provozní náklady jsou ve srovnání s některými jinými zobrazovacími metodami relativně nízké. Mezi další výhody patří absence ionizujícího záření a kontraindikací. Zároveň se UZ vyšetření těší oblíbenosti i mezi pacienty, protože je to vyšetření nebolestivé a neinvazivní a mohou jej sledovat přímo na obrazovce, tzv. sono-feedback (Çağlayan et al., 2016). Ultrazvukové přístroje jsou i přenosné a trendem poslední doby je jejich miniaturizace, což umožňuje vyšetření přímo u lůžka („bed side examination“) nebo vyšetření přímo na sportovišti nebo v terénu. Jednou z významných výhod je možnost korelace obtíží pacienta, klinického vyšetření a UZ nálezu pomocí dynamických manévrů a „sonopalpace“, kdy se tlakem sondy v místě patologického nálezu snažíme reprodukovat pacientovy obtíže. Navíc lze nálezy porovnat s kontralaterální, nepostiženou stranou v případě jednostranných nálezů. Dnešní moderní přístroje mají velmi dobré rozlišení a lze zobrazit v podstatě veškeré tkáně, které nejsou kryté kostním povrchem nebo neleží v akustickém kostním stínu. V neposlední řadě lze UZ využít při navigaci jehly při intervenčních výkonech (Özçakar et al., 2015a). Ultrazvuková navigace zvyšuje nejen terapeutickou účinnost, ale i bezpečnost těchto procedur (Wu et al., 2015). Mezi hlavní nevýhody se uvádí dlouhá délka výcviku sonografisty a závislost interpretace výsledků na vyšetřujícím. Nicméně toto platí prakticky u všech zobrazovacích metod. Navíc v dnešní době existuje velké množství kvalitních kurzů a literatury, což délku výcviku zkracuje. Další nevýhodou je nemožnost zobrazení tkání ukrytých v kosti nebo v jejím akustickém stínu. Na druhou stranu povrch kosti lze zobrazit velmi dobře a UZ lze zobrazit např. únavovou zlomeninu kosti ještě před pozitivním nálezem na rentgenovém snímku. Jako u každé metody je potřeba znát její limity a v případě diagnostických pochyb zvolit jiné doplňující vyšetření. Özçakar a kolektiv v provedené retrospektivní studii s 309 pacienty srovnávali použití MSK UZ se zavedenými postupy. Výsledky ukazují, že při využití UZ došlo k poklesu čekací doby na zobrazovací vyšetření, snížení expozice ionizujícímu záření a snížení celkových finančních nákladů na péči (Özçakar et al., 2010). Přestože MSK UZ prakticky nemá kontraindikace a jedná se o metodu relativně bezpečnou, dochází při průchodu UZ vlnění tkáněmi k specifickým biologickým účinkům. Jsou to účinky tepelné, mechanické a fyzikálně-chemické. U diagnostického ultrazvuku se uplatňují především termické účinky, a to zejména při využití spektrálního dopplerovského režimu v porodnictví. Při běžném vyšetření pohybového aparátu jsou rizika poškození tkáně minimální. Přesto i zde je doporučeno řídit se tzv. principem ALARA (As Low As Reasonably Achievable), tzn. snížit intenzitu a dobu vyšetření na minimum nezbytné ke stanovení diagnózy (Hlinomazová a Hrazdira, 2005).

8. Závěry

Z provedené výzkumné části práce vyplývá, že ve sledovaných parametrech není rozdíl mezi dvěma způsoby UZ navigovaného obstřiku n. medianus při syndromu karpálního tunelu. Hydrodisekce i obstřik mezi šlachy flexorů vykazují stejnou účinnost ve zlepšení hodnocených parametrů, tj. subjektivní hodnocení bolesti, elektrodiagnostických a ultrasonografických parametrů ve 2. až 12. týdnu po obstřiku. Intervenující lékař se tak může rozhodnout dle svých preferencí a zkušeností a v souvislosti s anatomickým uspořádáním u konkrétního pacienta. Obstřik mezi šlachy flexorů lze považovat za bezpečnější, nedochází při něm k přiblížení hrotu jehly k nervu, je proto optimální volbou pro začínající sonografisty. Obstřik hydrodisekcí lze využít u komplikovanějších případů, jako je například neúčinný operační výkon. Je zároveň možné provést hydrodisekci nejen od šlach flexorů, ale i od retinaculum musculorum flexorum nebo případných adhezí s pooperační jizvou.

Ultrazvukové vyšetření přímo v ordinaci lékaře je relativně dostupné a nezatěžuje pacienta ionizujícím zářením. Může přinést nečekané diagnostické vyústění, tak jako v případě výše uvedené kazuistiky, kdy původní pracovní diagnóza tendinitídy šlach flexorů předloktí, resp. m. flexor pollicis longus, byla díky UZ vyšetření změněna a úspěšně léčena jako intramuskulární hemangiom svalů předloktí, resp. thenaru. UZ tak může napomoci k rychlejšímu stanovení diagnózy a k včasnější odpovídající léčbě.

Prezentovaná modifikace léčebného obstřiku při hypertrofii anulárního poutka může sloužit jako alternativa k všeobecně používané variantě z palmárního přístupu. Dle zkušeností z praxe je spojena s menší periprocedurální bolestivostí a je pacienty dobře tolerována.

Přehledové články shrnují dosavadní poznatky v UZ diagnostice a léčbě vybraných patologií v oblasti lokte a zápěstí. Se zvyšujícím se rozlišením UZ sond a s rozvojem nových metod, jako je například sonoelastografie, vzniká potřeba dalších kvalitních studií k objasnění některých patologií a jejich diagnostiky. Představené přehledové články také upozornily na potřebu sjednocení terminologie v odborném písemnictví.

9. Souhrn

Ultrasound-Guided Perineural vs. Peritendinous Corticosteroid Injections in Carpal Tunnel Syndrome: A Randomized Controlled Trial

Cílem studie byla identifikace optimálního místa obstřiku n. medianus při syndromu karpálního tunelu s prokazatelně lepším účinkem na a) subjektivní vnímání příznaků, b) snížení hodnoty plochy příčného řezu (CSA) n. medianus v KT, c) zlepšení hodnot distální motorické latence (dml). Hypotézou bylo, že hydrodisekce bude mít větší účinek na zlepšení sledovaných parametrů, vzhledem k mechanickému rozrušení adhezí mezi nervem a šlachami flexorů. Jednalo se o randomizovanou, jednoduše zaslepenou, kontrolovanou studii. Čtyřicet šest pacientů bylo náhodně, obálkovou metodou, rozděleno do dvou skupin. Skupina A (18 žen a 5 mužů; průměrný věk 50 ± 15,9 let; průměrná délka trvání příznaků 5,9 ± 3,3 měsíce). Skupina B (19 žen a 4 muži; průměrný věk 54,3 ± 15,0 let; průměrná délka trvání příznaků 5,9 ± 4,7 měsíce). Pacienti ze skupiny A podstoupili obstřik směsí 1 ml 1% trimecain chloridu (Mesocain) a 1 ml (40 mg) methylprednisolon acetátu (Depo-Medrol) mezi n. medianus a šlachy flexorů, pacienti skupiny B absolvovali obstřik stejnou směsí ke šlachám flexorů. Jako primární ukazatel zlepšení byla sledována vizuální analogová škála bolesti, sekundárně byly hodnoceny dvě části Bostonského dotazníku. Pro objektivní hodnocení účinku byla použita hodnota dml, CSA n. medianus, dvoubodové diskriminační čití a síla stisku pomocí dynamometru. Data byla sbírána vstupně, 2., 6. a 12. týden po intervenci. V obou skupinách jsme zaznamenali zlepšení v 2. týdnu po intervenci jak v objektivních, tak v subjektivních parametrech. Toto zlepšení přetrvávalo i 12. týden. Mezi dvěma skupinami nebyl zaznamenán statisticky signifikantní rozdíl v účinnosti obstřiku. Během studie nebyly pozorovány žádné závažné nežádoucí účinky. Obě technické varianty obstřiku při SKT přinášejí stejný účinek pro pacienta, přičemž variantu obstřiku ke šlachám flexorů lze považovat za bezpečnější z hlediska možného poranění nervu, je proto vhodná pro začínající sonografisty. Metodu obstřiku s hydrodisekcí lze využít u pacientů po neúspěšném chirurgickém zákroku.

Two Cases of Intramuscular Hemangiomas in the Upper Limbs. From Sonography to Pathology

Kazuistika představuje záchyt dvou případů intramuskulárního hemangiomu na horní končetině v relativně krátkém časovém sledu. Oba případy byly iniciálně léčeny jako tendinitída, resp. svalové přetížení. Ultrazvukové vyšetření prokázalo intramuskulárně uložené dobře ohraničené lobulární ložisko, vyplněné kompresibilními kavernami. Byl přítomen ojedinělý signál power Doppler, v jednom případě byly patrné intravaskulární kalcifikace. Oba pacienti byli odesláni ve zrychleném režimu na vyšetření magnetickou rezonancí, jímž se potvrdilo podezření na intramuskulární hemangiom. Intramuskulární hemangiomy jsou relativně málo časté a jejich včasné rozpoznání je klinicky důležité. Muskuloskeletální ultrazvuk se ukázal jako vhodné vyšetření pro iniciální rozpoznání nádoru.

Interdigital Approach to Trigger Finger Injection Using Ultrasound Guidance

Stenozující tendovaginitída neboli lupavý prst je poměrně častá příčina vyhledání ošetření lékařem. Při ultrazvukovém vyšetření se obvykle zobrazuje jako zbytnělé, hypoechogenní anulární poutko povrchově nad šlachou flexoru. V dynamickém zobrazení pasivní flexe prstu lze někdy zobrazit konflikt se šlachou. Mezi standardní nechirurgická řešení patří imobilizace, podání NSA a obstřik kortikosteroidy. Obvykle se obstřik provádí z dlaňové strany prstu, což je vzhledem k vysoké koncentraci hmatových tělísek spojeno s periprocedurálním diskomfortem. V článku je představen alternativní způsob obstřiku z meziprstního prostoru za využití UZ navigace, který může představovat méně bolestivou variantu.

Ultrasound-Guided Procedures in Common Tendinopathies at the Elbow: From Image to Needle, Ulnar Neuropathy at the Elbow: From Ultrasound Scanning to Treatment, Ultrasound Imaging and Guidance in Common Wrist/Hand Pathologies

Přehledové články, jejichž cílem je rozšířit povědomí o možnostech UZ diagnostiky v praxi rehabilitačního lékaře. V článcích jsou shrnuty základní anatomické poznatky a odpovídající ultrazvukové nálezy. Jsou zde popsány nejčastější patologie, se kterými se lze v praxi setkat a postupy intervenčních procedur.

10. Summary

Ultrasound-Guided Perineural vs. Peritendinous Corticosteroid Injections in Carpal Tunnel Syndrome: A Randomized Controlled Trial

The aim of the study was to identify which median nerve (MN) injection site in carpal tunnel syndrome would have a superior effect on a) subjective symptom perception, b) reduction of cross-sectional area (CSA) values, and c) improvement in distal motor latency (dml) values. It was hypothesized that hydrodissection would have a greater effect on the improvement of the parameters due to the mechanical disruption of the adhesions between the nerve and the flexor tendons. This was a randomized, single-blinded, controlled trial. Forty-six patients were randomly divided into two groups. Group A (18 women and five men; mean age 50 ± 15.9 years; mean duration of symptoms 5.9 ± 3.3 months). Group B (19 women and four men; mean age 54.3 ± 15.0 years; mean symptom duration 5.9 ± 4.7 months). Patients in group A underwent injection with a mixture of 1 ml of 1% trimecain chloride (Mesocain) and 1 ml (40 mg) of methylprednisolone acetate (Depo-Medrol) between the MN and flexor tendons; patients in group B underwent injection with the same mixture to the flexor tendons only. The visual analog scale (VAS) of pain was used as the primary outcome measure of improvement. The symptom severity scale and functional status scale of the Boston Carpal Tunnel Questionnaire were used as the secondary subjective outcome measures. Two-point discrimination, grip strength, cross-sectional area, and distal motor latency were assessed as objective outcome measures. The data were collected at baseline, and 2, 6, and 12 weeks after the injection. In both groups, we observed improvement in the second week after intervention in both objective and subjective parameters. This improvement persisted at week 12. There was no statistically significant difference between the two groups. No serious adverse effects of treatment were observed in both groups during the study. Both technical variants have shown the same effect on the patients. Notably, the variant of injection to the flexor tendons can be considered safer regarding possible nerve injury and is, therefore, suitable for less experienced/novice sonographers. The hydrodissection can be a promising technique in patients after unsuccessful surgery.

Two Cases of Intramuscular Hemangiomas in the Upper Limbs. From Sonography to Pathology

This case report presents the detection of two cases of intramuscular hemangioma in the upper limb in a relatively short time sequence. Both cases were initially treated as tendinitis and muscle strain, respectively. Ultrasound examination showed an intramuscularly deposited well-marginated lobulated lesion filled with compressible caverns. Occasional power Doppler signal was present, and intravascular calcifications were evident in one case. Both patients were referred for magnetic resonance imaging, where a suspected intramuscular hemangioma was confirmed. Intramuscular hemangiomas are relatively uncommon but not as rare as one might think. MSK ultrasound proved to be an appropriate diagnostic tool for initial tumor recognition.

Interdigital Approach to Trigger Finger Injection Using Ultrasound Guidance

Stenosing tenovaginitis or trigger finger is a relatively common cause to seek treatment by a physician. On ultrasound examination, it usually appears as a thickened, hypoechoic annular pulley superficial to the flexor tendon. Dynamic imaging of passive finger flexion can sometimes show conflict with the tendon. Standard nonsurgical treatment includes immobilization, NSAID administration, and corticosteroid injection. It is standardly performed from the palmar side of the finger, which is associated with periprocedural pain due to the high concentration of tactile bodies. This article presents an alternative injection method from the interdigital space using ultrasound guidance, which may represent a less painful option.

Ultrasound-Guided Procedures in Common Tendinopathies at the Elbow: From Image to Needle, Ulnar Neuropathy at the Elbow: From Ultrasound Scanning to Treatment, Ultrasound Imaging and Guidance in Common Wrist/Hand Pathologies

Review articles designed to increase awareness of the potential of ultrasound diagnostics in the rehabilitation physician's practice. The articles summarize basic anatomical findings and corresponding ultrasound findings. The most common pathologies encountered in practice and interventional procedures are described.

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P1. MEZIAN, K., **SOBOTOVÁ K (sdílené prvoautorství)**, CHANG K.V. KULIHA M., CEÉ J., ANGEROVÁ Y., ÖZÇAKAR L. Ultrasound-Guided Perineural vs. Peritendinous Corticosteroid Injections in Carpal Tunnel Syndrome: A Randomized Controlled Trial. *European Journal of Physical and Rehabilitation Medicine*. 2021; 57(5):775-782. **IF=5,313; D1**.

P2. SOBOTOVÁ, K., MEZIAN K., ABDULSALAM A.J. et al. Report of Two Cases With Intramuscular Hemangiomas in the Upper Limbs: From Sonography to Pathology. *American Journal of Physical Medicine & Rehabilitation*. 2021; 100(6):e82-e84. **IF=3,412; Q1**.

P3. ABDULSALAM, A.J., MEZIAN K., RICCI V., **SOBOTOVÁ K.,** ALKANDARI S.A., AL-MEJALHEM A.Y., ALBARAZI N.B., ÖZÇAKAR L. Interdigital approach to trigger finger injection using ultrasound guidance. *Pain Medicine.* 2019; 20(12):2607-2610. **IF=2,513; Q2.**

P4. MEZIAN, K., JAČISKO J., NOVOTNÝ, T., HREHOVÁ L., ANGEROVÁ Y., **SOBOTOVÁ K.**, NAŇKA O. Ultrasound Guided Procedures in Common Tendinopathies at the Elbow: from Image to Needle. *Applied Sciences-Basel*. 2021; 11(8):3431. **IF=2,838; Q2.**

P5. MEZIAN, K., JAČISKO J., KAISER R., MACHAČ S., STEYEROVÁ P., **SOBOTOVÁ K.**, ANGEROVÁ Y., NAŇKA O. Ulnar Neuropathy at the Elbow: From Ultrasound Scanning to Treatment. *Frontiers in Neurology.* 2021; 12:661441. **IF=4,086; Q2.**

P6. MEZIAN, K., RICCI V., JAČISKO J., **SOBOTOVÁ K.**, ANGEROVÁ Y., NAŇKA O., ÖZÇAKAR L. Ultrasound Imaging and Intervening in Common Wrist/Hand Pathologies. *American Journal of Physical Medicine & Rehabilitation.* 2021; 100(6):599-609. **IF=3,412; Q1**.

13. Přílohy

Příloha 1. Bostonský dotazník hodnocení syndromu karpálního tunelu a vizuální analogová škála bolesti

Dotazník BCTSQ

Následující otázky se vztahují k Vašim potížím během typického 24-hodinového období v posledních dvou týdnech (zaškrtněte jen jednu odpověď pro každou otázku).

Symptom severity scale

1. Jak silné jsou bolesti ruky nebo zápěstí, které máte v noci?
1 ☐ V noci nemám bolesti ruky nebo zápěstí
2 ☐ Slabá bolest
3 ☐ Mírná bolest
4 ☐ Silná bolest
5 ☐ Velmi silná bolest

2. Jak často Vás v posledních dvou týdnech během typické noci vzbudila bolest ruky nebo zápěstí?
1 ☐ Nikdy
2 ☐ Jednou
3 ☐ Dvakrát až třikrát
4 ☐ Čtyřikrát až pětkrát
5 ☐ Více než pětkrát

3. Míváte obvykle bolesti ruky nebo zápěstí během dne?
1 ☐ Nemám bolesti během dne
2 ☐ Mám slabé bolesti během dne
3 ☐ Mám mírné bolesti během dne
4 ☐ Mám silné bolesti během dne
5 ☐ Mám velmi silné bolesti během dne

4. Jak často míváte bolesti ruky nebo zápěstí během dne?
1 ☐ Nikdy
2 ☐ Jednou nebo dvakrát za den
3 ☐ Třikrát až pětkrát za den
4 ☐ Více než pětkrát za den
5 ☐ Bolest je trvalá

5. Jak dlouho, průměrně, trvá jedna epizoda bolestí během dne?
1 ☐ Nemám bolesti během dne
2 ☐ Méně než 10 minut
3 ☐ 10 až 60 minut
4 ☐ Více než 60 minut
5 ☐ Bolest je stálá během celého dne

6. Míváte necitlivost (sníženou citlivost) ruky?
1 ☐ Ne
2 ☐ Mám slabou necitlivost
3 ☐ Mám mírnou necitlivost
4 ☐ Mám silnou necitlivost
5 ☐ Mám velmi silnou necitlivost

7. Pociťujete slabost ruky nebo zápěstí?
1 ☐ Ne
2 ☐ Jemnou slabost
3 ☐ Mírnou slabost
4 ☐ Silnou slabost
5 ☐ Velmi silnou slabost

8. Míváte brnění v ruce nebo v zápěstí?
1 ☐ Ne
2 ☐ Slabé brnění
3 ☐ Mírné brnění
4 ☐ Silné brnění
5 ☐ Velmi silné brnění

9. Jak velké je toto brnění nebo necitlivost (snížená citlivost) v noci?
1 ☐ V noci nemám brnění nebo necitlivost
2 ☐ Slabé
3 ☐ Mírné
4 ☐ Silné
5 ☐ Velmi silné

10. Jak často Vás v posledních dvou týdnech během typické noci vzbudila necitlivost nebo brnění ruky?
1 ☐ Nikdy
2 ☐ Jednou
3 ☐ Dvakrát až třikrát
4 ☐ Čtyřikrát až pětkrát
5 ☐ Více než pětkrát

11. Máte potíže s uchopením a používáním drobných předmětů jako jsou třeba klíče nebo propiska?
1 ☐ Nemám potíže
2 ☐ Slabé potíže
3 ☐ Mírné potíže
4 ☐ Silné potíže
5 ☐ Velmi silné potíže

Pokračujte na druhé straně…

Zdroj: Levine DW et al. A self-administered questionnaire for the assessment of severity of symptoms and functional status in carpal tunnel syndrome. J Bone Joint Surg Am 1993;75A: 1585-92.
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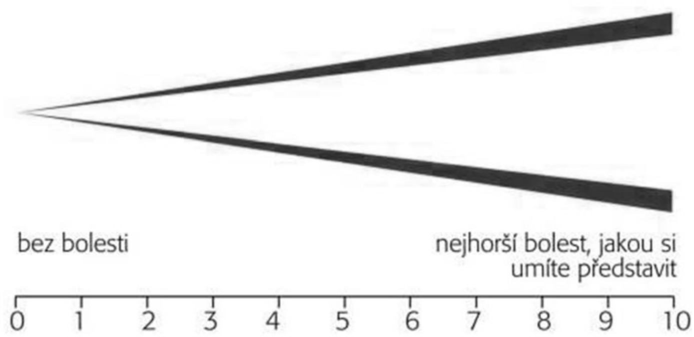
Functional status scale

Měl(a) jste během typického dne v posledních dvou týdnech potíže s rukou nebo zápěstím při vykonávání níže uvedených činností? Prosím zakroužkujte číslo, které nejlépe odpovídá Vaší schopnosti provádět příslušné činnosti:

Činnost	Nemám potíže	Mám slabé potíže	Mám mírné potíže	Mám vážné potíže	Nejsem schopen(a) kvůli potížím s rukou
12. Psaní	1	2	3	4	5
13. Zapínání knoflíku košile	1	2	3	4	5
14. Držení knihy během čtení	1	2	3	4	5
15. Držení telefonního sluchátka	1	2	3	4	5
16. Otvírání závitu zavařovací sklenice	1	2	3	4	5
17. Práce v domácnosti	1	2	3	4	5
18. Nesení nákupní tašky	1	2	3	4	5
19. Koupání a oblékání	1	2	3	4	5

Děkujeme za vyplnění tohoto dotazníku!



Zdroj: Levine DW et al. A self-administered questionnaire for the assessment of severity of symptoms and functional status in carpal tunnel syndrome. J Bone Joint Surg Am 1993;75A: 1585-92.

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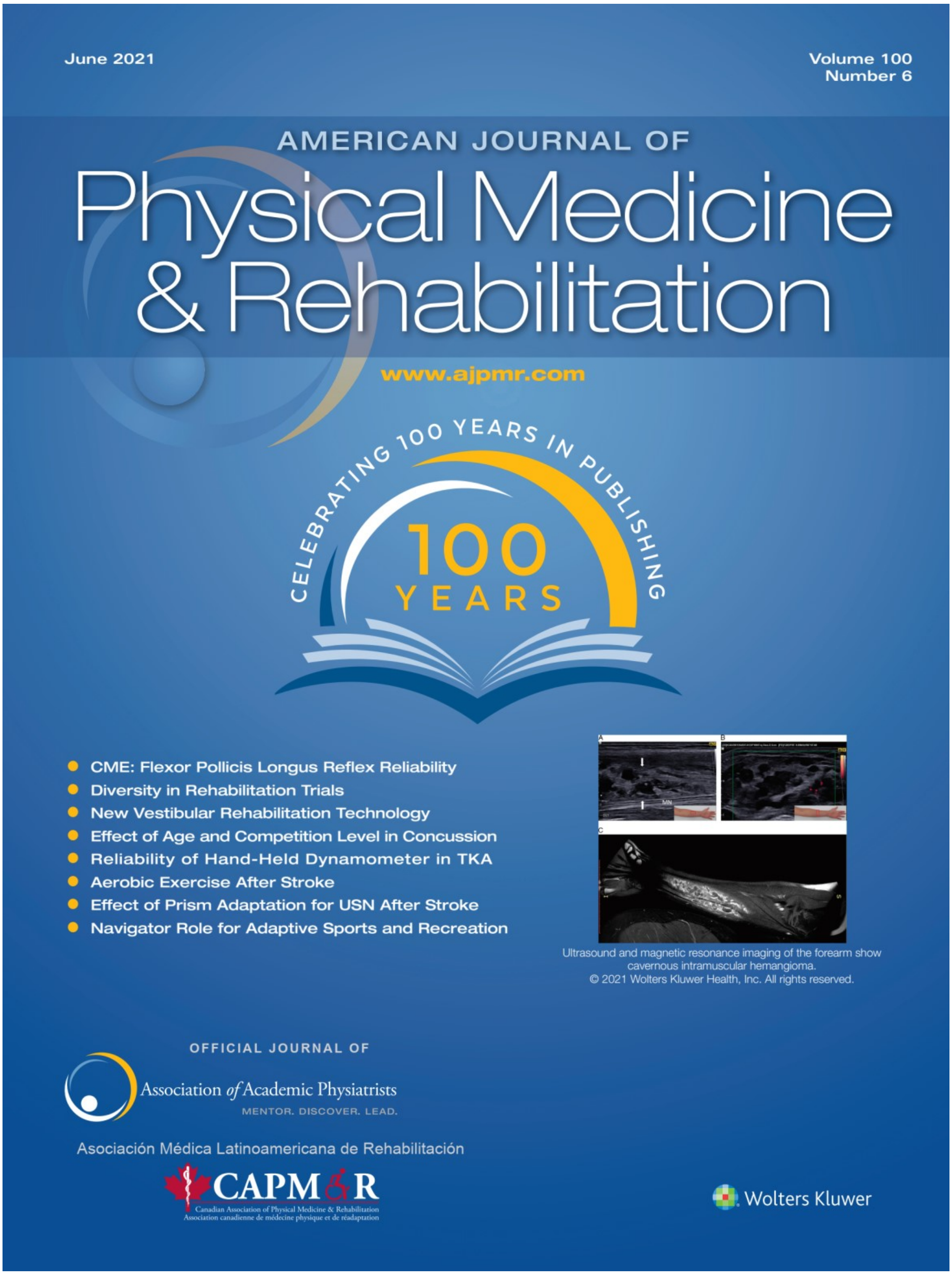
Příloha 2. Titulní strana časopisu American Journal of Physical Medicine & Rehabilitation (červen 2021, ročník 100, číslo 6).



14. Přehled publikační činnosti se vztahem k disertační práci

recenzované publikace s IF

ABDULSALAM, A.J., MEZIAN K., RICCI V., **SOBOTOVÁ K.**, ALKANDARI S.A., AL-MEJALHEM A.Y., ALBARAZI N.B., ÖZÇAKAR L. Interdigital approach to trigger finger injection using ultrasound guidance. *Pain Medicine.* 2019; 20(12):2607-2610. **IF=2,513; Q2.**

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MEZIAN, K., RICCI V., JAČISKO J., **SOBOTOVÁ K.**, ANGEROVÁ Y., NAŇKA O., ÖZÇAKAR L. Ultrasound Imaging and Intervening in Common Wrist/Hand Pathologies. *American Journal of Physical Medicine & Rehabilitation.* 2021; 100(6):599-609. **IF=3,412; Q1**.

MEZIAN, K., **SOBOTOVÁ K. (SDÍLENÉ PRVOAUTORSTVÍ)**, CHANG K.V., KULIHA M., CEÉ J., ANGEROVÁ Y., ÖZÇAKAR L. Ultrasound-Guided Perineural vs. Peritendinous Corticosteroid Injections in Carpal Tunnel Syndrome: A Randomized Controlled Trial. *European Journal of Physical and Rehabilitation Medicine*. 2021; 57(5):775-782. **IF=5,313; D1**.

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15. Seznam publikovaných prací in extenso uveřejněných v časopisech s IF

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kapitola v monografii

MEZIAN, K., **SOBOTOVÁ K.**, ABDULSALAM A.J., ÖZÇAKAR L. Sacroiliac, Caudal and Coccyx Injections. In: Özçakar L. et al. Ultrasound imaging & guidance for Musculoskeletal Interventions in Physical and Rehabilitation Medicine. Milan: edi-ermes, 2019; s. 247-255. ISBN 9788870516982.