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Klinik für Orthopädie und Unfallchirurgie

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Untersuchungen zur Pathogenese und Therapie von Läsionen der langen Bizepssehne

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Inhaltsverzeichnis

Anlagen

Abkürzungsverzeichnis

AI:	Acromion Index
ASES:	American Shoulder and Elbow Surgeon Score
AS:	Acromion Slope
CMS:	Constant Murley Score
CSA:	Critical Shoulder Angle
LAA:	Lateral Acromion Angle
LBS:	Lange Bizepssehne
SLAP:	*Superior Labrum from anterior to posterior*
SGHL:	Superiores Glenohumerales Ligament
SST:	Simple Shoulder Test

Übersicht der beitragenden Originalarbeiten

Hufeland M, Hamed G, Kubo H, Pilge H, Krauspe R, Filler T, Patzer T

Blood supply in the bicipital groove: A histological analysis

Orthop Rev (Pavia). 2019 Mar 29;11(1):8106.

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Zusammenfassung

Pathologien der langen Bizepssehne (LBS) sind eine der häufigsten Ursachen für Schulterschmerzen bei Patienten aller Altersgruppen. Während eine reine Tendinitis fast ausschließlich konservativ zu behandeln ist, sind instabile Einrisse des Sehnenursprungs, sogenannte SLAP Läsionen (*superior labrum from anterior to posterior*), häufig operativ zu therapieren. Diese Einrisse des superioren Labrums können sowohl durch repetitive Mikrotraumata, z. B. bei Überkopfsport oder –arbeit, als auch degenerativ entstehen. Möglicherweise sind jedoch auch individuelle anatomische Gegebenheiten für die Entstehung von SLAP Läsion mitverantwortlich. Daher wurde in der vorliegenden Arbeit das Ausmaß der Überdachung des Glenohumeralgelenks durch das Akromion bei Patienten mit SLAP Läsionen als möglicher Baustein in der Pathogenese untersucht.

Da eine Refixation des Sehnenursprungs mit dem SLAP Komplex am Glenoid nur bei akuten, traumatischen Läsionen bei jungen Patienten unter 35 Jahren gute Ergebnisse zeigt, ist die Tenodese mit Reinsertion der LBS am Caput humeri ober- oder unterhalb des Sulcus bicipitalis die etablierte operative Therapie. Um weitere Erkenntnisse zur Auswahl der Lokalisation für die Tenodese zu erhalten wurde in der vorliegenden Arbeit die vaskuläre Anatomie im Sulcus bicipitalis auf histologischer Ebene analysiert.

Bei Patienten über 60 Jahren oder mit geringem sportlichem und kosmetischem Anspruch ist hingegen eine einfache Tenotomie der Sehne zur Schmerzreduktion indiziert. Im Hinblick auf die klinischen Ergebnisse sind als Nachteile der Tenotomie jedoch kosmetische Veränderungen mit einer sichtbaren Distalisierung des Muskelbauchs sowie vorübergehende Krämpfe im Bizepsmuskel beschrieben. Ein Kraftverlust bei der Ellenbogenflexion und -supination nach Tenotomie wird jedoch kontrovers diskutiert.

Eine suffiziente Tenodese kann eine Distalisierung des Muskelbauchs verhindern aber auch den Muskel überspannen. Ferner sind das Einbringen von Ankern als Fremdmaterial sowie eine Verlängerung der Operationszeit und damit auch höhere Kosten zu berücksichtigen. Bisher wurden die operativen Verfahren zur Behandlung von LBS Läsionen, abgesehen von der SLAP Refixation, hauptsächlich an Patienten untersucht, bei denen eine Ruptur der Rotatorenmanschette und nicht die LBS Läsion die Hauptindikation zur Schulteroperation darstellte. Da jedoch neben der Rotatorenmanschettenrekonstruktion als Haupteingriff auch die Nachbehandlung eine gänzlich andere ist, können aus einem solchen Patientenkollektiv heraus die operativen Strategien für die LBS Läsion und deren Ergebnis nicht beurteilt werden. In der hier vorgelegten Arbeit wurde daher zunächst eine in der Arbeitsgruppe entwickelte arthroskopische Tenodesetechnik im Hinblick auf die Ellenbogenflexions- und – supinationskraft, die Schmerzreduktion sowie das kosmetische Ergebnisse für isolierte LBS Läsionen prospektiv untersucht. Auf den Ergebnissen aufbauend erfolgte, zur weiteren Evaluation der Vor- und Nachteile der Therapieverfahren, der prospektiv randomisierte Vergleich zur Tenotomie ebenfalls bei isolierten LBS Läsionen.

Einleitung

Der Ursprung der langen Bizepssehne (LBS) ist das Tuberculum supraglenoidale und das superiore Labrum, der sogenannte SLAP Komplex (*superior labrum from anterior to posterior*) [78]. Der Processus coracoideus ist der Ursprung der kurzen Bizepssehne. Von ihrem Ursprung am SLAP Komplex verläuft die LBS zunächst frei über das Caput humeri. Im Hinblick auf die Innervation fanden Alpantaki et al konzentriert am SLAP Komplex und nach distal abnehmend eine netzartige Verteilung von sensiblen und sympathischen Nervenfasern, was die ausgeprägten Beschwerden von Patienten mit SLAP Läsionen erklärt [3]. Die Gefäßversorgung des intraartikulären Anteils der LBS erfolgt über aufsteigende Äste der Arteria circumflexa humeri anterior [39].

Beim Verlassen des Gelenks und vor dem Eintritt in den knöchernen Sulcus bicipitalis wird die LBS durch einen Kapsel-Band-Komplex das *Pulley-System* stabilisiert. Dieses wird gebildet vom Ligamentum glenohumerale superius, dem Ligamentum coracohumerale, dem oberen Rand der Sehne des Musculus subscapularis und den anterioren Fasern der Sehne des Musculus supraspinatus [83]. Der knöcherne Sulcus bicipitalis wird nach Taylor et al in drei Zonen unterteilt. 1. Gelenkrand bis zum distalen Rand der Subscapularissehne, 2. Vom distalen Rand der Subscapularissehne bis zum proximalen Rand der Pektoralis major Sehne und 3. die subpektorale Zone [79]. Im Sulcus bicipitalis wird LBS vom Mesotenon umgeben, welches für die Blutversorgung dieses Sehnenabschnitts eine entscheidende Rolle spielt [80]. Die distale Bizepssehne inseriert schlussendlich nach Vereinigung der Muskelbäuche an der Tuberositas radii. Die dezidierte Funktion der LBS für das Glenohumeralgelenk wird weiterhin kontrovers diskutiert. Biomechanische Arbeiten konnten zeigen, dass der proximale Anteil der LBS das Glenohumeralgelenk stabilisiert und diesem eine Depressorfunktion für das Caput humeri zukommt [41, 59].

Warner et al beschreiben eine Stabilisierung des Caput humeri während der Schulterabduktion, insbesondere in anterosuperiorer und anteriorer Richtung [84]. Rodosky et al simulierten an einem biomechanischen Kadavermodell die Kräfte der Rotatorenmanschette und des M. bizeps brachii und konnten zeigen, dass die LBS zur anterioren Stabilisierung des Glenohumeralgelenks beiträgt und hier insbesondere den Widerstand gegen Torsionskräfte in der vulnerablen Abduktions-Außenrotations-Position erhöht [69]. Levy und Yamaguchi hingegen konnten mittels Elektromyographie demonstrieren, dass bei aktiver Schulterbewegung aber Ruhigstellung von Ellenbogen und Hand, die LBS möglicherweise nicht aktiv angesteuert wird [43, 84].

Die häufigste Pathologie der LBS ist die Tendinitis, welche häufig mit begleitenden strukturellen Pathologien am Schultergelenk wie degenerative Läsionen der Rotatorenmanschette oder anterosuperiorem Impingement assoziiert ist [46]. Pathologische Veränderungen des LBS Ursprungs am superioren Labrum wurden erstmals 1985 von Andrews et al beschrieben [4]. Snyder prägte die Definition als „*SLAP*" Läsion (*superior labrum from anterior to posterior*), da sich die Lokalisation von anterior bis posterior im Bereich der superioren Labrums befinden kann [78]. Bei einer Typ I Läsion nach Snyder ist das superiore Labrum aufgefasert aber noch stabil am Glenoid verankert. Der häufigste Typ II ist die instabile Avulsion des SLAP Komplexes vom superioren Glenoid und wird weiter unterteilt in IIa (anterior), IIb (posterior) und IIc (anterior bis posterior). Typ III ist eine sogenannte Korbhenkelläsion des superioren Labrums bei intakter LBS und der seltene Typ IV entspricht Typ III, jedoch mit Dislokation des Labrums und Fortsetzung der Ruptur in die LBS nach distal [78]. Isolierte SLAP-Läsionen können durch repetitive Mikrotraumata besonders bei Überkopfarbeit und -sport oder Unfälle verursacht werden [44]. Degenerative SLAP Läsionen sind zudem häufig mit Rupturen der Rotatorenmanschette assoziiert [25, 49, 77].

Verletzungen des Pulley-Systems, der ligamentären Führung der LBS am Eingang in den Sulcus bicipitalis, führen zu einer Instabilität der LBS im Sulcus. Habermeyer und Lafossse postulieren, dass eine Krafteinwirkung oder ein Trauma in der Abduktions-Außenrotations-Position ein Risikofaktor für die seltenen, isolierten Pulley Läsionen darstellt [29, 42]. Degenerative Pulley Läsionen sind häufiger und ebenfalls mit Rupturen der Rotatorenmanschette, insbesondere der Subscapularissehne, assoziiert [9]. Habermeyer et al definierten vier Typen: Typ I entspricht einer isolierten Läsion des Superioren Glenohumeralen Ligaments (SGHL), Typ II einer SGHL-Läsion mit einer artikularseitigen Partialruptur der Supraspinatussehne, Typ III einer SGHL-Läsion mit einer Partialruptur der Subscapularissehne und Typ IV einer Läsion des SGHL in Kombination mit einer Ruptur der Supraspinatus- und Subscapularissehne [29].

Pathologien der LBS, insbesondere die Tendinitis, können zunächst konservativ mit Belastungsmodifikation, nichtsteroidalen Antiphlogistika und Physiotherapie behandelt werden. Eine operative Therapie ist bei Beschwerdepersistenz oder höhergradigen strukturellen Läsionen indiziert. Hier ist ein Durchtrennen der LBS im intraartikulären Anteil (Tenotomie) oder eine Reinsertion der Sehne am proximalen Humerus (Tenodese) möglich. Eine Rekonstruktion des superioren Labrums mit Refixation des SLAP Komplexes ist nach den Untersuchungen von Denard hingegen nur bei jungen Patienten unter 35 Jahren erfolgversprechend [18]. Im Hinblick auf die operativen Techniken für eine Tenodese sind sowohl offene als auch arthroskopische Techniken sowie eine proximale oder distale suprapektorale und eine subpektorale anatomische Lokalisation zur Reinsertion der LBS etabliert [17, 36]. Eine intraossäre Fixation mittels Interferenzschrauben zeigte hier in biomechanischen Untersuchungen die höchste Primärstabilität [30, 61, 62]. Beide Verfahren zeigen in Bezug auf die Schmerzreduktion und die Funktionsverbesserung vergleichbare Ergebnisse [15, 22].

Erwiesen ist, dass es nach Tenotomie vermehrt zu schmerzhaften Krämpfen im Oberarm sowie häufiger, zu einer sichtbaren Distalisierung des Muskelbauchs (*Popeye-Zeichen*) kommt, was insbesondere schlanke und sportliche Patienten stört [28, 76]. Für eine Beeinflussung der Ellenbogenflexions- und supinationskraft nach Tenotomie ist die jedoch die aktuelle Studienlage nicht ausreichend, da hier insbesondere prospektiv randomisierte Untersuchungen bei isolierten LBS Läsionen im Vergleich zu einer biomechanisch suffizienten Tenodese fehlen [74, 87]. Im Hinblick auf strukturelle Veränderungen konnten The et al zeigen, dass es nach Tenotomie zumindest zu keiner relevanten Atrophie oder fettigen Degeneration des Muskelbauchs kommt [82].

Frost et al kommen in ihrer Metaanalyse zu dem Schluss, dass die Inzidenz eines postoperativen Popeye-Zeichens nach Tenotomie höher ist und besonders Patienten < 60 Jahren eine verminderte Ellbogenflexionskraft wahrnehmen können. Weiterhin betonen die Autoren, dass keine aussagekräftigen Studien höheren Evidenzniveaus für den Vergleich von Tenotomie und Tenodese vorliegen und zudem viele publizierte Tenodesetechniken, wie eine epiossäre oder auch eine weichteilige Refixation der LBS, nicht zu einer ausreichenden Stabilität führen, was den direkten Vergleich zur Tenotomie erschwert [23]. Ein Bias auch aktuellster prospektiv randomisierter Studien ist zudem weiterhin, dass Patienten mit Rotatorenmanschettenruptur als Hauptindikation zur Operation eingeschlossen werden [8].

Eigene Studien und Ergebnisse

Histologische Untersuchung der Gefäßverteilung um die lange Bizepssehne im Sulcus bicipitalis

Hufeland M, Hamed G, Kubo H, Pilge H, Krauspe R, Filler T, Patzer T

Blood supply in the bicipital groove: A histological analysis

Orthop Rev (Pavia). 2019 Mar 29;11(1):8106.

Bei einer Tenodese kann die LBS entweder arthroskopisch intraartikulär am Eingang zum knöchernen Sulcus bicipitalis und oberhalb der Sehne des M. pektoralis major (suprapektoral) oder aber extraartikulär und offen distal des Sulcus bicipitalis und der Sehne (subpektoral) refixiert werden. Als Vorteil der subpektoralen Position ist beschrieben, dass sogenannte „*hidden lesions*“, also seltene pathologische Veränderungen der Sehne im Sulcus bicipitalis, ebenfalls behandelt werden [51]. Die Technik der offenen subpektoralen Tenodese hat jedoch ein erhöhtes Risiko für Komplikationen wie eine Affektion des Plexus brachialis [67, 73] oder sogar Humerusschaftfrakturen [58].

Die Gefäßversorgung des Abschnitts der LBS im Sulcus bicipitalis erfolgte über aufsteigende Äste der Arteria circumflexa humeri anterior [39], welche bei der subpectoralen Tenodese mit dem Mesotenon entfernt werden. Das Ziel dieser Studie ist daher, die vaskuläre Anatomie im geschlossenen Sulcus bicipitalis, welcher die LBS und das Mesotenon enthält, auf histologischer Ebene zu analysieren um weitere Erkenntnisse über die möglichen Vor- und Nachteile der anatomischen Lokalisationen für die Tenodese zu erhalten.

Für diese Untersuchung wurden 24 Formaldehyd-fixierte Schultergelenke von Körperspendern präpariert. Der knöcherne Sulcus bicipitalis wurde *en bloc* mit der LBS und dem Ligamentum transversum in situ entnommen, fixiert, in 7 µm Schichten geschnitten und Azan gefärbt (Abb. 1).

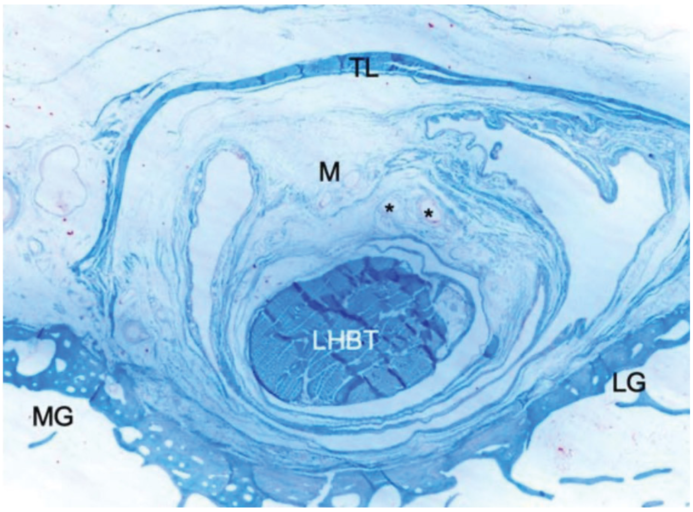

Abbildung 1: Azanfärbung eines Querschnittes durch den intakten Sulcus bicipitalis. Der knöcherne mediale (MG) und laterale Wall (LG) enthalten die LBS (LHBT). Das Mesotenon (M), welches arterielle Äste zur Blutversorgung enthält (*), begleitet die Sehne. Das Ligamentum transversum (TL) bedeckt den Sulcus bicipitalis nach ventral. Nachdruck mit freundlicher Genehmigung [32]

Für die Analyse der vaskulären Anatomie wurden die Arterien, welche die LBS im Mesotenon begleiten identifiziert sowie anschließend jeder Seitenast über mehrere Schnittebenen bis in das Zielgebiet verfolgt (Abb. 2.). Im Durchschnitt konnte je Schulterpräparat 2,71 ± 1,85 arterielle Äste identifiziert werden. Von den insgesamt 65 arteriellen Seitenästen in allen Präparaten verliefen 22 (33,8%) in den knöchernen medialen Wall des Suclus bicipitalis und 40 (61,5%) in den lateralen Wall (P <0,01). Für 3 Seitenäste (4,6%) konnte kein eindeutiges Zielgebiet identifiziert werden.

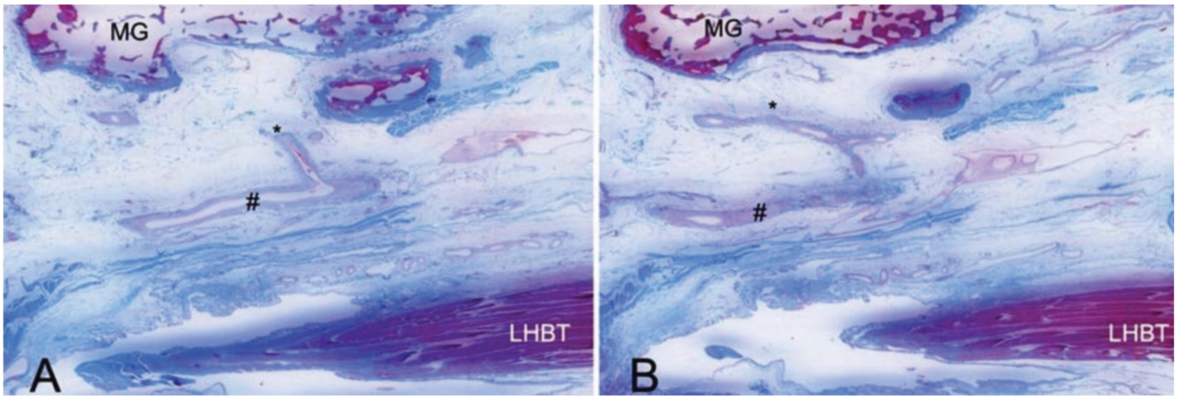

Abbildung 2: Azanfärbung von aufeinander folgenden Längsschnitten des Sulcus bicipitalis. Der Seitenast (*) der parallel zur Sehne (LHBT) verlaufenden Hauptarterie (#) kann über die beiden Schnitte (A, B) bis in den knöchernen medialen Wall des Sulcus bicipitalis verfolgt werden (MG). Nachdruck mit freundlicher Genehmigung [32].

Die arteriellen Äste verliefen im knöchernen Sulcus in Kanälen mit einem mittleren Durchmesser von 630 ± 597,47 µm (83–3722 µm). Der mittlere Durchmesser des Arterienastes innerhalb dieser Kanäle war 140 ± 104,09 µm (45-556 µm). Begleitende Nervenfasern im knöchernen Kanal konnten in 38 (58,4 %) Präparaten identifiziert werden, 18 (47,4 %) waren myelinisiert. Darüber hinaus konnten in 9 (37,5 %) Präparaten Pachini Mechanorezeptoren im Mesotenon der Sehne identifiziert werden, was bisher noch nicht beschrieben wurde.

Die akromiale Überdachung des Glenohumeralgelenks und SLAP Läsionen

Patzer T, Wimmer N, Verde PE, **Hufeland M**, Krauspe R, Kubo HK

The association between a low critical shoulder angle and SLAP lesions.

Knee Surg Sports Traumatol Arthrosc. 2019 Jun 27.

SLAP Läsionen können durch akute Schulterverletzungen, aber auch durch repetetive Mikrotraumata bei Überkopfsport oder -arbeit verursacht werden [13, 27, 77]. Hier wurde von Burkhart et al eine repetive posterosuperiore Verschiebung des Humeruskopfes mit Kompression des SLAP Komplexes als ein möglicher Pathomechanismus beschrieben [14]. Möglicherweise sind jedoch auch individuelle anatomische Gegebenheiten für die Entstehung von SLAP Läsion mitverantwortlich. Als Einflussfaktor auf das Vorhandensein einer Rotatorenmanschettenruptur oder einer Omarthrose haben Moor et al den sogenannten Crititcal Shoulder Angle (CSA) als Quantifizierung für akromialen Überdachung des Glenohumeralgelenks beschrieben [52]. Die CSA ist definiert als der Winkel zwischen der Linie vom supraglenoidalen zum infraglenoidalen Tuberkel des Glenoids und der lateralen Akromionkante, gemessen auf einem streng anterior-posteriorem Röntgenbild der Schulter (Abb. 3) [52]. Ein CSA > 35° ist mit dem Auftreten von Rotatorenmanschettenrupturen assoziiert, ein niedrigerer CSA-Wert < 30 ° weist dagegen einen signifikanten Zusammenhang mit dem Vorhandensein einer Omarthrose auf [52, 53]. Die Entstehung der Omarthrose wird hier durch eine verstärkt nach medial gerichtete Kraft des M. deltoideus bei geringer Überdachung des Caput humeri durch das Akromion begünstigt. Hierbei erfolgt, vergleichbar zu der von Burkhart postulierten Pathogenese von SLAP Läsionen, eine Kompression des Caput humeri in das Glenoid und das Labrum glenoidale [10, 14, 50].

Ziel dieser Studie war es daher, einen möglichen Zusammenhang zwischen dem CSA und anderen radiologischen Akromionparametern, welche die individuelle Anatomie des Akromions erfassen, mit dem Auftreten von SLAP Läsionen zu untersuchen.

Hierfür wurden folgende Akromionparameter gemessen:

- CSA nach Moor et al [52] (Abb. 3)
- Akromionindex (AI) nach Nyffeler et al [56]
- Lateraler Akromion Winkel (LAA) nach Banas et al [7]
- Akromion Slope (AS) nach Aoki et al [6]

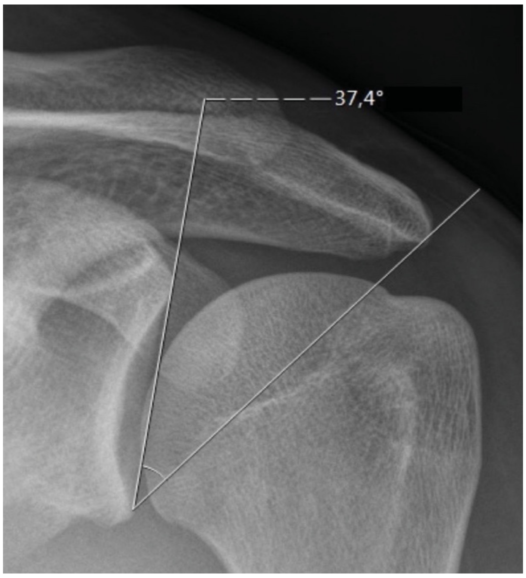

Abbildung 3: Anterior posterior Röntgenbild der linken Schulter eines 22-jährigen Patienten. Eingezeichnet ist der Critical Shoulder Angle (CSA) nach Moor et al als Winkel zwischen der Linie vom supraglenoidalen zum infraglenoidalen Tuberkel des Glenoids und der lateralen Akromionbegrenzung [52]. Eigene Abbildung.

Die Parameter wurden auf Röntgenbildern von 75 Patienten mit einem Durchschnittsalter von 46,5 Jahren und arthroskopisch gesicherten isolierten SLAP Läsionen gemessen und mit Kontrollgruppen von Patienten ohne SLAP-Läsionen sowie ohne (Kontrollgruppe I) oder mit (Kontrollgruppe II) kompletten Rupturen der Supraspinatussehne verglichen.

Der mittlere CSA in der Studiengruppe betrug 29,6° ± 3,5 im Vergleich zu 33,8 ° ± 3,7 in Kontrollgruppe I ($p < 0,001$) und 36,7° ± 3,6 in Kontrollgruppe II ($p < 0,001$). Der mittlere AI in der Studiengruppe betrug 0,65 ± 0,07, 0,68 ± 0,68 ($p = 0,034$) in Kontrollgruppe I und 0,71 ± 0,07 ($p < 0,001$) in Kontrollgruppe II. Der mittlere LAA in der Studiengruppe betrug 84,0 ° ± 5,6, 82,1 ° ± 5,4 (nicht signifikant) in Kontrollgruppe I und 80,2 ° ± 5,4 ($p < 0,001$) in Kontrollgruppe II. Die mittlere AS in der Studiengruppe betrug 32,0 ° ± 5,0, 34,4 ° ± 5,4 ($p < 0,01$) in Kontrollgruppe I und 34,5 ° ± 5,6 ($p < 0,01$) in Kontrollgruppe II.

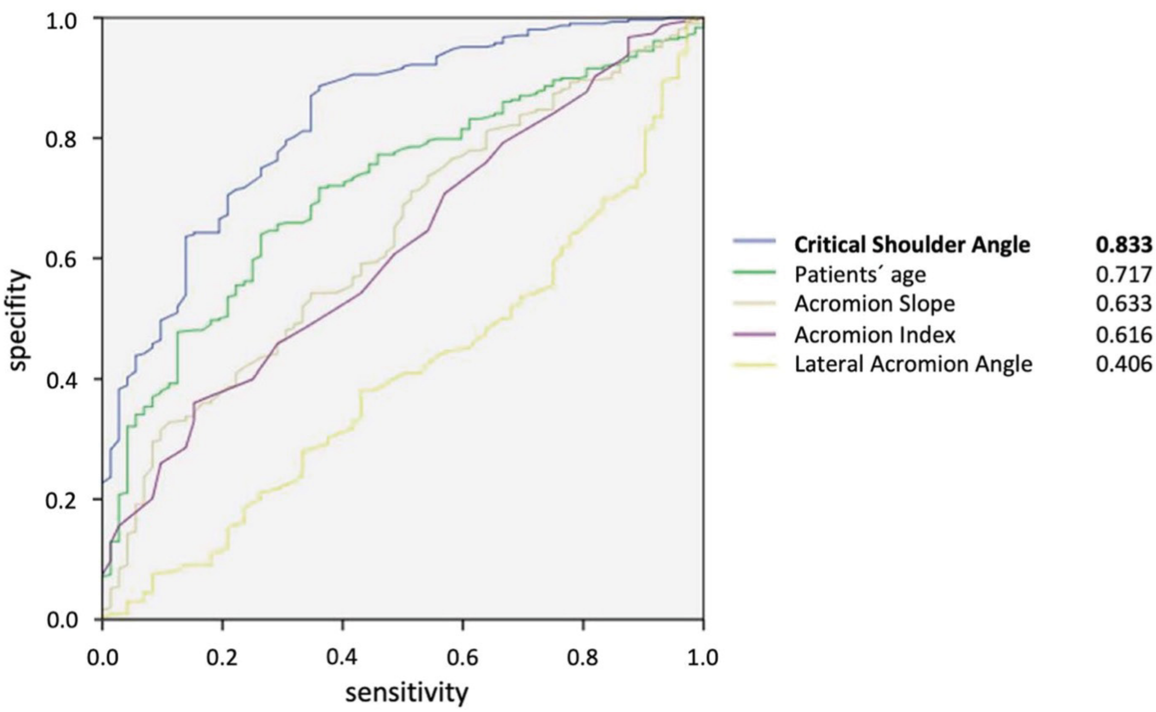

Abbildung 4: *Area Under the Curve* (AUC) Korrelation der vier verschiedenen Akromion-Parameter und des Patientenalters mit SLAP-Läsionen. Nachdruck mit freundlicher Genehmigung [63].

Die *Area Under the Curve* (AUC) für den CSA betrug 0,83 für SLAP-Läsionen (Abb. 4), was zu einer Wahrscheinlichkeit von 83% für Patienten mit SLAP-Läsionen führte, mit einem geringen CSA assoziiert zu sein. Das individuelle Ausmaß der akromialen Überdachung scheint somit einen weiteren Baustein in der Pathogenese von SLAP Läsionen darzustellen.

Ellenbogenflexions- und supinationskraft nach Tenodese und prospektiv randomisierter Vergleich zur Tenotomie bei isolierten SLAP Läsionen.

Hufeland M, Kolem C, Ziskoven C, Kircher J, Krauspe R, Patzer T

The influence of suprapectoral arthroscopic biceps tenodesis for isolated biceps lesions on elbow flexion force and clinical outcomes.

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Hufeland M, Wicke S, Verde PE, Krauspe R, Patzer T

Biceps tenodesis versus tenotomy in isolated LHB lesions: a prospective randomized clinical trial.

Arch Orthop Trauma Surg. 2019 Jul;139(7):961-970.

Basierend auf biomechanischen Vorarbeiten wurde in der Arbeitsgruppe, von Patzer et al, eine Technik der arthroskopischen proximalen suprapektoralen Tenodese mit intraossärer Sehnenfixation entwickelt [60, 88]. Ziel der prospektiven Untersuchung dieser Technik war der Vergleich der Ellenbogenflexionskraft sowie der objektivierbaren Distalisierung des Muskelbauchs (*Popeye Zeichen*) bei isolierten LBS Läsionen. Die Primärhypothese war hier eine signifikante Verbesserung der erhobenen klinischen Scores sowie eine signifikante Kraftzunahme für die Ellenbogenflexionskraft im Vergleich zum präoperativen Status und ohne Unterschied zur gesunden Gegenseite. Als Sekundärhypothese wurde aufgestellt, dass eine objektiv gemessene Distalisierung des Muskelbauchs durch die Tenodese verhindert werden kann.

Prospektiv eingeschlossen wurden Patienten mit isolierten LBS Läsionen in Form von Bizeps-Pulley-Läsionen Typ I – IV nach Habermeyer et al [29] bzw. SLAP Läsionen Typ II – IV nach Maffet et al [45] und Snyder et al [78]. Patienten mit Rotatorenmanschettenruptur, SLAP-Läsionen ≥ Typ 5 und Omarthrose ≥ Grad II nach Samilson und Prieto wurden ausgeschlossen [70].

Die klinischen Scores, die Kraftmessungen und die Beurteilung des Popeye-Zeichens wurden präoperativ, 3, 6, 12 und 24 Monate postoperativ erhoben. Die Ellenbogenflexionskraft wurde in 10° und 90° Flexion gemessen. Weiterhin erfolgte die Messung der nach kranial gerichteten Kraft in der O'Brien Position. Eine schmerzhafte Kraftminderung in dieser Position wurde als sogenannter *active compression test* nach O'Brien et al mit SLAP Läsionen korreliert [57]. Präoperativ erfolgte ebenfalls die Messung der gesunden Gegenseite. Zur Beurteilung der Distalisierung des Muskelbauches wurde der maximale Umfang des Oberarms in 90° Ellenbogenflexion und voller Supination und die Distanz dieses maximalen Umfangs zum radialen Epicondylus in Zentimetern gemessen. Eine Distalisierung um mehr als 20 % im Vergleich zum präoperativen Status wurde als Popeye-Zeichen gewertet.

Der Behandlungserfolg mit Verbesserung der Beweglichkeit und Schmerzreduktion wurde mit dem Simple Shoulder Test (SST), dem American Shoulder and Elbow Surgeon Score (ASES), dem Constant Murley Score (CMS) [5] sowie dem LHB Score evaluiert, welcher auch die Ellenbogenfunktion, das Auftreten von Muskelkrämpfen und das kosmetische Ergebnis im Hinblick auf das Popeye-Zeichen umfasst [71]. Insgesamt konnten 24 Patienten prospektiv eingeschlossen werden, 7 waren im Verlauf der prospektiven Untersuchungen nicht mehr erschienen. 17 Patienten (70,8 %, Durchschnittsalter 49,0 ± 10,1 Jahre; 22–69; 10 männlich; 58,8 %) absolvierten alle Nachuntersuchungen.

In der präoperativen Messung war die Kraft in 10 ° ($p = 0{,}002$) und 90 ° ($p < 0{,}001$) Flexion signifikant verringert im Vergleich zur gesunden Gegenseite. Ab drei Monaten postoperativ zeigte sich bei allen Nachuntersuchungen für beide Flexionsgrade kein signifikanter Unterschied mehr. In Bezug auf die kranial gerichtete Kraft, die in der O'Brien Position gemessen wurde, konnte präoperativ ein signifikanter Unterschied ($p <0{,}001$) zwischen der operierten und der gesunden Gegenseite festgestellt werden. Während der Nachbeobachtung konnte 6 und 12 Monate nach der Operation kein signifikanter Unterschied mehr zur kontralateralen Seite festgestellt werden. Nach 24 Monaten trat jedoch ein signifikanter Unterschied im Vergleich zur Gegenseite wieder auf ($p = 0{,}012$) (Abb. 5). Drei Patienten (17,6 %) zeigten nach Tenodese eine Distalisierung des Bizepsbauches von über 20% im Vergleich zur präoperativen Position. Alle erhobenen Scores, der SST der ASES und der CMS zeigten eine signifikante Verbesserung bereits ab der Untersuchung 3 Monate postoperativ (Abb. 5).

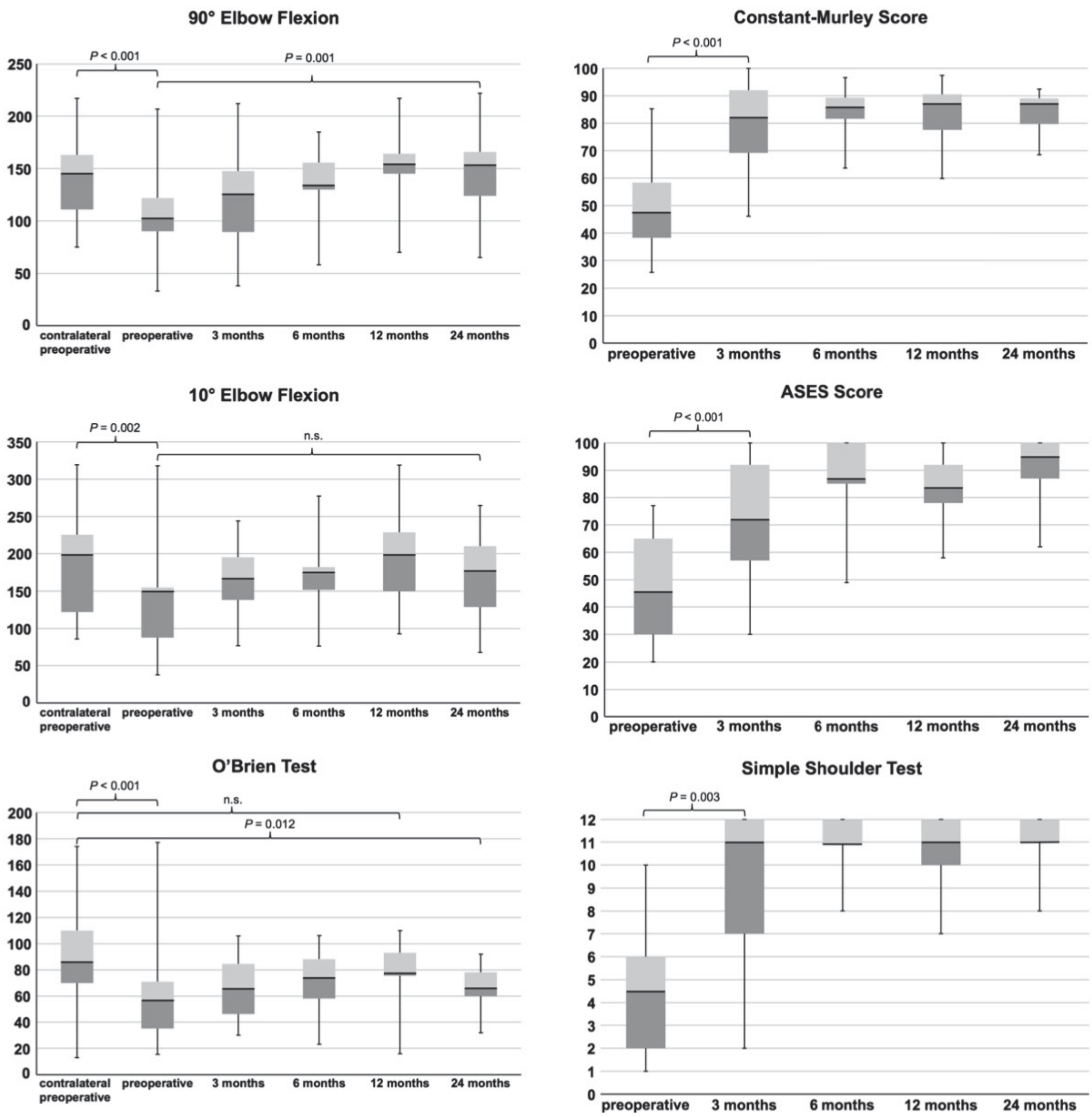

Abbildung 5: Boxplotanalyse der Kraftmessungen und der erhobenen klinischen Scores. Horizontale Linie = median. Abbildung mit freundlicher Genehmigung [33].

Aufbauend auf den Ergebnissen dieser Arbeit wurde eine prospektiv randomisierte Studie zum direkten Vergleich zwischen der Tenodese in der beschriebenen Technik und der einfachen Tenotomie durchgeführt. Da sich in der ersten Studie jedoch noch in 17,6 % der Fälle ein Popeye-Zeichen zeigte, wurde nun anstatt einer 6,5 mm eine Schraube mit 7,0 mm Durchmesser bei gleichem Bohrlochdurchmesser verwendet um die Primärstabilität weiter zu erhöhen. Ergänzend zu der Messung der Ellenbogenflexionskraft wurde nun auch eine Messung der Supinationskraft in Neutral- und Pronationsstellung des Handgelenkes durchgeführt (Abb. 6). Aufgrund der wenig aussagekräftigen Ergebnisse für die Kraftmessung in der O'Brien Position in der ersten Studie, wurde diese Messung nicht mehr fortgeführt.

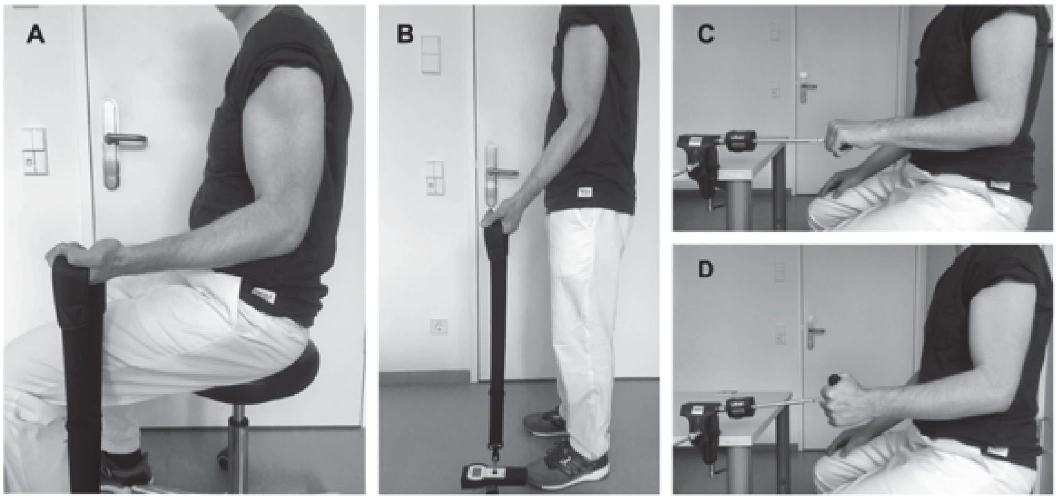

Abbildung 6: Messung der Ellenbogenflexionskraft in 90° (A) und 10° (B) sowie Messung der Supinationskraft in Pronations- (C) und Neutralstellung (D) des Handgelenks. Nachdruck mit freundlicher Genehmigung [33].

Einschlusskriterien waren Patienten zwischen 30 und 70 Jahren mit isolierten LBS Läsionen in Form von Bizeps-Pulley-Läsionen Typ I – IV nach Habermeyer et al [29] bzw. SLAP Läsionen Typ II – IV nach Maffet et al [45] und Snyder et al [78]. Auch in dieser Studie wurden Patienten mit Rotatorenmanschettenrupturen, SLAP-Läsionen ≥ Typ 5 und glenohumeraler Arthrose ≥ Grad II nach Samilson und Prieto ausgeschlossen [70]. Die Kraftmessungen erfolgten präoperativ beidseits sowie 6 und 12 Monate postoperativ für die operierte Schulter. Die Erhebung der klinischen Scores (ASES, SST, CMS) erfolgte ebenfalls zu allen Untersuchungszeitpunkten.

Die Messung der Distalisierung des Muskelbauchs zur Bestimmung des Popeye-Zeichens erfolgte analog zur ersten Studie. Insgesamt konnten 22 Patienten mit isolierten LBS Läsionen eingeschlossen und prospektiv für die Behandlung mit Tenodese oder Tenotomie randomisiert werden. Die Randomisierung erfolgte mittels versiegelter Umschläge. Die physiotherapeutische Nachbehandlung war bei beiden Verfahren identisch. Zwei Patienten der Tenodesegruppe erschienen nicht zur Nachuntersuchung nach 12 Monaten.

Insgesamt 20 Patienten (Durchschnittsalter 52,0 ± 8,5 Jahre; 36–63 Jahre, 11 Männer) absolvierten alle Nachuntersuchungen. Bei 9/20 Patienten (Durchschnittsalter 51,5 ± 9,5; 37 - 63 Jahre, 7 Männer) erfolgte eine Tenodese, eine Tenotomie wurde bei 11/20 (Durchschnittsalter 52,8 ± 8,0; 36 - 62 Jahre, 4 Männer) durchgeführt. In Bezug auf Alter ($p = 0,45$) und Geschlecht ($p = 0,37$) wurde kein signifikanter Unterschied zwischen den Gruppen festgestellt. Nach Tenodese zeigte sich schon nach 6 Monaten ein signifikanter Anstieg der Flexionskraft in 10 ° und 90 ° im Vergleich zu den präoperativen Werten, während in der Tenotomiegruppe erst nach 12 Monaten ein signifikanter Anstieg im Vergleich zu präoperativ gemessen wurden. Für die Supinationskraft in neutraler und pronierter Position des Handgelenks konnte in beiden Gruppen nach 6 und 12 Monaten kein signifikanter Anstieg im Vergleich zu den präoperativen Werten festgestellt werden. Im direkten Vergleich zwischen Tenodese und Tenotomie mittels bivariater Regressionsanalyse zeigte sich im Hinblick auf die Kraftmessungen kein signifikanter Unterschied zwischen den beiden operativen Verfahren (Abb. 7).

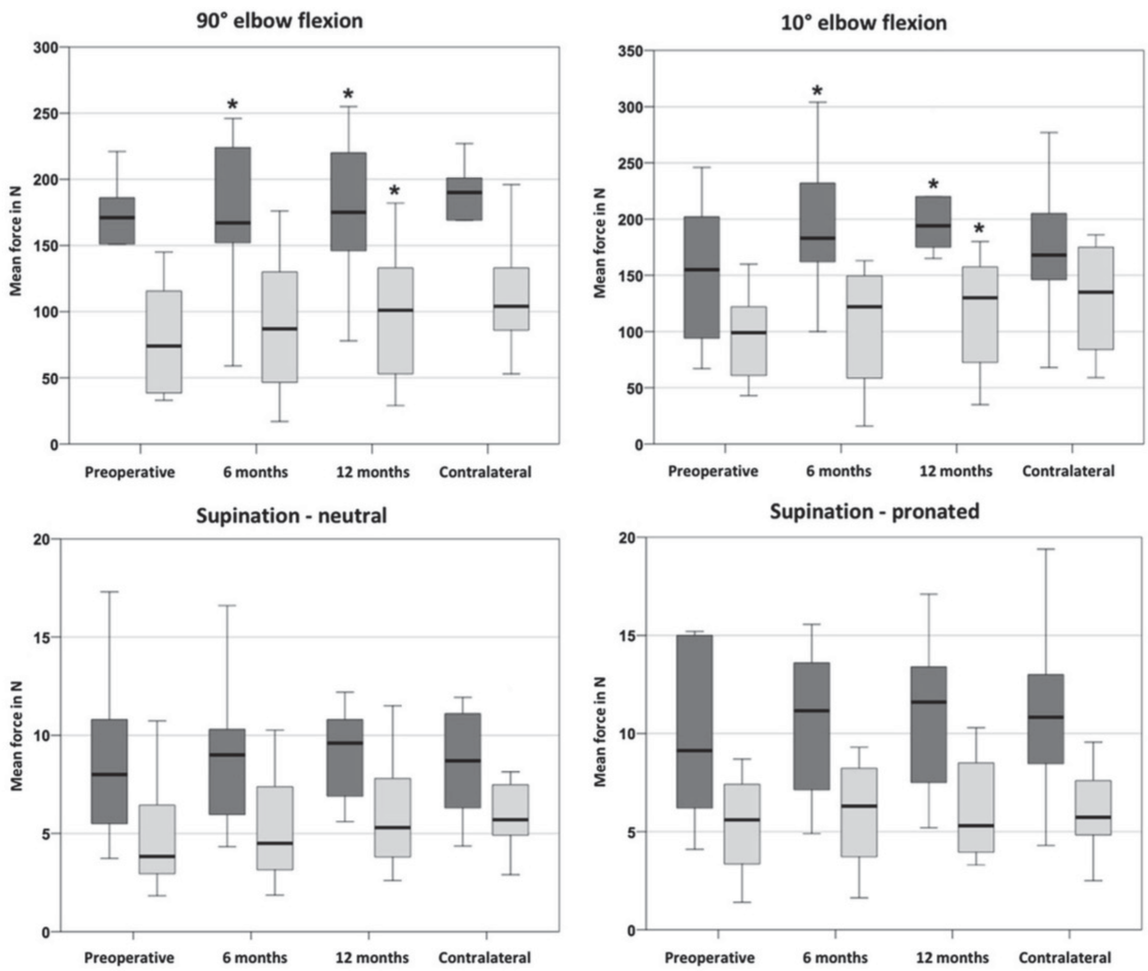

Abbildung 7: Boxplot-Analyse der Flexions- und Supinationskraftmessungen. Dunkelgraue Box = Tenodese; hellgraue Box = Tenotomie, horizontale Linie = Median. * $p < 0{,}05$ im Vergleich zur präoperativen Messung. Nachdruck mit freundlicher Genehmigung [34].

