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Current Concepts Review

Publication trends in ligament augmentation techniques: current concepts

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ABSTRACT

Importance: Ligament augmentation techniques (LATs) are surgical procedures, in which an anatomical ligament repair or reconstruction is strengthened with a synthetic material. During the last decade, LATs have increased in prevalence in clinical practice and academic literature. Observing the trends in LAT publications can be used to identify clusters of strong evidence for clinical practice and to highlight areas of the literature which need further development.

Objective: This article aims to define ligament augmentation as a technique category, observe anatomical, procedural, and temporal trends in LAT publication, and report on the state of current research in this field.

Evidence review: Primary literature in the English language, which describes ligament augmentation and reports on human, cadaveric, or biomechanical models, and published prior to May 24th, 2022, was targeted for analysis. PubMed, Embase, and Cochrane CENTRAL databases were explored using a focused keyword search strategy, and the resulting publications were reviewed in accordance with the Preferred Reporting Items for Systematic Reviews and Meta-Analyses guidelines. Data were collected and analysed using descriptive statistics.

Findings: Two hundred eighty-three publications reporting ligament augmentation techniques, published from May 1989 to May 2022, were included for final analysis. A wide technical and anatomical variety of procedures are reported. 36.8% of LAT publications describe knee ligaments, among which the anterior cruciate ligamenthas the highest focus in ligament augmentation publications (31.8% of articles). LAT literature has recently expanded in anatomical scope, with many contemporary articles describing the usage of a LAT in the ankle syndesmosis and coracoclavicular ligaments. 60.4% of LAT literature has been published since 2017. There has been an 11% average increase in the rate of LAT publication reports since 2015. Novel fixation devices—suture buttons and suture anchors—have gained wide popularity in the literature.

Conclusions and relevance: In this review, we define LATs and quantitatively describe the expansion of LAT use reported in the literature. This data will provide physicians an overview of the history of these methods, as well as illustrate the broad range of applications available for the use of LATs.

Level of Evidence: 3.

Current Concepts

- Ligament augmentation techniques have gained popularity in clinical use amongst orthopaedic surgeons
- There is a large diversity in the materials used in fixation and augmentation

Future Perspectives

- The library of ligament augmentation technique publications has grown tremendously over the past decade
- Use has expanded to many different ligaments and anatomic regions

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- There is a large diversity in the materials used in fixation and augmentation
- The number of ligament augmentation publications numbers can be expected to grow further

1. Introduction

Untreated ligament tears can decrease the stability of a joint and may lead to further damage of their surrounding structures, thereby leading to decreased quality of life as compared to reconstructed ligaments [1]. Ligament repairs and reconstruction are performed across orthopaedic subspecialties, with various degrees of success depending on the indication. While surgical repair of damaged ligaments tends to improve outcomes overall, a significant gap between pre-injury functional status and post-surgical repair may remain [2].

In pursuit of better outcomes, orthopaedic surgeons have moved toward incorporating synthetic ligaments, or ligament augmentation devices, to provide additional stability to native tissues in ligament repair and reconstruction. