Distal Biceps Tendon Tears: Diagnosis and Treatment Algorithm

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Abstract

» Distal biceps tendon (DBT) tears occur most commonly in middle-aged men after a sudden, forced eccentric contraction of the flexed elbow.

» An understanding of the multiple risk factors, mechanisms, and pathophysiological causes is essential for proper and timely diagnosis.

» High clinical suspicion and routine physical examination with appropriate special examination tests, including the hook test, the passive forearm pronation test, the biceps crease interval test, and the bicipital aponeurosis flex test, can help with rapid and accurate diagnosis and guide appropriate and timely management.

» Treatment for DBT tears depends on the extent (complete versus incomplete) and timing (acute versus chronic) of the injury, and options include nonoperative management, repair, and reconstruction with or without repair of the bicipital aponeurosis.

In this review article, we provide an updated overview of distal biceps tendon (DBT) tears. A good understanding of the epidemiology, risk factors, mechanisms, diagnostic tools, and current repair methods allows for prompt diagnosis and appropriate treatment. This review incorporates new information regarding physical examination findings, magnetic resonance imaging (MRI), and some treatment strategies, including recent knowledge about the controversial bicipital aponeurosis (BA) repair. We propose a practical treatment algorithm that has been guided by the available evidence.

Epidemiology

Three percent of all biceps injuries are DBT tears[1]. As clinicians' knowledge and tools for diagnosis have become more sophisticated, there has been increased recognition of this injury and a subsequent increase in its reported incidence. Safran and Graham initially reported an incidence of 1.2 per 100,000 patients[1]. However, their study was underpowered because it included only 14 patients with biceps ruptures. In a more recent study that assessed a national database, Kelly et al. estimated an incidence between 2.55 and 5.35 per 100,000, with a mean age of presentation of 46.3 years. A vast majority of the tears occurred in men between the ages of 35 and 54 years[2].

Most injuries in men are complete ruptures; partial ruptures are less common[3]. In the literature, most of these injuries are described in case reports[4-6], and related robust studies are lacking. To our knowledge, the first case of partial rupture was reported by Nielsen in 1987[7]. Although the 2002 study by Safran and Graham reported a preponderance of injury in the dominant arm (86%), more recent studies have reported a more equal incidence in the dominant and nondominant arms[2,8]. Green et al. reported an 8% cumulative incidence of staggered bilateral biceps tendon ruptures in a consecutive series of biceps tendon repair, with most

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occurring in men[8]. This suggests that patients with an injury to 1 limb are at a substantially higher risk for injuring the contralateral limb.

DBT injuries are much more common in men (>95%) than in women. Jockel et al. analyzed a cohort of women with this injury[9]. They noted that the presentation differed from that in men, who usually present with complete tears: half of the women reported a more gradual onset of symptoms and a vast majority of them had partial tears. The women were also older at presentation (mean age of 63 years). This suggests a different mechanism and pathophysiology. The lower frequency in women follows general trends that are seen with other tendon injuries such as Achilles, patellar, and quadriceps tendon tears[10].

Risk Factors

DBT injuries occur nearly exclusively in middle-aged men and result from a sudden, forced eccentric contraction of the elbow, which is usually associated with heavy lifting or athletic activities. Multiple activities, especially those that put the elbow at risk for sudden eccentric flexion, are associated with DBT tears. No difference has been noted between those having a labor-intensive job and those who were more sedentary[2].

Epidemiological studies first identified smoking as a substantial risk factor for a DBT tear. Smoking was associated with a 2.2 to 7.5 times greater risk of rupture[1,2]. The correlation was strongest in the study by Safran and Graham[1], where the smoking rate was 43% in the injured population versus 9% in the uninjured population. One possible physiological explanation is exacerbation of the tendon's zone of hypovascularity[11].

Elevated body mass index (BMI) has also been associated with an increase in tendon injury. Proposed rationales have alluded to increased load on the tendon and a diminished response to microinjury[12]. A significant association has been noted with a BMI of >30 kg/m^2; 66% of patients in the injured group were obese in 1 study[2]. The same study showed that diabetes mellitus did not appear to be a significant risk factor overall or for patients who were <65 years of age ($p = 0.709$). Diabetes mellitus has been associated with the overall number of tendon ruptures requiring hospitalization; however, to our knowledge, there has been no study to date clearly linking diabetes to the pathogenesis of DBT ruptures[13].

Although no robust epidemiological study has specifically analyzed the association of anabolic steroid use with DBT tears, case reports[14,15] and the relationship of steroid use with other tendon injuries in general[16] suggest a likely correlation. Similarly, limited studies have shown trends with the use of the statin family of medications but no definitive statistical correlation[17]. Interestingly, wild-type transthyretin cardiac amyloidosis, a recognized cause of a subset of heart failure, has also been linked to DBT ruptures[18]. On average, ruptures preceded the diagnosis of heart failure by 5 years. Complete rupture after periarticular corticosteroid injection, use of oral anabolic steroids, chronic prednisone use, and the diagnosis of Cushing syndrome also has been reported[1,19-21].

Anatomy

Understanding the anatomy of the DBT and its insertion is essential to properly recognize the injury and be able to treat it appropriately (Fig. 1). There are 2 distinct insertions: the short head attaches distally on the radial tuberosity, and the long head attaches proximally, deep to the tendon of the short head. The short and long heads both contribute to flexion and supination, with the short head having a slightly higher contribution to flexion[22]. The DBT inserts onto the posterior ulnar aspect of the radial tuberosity, which lies on the ulnar side of the proximal aspect of the radius. The insertion angle has been noted to be approximately 30° to 45° relative to the coronal plane when the forearm is fully supinated[23]. The distal tendon externally rotates 90° as it crosses the elbow joint. A cadaveric biomechanical study demonstrated that the load necessary to cause failure increased as the elbow flexion angle decreased[24].

The lateral antebrachial cutaneous nerve (LABCN) and the posterior interosseous nerve (PIN) are near the tendon insertion. The LABCN exits at the antecubital fossa between the biceps

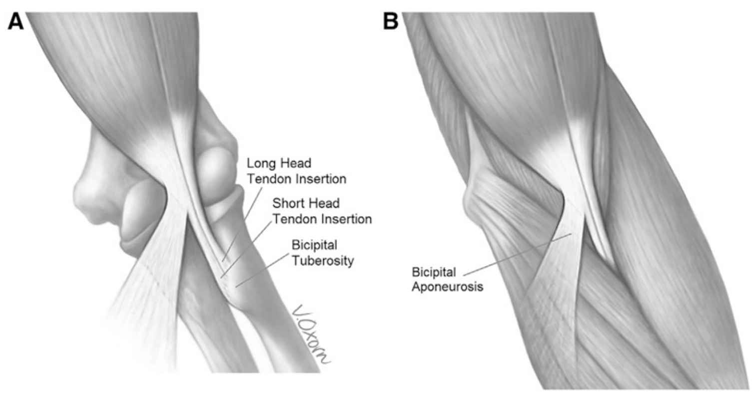

Fig. 1

Line art showing the anatomy of the DBT (**Fig. 1-A**) and the BA (**Fig. 1-B**). (Reprinted from J Should Elbow Surg, 22[7], ElMaraghy A, Devereaux M, The "bicipital aponeurosis flex test": evaluating the integrity of the bicipital aponeurosis and its implications for treatment of distal biceps tendon ruptures, 908-14, Copyright 2013, with permission of the Journal of Shoulder and Elbow Surgery Board of Trustees.)

and the brachialis and lies lateral to the tendon that overlies the brachioradialis muscle. The PIN also lies nearby laterally under the supinator muscle and near the posterior cortex of the radius. Both are susceptible to injury with laterally placed retractors[25] or instrumentation. The LABCN is more commonly injured, but the consequences of a PIN palsy are more serious[26]. Concomitant PIN entrapment[27] and median nerve compression[28] due to the initial injuries, not the fixation, have also been reported.

The BA fibers originate mostly from the medial border of the distal short head of the biceps muscle and tendon as a trapezoidal band of parallel fascia[29,30] (Fig. 2). The BA merges distally, fanning out and attaching to the superficial fascia of the forearm flexors as well as the ulna[31]. It links to the biceps tendon and pulls it distally and medially when the forearm flexor-pronator mass contracts[32]. Multiple functions have been attributed to the BA. It is a protective sheath for the underlying neurovascular structure and an additional anchor for the DBT, it contributes to proprioception based on forearm muscle contraction, and it contributes to elbow flexion[30,33]. A thickened BA can compress the median nerve and cause pronator teres syndrome[34].

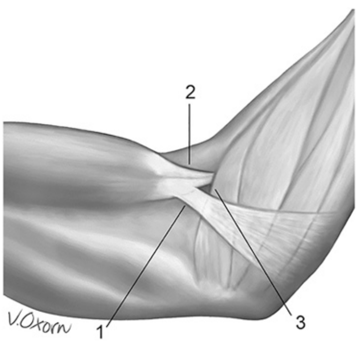

Fig. 2

Line art showing the BA (1), the DBT (2), and the flexor-pronator mass (3). (Reprinted from J Should Elbow Surg, 22[7], ElMaraghy A, Devereaux M, The "bicipital aponeurosis flex test": evaluating the integrity of the bicipital aponeurosis and its implications for treatment of distal biceps tendon ruptures, 908-14, Copyright 2013, with permission of the Journal of Shoulder and Elbow Surgery Board of Trustees.)

Mechanism of Injury

DBT tears often occur after an acute eccentric force is applied to the elbow, frequently from a flexed and supinated position[35]. Kelly et al. noted a mechanism of forced hyperextension of the arm in 80% of patients with DBT tears, while the remaining 20% were either chronic tears, caused by a direct blow to the forearm, or caused by a movement whose specifics the patients were unable to recall[2]. Partial tears tend to occur on the radial side[36]. The higher incidence of a contralateral tear in patients who have previously had a DBT tear suggests intrinsic causes, although increased demand on the uninjured side cannot be excluded. A degenerative process, mechanical impingement, and a hypovascular zone of the tendon all have been cited in the literature as possible causes[11].

Some have suggested that an initial degeneration of the tendon causes an incomplete or partial tear as a result of preexisting pathological changes. This predisposes to an acute episode of complete tendon rupture when the muscle suddenly contracts[37]. Structural degenerative changes, such as hypoxic degenerative tendinopathy, mucoid degeneration, tendolipomatosis, and calcifying tendinopathy, are seen in healthy patients, even in those who are in their thirties[38]; the changes are noted on histological evaluation of the ruptured biceps tendons[39].

Hypovascularity also has been postulated to be a contributing factor[11]. The DBT is covered by an extrasynovial paratenon with 3 zones of blood supply. Proximally, zone 1 is supplied by branches of the brachial artery, and distally, zone 3 is supplied by the posterior interosseous artery. Zone 2 has a much thinner paratenon and only receives blood through its extratendinous paratenon cover. This creates a zone of hypovascularity of approximately 2 cm, which is susceptible to degeneration and shortening.

Alternatively, during forearm pronation, the space between the lateral ulnar border and the radial tuberosity decreases by 50%[40]. Any osseous irregularity such as spurring or inflammation with corresponding hypertrophic changes could further reduce the available space and cause impingement[20,41].

Clinical Presentation

Patients often report hearing an audible "pop" that is associated with pain and/or bruising. This is followed by weakness with forearm supination and elbow flexion. Some patients will describe 2 instances of a "popping" sensation: the initial rupture of the DBT and a second sensation from the BA rupture. Patients often describe activity-related discomfort and fatigue, which can persist for weeks to months. Early diagnosis of complete tears is essential for timely surgical referral. Delays in treatment for >6 weeks can compromise the ability to obtain primary anatomic repair and increase subsequent complications[42,43].

There is often a palpable fullness in the antecubital fossa adjacent to the biceps. One diagnostic challenge is to distinguish between complete and partial tears. Symptoms associated with a partial rupture are similar but more subtle than those that are associated with a complete rupture, such as pain and tenderness in the antecubital fossa, swelling, and weakness of elbow flexion and forearm supination[4]. The only differences are found on physical examination; the biceps tendon appears absent in a complete rupture but palpable in a partial rupture.

We have proposed an algorithm for the evaluation and management of DBT tears that includes physical examination as well as confirmatory imaging, as needed (Fig. 3). It is important to note that although the evaluation and diagnostic components of the algorithm will work for any patient, the ultimate decision regarding the potential risks and benefits of any surgical recommendation will depend on individualized clinical judgment that considers patient sex, age, physical demand, and medical comorbidities.

Physical Examination

The physical examination starts with an inspection of the affected arm. Acute ruptures will typically present with

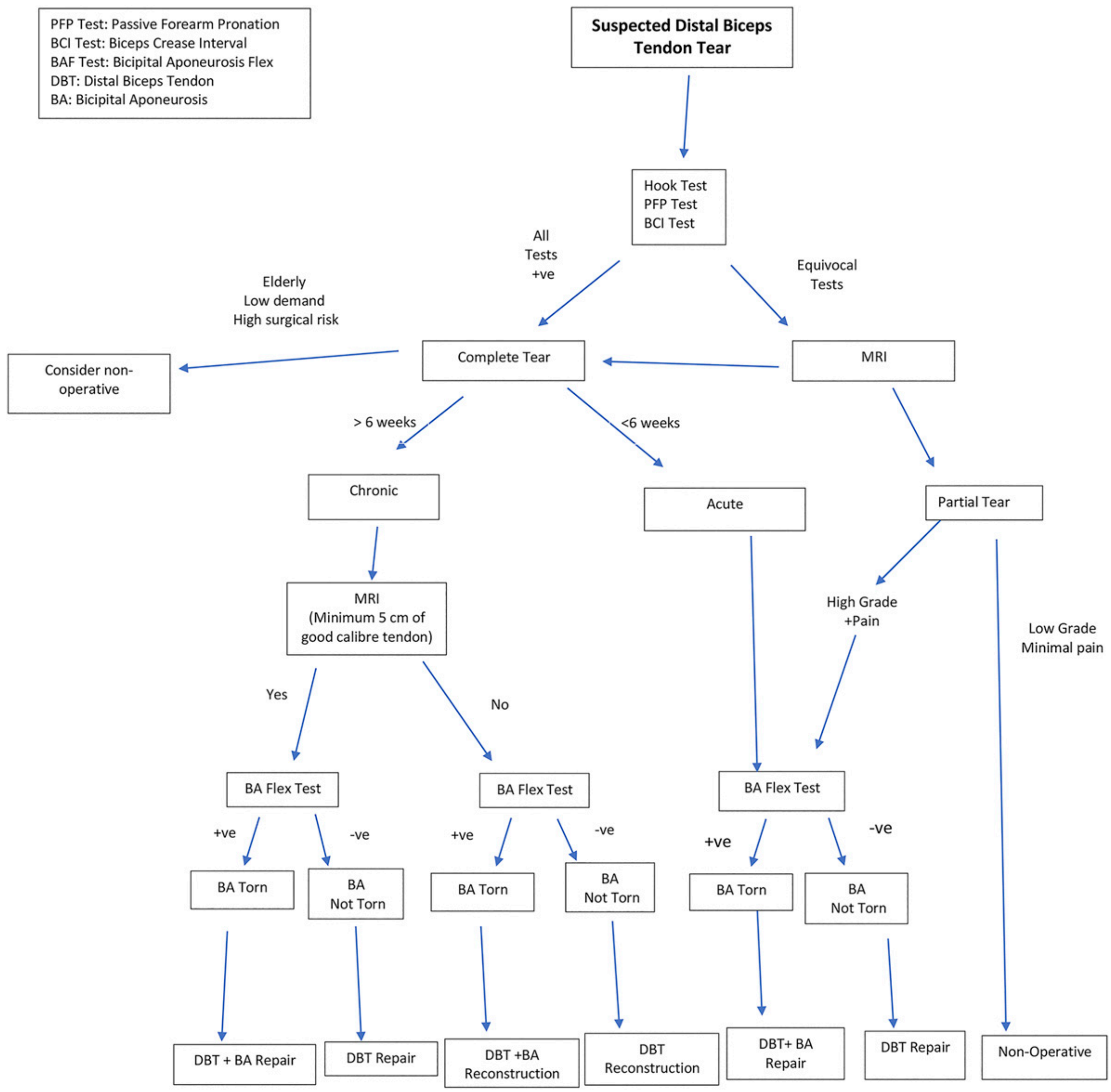

Fig. 3

DBT tear evaluation and management algorithm. +ve = positive, and -ve = negative.

medial-sided ecchymosis along the proximal aspect of the forearm. The proximal contour of the biceps muscle may be altered, and depending on the degree of retraction, a "reverse Popeye" sign[44] may be visible. With palpation, a physical gap may be present.

The motor examination, which focuses on supination and elbow flexion strength, may be limited by pain in the acute setting. On average, this injury leads to a 30% loss in flexion peak torque and a 40% to 50% loss in supination peak torque[45,46]. Various special tests have been proposed and are presented in Table I.

Any clinical test in isolation may not be sufficient for an accurate diagnosis. Data on diagnostic accuracy have demonstrated the sensitivity of each test in isolation, ranging from 81% to 100% for sensitivity and from not applicable to 100% for specificity[47]. With the combination of 3 tests (the hook test, the passive forearm pronation [PFP] test, and the biceps crease interval [BCI] test), the sensitivity and specificity for diagnosing complete tears improved to 100% when they were all in agreement[48], and this combination is recommended in the proposed algorithm (Fig. 3). With chronic ruptures, these tests may show false-negatives secondary to bandlike scar tissue that can easily be mistaken for the biceps tendon. Furthermore, an intact BA may also mislead the examiner; therefore, knowledge of the anatomic location of the BA and utilization of the BA flex test are critical.

Diagnostic Imaging

When in doubt, MRI is the preferential imaging modality for detecting DBT ruptures due to its high sensitivity and specificity for detecting tears. Partial tears, intramuscular tears, muscle retraction, and tendinosis all can be diagnosed and characterized using MRI. Fast-spin-echo

TABLE I Distal Biceps Tendon and Bicipital Aponeurosis Clinical Tests

Test	Description
Supination-pronation test	The biceps tendon is ruptured if there is no substantial change in the shape of the biceps as the arm moves between active supination (proximal movement of the biceps) and pronation (distal movement of the biceps)[98].
Passive forearm pronation (PFP) test	With the elbow flexed at 90°, the forearm is passively pronated from a fully supinated position. The biceps tendon is ruptured if distal advancement of the muscle is not seen[99].
Hook test	With active supination of the elbow flexed at 90°, a normal hook test allows the examiner to hook his or her index finger under the intact biceps tendon from the lateral side. Lack of a cordlike structure that cannot be hooked indicates distal avulsion of the biceps tendon and is considered an abnormal hook test[50].
Biceps squeeze test	The biceps squeeze test is done with the patient seated and the forearm resting in the patient's lap. With the elbow flexed at 60° to 80° and in slight pronation, the biceps is squeezed firmly with both hands, 1 hand at the distal myotendinous junction and the other around the belly of the muscle. Inability to elicit supination is considered a positive test[100].
Biceps crease interval (BCI)	The elbow flexion crease (antebrachial crease) is first traced with a pen. The contour of the distal biceps is lightly stroked back and forth along a central line parallel to its long axis. The sharpest curve (the "cusp" of distal descent) of the distal biceps is identified and marked. The BCI is calculated as the distance between the "biceps cusp" and the antebrachial crease. The nonaffected side is then similarly measured[101].
Biceps crease ratio (BCR)	The BCR is the ratio of the BCI of the injured arm divided by the BCI of the uninjured arm. A test is considered positive when the BCI is >6.0 cm or the BCR is >1.2[101].
Bicipital aponeurosis (BA) flex test	The integrity of the BA is assessed with the BA flex test. With the elbow in 75° of flexion, the patient is first instructed to make a fist and actively flex the wrist in a supinated position. This maneuver allows the BA to be under tension and allows the examiner's finger to palpate the sharp thin edge of the aponeurosis at the medial antebrachial fossa, if intact[33].

intermediate-weighted and T2-weighted or short tau inversion recovery (STIR) sequences are typically obtained. The FABS (flexed elbow with the shoulder abducted and the forearm in supination) view increases diagnostic sensitivity; it is obtained with the patient in a prone position, and allows a longitudinal view of the entire length of the DBT.

The use of ultrasonography is becoming increasingly common. The sensitivity, specificity, and accuracy of this imaging modality for the diagnosis of complete versus partial tears have been reported to be as high as 95%, 71%, and 91%, respectively[49]. With improvements in resolution, cost-effectiveness, and accessibility, it is becoming more of an attractive option. However, the user-dependent nature of ultrasonography raises concerns for false-negative or equivocal results that may delay treatment.

The threshold for obtaining advanced imaging is variable in the literature. Some authors have proposed the use of MRI for diagnosing partial tears or when the clinical examination is equivocal[3,50,51]. The increase in the positive predictive value of the diagnosis of complete rupture through the routine application of the 3 aforementioned clinical tests (the hook, PFP, and BCI tests) can decrease the need for confirmatory imaging and its associated costs as well as delays in treatment[48]. MRI may not be necessary for the preoperative workup of acute complete tears when the clinical diagnosis is clear (Fig. 3).

Nonoperative Management

Nonoperative management should focus on reducing swelling and inflammation, early range of motion of the elbow, and progressive secondary strengthening. This option is typically reserved for elderly, low-demand, and high-surgical-risk patients but may yield acceptable outcomes in younger patients who are willing to tolerate reduced strength in supination[52]. A loss of supination (40% to 50%) and flexion (30%) strength may be tolerated in these patients, especially when it affects the nondominant arm[45,46]. Some authors have advocated for nonoperative management of partial tears involving <50% of the thickness (Fig. 3), resulting in high rates of success[53]. However, patients with high-grade partial tears involving ≥50% of the thickness have reported a failure rate of 76% with nonoperative treatment, as demonstrated in a systematic review of 86 patients with partial tears[54]; these patients would likely benefit from surgical management (Fig. 3).

Operative Management

Acute DBT Tears

Single and Dual Incisions

The anterior single-incision approach was initially based on the classic volar Henry approach[55], which was extended proximally as an S-shaped incision centered over the antecubital fossa. However, this extensive approach led to high rates of PIN palsy[56]. With the introduction of newer fixation methods, less-invasive modifications (or "limited approaches") are now utilized. With these approaches, the interval lies between the pronator teres (retracted medially) and the brachioradialis (retracted laterally). The LABCN is identified and protected as it exits between the biceps and the brachialis at the level of the elbow joint. The forearm is kept in a supinated position to protect the PIN; the rate of injury of the PIN has been reported to range from 1% to 5%[57].

To limit exposure and decrease the risk of the neurological damage that was commonly seen with the single-incision approach, Boyd and Anderson described the dual-incision approach for easier access to the radial bicipital tuberosity[58]. However, this led to a high incidence of heterotopic ossification and, in its most extreme form, radioulnar synostosis. Thus, a modification where the dorsal muscles were split, preventing subperiosteal dissection over the ulna, greatly reduced the incidence of synostosis[59].

Complications associated with both techniques have been extensively reviewed in the literature[60-62]. Complications associated with biceps repair include nerve injury (the LABCN, the PIN, the superficial radial nerve, the radial nerve, the anterior interosseus nerve, the median nerve, and the ulnar nerve), heterotopic ossification, synostosis, proximal radial fracture, rerupture, superficial and deep wound infection, stiffness, weakness with forearm rotation and flexion, vascular injuries, chronic regional pain syndrome, and lateral epicondylitis. A randomized controlled trial by Grewal et al.[63] that compared single versus dual-incision techniques for repair reported no significant difference in outcomes other than a 10% advantage in final flexion strength with the double-incision technique. There were more early transient LABCN neurapraxias in the single-incision technique group (40.4% versus 6.9%). A meta-analysis by Amin et al. provided a detailed review of complications that were associated with both incision techniques; they found overall higher complication rates with single-incision techniques and, notably, a higher incidence of heterotopic ossification in the dual-incision group[64]. The rate of LABCN palsy, the most common complication, was noted to be 10% for the single-incision technique versus 2% for the dual-incision technique.

BA Repair

Multiple theories explaining the role of the BA have been proposed. These include protecting the underlying neurovascular structures, providing an additional anatomic anchor to the distal aspect of the biceps, providing pretension proprioceptive information to the biceps, and contributing to elbow flexion strength[31,33]. The BA may rupture in association with distal biceps injuries and typically fails at the most proximal portion near the short head of the biceps muscle and tendon. Biomechanical data suggest that BA repair in conjunction with distal biceps repair improves construct strength by 50%[65]. A retrospective review comparing DBT repairs with and without BA repair suggested that concomitant BA repair led to a faster return to recreational activities[66]. Repairing a torn BA may have some benefits, and routine evaluation of the BA as well as treatment recommendations have been incorporated into our proposed algorithm (Fig. 3).

Fixation Techniques

Various fixation techniques have been described to address DBT repair, including the use of transosseous tunnels, suture anchors, suspensory cortical buttons, and intraosseous screw fixation. There is currently a lack of consensus regarding the optimal fixation methods. A systemic review of 494 patients by Watson et al. reported a complication rate of 44.8% for intraosseous screws, 26.4% for suture anchors, 20.4% for bone tunnels, and 0% for cortical button fixation[67]. In contrast, another systematic review that included 1,074 patients found that transosseous tunnel fixation had significantly fewer complications than the other 3 fixation techniques[68].

Van der Vis et al. reported no difference in patient-reported outcomes (QuickDASH [shortened version of the Disabilities of the Arm, Shoulder and Hand questionnaire], MEPS [Mayo Elbow Performance Score], or EQ-5D-5L [EuroQol-5 Dimensions-5 Level] scores) between suture anchor repair and cortical button fixation[69]. Similarly, Recordon et al. found no difference in clinical outcomes in terms of patient rating, pain, range of motion, or supination strength between 2-incision suspensory cortical and transosseous tunnel fixation techniques[70]. Additionally, no difference was found in a retrospective study of complication rates and functional outcomes that compared a single-incision suspensory cortical fixation technique with a dual-incision approach with transosseous tunnels[71].

Biomechanical data show superiority with suspensory cortical fixation in terms of stiffness and greater load to failure (ultimate single tensile load to failure: 259 N; normal DBT: 210 to 221 N) than suture anchors, transosseous tunnels, and intraosseous screws (ultimate single tensile load to failure: 105 to 263 N, 125 to 210 N, and 131 to 192 N, respectively)[43]. Construct stiffness occurs more with 2 versus 1-suture anchor repairs. Failure of intraosseous screw fixation typically occurs because of tendon pullout or fracture of the bicipital tuberosity, whereas other repairs tend to fail because of shredding of the tendon that is adjacent to the suture[43]. Although there appears to be a biomechanical advantage with the suspensory cortical fixation technique, to our knowledge, there has yet to be any convincing evidence that this translates to meaningful improvements in clinical outcomes.

Chronic DBT Tears

There is no consensus on what time frame constitutes a chronic rupture, with opinions ranging from 3 weeks to 3 months[3,59,72,73]. Beyond 4 to 6 weeks, retraction, atrophy, and scarring of the ruptured tendon are substantial enough that MRI may be necessary to confirm reparability and to inform the likelihood of reconstruction. Chronicity also complicates dissection as the tract fills in and becomes more difficult to visualize. Delayed presentation could be due to a delay in timely diagnosis, failed nonoperative treatment, failed primary repair, or simply a patient's desire to avoid surgery. MRI is the most important imaging modality to evaluate the amount of tendon scarring and retraction. Furthermore, placing the patient prone with the affected arm in full abduction while the elbow is in 90° of flexion and the forearm is in full supination (FABS view) will provide optimal visualization of the biceps tendon[74].

There have been a variety of different surgical techniques for treating chronic DBT tears. These techniques can be divided into nonanatomic repair, anatomic repair, and reconstruction. Nonanatomic repair, also known as distal biceps tenodesis, was first described in 1941[75]. With this procedure, the ruptured tendon is inserted into the brachialis muscle or the coronoid process instead of the radial tuberosity in the proximal aspect of the radius[75,76]. Patients who underwent tenodesis to the brachialis had restoration of supination strength of only 43% to 50%[46,77]. This technique has a similar surgical risk profile and poorer results when compared with current techniques. Furthermore, a meta-analysis reported good results in only 60% of patients who underwent nonanatomic biceps tendon repair[78].

The role of anatomic repair with chronic DBT tears has been evaluated in a few studies[79-83]. A key element of the success of this intervention is the presence of an intact BA. The intact aponeurosis limits retraction and proximal scarring of the tendon, which increases the chances of repairing the tendon, regardless of the chronicity of the injury[50,84]. However, reconstruction of the DBT to restore the length of the tendon is necessary when the BA has been ruptured and the tendon is retracted and scarred proximally. Several techniques utilizing different graft choices have been described in the literature, but no technique has appeared to be superior. Graft choices include autogenous fascia lata[85,86], palmaris longus, plantaris, second and third toe long extensors[87], flexor carpi radialis[72], lacertus fibrosus (BA)[88], and hamstring tendons[89-91]. Allografts have also been reported as a graft choice, most commonly the Achilles tendon[92], but the hamstring and tibialis anterior tendons also have been used. Some authors have even advocated for augmented or synthetic grafts[88,93,94]. Whether the graft is fixed to the muscle or the tuberosity first, many authors tend to tension the graft at approximately 45° of elbow flexion[86,88,90,92,93,95].

A potential drawback of these tension techniques is that they do not account for variations in chronicity. In a recent publication regarding our experience with the "anatomic length method" of reconstruction, a surgical technique was described in which autogenous hamstring tendon graft is utilized[91]. The graft is attached proximally, truncated at the "anatomic length," and then attached distally to the radial tuberosity in a fashion that is identical to a primary 2-incision repair. This includes rotating the graft 90° externally ("supinating" the graft) so that its radial (long head) side is anatomically attached to the proximal portion of the radial tuberosity and vice versa. It is believed that if enough protection is provided for the graft to heal at the distal bone insertion and a proximal biceps Pulvertaft weave repair is used, then subsequent lengthening of the chronic retraction will occur at the muscular level, leading to a more ideal length-tension relationship than in previously reported uniform or empiric reconstruction techniques. For these types of procedures, a concomitant BA repair was also routinely performed with the DBT reconstruction[91].

Rehabilitation

Our standardized rehabilitation protocol for a routine DBT repair immobilizes the arm with a cast for 10 to 14 days. Once the wounds are healed, the cast is removed, and a simple collar and cuff are used for protection. Passive range of motion is allowed, avoiding terminal extension. After 6 weeks, active flexion is permitted, and after 12 weeks, resisted strengthening is allowed. A modified protocol with extended milestones is used for chronic repairs with tight tissue or poor tissue quality as well as for graft reconstructions. There are no special considerations for concomitant BA and DBT repair. An example of our detailed rehabilitation protocol is presented in the Appendix.

Overview

An improved understanding of the multifactorial etiology, mechanisms, and pathophysiology of DBT ruptures has led to many improvements in early diagnosis and better anatomic repair and reconstruction techniques. Many areas still warrant further investigation. For example, studies clarifying the use of ultrasonography and MRI with regard to their possible effect on cost and delay in diagnosis and treatment are needed. Clinical investigation regarding novel techniques is also required to improve operative outcomes in order to achieve maximum recovery and patient satisfaction after surgery, while minimizing the risk of complications. Newer techniques may go against conventional or prevalent thinking despite clinical evidence indicating otherwise (e.g., BA repair[32,65,91] or the use of flexible instrumentation[96,97]).

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Appendix

Supporting material provided by the authors is posted with the online version of this article as a data supplement at jbjs.org (http://links.lww.com/JBJSREV/A714).

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References

1. Safran MR, Graham SM. Distal biceps tendon ruptures: incidence, demographics, and the effect of smoking. Clin Orthop Relat Res. 2002 Nov;(404):275-83.

2. Kelly MP, Perkinson SG, Ablove RH, Tueting JL. Distal Biceps Tendon Ruptures: An Epidemiological Analysis Using a Large Population Database. Am J Sports Med. 2015 Aug;43(8):2012-7. Epub 2015 Jun 10.

3. Aldridge JW, Bruno RJ, Strauch RJ, Rosenwasser MP. Management of acute and chronic biceps tendon rupture. Hand Clin. 2000 Aug;16(3):497-503.

4. Bourne MH, Morrey BF. Partial rupture of the distal biceps tendon. Clin Orthop Relat Res. 1991 Oct;(271):143-8.

5. Frazier MS, Boardman MJ, Westland M, Imbriglia JE. Surgical treatment of partial distal biceps tendon ruptures. J Hand Surg Am. 2010 Jul;35(7):1111-4.

6. Rokito AS, McLaughlin JA, Gallagher MA, Zuckerman JD. Partial rupture of the distal biceps tendon. J Shoulder Elbow Surg. 1996 Jan-Feb;5(1):73-5.

7. Nielsen K. Partial rupture of the distal biceps brachii tendon. A case report. Acta Orthop Scand. 1987 Jun;58(3):287-8.

8. Green JB, Skaife TL, Leslie BM. Bilateral distal biceps tendon ruptures. J Hand Surg Am. 2012 Jan;37(1):120-3. Epub 2011 Nov 25.

9. Jockel CR, Mulieri PJ, Belsky MR, Leslie BM. Distal biceps tendon tears in women. J Shoulder Elbow Surg. 2010 Jul;19(5):645-50. Epub 2010 Apr 18.

10. Clayton RA, Court-Brown CM. The epidemiology of musculoskeletal tendinous and ligamentous injuries. Injury. 2008 Dec;39(12):1338-44. Epub 2008 Nov 25.

11. Seiler JG 3rd, Parker LM, Chamberland PD, Sherbourne GM, Carpenter WA. The distal biceps tendon. Two potential mechanisms involved in its rupture: arterial supply and mechanical impingement. J Shoulder Elbow Surg. 1995 May-Jun;4(3):149-56.

12. Del Buono A, Battery L, Denaro V, Maccauro G, Maffulli N. Tendinopathy and inflammation: some truths. Int J Immunopathol Pharmacol. 2011 Jan-Mar;24(1)(Suppl 2):45-50.

13. Zakaria MH, Davis WA, Davis TM. Incidence and predictors of hospitalization for tendon rupture in type 2 diabetes: the Fremantle diabetes study. Diabet Med. 2014 Apr;31(4):425-30. Epub 2013 Nov 16.

14. Visuri T, Lindholm H. Bilateral distal biceps tendon avulsions with use of anabolic steroids. Med Sci Sports Exerc. 1994 Aug;26(8):941-4.

15. Pagonis T, Givissis P, Ditsios K, Pagonis A, Petsatodis G, Christodoulou A. The effect of steroid-abuse on anatomic reinsertion of ruptured distal biceps brachii tendon. Injury. 2011 Nov;42(11):1307-12. Epub 2011 Apr 11.

16. Kanayama G, DeLuca J, Meehan WP 3rd, Hudson JI, Isaacs S, Baggish A, Weiner R, Micheli L, Pope HG Jr. Ruptured Tendons in Anabolic-Androgenic Steroid Users: A Cross-Sectional Cohort Study. Am J Sports Med. 2015 Nov;43(11):2638-44. Epub 2015 Sep 11.

17. Deren ME, Klinge SA, Mukand NH, Mukand JA. Tendinopathy and Tendon Rupture Associated with Statins. JBJS Rev. 2016 May 17;4(5):01874474-201605000-00002.

18. Geller HI, Singh A, Alexander KM, Mirto TM, Falk RH. Association Between Ruptured Distal Biceps Tendon and Wild-Type Transthyretin Cardiac Amyloidosis. JAMA. 2017 Sep 12;318(10):962-3.

19. Carpenito G, Gutierrez M, Ravagnani V, Raffeiner B, Grassi W; Advanced Rheumatology Sonography Group. Complete rupture of biceps tendons after corticosteroid injection in psoriatic arthritis "Popeye sign": role of ultrasound. J Clin Rheumatol. 2011 Mar;17(2):108.

20. Davis WM, Yassine Z. An etiological factor in tear of the distal tendon of the biceps brachii; report of two cases. J Bone Joint Surg Am. 1956 Dec;38-A(6):1365-8.

21. Ding DY, LaMartina JA 2nd, Zhang AL, Pandya NK. Acute distal biceps rupture in an adolescent weightlifter on chronic steroid suppression: a case report. J Pediatr Orthop B. 2016 Sep;25(5):447-9.

22. Jarrett CD, Weir DM, Stuffmann ES, Jain S, Miller MC, Schmidt CC. Anatomic and biomechanical analysis of the short and long head components of the distal biceps tendon. J Shoulder Elbow Surg. 2012 Jul;21(7):942-8. Epub 2011 Aug 3.

23. Hutchinson HL, Gloystein D, Gillespie M. Distal biceps tendon insertion: an anatomic study. J Shoulder Elbow Surg. 2008 Mar-Apr;17(2):342-6. Epub 2007 Nov 1.

24. Shukla DR, Morrey BF, Thoreson AR, An KN, O'Driscoll SW. Distal biceps tendon rupture: an in vitro study. Clin Biomech (Bristol, Avon). 2012 Mar;27(3):263-7. Epub 2011 Oct 24.

25. Lacheta L, Siebenlist S. Anatomy, Biomechanics, and Pathology of the Distal Biceps Tendon. Oper Tech Sports Med. 2018;26(2):110-3.

26. Matzon JL, Graham JG, Penna S, Ciccotti MG, Abboud JA, Lutsky KF, Beredjiklian PK. A Prospective Evaluation of Early Postoperative Complications After Distal Biceps Tendon Repairs. J Hand Surg Am. 2019 May;44(5):382-6. Epub 2018 Nov 13.

27. Waitzenegger T, Chammas M, Lazerges C, Coulet B. [Syndrome du nerf interosseux postérieur après rupture distale du tendon du biceps: physiopathologie et revue de la littérature, à propos d'un cas unique.] Chir Main. 2013 Feb;32(1):44-7. French.

28. Foxworthy M, Kinninmonth AW. Median nerve compression in the proximal forearm as a complication of partial rupture of the distal biceps brachii tendon. J Hand Surg Br. 1992 Oct;17(5):515-7.

29. Athwal GS, Steinmann SP, Rispoli DM. The distal biceps tendon: footprint and relevant clinical anatomy. J Hand Surg Am. 2007 Oct;32(8):1225-9.

30. Miyamoto RG, Elser F, Millett PJ. Distal biceps tendon injuries. J Bone Joint Surg Am. 2010 Sep 1;92(11):2128-38.

31. Congdon ED, Fish HS. The chief insertion of the bicipital aponeurosis is on the ulna; a study of collagenous bundle patterns of antebrachial fascia and bicipital aponeurosis. Anat Rec. 1953 Aug;116(4):395-407.

32. Bain GI, Johnson LJ, Turner PC. Treatment of partial distal biceps tendon tears. Sports Med Arthrosc Rev. 2008 Sep;16(3):154-61.

33. ElMaraghy A, Devereaux M. The "bicipital aponeurosis flex test": evaluating the integrity of the bicipital aponeurosis and its implications for treatment of distal biceps tendon ruptures. J Shoulder Elbow Surg. 2013 Jul;22(7):908-14. Epub 2013 May 7.

34. Laha RK, Lunsford D, Dujovny M. Lacertus fibrousus compression of the median nerve. Case report. J Neurosurg. 1978 May;48(5):838-41.

35. Bernstein AD, Breslow MJ, Jazrawi LM. Distal biceps tendon ruptures: a historical perspective and current concepts. Am J Orthop (Belle Mead NJ). 2001 Mar;30(3):193-200.

36. Kelly EW, Steinmann S, O'Driscoll SW. Surgical treatment of partial distal biceps tendon ruptures through a single posterior incision. J Shoulder Elbow Surg. 2003 Sep-Oct;12(5):456-61.

37. Chevallier CH. [Sur un cas de désinsertion du tendon bicipital inférieur]. Mem Acad Chir (Paris). 1953 Feb 11-18;79(6-7):137-9. French.

38. Kannus P, Józsa L. Histopathological changes preceding spontaneous rupture of a tendon. A controlled study of 891 patients. J Bone Joint Surg Am. 1991 Dec;73(10):1507-25.

39. Postacchini F, Puddu G. Subcutaneous rupture of the distal biceps brachii tendon; a report on seven cases. J Sports Med Phys Fitness. 1975 Jun;15(2):81-90.

40. Ray RD, Johnson RJ, Jameson RM. Rotation of the forearm; an experimental study of pronation and supination. J Bone Joint Surg Am. 1951 Oct;33-A(4):993-6.

41. Hovelius L, Josefsson G. Rupture of the distal biceps tendon. Report of five cases. Acta Orthop Scand. 1977;48(3):280-2.

42. Quach T, Jazayeri R, Sherman OH, Rosen JE. Distal biceps tendon injuries—current treatment options. Bull NYU Hosp Jt Dis. 2010;68(2):103-11.

43. Chavan PR, Duquin TR, Bisson LJ. Repair of the ruptured distal biceps tendon: a systematic review. Am J Sports Med. 2008 Aug;36(8):1618-24.

44. Magnussen RA, Chong PY, Oh LS, Walch G. Acute biceps brachii injuries. In: Kerkhoffs G, Servien E, editors. Acute muscle injuries. Springer; 2014. p 105-116.

45. Nesterenko S, Domire ZJ, Morrey BF, Sanchez-Sotelo J. Elbow strength and endurance in patients with a ruptured distal biceps tendon. J Shoulder Elbow Surg. 2010 Mar;19(2):184-9. Epub 2009 Aug 6.

46. Morrey BF, Askew LJ, An KN, Dobyns JH. Rupture of the distal tendon of the biceps brachii. A biomechanical study. J Bone Joint Surg Am. 1985 Mar;67(3):418-21.

47. Zwerus EL, Somford MP, Maissan F, Heisen J, Eygendaal D, van den Bekerom MP. Physical examination of the elbow, what is the evidence? A systematic literature review. Br J Sports Med. 2018 Oct;52(19):1253-60. Epub 2017 Mar 1.

48. Devereaux MW, ElMaraghy AW. Improving the rapid and reliable diagnosis of complete distal biceps tendon rupture: a nuanced approach to the clinical examination. Am J Sports Med. 2013 Sep;41(9):1998-2004. Epub 2013 Jun 26.

49. Lobo LdaG, Fessell DP, Miller BS, Kelly A, Lee JY, Brandon C, Jacobson JA. The role of sonography in differentiating full versus partial distal biceps tendon tears: correlation with surgical findings. AJR Am J Roentgenol. 2013 Jan;200(1):158-62.

50. O'Driscoll SW, Goncalves LB, Dietz P. The hook test for distal biceps tendon avulsion. Am J Sports Med. 2007 Nov;35(11):1865-9. Epub 2007 Aug 8.

51. Geaney LE, Mazzocca AD. Distal biceps brachii tendon rupture: what do we do with these? Curr Orthop Pract. 2009;20(4):374-81.

52. Freeman CR, McCormick KR, Mahoney D, Baratz M, Lubahn JD. Nonoperative treatment of distal biceps tendon ruptures compared with a historical control group. J Bone Joint Surg Am. 2009 Oct;91(10):2329-34.

53. Eames MH, Bain GI. Distal biceps tendon endoscopy and anterior elbow arthroscopy portal. Tech Shoulder Elbow Surg. 2006 Sep;7(3):139-42.

54. Behun MA, Geeslin AG, O'Hagan EC, King JC. Partial Tears of the Distal Biceps Brachii Tendon: A Systematic Review of Surgical Outcomes. J Hand Surg Am. 2016 Jul;41(7):e175-89. Epub 2016 May 20.

55. Friedmann E. Rupture of the distal biceps brachil tendon. Report on 13 cases. JAMA. 1963 Apr 6;184(1):60-3.

56. El-Hawary R, Macdermid JC, Faber KJ, Patterson SD, King GJ. Distal biceps tendon repair: comparison of surgical techniques. J Hand Surg Am. 2003 May;28(3):496-502.

57. Reichert P, Królikowska A, Witkowski J, Szuba Ł, Czamara A. Surgical Management of Distal Biceps Tendon Anatomical Reinsertion Complications: Iatrogenic Posterior Interosseous Nerve Palsy. Med Sci Monit. 2018 Feb 7;24:782-90.

58. Boyd HB, Anderson LD. A method for reinsertion of the distal biceps brachii tendon. J Bone Joint Surg Am. 1961;43(7):1041-3.

59. Kelly EW, Morrey BF, O'Driscoll SW. Complications of repair of the distal biceps tendon with the modified two-incision technique. J Bone Joint Surg Am. 2000 Nov;82(11):1575-81.

60. Garon MT, Greenberg JA. Complications of Distal Biceps Repair. Orthop Clin North Am. 2016 Apr;47(2):435-44.

61. Cain RA, Nydick JA, Stein MI, Williams BD, Polikandriotis JA, Hess AV. Complications following distal biceps repair. J Hand Surg Am. 2012 Oct;37(10):2112-7. Epub 2012 Aug 30.

62. Ford SE, Andersen JS, Macknet DM, Connor PM, Loeffler BJ, Gaston RG. Major complications after distal biceps tendon repairs: retrospective cohort analysis of 970 cases. J Shoulder Elbow Surg. 2018 Oct;27(10):1898-906. Epub 2018 Aug 20.

63. Grewal R, Athwal GS, MacDermid JC, Faber KJ, Drosdowech DS, El-Hawary R, King GJ. Single versus double-incision technique for the repair of acute distal biceps tendon ruptures: a randomized clinical trial. J Bone Joint Surg Am. 2012 Jul 3;94(13):1166-74.

64. Amin NH, Volpi A, Lynch TS, Patel RM, Cerynik DL, Schickendantz MS, Jones MH. Complications of Distal Biceps Tendon Repair: A Meta-analysis of Single-Incision Versus Double-Incision Surgical Technique. Orthop J Sports Med. 2016 Oct 7;4(10):2325967116668137.

65. Landa J, Bhandari S, Strauss EJ, Walker PS, Meislin RJ. The effect of repair of the lacertus fibrosus on distal biceps tendon repairs: a biomechanical, functional, and anatomic study. Am J Sports Med. 2009 Jan;37(1):120-3. Epub 2008 Nov 24.

66. Conlin CE, Naderipour A, ElMaraghy A. Outcome of Distal Biceps Tendon Repair With and Without Concomitant Bicipital Aponeurosis Repair. Orthop J Sports Med. 2019 Aug 22;7(8):2325967119865500.

67. Watson JN, Moretti VM, Schwindel L, Hutchinson MR. Repair techniques for acute distal biceps tendon ruptures: a systematic review. J Bone Joint Surg Am. 2014 Dec 17;96(24):2086-90.

68. Kodde IF, van den Bekerom MP, Mulder PG, Eygendaal D. The Size of the Radial Tuberosity is Not Related to the Occurrence of Distal Biceps Tendon Ruptures: A Case-Control Study. Open Orthop J. 2016 Feb 19;10:1-6.

69. van der Vis J, Janssen SJ, Haverlag R, van den Bekerom MPJ. Functional outcome in patients who underwent distal biceps tendon repair. Arch Orthop Trauma Surg. 2018 Nov;138(11):1541-8. Epub 2018 Aug 1.

70. Recordon JA, Misur PN, Isaksson F, Poon PC. Endobutton versus transosseous suture repair of distal biceps rupture using the two-incision technique: a comparison series. J Shoulder Elbow Surg. 2015 Jun;24(6):928-33. Epub 2015 Apr 7.

71. Cohen SB, Buckley PS, Neuman B, Leland JM, Ciccotti MG, Lazarus M. A functional analysis of distal biceps tendon repair: single-incision Endobutton technique vs. two-incision modified Boyd-Anderson technique. Phys Sportsmed. 2016;44(1):59-62. Epub 2015 Dec 30.

72. Levy HJ, Mashoof AA, Morgan D. Repair of chronic ruptures of the distal biceps tendon using flexor carpi radialis tendon graft. Am J Sports Med. 2000 Jul-Aug;28(4):538-40.

73. Frank T, Seltser A, Grewal R, King GJW, Athwal GS. Management of chronic distal biceps tendon ruptures: primary repair vs. semitendinosus autograft reconstruction. J Shoulder Elbow Surg. 2019 Jun;28(6):1104-10. Epub 2019 Mar 29.

74. Giuffrè BM, Moss MJ. Optimal positioning for MRI of the distal biceps brachii tendon: flexed abducted supinated view. AJR Am J Roentgenol. 2004 Apr;182(4):944-6.

75. Dobbie RP. Avulsion of the lower biceps brachiii tendon: analysis of fifty-one previously unreported cases. Am J Surg. 1941;51(3):662-83.

76. Meherin JM, Kilgore ES Jr. The treatment of ruptures of the distal biceps brachii tendon. Am J Surg. 1960;99(5):636-40.

77. Le Huec JC, Moinard M, Liquois F, Zipoli B, Chauveaux D, Le Rebeller A. Distal rupture of the tendon of biceps brachii. Evaluation by MRI and the results of repair. J Bone Joint Surg Br. 1996 Sep;78(5):767-70.

78. Rantanen J, Orava S. Rupture of the distal biceps tendon. A report of 19 patients treated with anatomic reinsertion, and a meta-analysis of 147 cases found in the literature. Am J Sports Med. 1999 Mar-Apr;27(2):128-32.

79. Bosman HA, Fincher M, Saw N. Anatomic direct repair of chronic distal biceps brachii tendon rupture without interposition graft. J Shoulder Elbow Surg. 2012 Oct;21(10):1342-7. Epub 2012 Apr 25.

80. Ryhänen J, Kaarela O, Siira P, Kujala S, Raatikainen T. Recovery of muscle strength after late repair of distal biceps brachii tendon. Scand J Surg. 2006;95(1):68-72.

81. Sharma DK, Goswami V, Wood J. Surgical repair of chronic rupture of the distal end of the biceps brachii. A modified anterior surgical repair technique. Acta Orthop Belg. 2004 Jun;70(3):268-72.

82. Dillon MT, Bollier MJ, King JC. Repair of acute and chronic distal biceps tendon ruptures using the EndoButton. Hand (N Y). 2011 Mar;6(1):39-46. Epub 2010 Jul 7.

83. Morrey ME, Abdel MP, Sanchez-Sotelo J, Morrey BF. Primary repair of retracted distal biceps tendon ruptures in extreme flexion. J Shoulder Elbow Surg. 2014 May;23(5):679-85.

84. Limpisvasti O, Singer DI. Single-incision suture anchor repair of distal biceps tendon rupture. Tech Hand Up Extrem Surg. 2003 Sep;7(3):82-6.

85. Bayat A, Neumann L, Wallace WA. Late repair of simultaneous bilateral distal biceps brachii tendon avulsion with fascia lata graft. Br J Sports Med. 1999 Aug;33(4):281-3.

86. Kaplan FT, Rokito AS, Birdzell MG, Zuckerman JD. Reconstruction of chronic distal biceps tendon rupture with use of fascia lata combined with a ligament augmentation device: a report of 3 cases. J Shoulder Elbow Surg. 2002 Nov-Dec;11(6):633-6.

87. Vastamäki M, Vastamäki H. A simple grafting method to repair irreparable distal biceps tendon. Clin Orthop Relat Res. 2008 Oct;466(10):2475-81. Epub 2008 Jul 18.

88. Hamer MJ, Caputo AE. Operative treatment of chronic distal biceps tendon ruptures. Sports Med Arthrosc Rev. 2008 Sep;16(3):143-7.

89. Hallam P, Bain GI. Repair of chronic distal biceps tendon ruptures using autologous hamstring graft and the Endobutton. J Shoulder Elbow Surg. 2004 Nov-Dec;13(6):648-51.

90. Hang DW, Bach BR Jr, Bojchuk J. Repair of chronic distal biceps brachii tendon rupture using free autogenous semitendinosus tendon. Clin Orthop Relat Res. 1996 Feb;(323):188-91.

91. Albishi W, Lam JJ, Elmaraghy A. Reconstruction of Chronic Distal Biceps Tendon Rupture With Autogenous Semitendinosis Graft Using the "Anatomic Length Method" and Concomitant Bicipital Aponeurosis Repair. Techniques in Shoulder & Elbow Surgery. 2019 Dec;20(4):125-129.

92. Sanchez-Sotelo J, Morrey BF, Adams RA, O'Driscoll SW. Reconstruction of chronic ruptures of the distal biceps tendon with use of an Achilles tendon allograft. J Bone Joint Surg Am. 2002 Jun;84(6):999-1005.

93. Darlis NA, Sotereanos DG. Distal biceps tendon reconstruction in chronic ruptures. J Shoulder Elbow Surg. 2006 Sep-Oct;15(5):614-9. Epub 2006 Aug 7.

94. Patterson RW, Sharma J, Lawton JN, Evans PJ. Distal biceps tendon reconstruction with tendoachilles allograft: a modification of the Endobutton technique utilizing an ACL reconstruction system. J Hand Surg Am. 2009 Mar;34(3):545-52.

95. Wright TW. Late distal biceps repair. Tech Hand Up Extrem Surg. 2004 Sep;8(3):167-72.

96. Tat J, Hart A, Cota A, Alsheikh K, Behrends D, Martineau PA. Anatomic Single-Incision Repair of Distal Biceps Tendon Ruptures Using Flexible

Reamers. Arthrosc Tech. 2018 Feb 1;7(2): e179-83.

97. Tat J, Hart A, Cota A, Alsheikh K, Behrends D, Martineau PA. Distal Biceps Repair With Flexible Instrumentation and Risk of Posterior Interosseous Nerve Injury: A Cadaveric Analysis. Orthop J Sports Med. 2018 Nov 27;6(11): 2325967118810523.

98. Metzman LS, Tivener KA. The Supination-Pronation Test for Distal Biceps Tendon Rupture. Am J Orthop (Belle Mead NJ). 2015 Oct; 44(10):E361-4.

99. Harding WG 3rd. A new clinical test for avulsion of the insertion of the biceps tendon. Orthopedics. 2005 Jan; 28(1):27-9.

100. Ruland RT, Dunbar RP, Bowen JD. The biceps squeeze test for diagnosis of distal biceps tendon ruptures. Clin Orthop Relat Res. 2005 Aug;(437):128-31.

101. ElMaraghy A, Devereaux M, Tsoi K. The biceps crease interval for diagnosing complete distal biceps tendon ruptures. Clin Orthop Relat Res. 2008 Sep;466(9):2255-62. Epub 2008 Jun 13.