In den klinischen Scores konnte abgesehen von der Kraftmessung im CMS nach 6 und 12 Monaten eine signifikante Verbesserung sowohl in der Tenodese als auch der Tenotomiegruppe festgestellt werden (Abb. 8). Die Kraftmessung im CMS zeigte sich in beiden Gruppen nach 12 Monaten signifikant erhöht. Der direkte Vergleich zwischen den Gruppen mittels bivariater Regressionsanalyse zeigte auch hier keinen signifikanten Unterschied (Abb. 7).

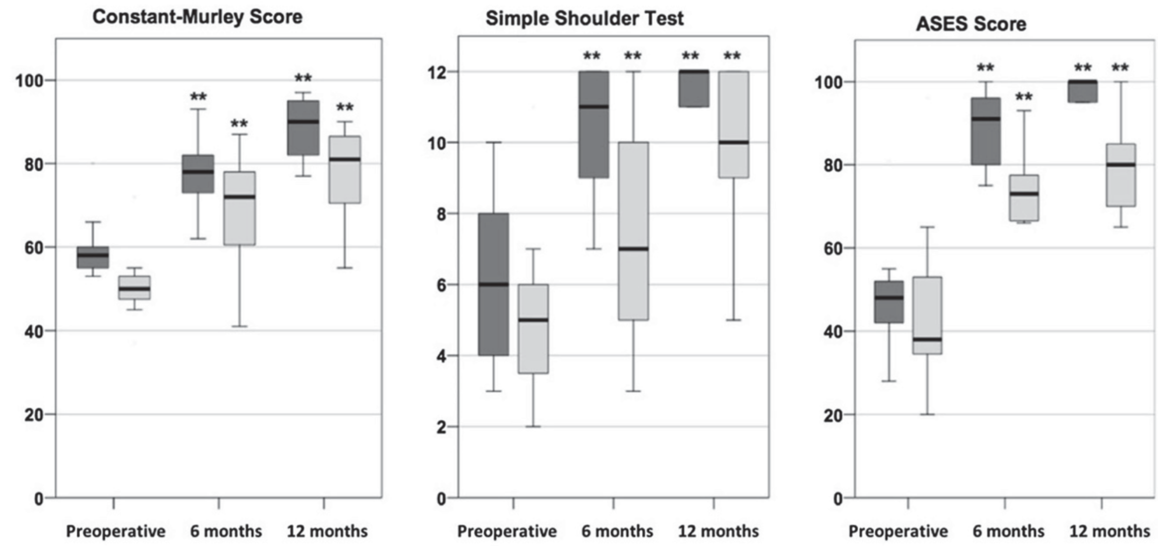

Abbildung 8: Boxplot-Analyse der klinischen Scores.

Dunkelgraue Box = Tenodese; hellgraue Box = Tenotomie, horizontale Linie = Median.

* $p < 0,05$, ** $p < 0,01$ im Vergleich zu präoperativ. Nachdruck mit freundlicher Genehmigung [34]

Ein Popeye-Zeichen konnte bei einem Patienten (11%) nach Tenodese und 3 Patienten (27%) nach Tenotomie objektiv nachgewiesen werden ($p = 0,52$). Im postoperativ erhobenen LHB-Score berichteten derselbe Patient nach Tenodese und dieselben drei Patienten nach Tenotomie über ein sichtbares Popeye-Zeichen. Weiterhin berichteten zwei Patienten in der Tenotomiegruppe bei der Nachuntersuchung 6 Monate postoperativ über Krämpfe im Bizeps, welche jedoch nach 12 Monaten nicht mehr vorhanden waren.

Diskussion

Die Ziele der vorliegenden Arbeit waren, durch histologische Untersuchung der vaskulären Anatomie um die LBS weitere Grundlagen für die Wahl der anatomischen Lokalisation einer Tenodese zu erhalten sowie, durch radiologische Analyse der individuellen akromialen Überdachung des Schultergelenks, einen weiteren möglichen Baustein in der Pathogenese von SLAP Läsionen zu identifizieren. Bezüglich der operativen Therapie von SLAP Läsionen wurde eine neue, vollständig arthroskopische Technik der suprapektoralen Tenodese etabliert, prospektiv nachuntersucht sowie randomisiert mit der Tenotomie verglichen.

Über die Gefäßversorgung des proximalen Anteils der LBS ist bekannt, dass diese hauptsächlich über die im Sulcus bicipitalis aufsteigenden Äste der Arteria circumflexa humeri anterior erfolgt (ACHA) [16, 19, 39, 40]. Hier konnte in der vorliegenden Arbeit gezeigt werden, dass diese Arterien weitere Seitenäste abgeben, die nach medial und lateral bis in den knöchernen Wall des Sulcus ziehen. Von diesen Seitenästen konnten signifikant mehr, in Richtung der lateralen knöchernen Begrenzung des Sulcus als nach medial ziehend identifiziert werden. Die im Sulcus aufsteigenden Äste der ACHA haben somit möglicherweise neben der LBS noch weitere Versorgungsgebiete. Als Limitation für die Beurteilung der Ergebnisse ist jedoch zu erwähnen, dass eine reine histologische Untersuchung des Gefäßverlaufs und keine Untersuchung der Perfusion zum Beispiel mittels Gefäßinjektion am Präparat, wie in den Arbeiten von Cheng et al erfolgte [16]. Somit kann eine klinische Relevanz identifizierter Seitenäste für die periostale oder ossäre Blutversorgung noch nicht abschließend beurteilt werden.

Gerber et al konnten bezüglich der Gefäßversorgung des Caput humeri zeigen, dass der anterolaterale Hauptast der ACHA, der den Hauptanteil an der Blutversorgung des proximalen Humerus hat, diesen distal des Sulcus bicipitalis kreuzt und anschließend medial, auf mittlerer Höhe des Sulcus, in den Knochen eintritt [26]. Die Untersuchungen von Boesmüller et al mittels computertomographischer Angiographie bestätigten zudem, dass die ACHA auch den Hauptanteil der Blutversorgung der LBS übernimmt. Hier ist auf angiographischer Ebene jedoch kein Anteil einer ossären Perfusion nachzuweisen, welche unmittelbar von den Gefäßen im Suclus bicipitalis und somit von den in der vorliegenden Arbeit identifizierten Seitenästen ausgehen könnte [11]. Nach subpektoraler Tenodese mit Resektion des Anteils der LBS und des Mesotenons im Sulcus bicipitalis wurde bisher über keine Beeinträchtigung der periostalen oder ossären Blutversorgung berichtet, so dass auch unter oben genannten Limitationen angenommen werden kann, dass die gefundenen Seitenäste zumindest keinen klinisch relevanten Anteil an der ossären Blutversorgung haben [2, 66].

Im Hinblick auf die Pathogenese von SLAP Läsionen gilt es als erwiesen, dass neben akuten Verletzungen wie Schulterluxationen auch Mikrotraumata mit repetitiver Überlastung des LBS Ursprungs bei Überkopfsport oder –arbeit ursächlich sein können. Snyder et al proklamieren, dass es beim Sturz auf den ausgestreckten Arm bei abduzierter Schulter durch eine forcierte kraniale Verschiebung des Caput humeri zu einer Avulsion des SLAP Komplexes kommt [78]. Burkhart beschreibt als Mikrotrauma einen repetitiven *Peel-Back-Mechanismus* insbesondere bei Überkopfsportlern [13]. Einflüsse der individuellen knöchernen Anatomie, wie ein unterschiedliches Ausmaß der akromialen Überdachung des Glenohumeralgelenks, wurden bezüglich einer Relevanz für Pathologien der LBS bisher nicht untersucht.

Der Critical Shoulder Angle (CSA) nach Moor als etabliertester radiologischer Parameter für das Ausmaß der akromialen Überdachung ist > 35° mit Rotatorenmanschettenrupturen und < 30° mit dem Vorhandensein einer Omarthrose assoziiert [10, 50, 52, 53]. In der vorliegende Arbeit wurde nun erstmals ein möglicher Zusammenhang zwischen einem niedrigen CSA und SLAP Läsionen analysiert. Es zeigte sich ein signifikant niedrigerer CSA bei Patienten mit isolierten SLAP-Läsion mit 29,6° im Vergleich zu 33,8° bei Patienten ohne SLAP Läsion, respektive 36,7° bei intaktem SLAP Komplex jedoch Vorhandensein einer transmuralen Ruptur der Supraspinatussehne.

Da SLAP Läsionen im konventionellen MRT nur sehr eingeschränkt zu beurteilen sind ist eine Auswertung von reinen Bilddaten für eine Korrelation mit dem CSA nicht ausreichend [64]. Eine Stärke der vorliegenden Arbeit ist daher der Einschluss von arthroskopisch, gemäß der von Burkhart et al definierten Kriterien [12], diagnostizierten SLAP Läsionen. Bei der Interpretation der Ergebnisse muss jedoch als Limitation berücksichtigt werden, dass keine Daten bezüglich einer traumatischen Genese der Beschwerden, repetitiven Mikrotraumata oder Überkopfaktivität ausgewertet werden konnten, da für die retrospektive Auswertung nur die Operationsberichte und Röntgenbilder vorlagen und die Beschwerdeanamnese nicht einheitlich dokumentiert wurde. Weiterhin muss bedacht werden, dass vorrangig bedingt durch die strengen Einschlusskriterien mit Reduktion auf isolierte SLAP Läsionen die Fallzahl in der Studiengruppe geringer ist als in den Kontrollgruppen. Eine *matched-pair* Analyse wurde hier nicht durchgeführt, da ausschließlich radiologische Parameter analysiert wurden und die Auswertung der Kontrollgruppen vorrangig dem Ziel diente die CSA Messung zu validieren und die Vergleichbarkeit mit anderen Studien herzustellen. Die vorliegende Arbeit bestätigt hier die Ergebnisse von Moor et al sowie anderen Arbeiten, dass ein CSA > 35° mit Rotatorenmanschettenrupturen assoziiert ist, welches die Aussagekraft des erstmals gezeigten Zusammenhangs zwischen einem niedrigen CSA und SLAP Läsionen weiter erhöht [24, 38, 53, 75].

Aktuell zeigt sich auch bei jungen Patienten eine Tendenz zur Tenodese in der operativen Versorgung anstatt des Versuchs der SLAP Refixation [18, 21, 48]. Eine aktuelle Metaanalyse von Hurley et al ergab eine höhere Patientenzufriedenheit und schnellere Rückkehr zum Sport nach Tenodese im Vergleich zur SLAP Refixation [35]. Möglicherweise ist ein niedriger CSA < 30° hier ein zusätzlicher negativer Einflussfaktor für die nicht immer zufriedenstellenden klinischen Ergebnisse nach SLAP Refixation.
Im Bezug auf die operative Technik der Tenodese sind offene subpektorale sowie arthroskopische suprapektorale Lokalisationen mit jeweils variablen Möglichkeiten der LBS Refixation beschrieben [1, 55, 73, 85]. Pogorzelski et al konnten zeigen, dass die offene subpektorale Tenodese bei isolierten SLAP Läsionen des jungen Patienten sehr gute klinische Ergebnisse sowie eine Rückkehr zum Überkopfsport auf gleichem Leistungsniveau in 80% der Fälle erreichen kann [65]. Die vorliegende Arbeit zeigt in der prospektiven Untersuchung einer vollständig arthroskopischen Technik der suprapektoralen Tenodese, bei Patienten mit einem mittleren Alter von 49 Jahren und isolierten SLAP Läsionen, ebenfalls sehr gute Ergebnisse in den klinischen Scores und eine hohe Patientenzufriedenheit. Ein Vorteil der untersuchten Technik ist der minimal invasive Zugang über ein ohnehin für die diagnostische Arthroskopie notwendiges Standardportal ohne offenen Zugang zum proximalen Humerus mit erhöhter Zugangsmorbidität [58, 67, 68, 73]. Als Nachteil haben Moon et al beschrieben, dass pathologische Veränderungen des LBS Anteils im Sulcus bicipitalis bei einer suprapektoralen Tenodese nicht erfasst werden [51].

Im Hinblick auf die Stabilität der Tenodese zeigt die, auch in der vorliegenden Arbeit verwendete, intraossäre Refixation mittels Interferenzschraube die höchste Primärstabilität [47, 62]. Da sich in der ersten Studie mit prospektiver Untersuchung der operativen Technik jedoch noch in 17,6 % der Fälle ein Popeye-Zeichen zeigte, wurde in der prospektiv randomisierten Folgestudie mit Vergleich zur Tenotomie anstatt der 6,5 mm Schraube eine Schraube mit 7,0 mm Durchmesser bei gleichem Bohrlochdurchmesser verwendet um die Primärstabilität weiter zu erhöhen. Epiossäre Refixationstechniken oder eine Weichteiltenodese stellen, wenn auch technisch weniger anspruchsvoll, auf Grund der geringen Stabilität keine suffiziente Tenodese dar [62].

Im Bezug auf eine relevante Reduktion der Ellenbogenflexions- und supinationskraft nach Tenotomie ist die Studienlage nicht eindeutig [22, 74, 81, 86]. In der vorliegenden Arbeit konnte gezeigt werden, dass durch eine suprapektorale Tenodese ein präoperativ bestehendes Kraftdefizit in der Ellenbogenflexion so wiederhergestellt werden kann, dass kein signifikanter Unterschied zur gesunden Gegenseite besteht. Im prospektiv randomisierten Vergleich zur Tenotomie zeigte sich jedoch kein signifikanter Unterschied. Da sich auch in der Tenotomiegruppe ein präoperatives Kraftdefizit gezeigt hat, welches zur Nachuntersuchung nicht mehr nachweisbar war, ist anzunehmen, dass die Reduktion der Flexionskraft bei SLAP Läsionen oder Tendinitis vorrangig schmerzbedingt ist. Duff et al konnten nach Tenotomie bei 103 Patienten keine Abnahme der Flexionskraft nachweisen [20]. Kerschbaum et al hingegen haben nach epiossärer Tenodese in einer retrospektiven Untersuchung ohne präoperative Kraftmessung eine signifikante höhere Flexionskraft im Vergleich zur Tenotomie beschrieben [37]. In der Arbeit von The et al zeigte sich nach Tenotomie eine Reduktion der Supinations- und Flexionskraft [81]. Wittstein et al wiederum konnte keinen Unterschied in der Flexionskraft jedoch eine verringerte Supinationskraft nach Tenotomie im Vergleich zur Tenodese feststellen [86].

In Bezug auf die Supinationskraft zeigte sich in der vorliegenden Arbeit kein signifikanter Unterschied sowohl im Vergleich prä- zu postoperativ als auch im Vergleich zwischen Tenodese und Tenotomie. Kraftmessungen nach Ruptur der distalen Bizepssehne hingegen haben einheitlich eine Reduktion der Supinations- und Flexionskraft gezeigt [54, 72]. Unbestrittene Nachteile der Tenotomie sind jedoch, dass es häufiger zu vorübergehenden Krämpfen sowie einer sichtbaren Distalisierung des Muskelbauchs kommt, was die vorliegende Arbeit bestätigt [20]. Obwohl die Tenodese in Bezug auf die Kraftwiederherstellung und die klinischen Ergebnisse in der vorliegenden und den meisten aktuellen Studien keinen signifikanten Vorteil gegenüber der Tenotomie zeigt, ergab eine aktuelle Umfrage unter Mitgliedern der American Shoulder and Elbow Society, dass 94% der spezialisierten Schulteroperateure bei einem 45-jährigen Patienten mit einer isolierten LBS Läsion eine Tenodese durchführen würden. Bei einem 50-jährigen Patienten mit einer begleitenden Rotatorenmanschettenruptur würden immer noch 60% der Befragten eine Tenodese wählen [17]. Da eine Distalisierung des Muskelbauchs bei schlanken Patienten eine starke kosmetische Beeinträchtigung darstellen kann und diese meist ebenfalls subjektiv eine Kraftminderung wahrnehmen, haben die von Hsu et al definierten Kriterien, Patient unter 50 Jahre, schlank und mit hohen funktionellem und kosmetischen Anspruch, für die Indikationsstellung zur Tenodese weiterhin Gültigkeit [31].

Die vorliegende Arbeit liefert zusammenfassend im Bereich der Grundlagenforschung neue Erkenntnisse zur vaskulären Anatomie um die LBS im Sulucs bicipitalis, kann einen Zusammenhang zwischen SLAP Läsionen und einem reduzierten CSA als möglichen ergänzenden Faktor in der Pathogenese aufzeigen und liefert erstmals in einer prospektiv randomisierten Studie zwischen Tenotomie und Tenodese wichtige Erkenntnisse für die Auswahl einer differenzierten operativen Therapie im klinischen Alltag.

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Eidesstattliche Erklärung

Hiermit erkläre ich, Dr. med. Martin Hufeland, geboren am 05.12.1982 in Hildesheim, an Eides statt, dass:

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Blood supply in the bicipital groove: A histological analysis

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Abstract

The vascular anatomy in the closed bicipital groove with the long head of the biceps brachii muscle tendon (LHBT), its mesotenon and the transverse ligament intact has not been analyzed on a histological level yet. An anatomic dissection and histologic study was conducted by using 24 cadaveric formaldehyde fixated shoulders. The bicipital groove including the LHBT and its intact sheath was cut *en-bloc*, fixated, sliced in 7 µm sections, Azan stained and the vascular anatomy analyzed under light microscopy. Each sideward branch deriving from the main ascending branches of the anterior humeral circumflex artery (ACHA) in the mesotenon of the LHBT was identified and followed through multiple sections to identify its direction and area of supply. Per specimen, a mean of 2.71±1.85 branches could be identified running through the soft tissue of the mesotenon towards the osseous walls of the groove. Of the total 65 arterial branches in all specimens, 22 (33.8%) were running into the medial wall of the groove and 40 (61.5%) into the lateral wall (P<0.01). The results indicate that branches of the ACHA in the mesotenon of the LHBT provide blood supply not only to the tendon but to the osseous bicipital groove as well and here significantly more to the lateral than to the medial osseous wall. In addition, Pacini-like mechanoreceptors could be identified in the mesotenon in 9 (37.5%) of the specimens which has not been described up to now.

Introduction

The bicipital groove which is bounded by the lesser tuberosity medially and the greater tuberosity laterally contains the tendon of the long head of the biceps brachii muscle (LHBT).[1] Taylor *et al.* defined three distinct anatomic zones of the bicipital groove: Zone 1extends from the articular margin to the distal margin of the subscapularis tendon, Zone 2 extends from the distal margin of the subscapularis tendon to the proximal margin of the pectoralis major tendon and Zone 3 is defined as the subpectoral region.[2]

The osseous bicipital groove in zone 1 is in the average about 30 mm long, 5 mm deep and covered by the so called transverse humeral ligament formed by tendinous fibers of the subscapularis and supraspinatus muscles.[1,3-5] The segment of the LHBT in the groove is circumferentially covered in synovial tissue and accompanied by its mesotenon.[2] Blood supply to the anterior humeral head, the bicipital groove and the LHBT in this segment is mainly provided by the anterior circumflex humeral artery (ACHA).[6,7] The ACHA bypasses the bicipital groove below the LHBT, sends out an anterolaral branch proximally along with the LHBT and, after delivery of smaller lateral branches, penetrates into the greater tuberosity to mainly supply the anterior and medial part of the humeral head.[8] This anterolaral branch of the ACHA and its subsequent branches in the mesotenon provide the main blood supply to the LHBT in this segment.[9-12] However, detailed knowledge about the vascular anatomy in the closed bicipital groove with the LHBT, the mesotenon and the transverse ligament still in place is sparse especially on a histological level as most studies evaluate either the blood supply to the segmented biceps tendon or to the dissected humeral head.[10-12]

The purpose of this histological study was therefore to further analyze the distinct vascular distributional pattern of arteries in the bicipital groove and the vascularization of this segment of the LHBT.

Materials and Methods

An anatomic dissection and histologic study was performed by using 24 cadaveric formaldehyde fixated shoulders. The mean age of the specimens was 82.6 years (range 61 to 96 years, 17 female). Dissection was conducted in a similar fashion for all specimens by the 2nd author.

The outer skin, subcutaneous tissues and the deltoid muscle were removed with the shoulder capsule, rotator cuff and LHBT sheath covered by the transverse humeral ligament left intact. Afterwards, the bicipital groove including the LHBT and its intact sheath is cut out en-bloc using chisels. The cranial border of the segmented block was defined the upper edges of tuberculum minus and majus and the distal border was defined by the insertion of the pectoralis major muscle. Laterally, the incision was placed 10 mm lateral to the LHBT to include the complete lateral wall of the osseous groove. Medially, 20 mm distance to the LHBT is kept in order to include the complete medial wall of the groove (Figure 1). A total of 24 bone blocks (each 25×30×12 mm) were obtained.

The blocks were then subsequently decalcified in diamine tetraacetic acid and embedded in paraffin. Each block was cut in 7 µm sections using an automated rotary microtome (Microm HM360, Thermo Fisher Scientific, Waltham, MA, USA). The sections are then stained according to a modified Heidenhain's Azan staining protocol. After staining, immersion of the sections in an ascending series of ethanol, mounting using a xylene miscible mountant (Depex, SERVA Electrophoresis GmbH, Heidelberg, Germany) and sealing of the slides for light microscopy was conducted. The histological evaluation was carried out using a standard light microscope (Motic, Wetzlar, Germany). The included microscope camera was used for documentation (Moticam 10.0 MP, Motic, Wetzlar, Germany) and the included software is used for measuring, scaling, and labelling. In the average 64±21.89, 7 µm sections are analyzed per specimen. Each branch deriving

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from the main arteries in the mesotenon of the LHBT was identified and followed through multiple sections to identify its direction and area of supply (Figure 2).

Statistical analysis

IBM SPSS Statistics 23 (Armonk, New York, USA) was used for statistical analysis. Statistical significance was indicated at a significance level of $P<0.05$. The Chi-Square test was used for comparison of anatomical distribution of the branches to the medial and lateral wall of the groove.

Compliance with ethical guidelines

All authors declare that they have no competing interests. All procedures performed were in accordance with the American Association of Clinical Anatomists (AACA) Best Practices for Donor Programs and the 1964 Helsinki declaration and its later amendments. The local ethics committee approved this study (registration number 5096).

Results

The LHBT was identified surrounded by synovial and loose connective tissue. Anterior to the LHBT, the mesotenon containing ascending branches of the ACHA running alongside the LHBT can be identified. Intratendinous vessels could not be found in any specimen. The bicipital groove was covered with a thick fibrous roof representing the transverse humeral ligament whereas the posterior groove with contact to the LHBT is covered with fibrous cartilage (Figure 3). In addition, Pacini-like mechanoreceptors could be identified in the mesotenon in 9 (37.5%) of the specimens.

Per specimen, a mean of 2.71±1.85 arteries branching off the main ascending artery could be identified running through the soft tissue of the mesotenon towards the osseous walls of the groove. Of the total 65 arterial branches in all specimens, 22

Figure 1. Humeral head after removal of the skin, subcutaneous tissues and the deltoid muscle revealing the shoulder capsule, rotator cuff and LHBT sheath covered by the transverse humeral ligament in the bicipital groove. A bone block (25×30×12 mm, dashed line) including the complete and intact bicipital groove is cut out for histological analysis.

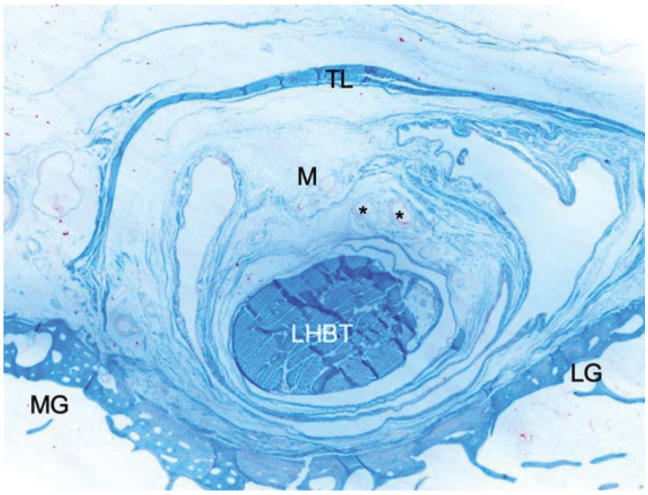

Figure 2. Azan stain of a transverse section through the bicipital groove. The osseous medial and lateral groove (MG; LG) contain the long head of biceps tendon (LHBT) surrounded by the mesotenon (M). Ascending arterial branches accompanying the tendon can be identified (*). The groove is covered by the transverse ligament (TL).

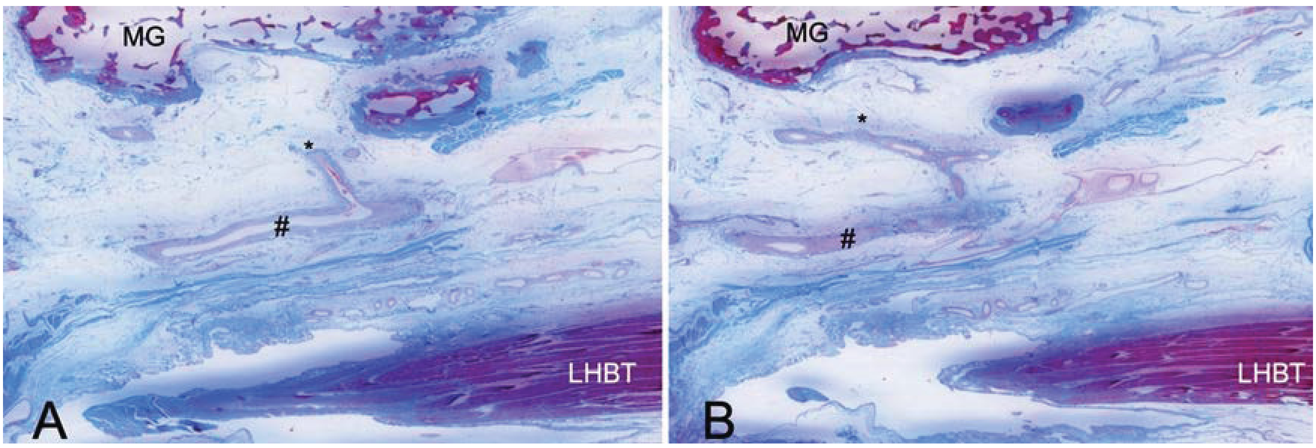

Figure 3. Azan stain of subsequent longitudinal sections. An artery (#) runs along the long head of biceps tendon (LHBT) with a branch (*) which can be followed through multiple sections (A, B) towards the osseous medial wall of the groove (MG).

(33.8%) were running into the medial wall of the groove and 40 (61.5%) into the lateral wall (P<0.01). For 3 branches (4.6%) a clear direction could not be identified.

In the bony wall of the bicipital groove, the arterial branches were found running inside canals with a mean diameter of 630±597.47 µm (range 83-3722 µm). The mean diameter of the arterial branch within those canals was 140±104.09 µm (range 45-556 µm). A nerve inside the osseous canal could be identified in 38 (58.4%), 18 (47.4%) of the nerves were found to be myelinated.

The mean diameter of the canals in the lateral groove was 596±513.92 µm (range 127-2676 µm) with an arterial branch with a mean diameter of 142±129.58 µm (range 45-556 µm). The mean diameter of the medial canals was 721±761.54 µm (range 83-3722 µm) with 141±62.61 µm (range 50-241 µm) for the arterial branch. An accompanying nerve was identified in 15 (39.4%) of the medial and 20 (52.6%) of the lateral canals (Table 1).

Discussion

The most important finding of the present study is that the ascending branches of the ACHA in the mesotenon of the LHBT provide blood supply not only to the LHBT but to the osseous bicipital groove as well. Concerning the distinct distributional pattern, we are able to show that the significantly more branches are directed to the lateral than to the medial wall of the bicipital groove. Our results of ascending arterial branches in the mesotenon confirm the findings of other authors.[9-13] According to Kolts *et al.* the distal portion of the LHBT is supplied by branches of the brachial and deep brachial artery and the proximal portion by branches of the ACHA.[10] Cheng *et at*. found an ascending branch of the ACHA entering the tendon surrounding mesotenon 4.5-6.5 cm distal from LHBT origin and providing blood supply to the LHBT in the groove.[12]

Boesmueller *et al.* confirmed by computed tomography angiography in cadaveric shoulder that the arterial supply of the LHBT in the bicipital groove always derived from an ascending branch of the ACHA.[11] In contrast, Determe *et al*. identified the main artery in the mesotenon as recurrent branch of the brachial artery in their gross anatomical study.[13]

One limitation of our study is that origin of arteries in the mesotenon was not identified by dissection prior to the histological analysis.

In regard to the blood supply to the osseous humeral head, Gerber *et al.* demonstrated that the anterolateral branch of the ACHA crossed under the LHBT and entered the humeral head directly to provide the main blood supply.[14] Hettrich *et al*. on the other hand report that the posterior humeral circumflex artery provides the majority of the blood supply.[7] Even though the amount of actual blood supply to the osseous groove and humeral head by arterial branches in the mesotenon has not been quantified in the present study, obliteration of the proximally directed blood supply for example by subpectoral biceps tenodesis seems not to have a considerable clinical impact.[15-18] This indicates that the blood supply by the branches ascending in the mesotenon, in contrary to the importance of the main anterolateral branch of the ACHA might not be of utmost clinical relevance for the osseous humeral head.

In addition, we identified Pacini-like mechanoreceptors in the soft-tissue of the mesotenon in 37.5% of the specimens. Numerous mechanoreceptors are found in the shoulder joint capsule, rotator cuff and the glenohumeral ligaments but have not been described in the soft tissue of the bicipital groove adjacent to the LHBT up to now.[19,20]

Snow et al histologically analyzed the transverse humeral ligament and found free nerve endings but no mechanoreceptors. However, their examination did not include the LHBT or the soft-tissue inside the groove.[21]

Even though not focus of the current study this accidental finding should be included in future studies to evaluate the detailed distributional pattern of mechanoreceptors in the bicipital groove and their relevance for pathologies of the LHBT.

Table 1. Overview of results.

Results	N.
Number of specimens	24
Age (median)	82.6
Male:female	7:17
Arterial branches from mesotenon to bone (total)	65
Branches per specimen (mean)	2.71
Lateral	40)
Medial	22
Indefinable	3
Diameter of osseous canals (mean)	630
Lateral	596
Medial	721
Diameter of arterial branch in the canal (mean), µ	140
Lateral	142
Medial	141
Nerve identified in the osseous canal (total),	35
Lateral	20
Medial	15

Conclusions

The branches of the ACHA in the mesotenon of the LHBT provide blood supply not only to the tendon but to the osseous bicipital groove as well and here significantly more to the lateral than to the medial osseous wall. Pacini-like mechanoreceptors can be found adjacent to the LHBT in the mesotenon.

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SHOULDER

The association between a low critical shoulder angle and SLAP lesions

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Abstract

Purpose To evaluate the critical shoulder angle (CSA), acromion index (AI) and further acromion parameters in patients with isolated SLAP lesions compared with patients without SLAP lesions.

Methods Between 2012 and 2016, the CSA, AI, lateral acromion angle (LAA) and acromion slope (AS) were radiologically examined in consecutive patients > 18 years having had a shoulder arthroscopy with isolated SLAP lesion types II–IV. These were compared to controls without SLAP lesions and without (control group I) or with (control group II) complete supraspinatus tendon (SSP) tears.

Results 75/103 patients with isolated SLAP lesion types II–IV with a mean age of 46.5 years (± 13.0, 18.1–76.3) were analyzed, 61% of them being male. For control, $n = 211$ consecutive patients (47% male) with an intact SSP and SLAP complex and a mean age of 52.3 years (± 15.0, 18.6–88.4) and $n = 115$ patients (60% male) with an intact SLAP complex but complete SSP tears, mean age 66.6 years (± 9.3, 44.7–87.9) were examined. The CSA in SLAP patients was 29.6° (± 3.5, 21.0–38.0), 33.8° (± 3.7, 25.1–46.9) in no SLAP and no SSP ($p < 0.001$) and 36.7° (± 3.6, 29.1–46.6) in no SLAP but SSP ($p < 0.001$). The area under the curve (AUC) for CSA was 0.83 for SLAP lesions resulting in a probability of 83% for patients with SLAP lesion to be associated with a specific CSA.

Conclusions Isolated SLAP lesion types II–IV are associated with a low CSA < 30°. The AI, the AS as well as the LAA showed no correlation with SLAP lesions.

Level of evidence Retrospective comparative study, Level III.

Keywords Shoulder arthroscopy · SLAP lesion · Critical shoulder angle · Acromion index · Risk factor · Overhead sports

Abbreviations

AI	Acromion index
AUC	Area under the curve
AS	Acromion slope
CSA	Critical shoulder angle
e.g.	Exempli gratia; for example
Fig	Figure
i.e.	Id est; that is to say
IRB	Institutional review board
ISP	Infraspinatus tendon
LAA	Lateral acromion angle
LHB	Long head of biceps tendon
ROC	Receiving operating characteristic
SLAP	Superior labrum from anterior to posterior
SSC	Subscapularis tendon
SSP	Supraspinatus tendon

Introduction

Lesions of the superior glenoidal labrum from anterior to posterior (SLAP complex) were first classified by Snyder et al. [41]. This classification was furthermore extended by Maffet and Morgan [21, 30]. The prevalence of SLAP lesions is reported to be 6% in overall shoulder arthroscopies [36, 40]. SLAP lesions have been currently described to be a major topic of shoulder pathologies [13, 27].

Macro-trauma [41] or repetitive micro-traumas in overhead activities are reported as causative factors for SLAP lesions [1, 7, 8, 12]. Here, a dynamic posterosuperior shift of the humeral head with subsequent compression of the

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SLAP complex has been proposed as an explanation for SLAP lesions [8].

Functionally, the long head of biceps tendon (LHB) including the SLAP complex acts as a stabilizer for the glenohumeral joint [32, 38]. SLAP lesions have been evaluated to lead to an increase in glenohumeral translation [24, 25, 35, 36], and the unstable LHB can furthermore cause humeral chondral lesions in the form of a characteristic bicipital chondral print [9, 10, 34, 37].

For rotator cuff tears as well as for osteoarthritis of the shoulder, special radiographic acromion parameters like the acromion index [31] and especially the critical shoulder angle (CSA) [4, 5, 26, 28, 29] have been proven to be sufficient predictors. The CSA is defined as the angle between the line from the supraglenoidal to infraglenoidal tubercle and the lateral acromion edge measured on a true anteroposterior radiograph. A CSA > 35° predicts rotator cuff tears [26, 29], rotator cuff re-tears [14] and secondary rotator cuff insufficiencies following shoulder arthroplasty [11]. On the other hand, a lower CSA < 30° has shown a significant association with glenohumeral osteoarthrtitis. This is explained by medially directed force vectors of the deltoid muscle in a low CSA with a high humeral offset leading to compression of the humeral head into the glenoid [4, 26, 28] (Fig. 1).

The CSA concept is therefore currently of high interest, and recently published studies even evaluated a reduction of the CSA by lateral acromioplasty [19] to prevent rotator cuff tears [22] or as adjunct to rotator cuff repair [15].

Only a few risk factors for SLAP lesions as well as for failed SLAP repairs could be identified [36, 43]. Therefore, in several SLAP lesions, the etiology remains unknown [36].

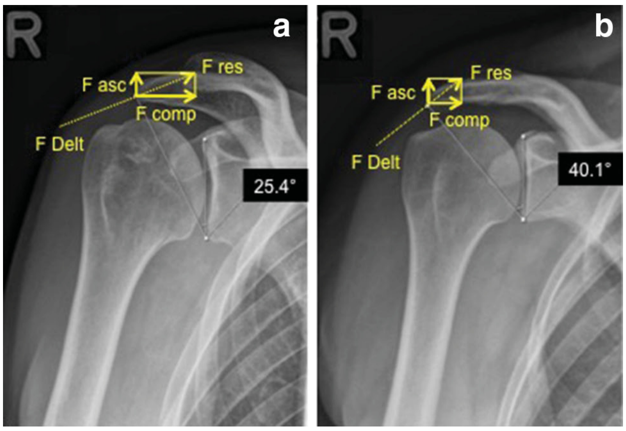


Fig. 1 Radiograph in true anteroposterior projection showing a glenohumeral joint with a low CSA **a** resulting in a medially directed force and a high CSA, **b** resulting in an upwards directed force. The following force vectors of the deltoid muscle are illustrated: F asc: ascending force in direction of the acromion. F comp: compression force in direction of the glenoid face. F res: resulting force vector of F asc and F comp

Until now, no specific investigation of a possible association between SLAP lesions and established radiological acromion parameters has been conducted.

Following the concept of the CSA, a lower CSA with increased medially directed force vectors of the deltoid muscle could not only predispose to osteoarthritis but also compress and ultimately injure the SLAP complex as well.

The purpose of this study was therefore to analyze a possible association between especially the CSA and acromion index (AI) as well as the lateral acromion angle (LAA) and the acromion slope (AS) with SLAP lesions.

The hypothesis was that SLAP lesions are associated with a low CSA and a low AI.

Materials and methods

The Ethical Committee of the medical faculty granted approval for this retrospective trial (IRB-number 5442).

Between 2012 and 2016, 103 consecutive patients were treated by shoulder arthroscopy with SLAP refixation, tenodesis or tenotomy of the LHB for treating SLAP lesion types II–IV according to Snyder et al. [41] and Morgan et al. [30]. $n = 28/103$ patients were excluded by virtue of a complete rotator cuff tear ($n = 22$), a shoulder dislocation in the past ($n = 4$) or due to osteoarthritis > stage I according to Samilson and Prieto [39] ($n = 2$).

A total of $n = 75$ patients with a mean age of 46.5 years (± 13.0, 18.1–76.3 years, 61% male) were included in the SLAP group.

Control group I consisted of 211 consecutive patients with a mean age of 52.3 years (± 15.0, 18.6–88.4 years, 47% male) who underwent surgery between 2015 and 2016 with an arthroscopically validated intact SLAP complex and intact SSP.

Control group II consisted of 115 consecutive patients with a mean age of 66.6 years (± 9.3, 44.7–87.9 years, 60% male) who underwent surgery between 2015 and 2016 without a SLAP lesion but a complete isolated tear of the SSP.

Inclusion and exclusion criteria

Inclusion criteria for the study group were consecutive cases (treated between 2012 and 2016) with an arthroscopically validated SLAP lesion types II–IV according to Snyder et al. [41] and Morgan et al. [30]. Inclusion criteria for the two control groups were control group (1): consecutive cases (treated between 2015 and 2016) with an arthroscopically validated intact SLAP complex and intact SSP. Control group (2): consecutive cases (treated between 2015 and 2016) with arthroscopically validated intact SLAP complex but an isolated full thickness tear of the SSP.

Excluded for all groups patients under 18 years of age, osteoarthritis > stage I according to Samilson and Prieto [39], SLAP lesions > type IV according to Snyder et al. [41], a history of shoulder dislocation or with complete tears of the subscapularis or infraspinatus muscles with indication for rotator cuff repair.

SLAP evaluation by arthroscopy

Shoulder arthroscopy was performed in beach chair positioning of the patient starting from the posterior viewing portal and with an anterior working portal. The integrity of the SLAP complex was evaluated using a probe via the anterior portal. Afterwards, the scope was positioned in the anterior portal and the probe was inserted from the posterior portal for better visualization of the posterosuperior labrum where most of the SLAP lesions are localized [36].

The diagnosis of a SLAP lesion was based on the criteria defined by Burkhart et al. [6] with a

1. superior sublabral sulcus > 5 mm in depth,
2. bare superior labral footprint,
3. displaceable biceps root and
4. positive peel-back sign in the abducted and externally rotated arm position.

Radiological measurements

For this study, only specifically standardized radiographs of the shoulder all done in the same radiological institute of the University clinic in the true anteroposterior projection with a straight projected glenoid with visible joint space and only minimal overlap between the posterior and anterior rim of the glenoid were selected. In addition, a standardized centered outlet view according to the methods described by Moor et al. [28] was chosen.

Radiological measurements were conducted by two physicians (second and last author) who were both blinded to the patients' diagnosis.

For the final calculation, the mean value of both measurements by the two investigators was chosen.

Four different acromion parameters were radiologically measured:

On a true anteroposterior radiograph:

- the CSA as described by Moor et al. [28],
- the AI as described by Nyffeler et al. [31] and
- the lateral acromion angle (LAA) according to Banas et al. [3]

On a standardized radiograph in outlet-view projection:

- the acromion slope (AS) was measured as published by Aoki et al. [2].

Statistical analysis

This is a retrospective case–control study without sample size determination by power calculation. However, a post hoc power calculation with a significance level of 0.05 showed that with Bonferroni correction and two comparisons (cases vs. control 1 and cases vs. control 2), a power of 86% was used to detect group differences in means for a standardized effect size of 0.5, when the sample sizes in the two groups are 75 (sample size for the cases) and 115 (sample size for the controls II).

Descriptive statistics are based on frequency tables for categorical data and means and standard deviations for continuous variables. In addition, box plots were used to compare the different sub-groups graphically (Fig. 2). The agreement analysis was performed by a graphic comparison of both measurements (Fig. 3).

A recursive partitioning regression and classification was used to investigate the association between covariates and the outcome variable (Fig. 4). This approach is based on the method described by Horhorn et al. [18]. This technique combines an algorithm for recursive partitioning together with a well-defined theory of permutation tests. Multiple test procedures are applied to determine whether a significant association between any of the covariates and outcome variables could be stated. The resulting partitioning regression analysis is graphically displayed as a classification tree. The partitioning nodes are displayed by an optimal cutoff point for continues covariables and with a classification split for categorical covariables. Each node split is assessed with a

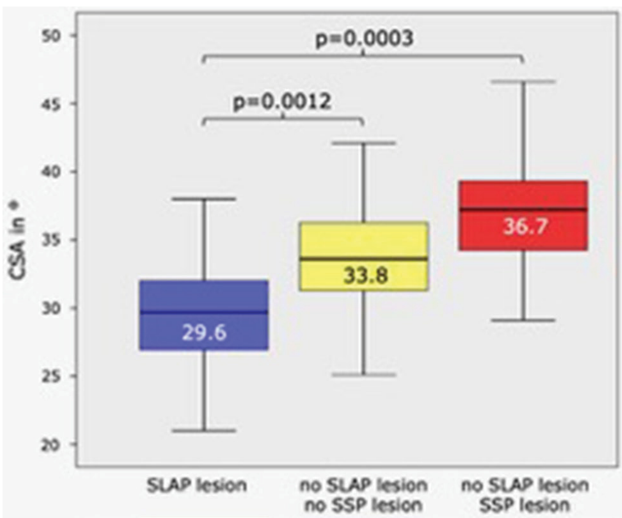


Fig. 2 Box plot showing the CSA in the SLAP group and in both the control groups

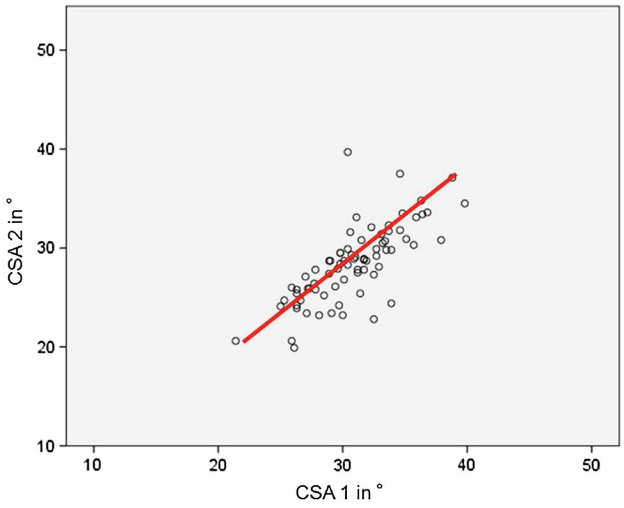


Fig. 3 Inter-rater reliability of the CSA measurements of patients with isolated SLAP lesions. CSA 1: second author; CSA 2: last author

p value calculated by a permutation test. In addition, for each potential covariate, a descriptive analysis based on the receiving operating characteristic (ROC) curves and the area under the curve (AUC) were calculated (Fig. 5). Data analysis was performed using the statistical software R version 3.4.0 (R core team) and SPSS Statistics version 23.0 (IBM®).

Results

A SLAP lesion type II was found in 81% of the cases (SLAP lesion type IIC according to Morgan in 37%, type IIB in 25%, type IIA in 19%), a SLAP lesion type III in 8% and a type IV in 11%.

Radiological measures

All four evaluated acromion parameters showed significant differences when comparing the study group (SLAP lesion) to control group II (no SLAP lesion but SSP tear).

For the AI and LAA, no significant differences could be seen when comparing the study group to the control group I (no SLAP lesion and no SSP tear).

The mean CSA in the study group was 29.6° (±3.5, 21.0–38.0°), 33.8° (±3.7, 25.1–46.9°, $p<0.001$) in control group I and 36.7° (±3.6, 29.1–46.6°, $p<0.001$) in control group II.

Fig. 4 Classification tree demonstrating the two cutoff values of angles of CSA associated with SLAP lesions. The important cutoff value of CSA was calculated to be 30.3°: CSA < 30.3° includes 65% ($n=49$) of the SLAP lesions A second cutoff value of CSA was measured to be 26.6°: CSA < 26.6° includes 23% ($n=17$) of all SLAP lesions

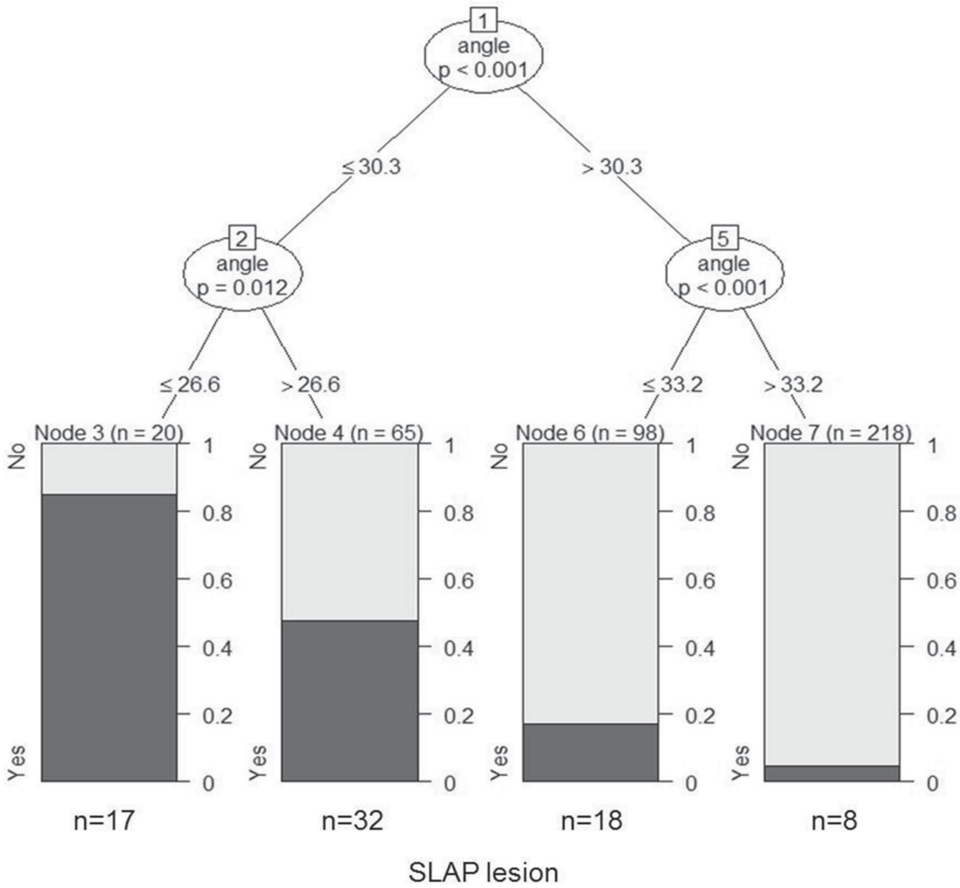
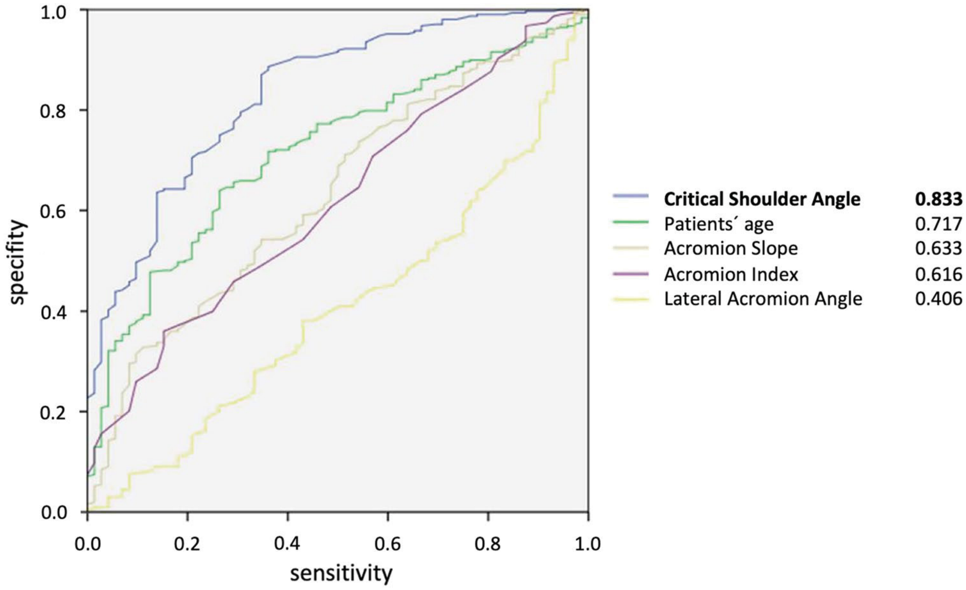


Fig. 5 AUC curves presenting the influence of the four different acromion parameters and the patients´ age on the presence of SLAP lesion types II–IV



The mean AI in the study group was 0.65 (±0.07, 0.49–0.78), 0.68 (±0.68, 0.51–0.85, $p=0.034$) in control group I and 0.71 (±0.07, 0.52–0.85, $p<0.001$) in control group II.

The mean LAA in the study group was 84.0° (±5.6, 60.9–94.5°), 82.1° (±5.4, 65.5–96.2°, n. s.) in control group I and 80.2° (±5.4, 65.5–96.2°, $p<0.001$) in control group II.

The mean AS in the study group was 32.0° (±5.0, 21.5–45.2°), 34.4° (±5.4, 19.2–50.7°±5.4, $p<0.01$) in control group I and 34.5° (±5.6, 22.1–50.7°, $p<0.01$) in control group II.

Discussion

The most important finding of the present study was a significant difference in the CSA in patients with an arthroscopically diagnosed isolated SLAP lesion types II–IV compared with patients without a SLAP lesion and with or without a complete SSP tear. Patients with an isolated SLAP lesion had a mean CSA of 29.6°, patients with an intact SLAP and intact SPP had a mean CSA of 33.8° and patients without a SLAP lesion but with a complete SSP tear had a mean CSA of 36.7° (Fig. 2). The cutoff value for the CSA in SLAP lesions was measured with 30.3° (Fig. 4) and the area under the curve for the CSA in SLAP lesions was 0.83 (Fig. 5) resulting in a high association between a low CSA and SLAP lesions.

A low CSA < 30° has been described to be associated with glenohumeral osteoarthritis [4, 26, 28, 29]. It has been proclaimed as explanation of the pathogenesis that a low CSA with a short acromion overhang and a high humeral offset leads to increased medially directed force vectors of the deltoid muscle (Fig. 1) resulting in humeral protrusion into the glenoid. Those medially directed forces in a CSA < 30° might herewith increase the pressure of the humeral head on the SLAP complex as well.

Several mechanisms causing SLAP lesions have been described. However, real risk factors or predictors for SLAP lesions could not be identified yet. One study described SLAP lesions without a history of trauma and without typical overuse of the shoulder [36]. Snyder et al. reported that the humeral head pushes especially the superior labrum including the biceps origin upwards when touching the ground with the hand while in abduction of the shoulder joint resulting in a typical type II SLAP lesion [41]. Burkhart described the peel-back mechanism of the SLAP complex in the late-cocking acceleration phase in overhead athletes [8] with a glenohumeral internal rotation deficit concept (GIRD) and increased anterior glenohumeral translation. This translation develops due to a special form of pseudolaxity of the posterosuperior capsule and with a contracted posteroinferior capsule, a consecutive dynamic posterosuperior shift of the humeral head. The humeral head hereby compresses the SLAP complex furthermore. This humeral compression theory of the SLAP complex could confirm the results of the present study. Here the medially directed forces of the deltoid muscle could be reinforced by a low CSA (Fig. 1). In this context, a low CSA < 30° could be seen as a potential predictor for SLAP lesions by enhancing the factors described by Burkhart et al. [8] for overhead athletes.

SLAP lesions have been described to cause sub-bicipital humeral chondral lesions [9, 10, 34, 37]. The SLAP lesion-associated humeral chondral print combined with a low CSA can be considered as increased risk factor for osteoarthritis confirming the findings of the present study, because a low

CSA alone is seen as a risk factor for osteoarthritis as well as a risk factor for SLAP lesions. Both factors combined hereby might induce prearthrotic glenohumeral changes even further.

Regarding the specific radiological measurements of the acromion parameters, a high inter-rater reliability was seen in the present study (Fig. 3). Only correctly positioned and standardized radiographs all taken in the same radiological institute of the university clinic were included. In addition to that, all measurements were conducted by two different physicians blinded to the patients´ diagnosis. A mean CSA of 36.7° in the control group including patients with complete SSP tears confirms other results having evaluated a CSA > 35° associated with rotator cuff tears [29]. For radiographs, a CSA > 35° has shown to have a high performance for diagnosing rotator cuff tears as described by Song et al. [42].

The AI as well as the AS were significantly lower in patients with SLAP lesions in comparison to the controls and the lateral acromion angle was significantly higher in patients with SLAP lesions in comparison to control group II including patients with an intact SLAP but complete SSP tears. However, in contrast to the CSA, the further acromion parameters were neither predictive for SLAP lesions (AUC 0.41–0.63, Fig. 5) nor for complete SSP tears. This supports the findings by Hamid et al. [17] who reported that the AI is not associated with rotator cuff tears. This could be explained by the fact that the AI concept not only reflects the acromion overhang, like the CSA, but also includes the humeral offset with the greater tuberosity as reference. Hereby a variance in humeral rotation is a considerable bias for the AI measurements independent from the acromion parameters.

The diagnosis of a pathologic SLAP lesion can be difficult even by arthroscopy, as it is not easy to differentiate these lesions from anatomical variations [16] such as a sublabral recess or a sublabral hole [20]. However, unstable norm variants of the posterosuperior labrum are very rare. With regard to the anatomy of the SLAP complex, the origin of the long head of biceps tendon fibers is located at the posterosuperior labrum in 75% of the cases [33]. Agreeing with those findings, in the present study, an anterosuperior SLAP lesion type IIA according to Morgan et al. [30] was only found in 19% of all SLAP lesions. Most SLAP lesions (62%) were found posteriorly (type IIC: 37%, type IIB: 25% according to Morgan [30]). To reduce this bias in the SLAP lesion evaluation and to increase diagnostic specificity, the arthroscopic evaluation of the SLAP complex was always performed with an arthroscopic visualization from the posterior and anterior portal by switching the camera to better visualize this posterosuperior part and to differentiate pathological from anatomical norm variants. Using the standardized criteria for SLAP lesions according to Burkhart et al. [6], the specificity could be furthermore enhanced in the present study. SLAP lesions were seen more in male than female patients, which agrees with the findings by Zhang et al. [44]. The number of patients in the SLAP group is lower than the number of patients in both control groups. However, it was not necessary to perform a matched pair analysis, because only radiological parameters were measured and the primary aim of the study was the evaluation of the different specific acromion parameters in patients with SLAP lesions. The measurements of the acromion parameters in the control groups were only conducted to prove the validity of the measurements and to verify the quality of the methods for comparison with previous studies. Due to the high number of measurements, only patients operated in 2015–2016 were included for both the control groups.

A further limitation of this study is that specific anamnestic information concerning the etiopathogenesis of the SLAP lesions in the patients is not included (i.e., macro- or repetitive micro-trauma, overhead activities). This information could not be evaluated thoroughly due to a retrospective study design with only the arthroscopic findings and radiographs being available. However, this study is the first description of a potential association between SLAP lesions and a specific low CSA and further established acromion parameters. Further prospective studies including a detailed evaluation of the patient's history and clinical outcome parameters are needed to confirm these findings.

A strength of this study is that only isolated SLAP lesion types II–IV were included in the study group. Patients with complete rotator cuff tears and osteoarthritis of the shoulder were excluded from the SLAP group to minimize the influence of other concomitant pathologies on the measured acromion parameters. Furthermore, patients with a history of shoulder dislocation were excluded, as they often present with extensive Bankart—SLAP lesions > type IV. Those lesions should not be considered in the concept of the present study due to the macro-traumatic etiology.

In terms of clinical relevance, the current trend in the surgical treatment of SLAP lesions is in favor of biceps tenodesis instead of SLAP repairs [13] especially in patients over 36 years of age [23]. Here a low CSA < 30° could potentially be a predictor for an insufficient unhealing of the SLAP complex due to the biomechanical arguments discussed above and support the surgical decision making towards biceps tenodesis.

This is the first description of an association between the CSA and further acromion parameters in SLAP lesions and the results of this study do not evidence this hypothesis enough. Further prospective clinical studies evaluating the outcome of SLAP repairs and the influence of the CSA are necessary to reveal whether a low CSA might be potentially seen as one of the risk factors for insufficient healing of SLAP repairs.

Conclusions

Isolated SLAP lesion types II–IV are associated with a low CSA < 30°. The AI, the AS as well as the lateral acromion angle showed no correlation with SLAP lesions.

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Compliance with ethical standards

Conflict of interest The authors declare that they have no conflict of interest.

Ethical approval All procedures performed in studies involving human participants were in concordance with the ethical standards of the institutional research committee and with the 1964 Helsinki declaration and its later amendments or comparable ethical standards.

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SHOULDER

The influence of suprapectoral arthroscopic biceps tenodesis for isolated biceps lesions on elbow flexion force and clinical outcomes

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Abstract
Purpose To prospectively evaluate elbow flexion force, cosmetic and clinical outcome of all-arthroscopic suprapectoral biceps tenodesis for isolated biceps lesions.
Methods Tenodesis was performed using a 6.25-mm absorbable interference screw for intraosseous fixation. Seventeen out of 24 patients (70.8 %, median age 49.0 ± 10.1 years; 10 = male) could be included for 24 months follow-up. Elbow flexion strength in 10° and 90° elbow flexion, the upward-directed force of the upper arm in the O'Brien position, objective evaluation of a Popeye-sign deformity and validated clinical scores (CMS, SST, ASES) were assessed preoperatively, 3, 6, 12 and 24 months postoperatively.
Results Elbow flexion strength in 90° improved significantly from 12 months onwards ($P = 0.001$) without significant difference to the contralateral arm from 3 months postoperatively (n.s.). At 24 months, an average increase of 46.4 % (median 37.7 %) from preoperative could be seen. The dominant arm was affected in 70.6 %. All scores showed a significant improvement 3 months postoperatively: SST ($P = 0.003$), ASES ($P = 0.006$) and total CMS ($P < 0.001$). Three patients (17.6 %) developed a distalization of the maximum biceps circumference of more than 20 % compared to preoperative.
Conclusions All-arthroscopic proximal suprapectoral intraosseous single-limb biceps tenodesis for the treatment of isolated biceps lesions provides good-to-excellent clinical results with significant improvement of elbow flexion strength and clinical scores and no significant difference to the unaffected contralateral arm.
Level of evidence IV.

Keywords Shoulder · Biceps tenodesis · Interference screw · SLAP · Biceps pulley · Elbow flexion force

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Introduction

Instability of the long head of biceps brachii tendon (LHB) due to biceps pulley lesions and traumatic or degenerative lesions of the biceps anchor are common causes of anterior shoulder pain [38]. When despite activity modification and physiotherapy complains are persistent, surgical therapeutic options aim at pain reduction and functional improvement both of which can be achieved by tenotomy or tenodesis [5, 21]. Both techniques show comparably favourable results in the literature without significant differences in regard to pain and function but a higher incidence of cosmetic Popeye-sign deformity after tenotomy [10, 35]. Nevertheless, the absence of prospective randomized trials leaves a great lack of evidence.

In biomechanical trials, the intraosseous tendon fixation with an interference screw resulted in a primary stability of >200 N [1–3, 19, 26–28]. In this technique, flush reinsertion of the tendon prevents secondary impingement of the construct and intraosseous fixation achieves a high primary stability with subsequent fibroblastic ingrowth [26, 30]. Suprapectoral [3, 19, 26–29] and subpectoral [19, 28] position for biceps tenodesis have been biomechanically evaluated. Subdeltoidal as well as glenohumeral approaches are possible for arthroscopic tenodesis in distal and proximal suprapectoral position. Resection of the tendon below the bicipital groove is considered an advantage of the subpectoral and distal suprapectoral position as the intracanalicular part of the tendon has been described to obtain synovitis, fraying and hypertrophic degeneration [4, 24]. Werner et al. [39] evaluated an increased incidence of postoperative stiffness after arthroscopic distal suprapectoral tenodesis performed in the subdeltoidal space compared with open subpectoral tenodesis. Despite that, there is no clinical data indicating that suprapectoral tenodesis is a source of ongoing complaints [19]. Brady et al. [6] have recently published a complication rate of 4 % after suprapectoral intraosseous biceps tenodesis at the entrance of the bicipital groove. Good functional results following epiosseous suprapectoral tenodesis using a knotless suture anchor technique without fixation of the tendon in the bone were recently evaluated, whereas 69 % of the patients developed a Popeye-sign deformity [12].

Based on the clinical results and on our own biomechanical investigations, we devolved a technique for all-arthroscopic proximal suprapectoral tenodesis performed in the glenohumeral space with modified lasso-loop stitch tendon arming and fixation in a bony canal at the entrance to the bicipital groove with a 6.25 × 23 mm Bio SwiveLock™ screw (Arthrex, Naples, FL) fixation [27, 43].

Up to now, the influence of biceps tenodesis for the treatment of isolated biceps lesions on elbow flexion force and specific objective assessment of the muscle belly distalization comparing the pre- and postoperative status has not been published yet. The main purpose of the present study was to prospectively analyse the elbow flexion force as well as upper arm circumference measurements and the clinical outcome. The first hypothesis was that elbow flexion force and clinical scores significantly improve following all-arthroscopic suprapectoral biceps tenodesis for the treatment of isolated biceps lesions. As secondary hypothesis it was stated that a distalization of the maximum circumference defined as a positive Popeye-sign deformity can be prevented.

Materials and methods

Inclusion criteria were isolated LHB lesions in the form of biceps pulley lesions type I–IV according to Habermeyer et al. [11] respectively, SLAP (superior labrum anterior to posterior) lesions type II–IV according to Maffet et al. and Snyder et al. [16, 36]. Patients with full thickness rotator cuff tears, SLAP lesions ≥ type 5, glenohumeral osteoarthritis ≥ grade II according to Samilson and Prieto [31], infections of the shoulder girdle, active malignancy and with a shoulder-associated trauma during follow-up were excluded.

Of a total of 27 consecutive patients (Fig. 1) that underwent tenodesis with this technique for the treatment of isolated LHB lesions during 1 year, 24 could be included respecting the inclusion criteria, of which seven did not show up for the scheduled follow-up examination but went well as evaluated in a telephone call.

Surgical technique

Proximal suprapectoral tenodesis was performed by the senior author (TP) in all patients using a standardized

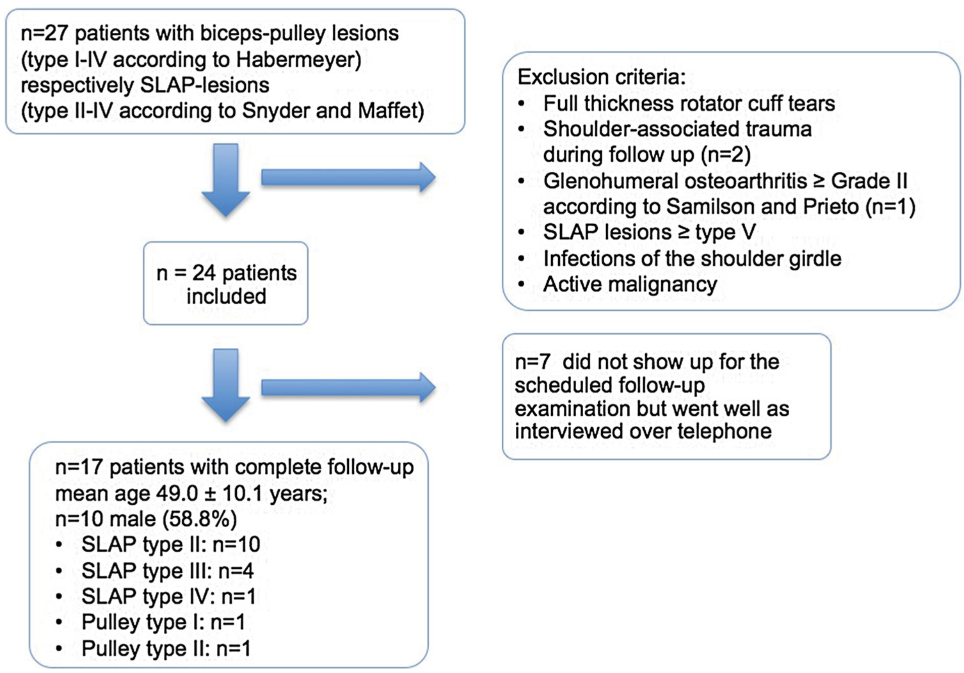

Fig. 1 Flow diagram of the patient recruitment

technique as published in detail before [27]. The patient was operated in standard beach chair position. The elbow is flexed 90° and the forearm is supinated. After establishment of the standard portals, the tendon is pierced exactly 20 mm proximal to the entrance of the bicipital groove through the anterior portal with a straight Penetrator Suture Retriever™ (Arthrex, Naples, FL) and is thus secured by a modified lasso-loop stitch with No. 2 Orthocord (DePuy Mitek, Raynham, MA) suture. Tenotomy is performed directly proximal to the stitch using a 45° right angulated punch (right shoulder).

The remnant is resected adjacent to the SLAP complex. With glenohumeral flexion of 45°, an exactly 20-mm-deep osseous canal in 135° angulation to the humeral shaft is established using a hand-operated spiked drill (Arthrex, Naples, FL), 6.5 or 7.0 mm depending on the tendon diameter, directly at the entrance of the bicipital groove. With 20 mm depth of the bony canal and a biceps arming and tenotomy 20 mm proximal to the entrance, an anatomical tendon tension is achieved.

The tip of the tendon is guided with the arming suture in the eyelet of the SwiveLock™ to the bottom of the bony canal, and intraosseous tendon fixation is then conducted with screwing in of the 6.25-mm Bio SwiveLock™ Screw anterior to the tendon. The two double-suture limbs (one of the arming suture and the other of the SwiveLock™) can be cut or used for a subscapularis tendon refixation (Fig. 2).

Postoperative rehabilitation

All patients underwent a standardized rehabilitation protocol with early functional physiotherapy starting on the first day after surgery without restriction of glenohumeral motion. Forced supination of the forearm was to be avoided and active elbow flexion was limited to <500 g in the hand for 6 weeks postoperatively. Following this, we advised the patients to avoid lifting heavy items >1 kg for another 6 weeks.

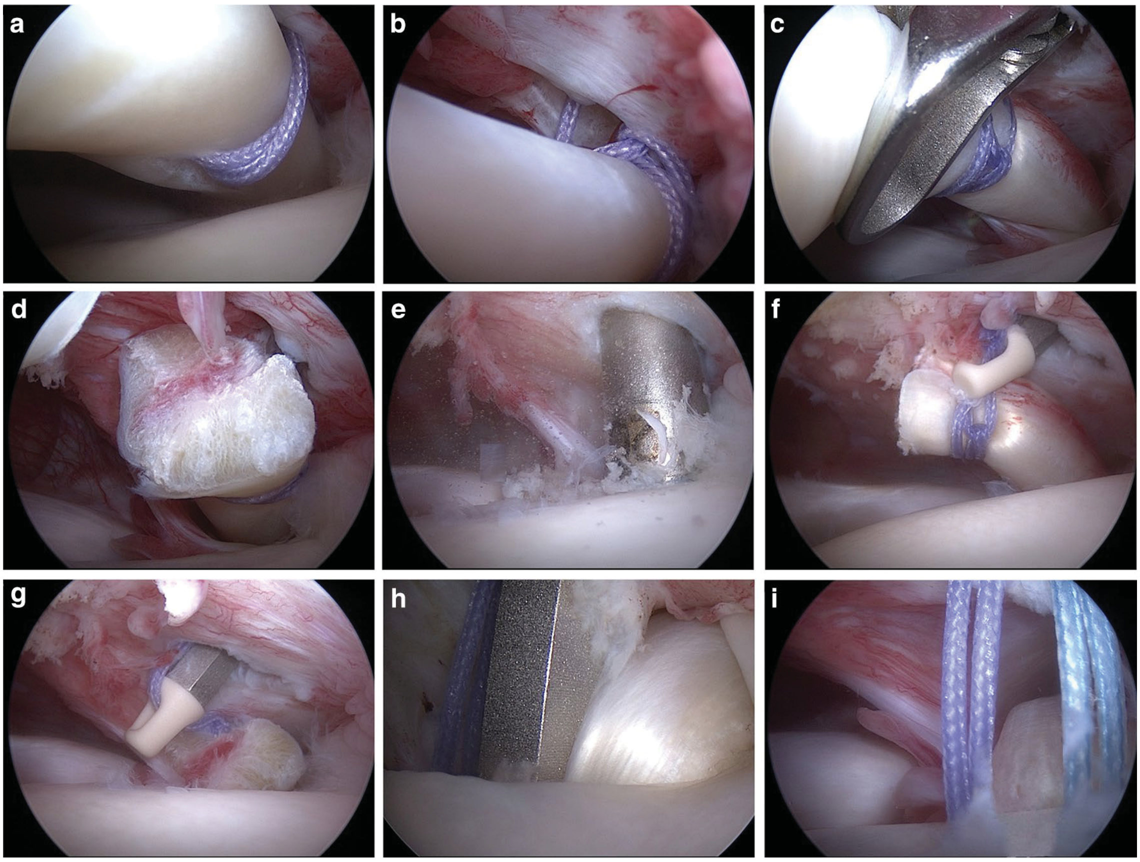

Fig. 2 Glenohumeral arthroscopy, *right* shoulder, beach chair position, view from the posterior portal, working from the anterior portal: LHB is secured by a modified lasso-loop stitch (**a** + **b**); LHB tenotomy is performed directly proximal to the stitch using a 45° right angulated punch (**c**). A 20-mm-deep drill hole is created using a spiked drill (**e**). The tip of the tendon is guided with the arming suture in the eyelet of the SwiveLock™ to the *bottom* of the bony canal, and intraosseous tendon fixation is then conducted with screwing in of the 6.25-mm Bio SwiveLock™ Screw anterior to the tendon (**e**, **f**, **g**, **h**). The *two double*-suture limbs (one of the arming suture and the other of the SwiveLock™) can be cut now or used for an additional subscapularis tendon refixation (**i**)

Outcome evaluation

The subjective outcome, clinical scores, strength measurements and cosmetic evaluation of the Popeye-sign deformity were assessed prior to, then 3, 6, 12 and 24 months after surgery in all 17 patients. Elbow flexion strength was evaluated in 10° (patient standing) and 90° (patient sitting). In addition, the upward-directed force in the O'Brien test with the shoulder positioned in 90° flexion, full internal rotation, 10°–15° adduction and the patient sitting was also assessed. Maximum and average force in Newton (N) was recorded continuously over 5 s with the IsoforceControl-Device (Medical Device Solutions AG, Oberburgüber, Switzerland) which is validated and commonly used for shoulder strength measurement [13]. Prior to surgery, the contralateral side was also measured. Ultrasound examination for verification of the intraosseous tendon fixation was performed at the 12-month follow-up examination.

In regard to the cosmetic appearance, the maximum circumference of the upper arm with the biceps in full active contraction and the forearm fully supinated was measured using a tape measure and compared to the contralateral side. For evaluation of a Popeye-sign deformity, the distance from the maximum circumference of the biceps belly to the lateral epicondyle of the humerus was measured at each follow-up examination. More than 20 % distalization compared to the preoperative status was defined as positive Popeye-sign deformity.

The clinical outcome was assessed using the Simple Shoulder Test (SST) [14], the American Shoulder and Elbow Surgeons Score (ASES) [22], the Constant Murley Score (CMS) [7] and a modified LHB score [32], which evaluates elbow function, occurrence of biceps cramps and cosmetic appearance.

Ethics statement

The Ethics Committee of the Medical Faculty, University of Duesseldorf granted ethical approval for this prospective trial. The registration number was 4173. Written informed consents were obtained from all subjects.

Statistical analysis

Statistical analysis was conducted using IBM SPSS Statistics 21 (Armonk, NY, USA). A review of all collected values of objective measurement methods as well as the patient-based tests for significance was performed comparing the affected shoulder and unimpaired contralateral shoulder using the *t* test for dependent samples, 3, 6, 12 and 24 months postoperative. For evaluation of the postoperative compared with the preoperative values, analysis of variance (ANOVA) was conducted. Statistical significance was indicated at a significance level of $P < 0.05$. All values obtained were analysed for Gaussian distribution using the Kolmogorov–Smirnov tests. For non-Gaussian distributed samples, the Wilcoxon matched-pairs test was used. Non-Gaussian distributed samples were expected in the patient-based tests with evaluation of the contralateral shoulder because all included patients demonstrated an unaffected joint. At first the values of the operated shoulder were analysed with Mauchly's test of sphericity to validate the repeated measures analysis of variance (two-way repeated measures ANOVA). If this could not be confirmed, Greenhouse–Geisser correction was used for calculation of significance.

The two-way repeated measures ANOVA was used for calculation of a significance level in all parameters measured over the four follow-up examinations. In case of a significant result of the ANOVA ($P < 0.05$), pairwise post hoc comparison of all postoperative values was conducted using the Bonferroni test in order to determine the interval of the maximum postoperative improvement.

Results

A total of 17 patients (70.8 %, median age 49.0 ± 10.1 years; range 22–69; 10 male; 58.8 %) could be followed up in the present study (Table 1). All 17 included patients underwent four follow-up examinations. The average follow-up was 3.2 ± 0.2 for the first, 7.2 ± 1.4 for the second, 14.1 ± 4.3 for the third and 29.3 ± 4.2 months for the final follow-up. There were no severe adverse events (haematoseromas, infections or nerve injuries) and no indication for further therapy. The dominant arm was affected in 70.6 %.

Strength measurements

In the preoperative examination, the evaluation of the elbow flexion strength in 10° ($P = 0.002$) as well as 90° ($P < 0.001$) elbow flexion showed a significant difference in comparison to the unimpaired contralateral arm. From 3 months postoperative, no significant difference to the contralateral arm could be seen over all follow-up examinations for both degrees of flexion (n.s. for 10° and 90°) (Fig. 3).

Analysis for the operated shoulder resulted in a significant improvement in 90° of flexion from 12 months onwards ($P = 0.001$) which allowed to narrow the time span where the improvement became significant to the interval of 6–12 months postoperative. At 24 months, an average increase in strength of 46.4 % (median 37.7 %) could be seen.

The measurements in 10° of flexion also showed an improvement compared to the preoperative values for the operated shoulder but not significant over the four follow-up examinations (n.s.).

In regard to the upward-directed force measured in the O'Brien position, a significant difference ($P < 0.001$) between the operated and the unimpaired shoulder could be detected preoperative. During follow-up no significant difference to the contralateral side could be seen at 6 (n.s.) and 12 months (n.s.) postoperative, but at 24 months a decrease resulted in the reoccurrence of a significant difference when compared to the contralateral arm ($P = 0.012$). Improvement of the O'Brien force in comparison with the contralateral side over all measurement points was not significant (n.s.).

Popeye-sign deformity and upper arm circumference measurements

Successful tenodesis could be verified by postoperative ultrasound in all patients 12 months postoperatively with the biceps tendon emerging from the drilling hole and the interference screw placed flush in the osseous canal. Nevertheless, three patients (17.6 %) showed a distalization of the biceps belly of >20 % compared to the preoperative position.

Evaluation of the maximum upper arm circumference under biceps contraction (n.s.) and the distance of the muscle belly to the lateral epicondyle of the humerus (n.s.) did not show significant changes. Subgroup analysis of patients with and without biceps distalization in regard to the improvement of elbow flexion strength in 10° (n.s.), 90° (n.s.) and the O'Brien force (n.s.) did not show significant differences postoperatively.

Clinical scores

SST, ASES and the total CMS score showed significant improvement in the postoperative follow-up. For all scores, the improvement was significant already 3 months postoperatively (Fig. 4, Table 2).

As the LHB score was not included in the preoperative assessment, statistical analysis was not performed (Table 2). No patients reported pain while resting. Two patients reported cramps in the biceps, which disappeared in days in one patient, and weeks in the other. At final follow-up after 24 months, 16 of 17 patients would choose this operation also for the contralateral side if similar complaints would occur. Furthermore also 16 patients would recommend this procedure to a friend or family member.

Table 1 Patient details, lesion types and associated pathologies

Demographics	
Age, median (range), years	49.0 (22–69)
Sex, male: female, number	10:7
Dominant arm affected	70.6%
Type of lesion	n
SLAP type II[a]	10
SLAP type III[a]	4
SLAP type IV[a]	1
Pulley type I[b]	1
Pulley type II[b]	1
Associated pathologies	n
Simultaneous acromioclavicular joint resection and subacromial decompression	9

[a] According to Maffet et al. and Snyder et al. [16, 36]

[b] According to Habermeyer et al. [11]

Discussion

The most important finding of this study was a significant increase in elbow flexion force in 90° of flexion as well as the clinical scores following biceps tenodesis compared with the preoperative status and without significant difference to the contralateral unaffected arm agreeing with our first hypothesis. It is the first study analysing the influence of biceps tenodesis on elbow flexion strength comparing the preoperative status with postoperative measurements at defined intervals.

For biceps tenodesis, various techniques have been described, including implant free bone tunnel and keyhole techniques using various suture anchors, bi- and unicortical buttons and interference screws for fixation. The intraosseous single tendon limb fixation using an interference screw has proven biomechanically superior with a primary stability of >200 N and has been defined as the gold standard [1, 3, 8, 15, 26, 28].

In regard to the anatomical position, an advantage of the proximal suprapectoral tenodesis performed from the glenohumeral space at the entrance of the bicipital groove is the option for a simultaneous subscapularis repair for example in pulley lesions without the necessity of additional anchors.

Up to now there is no evidence that indicates a clear superiority of either the subpectoral or suprapectoral position in regard to the clinical outcome [9]. Agreeing with our findings, Brady et al. [6] have recently published a very low complication rate of 4 % after arthroscopic proximal biceps tenodesis similar to our technique. However, also mini-open subpectoral tenodesis with intraosseous tendon fixation has shown to have excellent results [23].

Recently, Moon et al. [24] analysed the resected, remaining proximal tendon after subpectoral biceps tenodesis and identified biceps tears accompanied by tenosynovitis reaching below the bicipital groove in 28 of 35 patients (77.8 %) but whether this would have a clinical significance if treated by suprapectoral tenodesis remains unclear. Nevertheless,

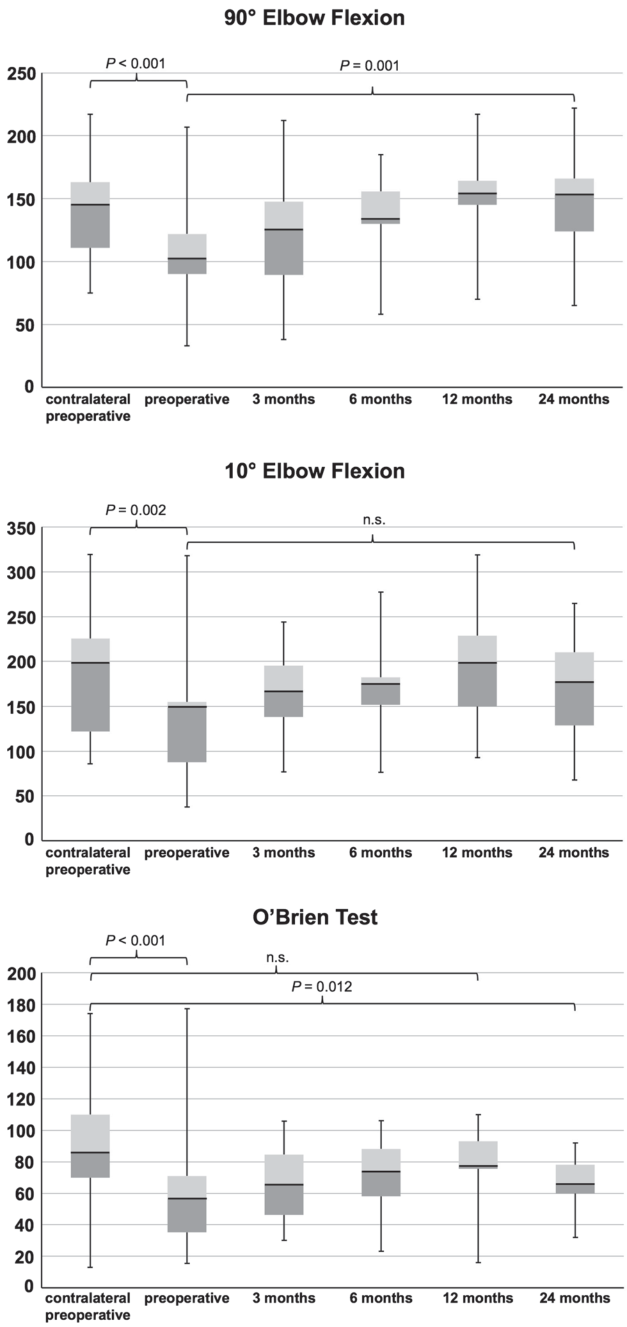

Fig. 3 *Boxplot* analysis of the strength measurements in comparison with the preoperative status of both shoulders. Mean force in Newton; *horizontal line* = median

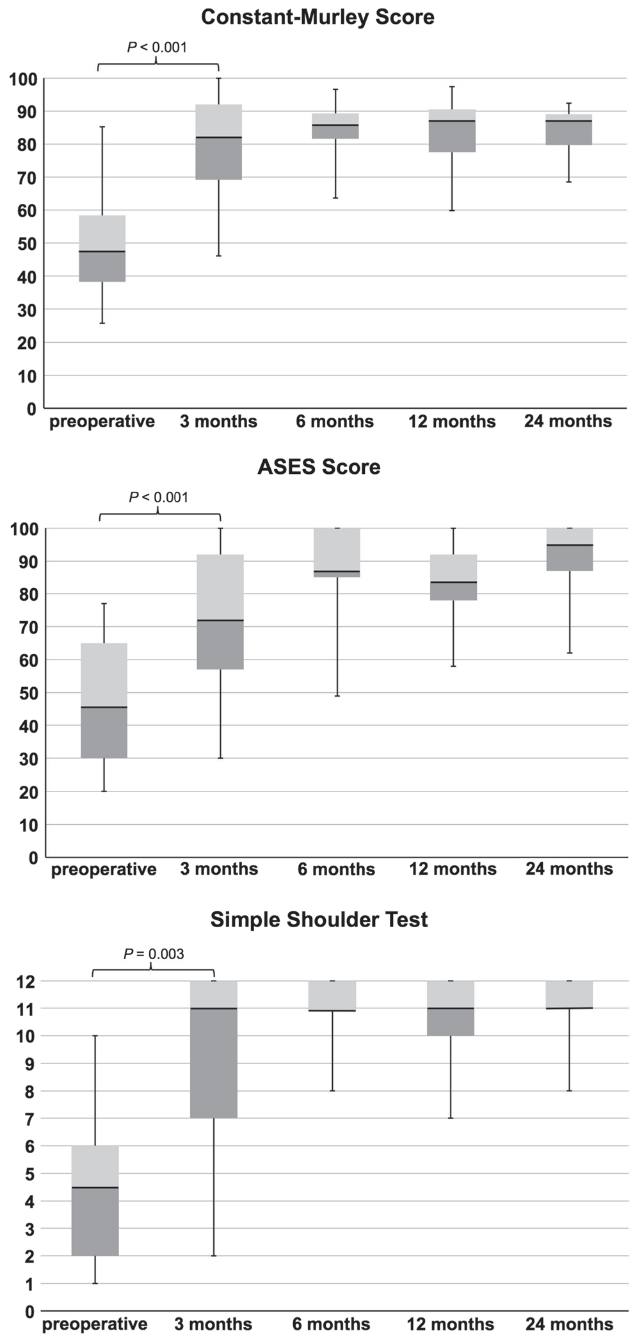

Fig. 4 *Boxplot* analysis of the clinical scores in comparison to preoperative. *ASES* American shoulder and elbow surgeons society, *horizontal line* = median

one disadvantage of the open subpectoral tenodesis remains the risk of neurovascular complications [17, 33].

Werner et al. [40] reported a higher rate of postoperative stiffness in patients treated with arthroscopic distal suprapectoral tenodesis performed from the subdeltoid space compared to those who underwent mini-open tenodesis in subpectoral position. These results cannot be confirmed by the present study with tenodesis in the proximal suprapectoral position as none of our patients showed stiffness during the follow-up examinations. One explanation for the postoperative stiffness could be a higher amount of soft tissue sacrificing in subdeltoid arthroscopy. An additional reason could be that the patients were immobilized for 6 weeks in a sling postoperative. This stands in contrast to the treatment of our patients with isolated LHB lesion who underwent early functional physiotherapy

Table 2 Clinical scores outcome overview

	Preoperative	3 months	*P* value Pre versus 3 months	6 months	*P* value Pre versus 6 months	12 months	*P* value Pre versus 12 months	24 months	*P* value Pre versus 24 months
SST	4.5 ± 3.0	9.6 ± 3.3	$P = 0.003$	10.9 ± 1.1	$P < 0.001$	10.7 ± 1.5	$P < 0.001$	11.1 ± 1.2	$P < 0.001$
ASES	45.6 ± 20.7	71.8 ± 23.7	$P = 0.006$	85.0 ± 16.0	$P < 0.001$	83.5 ± 13.2	$P < 0.001$	90.4 ± 12.8	$P < 0.001$
CMS total	50.1 ± 17.5	79.4 ± 15.7	$P < 0.001$	82.8 ± 10.2	$P < 0.001$	84.6 ± 9.5	$P < 0.001$	84.0 ± 7.0	$P < 0.001$
Pain	5.2 ± 3.1	11.3 ± 3.2	$P < 0.001$	12.9 ± 2.9	$P < 0.001$	13.1 ± 2.2	$P < 0.001$	13.4 ± 2.3	$P < 0.001$
ADL	8.8 ± 4.3	15.6 ± 4.6	$P < 0.001$	17.4 ± 3.9	$P < 0.001$	17.2 ± 3.4	$P < 0.001$	18.0 ± 2.5	$P < 0.001$
Mobility	23.9 ± 9.9	35.1 ± 6.2	$P = 0.003$	37.2 ± 3.7	$P < 0.001$	38.9 ± 2.5	$P < 0.001$	39.2 ± 2.1	$P < 0.001$
Strength	12.3 ± 6.5	13.3 ± 4.6	n.s.	15.0 ± 4.5	n.s.	15.4 ± 5.6	n.s.	13.4 ± 3.3	n.s.
LHB score	–	15.0 ± 3.1		15.9 ± 1.7		15.9 ± 1.6		16.8 ± 1.0	

SST simple shoulder test, *ASES* American shoulder and elbow surgeons society, *CMS* Constant Murley score, *ADL* activities of daily living

without restriction of glenohumeral motion from the first day postoperatively.

Our postoperative rehabilitation protocol was developed on the basis of biomechanical studies in which the intraosseous single-limb fixation resulted in the highest primary stability [15, 26, 28]. According to Nordin, the load of 50 N on the proximal biceps tendon in 90° elbow flexion is increased to 112 N when holding a weight of 1 kg in the hand [25]. Our rehabilitation protocol was based on these results and accordingly forced supination of the forearm was to be avoided and active elbow flexion was limited to <500 g in the hand for 6 weeks postoperatively and <1 kg for another 6 weeks. Therefore, the microprocessor-assisted strength measurement was first conducted 3 months after surgery. A decrease in elbow flexion force has been proven as effective parameter to evaluate LHB-associated functional impairment [34]. Recently Kerschbaum et al. [12] reported that despite good functional results, 31 of 45 (69 %) patients developed a Popeye-sign deformity following epiosseous suprapectoral tenodesis using a knotless suture anchor technique. In the biomechanical analysis epiosseous tenodesis with a suture anchor resulted in mean primary stability of only 111 N in contrast to 218 N for intraosseus tenodesis using an interference screw as in the present study [28]. This could contribute to the high rate of objective Popeye-sign deformity in the results presented by Kerschbaum et al.

The results of the force measurements and the patient-based scores showed a significant improvement and therefore have proven to be eligible parameters for outcome evaluation. These results are comparable to prior studies evaluating biceps tenodesis [19, 32]. In the study by Mazzocca et al., one out of 41 patients developed a Popeye-sign deformity with complete tendon dislocation from the osseous canal. There is no further information about a certain biceps belly distalization after tenodesis in this study and a precise definition of Popeye-sign deformity is not described either. In the present study, three patients (17.6 %), two at 12-month follow-up and one at 3 months, developed a biceps belly distalization despite the tendon could be identified in correct position in the osseous canal by ultrasound and the statistical sub-analysis did not show any significant changes in elbow flexion strength.

Werner et al. [41] recently published biomechanical results indicating that arthroscopic distal suprapectoral tenodesis bears a higher risk of biceps overtensioning. This might contribute to a partial pull out but by dissecting the tendon 20 mm proximal to the bicipital groove, suture fixation over 20 mm length and also usage of a 20 mm osseous canal as in our technique, the initial length and tension can be preserved. A partial tendon pull out due to insufficient primary stability might be a further explanation. Mazzocca et al. performed a mini-open subpectoral arthrodesis with an extra-articular baseball-stitch tendon fixation, using a larger drill hole of 8 mm as well as a larger 8 × 12 mm interference screw. A suboptimal relation of tendon size, screw (6.25 mm) and drill hole diameter (6.5, 7.0 mm) could be the reason for a partial tendon pull out and consecutive muscle belly distalization in the present study. Based on these results, the 6.25 × 23 mm Bio SwiveLock™ was changed to a 7.0 × 19 mm Biocomposite (BC) SwiveLock™, which was not yet available when the study was conducted. With usage of an identical 6.5 or 7.0 mm diameter drill depending on the tendon size, the larger diameter of the screw seems to result in a higher press-fit. A further reason for the implant exchange was the described rate of periimplantary osteolysis using poly-L-lactic acid (PLLA) implants [20].

ANOVA showed a significant improvement of the force measurement in 90° elbow flexion in the timespan of 6–12 months postoperative. No significant difference to the contralateral side was seen after 3 months in both degrees of flexion. For the O'Brien force, no significant difference was seen at 6 months but reoccurred at 24 months. Whether this decrease occurs due to a remodelling of the biceps or altered biomechanics remains speculative at this point.

Nevertheless, this decrease was not reflected in the other outcome parameters as we saw a continuous improvement in the SST, ASES and CMS scores. The strength measurement in 10° of flexion did show an improvement without significant difference to the contralateral shoulder from 3 months onwards but the increase in the operated shoulder compared to preoperative was not significant. A higher contribution of the brachial muscle in this low degree of elbow flexion is a possible explanation. No comparative studies have been published explaining these results.

A specific objective assessment for biceps belly distalization has been developed which is a major strength of this study given the fact that the term "Popeye-Sign" as used in several other studies has not been precisely defined yet. We followed a prospective study design including only isolated biceps lesions with exclusion of rotator cuff tears, osteoarthritis and fractures to specifically focus on the biceps tendon. The surgical technique as well as the rehabilitation concept was based on biomechanical studies. All pathologies were evaluated with respect to common standard classifications. The all-arthroscopic approach avoids tendon arming outside the joint, which could bear a risk for contamination. Biceps-specific tests and furthermore items evaluating the activities of daily living, pain and patient satisfaction have been included in the outcome evaluation.

Potential study limitations should be considered. The low number of patients and the lack of a sample size calculation are based on the strict inclusion criteria limited to isolated pulley or SLAP lesions. There has not yet been published a study analysing biceps tenodesis for isolated biceps lesions which could serve as a base for sample size calculation. A further limitation is the absence of a supination strength evaluation, which could not be conducted reliably at the beginning of the study due to the necessity of a calibrated torque measurement. Available studies show 11 % [37], respectively, 21 % [18] loss of forearm supination strength in patients with proximal LHB tendon rupture. Other studies did not see any difference in elbow flexion as well as forearm supination strength following biceps tenotomy or tenodesis in comparison with the unaffected contralateral side [34, 42].

In regard to the clinical relevance, next to early functional postoperative mobilization of the shoulder, relief from LHB-associated complains, restoration of flexion strength and furthermore preservation of biceps muscle cosmesis could be achieved with the analysed technique.

Conclusions

Proximal suprapectoral intraosseous single-limb biceps tenodesis performed from the glenohumeral space for the treatment of isolated biceps lesions provides good-to-excellent clinical results with significant improvement of elbow flexion strength in 90° of flexion as well as the clinical scores without significant difference to the unaffected contralateral side. Even though the refixed tendon is entering the intraosseous canal, a distalization of the maximum circumference of the upper arm and biceps cramps cannot be avoided in all patients.

Compliance with ethical standards

Conflict of interest The senior author received royalties and consultant payments from Arthrex Inc., Naples, Florida, USA and Limacorporate S.p.a., Udine, Italia that are not related to this work. The authors declare that they have no conflict of interest.

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ARTHROSCOPY AND SPORTS MEDICINE

Biceps tenodesis versus tenotomy in isolated LHB lesions: a prospective randomized clinical trial

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Abstract

Introduction Currently there exists no clear evidence concerning the surgical treatment of LHB lesions with either tenotomy or tenodesis. The aim of the study is therefore to evaluate elbow flexion and forearm supination force as well as the biceps muscle distalization according to both techniques in isolated LHB lesions.

Methods Consecutive patients aged 40–70 years with shoulder arthroscopies for isolated SLAP or biceps pulley lesions were prospectively randomized to arthroscopic suprapectoral intraosseous LHB tenodesis or tenotomy. Pre-, 6 and 12 months postoperatively, the SST, ASES, Constant–Murley and LHB scores were recorded. The elbow flexion force was measured in 10°/90° flexion, the supination force in neutral/pronation position. In addition, the maximum upper-arm circumference and its position relative to the radial epicondyle of the humerus were evaluated preoperatively and in follow-up.

Results 20/22 patients (mean age 52.0 ± 8.5; range 36–63 years, 11 male) completed the follow-up. 9/20 were treated with LHB tenodesis (mean age 51.5 ± 9.5; range 37–63 years, 7 male) and 11/20 with tenotomy (mean age 52.8 ± 8.0; range 36–62 years, 4 male). The force measurements and scores showed no significant difference after 12 months. Tenodesis achieved a significant increase in force 6 months postoperatively compared to preoperatively. One tenodesis patient and three tenotomy patients showed a postoperative popeye-sign deformity.

Conclusion This prospective randomized study comparing LHB tenodesis and tenotomy in isolated LHB lesions has shown no significant difference in elbow flexion and forearm supination force and clinical scores after 12 months. After LHB tenotomy, there was a non-significant trend for a higher rate of popeye-sign deformities of the upper arm and biceps muscle cramps.

Keywords Biceps · SLAP lesion · Biceps pulley lesion · Tenodesis · Tenotomy · Thrower shoulder

Introduction

Tears of the proximal long head of biceps tendon (LHB) as SLAP lesions at its origin or biceps pulley lesions more distally resulting in LHB instability in the glenohumeral joint are common causes of persistent shoulder pain.

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If conservative treatment is not successful, surgical therapy is indicated. In particular, the focus is on pain reduction and functional improvement. In young patients, a repair of the SLAP complex is indicated, whereas in patients over 35 years tenodesis tends to show better results [5]. Concerning the options for tenodesis, both open and arthroscopic techniques as well as a proximal or distal suprapectoral and a subpectoral position have been established [4, 14, 24]. Here, intraosseous tendon fixation using interference screws results in the highest primary stability [11, 21]. In our own research group, a technique of arthroscopic proximal suprapectoral tenodesis with lasso-loop stitch tendon securing and intraosseous single-limb LHB interference screw fixation was developed, biomechanically tested and clinically evaluated [20, 33].

LHB tenodesis and tenotomy have shown comparable results in regard to pain reduction and functional improvement [2, 7]. Simple tenotomy also shows good clinical long-term results without evidence of fatty infiltration or atrophy of the biceps muscle [29]. It is unquestioned that distal biceps tendon rupture results in a significant loss of elbow flexion and supination force [27, 30] but in regard to LHB tenotomy, varying results are reported [25, 31]. After tenotomy, a visible distalization of the muscle belly (popeye-sign deformity of the upper arm) and cramps in the area of the ventral upper arm are more common [10, 26].

Frost et al. showed in their comparative review that the incidence of a postoperative popeye-sign deformity is higher after tenotomy and patients < 60 years of age may perceive a reduced elbow flexion force. The authors also concluded that currently no higher-level evidence exists comparing both therapeutic surgical options and furthermore, that several techniques for biceps tenodesis do not result in sufficient primary or even secondary stability, making it difficult to compare tenotomy with a sufficient tenodesis [8]. To date, there is a lack of evidence and a prospective randomized trial comparing LHB tenotomy and tenodesis for the treatment of isolated LHB lesions has not been published yet. Therefore, the main goal of this study is the prospective randomized evaluation of elbow-flexion and supination force, specific objectification of a popeye-sign deformity and established clinical scores after sufficient primary stable biceps tenodesis or tenotomy for the treatment of isolated LHB lesions without concomitant rotator cuff pathologies. It has been hypothesized that a primary stable LHB tenodesis using an interference screw is significantly superior to tenotomy both in terms of the clinical scores and restoration of elbow flexion and supination force. It was further hypothesized that a popeye-sign deformity and upper arm cramps are more common after tenotomy.

Patients and methods

Study population

Defined as inclusion criteria were isolated SLAP lesion type II–IV according to Snyder and Maffet [18] in patients 40–70 years of age. Exclusion criteria included full thickness rotator cuff tears, osteoarthritis higher than grade II according to Samilson and Prieto [22] in the standard preoperative radiograph, postoperative trauma affecting the operated shoulder, as well as malignant disease and joint infection.

Clinical scores and force measurements were assessed preoperatively, 6 and 12 months postoperatively. Complications were documented. Study enrolment and the first data collection took place the day before surgery. Randomization was conducted using 22 blinded sealed envelopes including a note inside with "TD" ($n = 11$) or "TN" ($n = 11$), respectively. The envelope was opened directly at the beginning of each operation after having confirmed indication for LHB treatment and after having checked the inclusion and exclusion criteria.

Surgical technique

The operative therapy of tenodesis (Fig. 1) was conducted by the senior author in all included patients in a modification of the technique already published and evaluated [13, 33]. The operation is performed in standard beach chair position. The elbow is placed in 90° flexion, the forearm in neutral position in an arm holder. After establishing the standard portals, the tendon is secured intraarticularly via the anterior rotator interval portal with a modified lasso-loop-stitch directly at the entrance of the bicipital groove. The tendon is hereby secured and its anatomical position at the entrance of the groove is marked before tenotomy 20 mm proximally using a 45° angled punch. The LHB is then pulled out above skin level through the anterior portal. Here, the proximal 20 mm of the tendon are armed with a non-interlocking Krackow stitch using a no. 2 Orthocord suture (DePuy Mitek, Raynham, MA, USA). The suture limbs are inserted into the eyelet of a 7.0-mm BC SwiveLock™ (Arthrex, Naples, FL, USA) interference screw. The remaining tendon remnant is resected adjacent to the SLAP complex. In 45° glenohumeral flexion, a 20-mm-deep osseous canal in 135° angulation to the humeral shaft axis is now established with a hand-operated drill (Arthrex, Naples, FL, USA). Depending on the diameter of the biceps tendon, a 6.5-mm drill is used especially in female patients and a 7.0-mm drill in male patients.

Now the tendon is directed into the glenohumeral joint again and pushed 20 mm deep into the bone tunnel guided by the tip of the SwiveLock™. Hereby the suture marked position of the tendon directly at the entrance of the bicipital groove is kept exactly to preserve anatomical tension of the biceps muscle. Now the 19.5-mm-long SwiveLock™ is completely screwed in, herewith compressing and fixating the single tendon limb in the tunnel. At the end the screw ends up flush to the cortex with the tendon securely reinserted.

LHB tenotomy was performed in all patients by the senior author by transecting the tendon directly at the SLAP complex with an angulated punch.

In all patients, the subacromial space was inspected and a subacromial bursectomy and subacromial decompression were performed if indicated. Depending on the preoperative clinical and radiological findings, arthroscopic resection of the acromioclavicular joint was conducted.

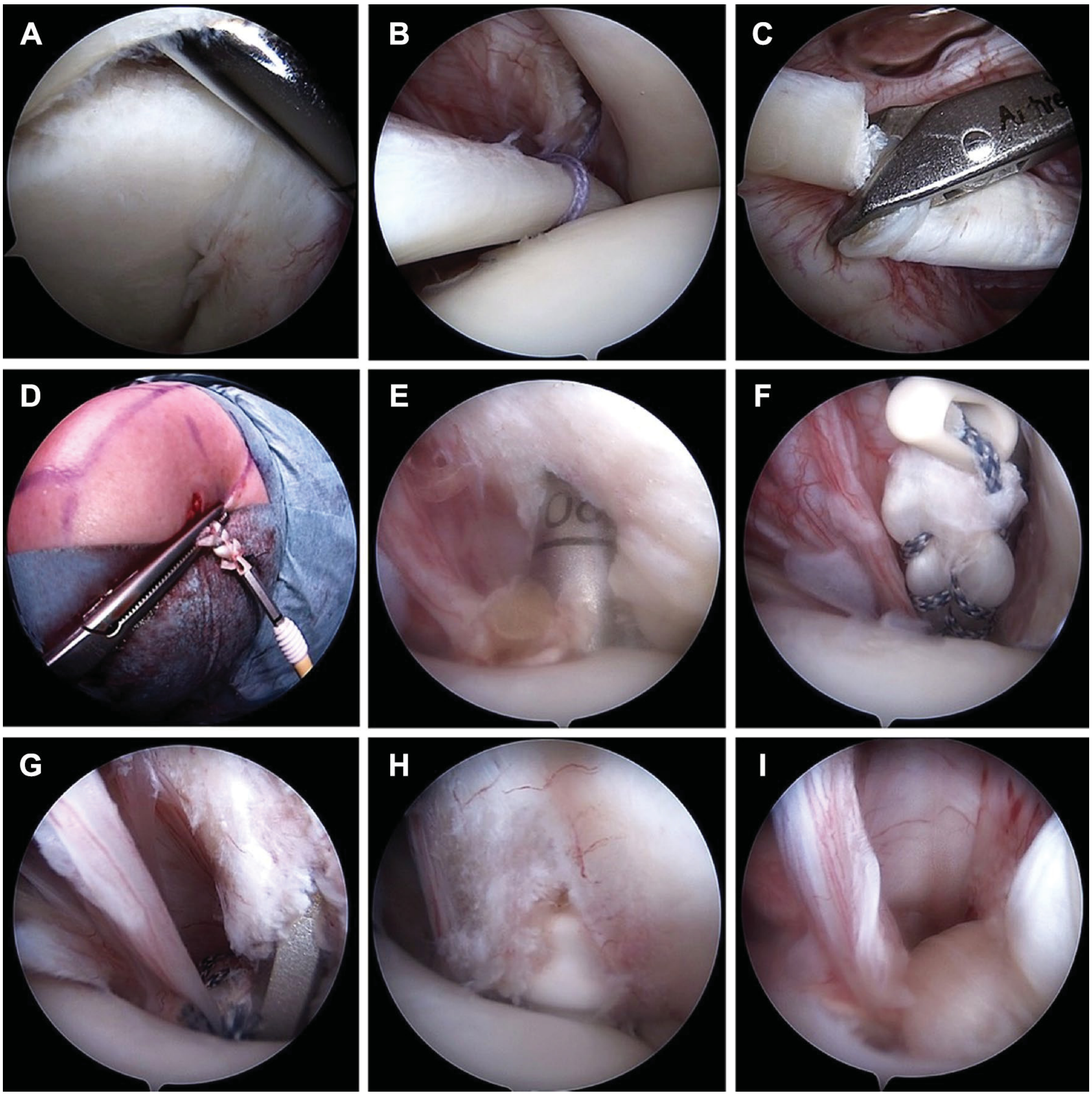

Fig. 1 Surgical technique of the tenodesis. Shoulder arthroscopy in a 45-year-old woman, right shoulder, beach chair positioning of the patient, view from the posterior standard portal. **a** SLAP-IIC lesion; **b** intraarticular securing of the LHB directly at the entrance to the bicipital groove with a modified lasso-loop stitch using a BirdBeak™ via the anterior rotator interval portal; **c** tenotomy of the LHB at the origin after securing; **d** the LHB is pulled above skin level, reinforced proximally to a length of 20 mm with a non-interlocking Krackow stitch and then placed at the eyelet of a 7.0 × 20 mm BC SwiveLock™ interference screw anchor; **e** manual drilling of a 6.5 × 20 mm osseous canal directly at the entrance of the bicipital groove; **f** guiding the tendon with the eyelet of the suture anchor into the osseous canal; **g** screwing in of the SwiveLock™; **i** the LHB lies flush between SSC and SSP tendon without impingement or soft tissue irritation. With intraosseous interference screw fixation, a high primary stability of the tenodesis is achieved

Rehabilitation protocol

Early functional physiotherapy with active and passive free glenohumeral motion without immobilization was allowed from the first day postoperatively. Elbow flexion was limited to less than 1 kg for 12 weeks postoperatively.

Objective outcome measurements

All measurements were conducted by the second author who was blinded for the type of surgical therapy. Preoperatively and at each follow-up appointment, the elbow flexion force was measured using the IsoforceControl microprocessor-controlled device (Medical Device Solutions AG, Oberburg, Switzerland). The flexion force was recorded continuously over 5 s with determination of the maximum and average in Newton (N) in 90° of elbow flexion with the patient sitting and in 10° of elbow flexion with the patient standing (Fig. 2). Preoperatively, the measurements were additionally performed on the contralateral side.

For the measurement of the supination force, a T-handle attached to a digital torque measurement adapter with 0.1 mm accuracy (Digital Torque Adapter 412 V1760, Hebesberger Messtechnik, Neuhofen, Austria) was fixed to the tabletop in a standard vise. The measurements were conducted with the shoulder in neutral position, the elbow flexed 90° and the patient sitting (Fig. 2). Three repeated measurements of the maximum force in Newton (N) were recorded in neutral position and in 90° pronation of the forearm with subsequent calculation of the mean value. Preoperatively, the measurements were additionally performed on the contralateral side.

Popeye-sign deformity

Preoperatively, the maximum biceps circumference of both upper arms in forearm supination and maximum contraction was measured and its distance to the lateral epicondyle in centimetre was documented (Fig. 3). At the follow-up examinations this distance was measured again on the operated side. An objective popeye-sign deformity was defined when a distalization of the maximum circumference by more than 20% compared to the preoperative status was present.

Standardized patient-based scores

As standardized scores the Simple Shoulder Test, the ASES [1], the age- and sex-specific Constant–Murley [3] and a modified LHB score [23] were included. In addition to information on elbow function and strength, the LHB score evaluates the occurrence of nocturnal biceps cramps and the external appearance of the upper arm contour an herewith subjective assessment of the popeye-sign deformity.

Statistical analysis

The statistical analysis was carried out using IBM SPSS Statistics (Armonk, New York, USA) in the latest version and in collaboration with the Coordination Centre for Clinical Trials (KKS) of the local University Hospital. Normal distribution was verified using the Kolmogorov–Smirnov test. As a parametric test method for analysing the mean values, the *t* test for dependent samples was carried out. To analyse the influence of the surgical therapy (tenotomy or tenodesis) on the force measurements and the clinical scores, bivariate regression analysis was conducted.

Results

A total of 22 patients were included and prospectively randomized for tenodesis or tenotomy. Two patients in the tenodesis group did not appear for the appointment 12 months postoperatively. 20 patients (mean age 52.0 ± 8.5; range

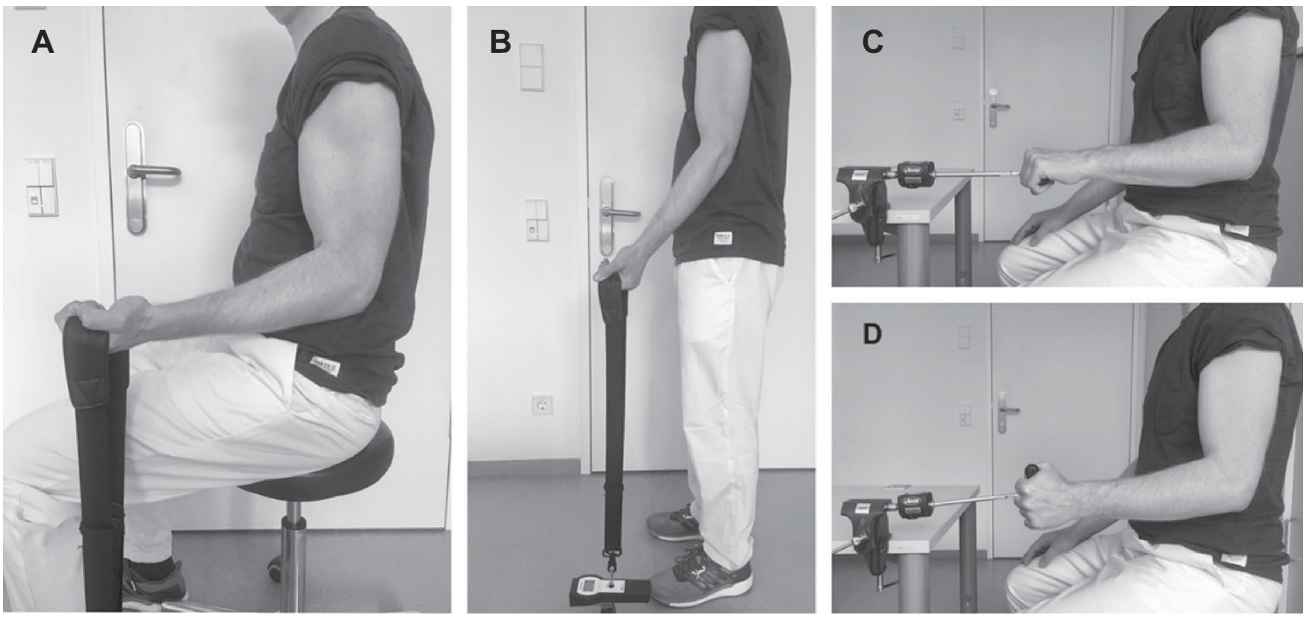

Fig. 2 Force measurements. **a** Measurement in 90° of elbow flexion; **b** measurement in 10° of elbow flexion. **c** Supination force with the forearm pronated; **d** supination force with the forearm in neutral position

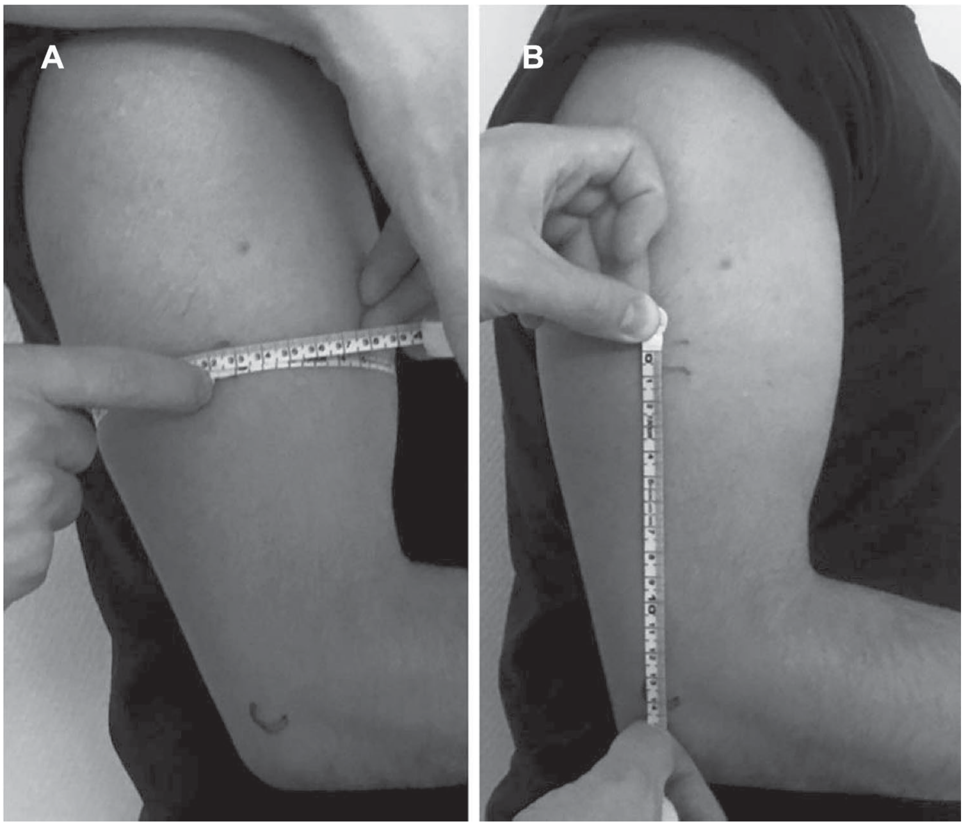

Fig. 3 Popeye-sign measurements. The maximum biceps circumference of both upper arms in forearm supination is measured in maximum contraction (**a**) and its distance to the lateral epicondyle in centimetre is documented (**b**). An objective popeye-sign deformity was defined when a distalization of the maximum circumference by more than 20% compared to the preoperative status was present at follow-up

Table 1 Patient details

Demographics	
Mean age ± SD (range)	52.0 ± 8.5 (36–63)
Gender, male:female	11:9
Type of LHB lesion	*n*
SLAP type II	15
SLAP type III	1
SLAP type IV	2
LHB tendinitis	2
Associated pathologies	*n*
Simultaneous acromioclavicular joint resection and/or subacromial decompression	17

36–63 years, 11 male) completed all follow-up examinations (Table 1). Tenodesis was conducted in 9/20 patients (mean age 51.5 ± 9.5; range 37–63 years, 7 male), tenotomy in 11/20 (mean age 52.8 ± 8.0; range 36–62 years, 4 male). In regard to age ($p = 0.45$) and gender ($p = 0.37$) no significant difference between the groups was seen.

Strength measurements

Tenodesis resulted in a significant increase in 10° and 90° elbow flexion force after 6 and 12 months in comparison to the preoperative values. After tenotomy no significant difference in 10° and 90° elbow flexion force was seen at 6 months postoperatively but 12 months postoperatively, a significant increase in 10° and 90° elbow flexion force was observed in comparison to the preoperative values (Table 2). For the supination force in the neutral and pronated position of the forearm no significant increase after 6 and 12 months in comparison to the preoperative values could be seen. In the direct comparison between tenodesis and tenotomy by bivariate regression analysis, the improvement of the flexion and supination force was not significant at 6 and 12 months postoperative (Fig. 4). The improvement in the flexion force in 10° flexion was greater in the tenodesis group than in the tenotomy group in all postoperative measurements ($p = 0.09$).

Patient-based clinical scores

In the clinical scores, apart from the force measurement in the CMS, a significant improvement for both tenodesis and tenotomy could be seen at 6 and 12 months (Table 3). The force measurement in the CMS was increased significantly in both groups at the 12 months follow-up. In the direct comparison by bivariate regression analysis there was no significant difference in the scores obtained between tenodesis and tenotomy (Fig. 5). The postoperative LHB score for the

Table 2 Force measurements

	Preoperative	6 months	12 months	Contralateral
Tenodesis				
90° elbow flexion	152.3 ± 59.9	166.8 ± 63.1*	172.0 ± 60.5*	180.9 ± 82.8
10° elbow flexion	154.3 ± 63.1	199.3 ± 63.3*	213.3 ± 54.0*	173.7 ± 68.6
Supination pronated	8.4 ± 4.4	9.2 ± 3.7	9.8 ± 3.6	9.2 ± 4.6
Supination neutral	9.5 ± 4.6	10.1 ± 4.1	10.7 ± 4.2	10.8 ± 4.7
Tenotomy				
90° elbow flexion	80.8 ± 43.9	91.1 ± 52.2	97.4 ± 50.6*	113.2 ± 43.9
10° elbow flexion	94.3 ± 38.2	103.3 ± 52.2	117.3 ± 52.2*	126.5 ± 49.4
Supination pronated	4.9 ± 2.7	5.2 ± 2.7	5.8 ± 2.8	6.2 ± 2.6
Supination neutral	5.3 ± 2.4	5.8 ± 2.6	6.7 ± 2.7	6.1 ± 2.1

Mean force in Newton ± SD

*$p < 0.05$

**$p < 0.01$

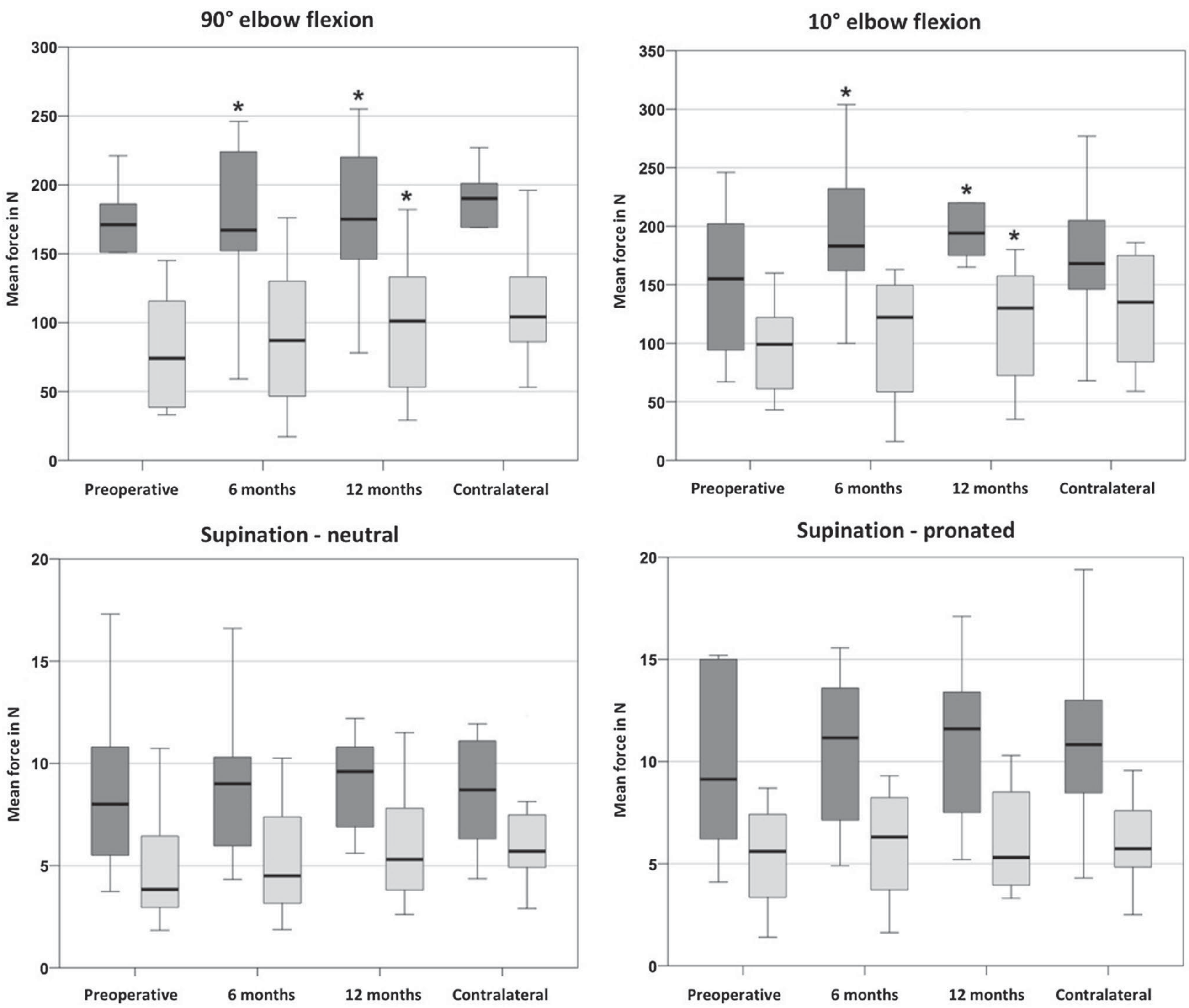

Fig. 4 Boxplot analysis of the flexion and supination force measurements. Dark grey box: tenodesis; light grey box: tenotomy, horizontal line = median. *$p < 0.05$ in comparison to preoperative

Table 3 Clinical scores outcome overview

	Preoperative	6 months	12 months
Tenodesis			
SST	6.1 ± 2.6	10.3 ± 2.1**	11.4 ± 1.1**
ASES	48.7 ± 14.8	85.9 ± 15.5**	95.2 ± 10.8**
CMS			
Pain	8.2 ± 2.4	12.1 ± 3.6*	14.56 ± 0.9**
ADL	10.9 ± 2.8	16.4 ± 3.6**	18.7 ± 2.0**
Mobility	29.3 ± 6.7	35.8 ± 3.4*	39.1 ± 1.4**
Strength	11.7 ± 4.5	13.9 ± 4.9	15.9 ± 4.9**
Total	60.1 ± 8.5	77.7 ± 10.2**	88.1 ± 7.5**
Tenotomy			
SST	5.0 ± 2.7	7.6 ± 3.3**	10.2 ± 2.2**
ASES	45.9 ± 20.7	68.5 ± 22.5**	76.9 ± 20.3**
CMS			
Pain	8.4 ± 3.4	12.1 ± 3.3*	12.6 ± 4.2*
ADL	7.9 ± 3.2	13.5 ± 4.3**	15.9 ± 3.5**
Mobility	26.2 ± 5.7	33.6 ± 4.8**	37.8 ± 3.4**
Strength	8.7 ± 5.8	9.2 ± 4.5	11.0 ± 5.2*
Total	50.9 ± 8.5	68.5 ± 14.0**	77.4 ± 11.8**

Mean ± SD

*$p < 0.05$

**$p < 0.01$

tenotomy group was 15.3 ± 2.2 after 6 months and 17.2 ± 0.6 points at 12 months. In the tenodesis group the score was 16.6 ± 1.6 after 6 months and 17.3 ± 1.1 at 12 months without significant difference in comparison.

Popeye-sign deformity

One patient (11%) after tenodesis and 3 patients (27%) after tenotomy showed an objective postoperative popeye-sign deformity ($p = 0.52$). In the LHB score, the same patient after tenodesis and the same three patients after tenotomy reported a visible difference in the upper arm contour representing a subjective popeye-sign deformity. In the LHB score, two patients in the tenotomy group reported cramps in the biceps at the 6-months follow-up. At the 12 months follow-up no patient reported any biceps cramps.

Discussion

The present clinical trial is the first prospective randomized evaluation of biceps tenodesis compared to biceps tenotomy in patients with isolated LHB pathologies including the evaluation of elbow flexion and forearm supination force, objective and subjective assessment of a popeye-sign deformity and established clinical scores.

The most important finding of this study was that neither the force measurements for elbow flexion and forearm supination nor the clinical scores revealed a significant difference between LHB tenodesis and tenotomy for the treatment of isolated biceps pathologies. In addition to these findings a not significant trend to a higher rate of popeye-sign deformities (27%) after biceps tenotomy compared with tenodesis (11%) and a higher rate of postoperative biceps muscle cramps following tenotomy were found.

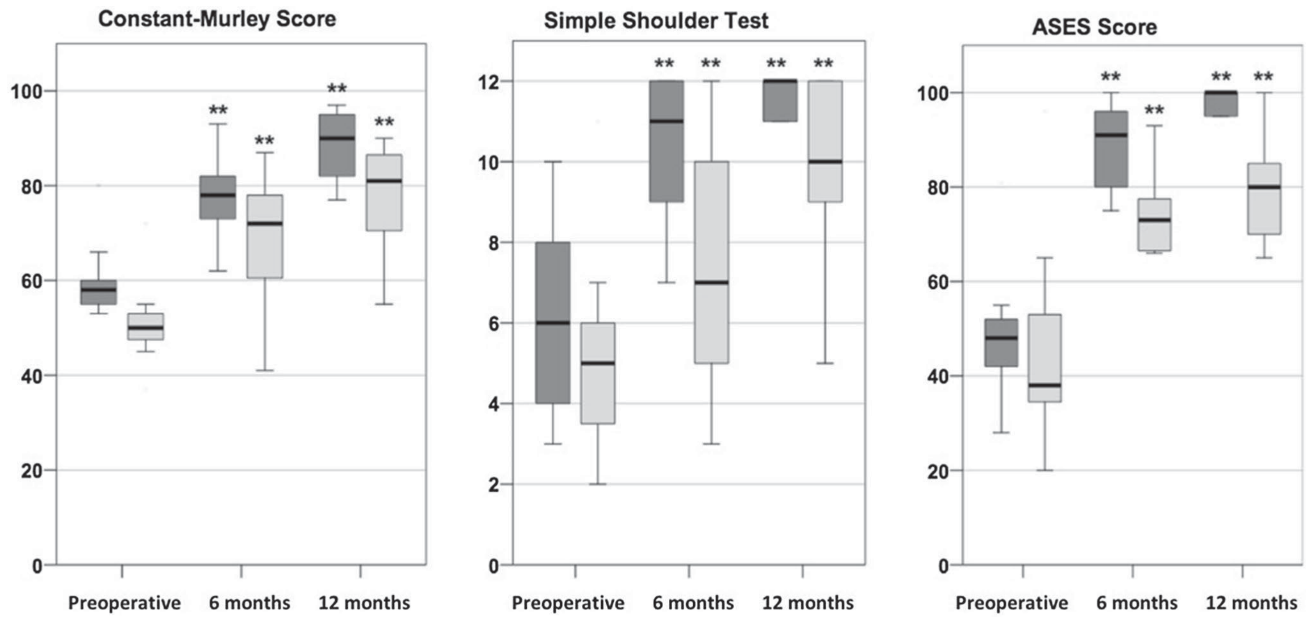

Fig. 5 Boxplot analysis of the clinical scores. Dark grey box: tenodesis; light grey box: tenotomy, horizontal line = median *$p < 0.05$ in comparison to preoperative; **$p < 0.01$ in comparison to preoperative

After both surgical options, LHB tenotomy and tenodesis, a significant increase in the elbow flexion force of the operated side compared to preoperatively without significant difference to the unimpaired contralateral side could be seen 12 months after surgery. Shank et al. also found no significant loss of force for both flexion and supination after tenodesis or tenotomy [25]. Zhang et al. randomized the treatment of the LHB in 151 patients with concomitant rotator cuff repair and found no difference in flexion or supination force as well.

In contrast, Kerschbaum et al. have reported in a retrospective study of preselected patients according to the decision criteria described by Hsu [12], a significantly higher flexion force in patients after knot-free epiosseous proximal suprapectoral tenodesis compared to tenotomy but without comparison to the preoperative status [16]. However, 6% of the tenodesis patients developed a subjective and 69% an objective popeye-sign deformity [17] which may be explained by the biomechanically proven lower primary stability (mean load to failure: 111 N) of epiosseous tenodesis compared to intraosseous tenodesis using an interference screw (mean load to failure: 218 N) [21].

Duff et al. have conducted flexion force measurements on 103 patients following tenotomy and found no significant decrease [6]. However, Wittstein et al. showed a significant reduction of the supination, but not of the flexion force in comparison to the contralateral side and to the treatment by tenodesis [31]. At a median follow-up of nearly 7 years after tenotomy, The et al. found a significant loss of flexion and supination force in their patient collective compared to the opposite side [28]. In the same study population, no muscle degeneration or fatty infiltration could be seen [29]. In the present study, tenotomy resulted in a subjective and objective popeye-sign deformity in 27% of the patients, which is comparable to other studies [6]. Here, the vinculum of the LHB may partially limit further distalization of the tendon below the bicipital sulcus [9]. If the proximal end of the LHB including a part of the SLAP is prominent enough, a certain *"autotenodesis effect"* is possible and the force needed to further distalize the tendon is significantly greater than if the tendon is severed in the distal intra-articular portion.

The allowance of free functional rehabilitation in the present study is based on biomechanical measurements that have shown a primary stability of > 218 N for the intraosseous LHB tenodesis with interference screw fixation [21]. For a comparable operative technique, Wolf et al. have reported a load to failure of 310 N. In the same study used as the basis for the ISAKOS recommendation in favour of LHB tenodesis the authors analysed 10 LHB tenotomies in a cadaveric biomechanical setting, of which 40% failed after a cyclic load of 50 N, the other 60% failed at a load of 110 N [32]. Nordin et al. were able to show that with 1 kg of load in the hand in elbow flexion a load of 112 N results at the proximal LHB [19]. Thus, for an early functional therapy after LHB tenotomy, a load of 1 kg in the hand would already be higher than the load to failure. Frost et al. have concluded in their comparative review that restrictive physiotherapy with immobilization following tenodesis may possibly reduce some benefits compared to tenotomy [8].

After tenodesis a greater increase especially in 10° flexion force, albeit not significant, compared to tenotomy could be seen in the present study. This may be explained by an improved pretensioning of the biceps muscle after tenodesis. The low incidence of popeye-sign deformities after LHB tenodesis in this study with consecutively less biceps cramps despite early functional rehabilitation without limitation of the shoulder activity is most likely based primarily on the high primary stability (> 218 N) of the intraosseous tendon fixation [21]. In the present study, using the absorbable 7.0-mm biocomposite interference screw for tenodesis, 11% of the patients showed a subjective and objective popeye-sign deformity at 12 months compared to 18% in our study population in which the absorbable 6.25 mm PLLA screw was used [13, 33] with the same size of the drilled bone tunnel (6.5 in female or 7.0 mm in male patients) which may indicate a further increase in primary stability by using the larger screw.

Limitations

No power calculations were conducted prior to the beginning of the study and the number of patients is low for a prospective randomized study design. The low number of included patients is mainly based on the restrictive inclusion criteria with isolated LHB pathologies. Two patients in the tenodesis group did not appear at the 12 months follow-up appointment.

Although established and used in most LHB studies with flexion force measurements, the comparison with the healthy contralateral side can be seen critically. Kerschbaum et al. showed in healthy volunteers that there are significant differences in elbow flexion and supination strength between the dominant and non-dominant arms, and therefore, do not recommend to use the non-operated side as a reference [15].

Strengths

The study presented follows a prospective randomized study design including only isolated LHB lesions. Surgical therapy was performed standardized by a single surgeon (senior author). The operative technique for tenodesis was developed on the basis of biomechanical studies and has already been successfully evaluated after 12 and 24 months [13, 33]. Standardized and internationally validated patient-based scores were used. All force measurements were performed standardized by a single investigator (second author) who was blinded for the patients' surgical treatment option.

Although there was no significant benefit of tenodesis over tenotomy in terms of strength restoration and clinical scores in the present and most available studies, a recent survey among members of the American Shoulder and Elbow Society showed that 94% of the specialized shoulder surgeons ($n = 142$) would prefer an LHB tenodesis in a 45-year-old patient with an isolated LHB lesion. In a 50-year-old patient with a concomitant rotator cuff tear, 60% of the surgeons would still choose a tenodesis [4]. Hsu postulated that especially young and slender patients with high functional and cosmetic demands benefit from tenodesis [12]. This certainly remains in our opinion valid for further practice even if, as confirmed by the present work, the objective parameters do not provide any justification.

Conclusion

This prospective randomized study comparing a primary stable biceps tenodesis and biceps tenotomy in isolated LHB lesions revealed no significant differences in flexion and supination strength as well as in the clinical scores after 12 months. Following LHB tenotomy, there was a trend to a higher rate of cosmetic deficits in the form of a popeye-sign deformity of the upper arm with distalization of the biceps muscle and a higher rate of temporary biceps muscle cramps.

Compliance with ethical standards

Conflict of interest All authors declare that they have no competing interests. The senior author receives royalties by Arthrex, (Freiham, Germany), Smith & Nephew (Hamburg, Germany) and Lima (Hamburg, Germany) which have no influences on this study.

Research involving human and animal participants All procedures performed in studies involving human participants were in accordance with the ethical standards of the institutional and/or national research committee and with the 1964 Helsinki declaration and its later amendments or comparable ethical standards. The local ethics committee approved this study (Registration Number 4647R).

Informed consent Written consent was given by all participants.

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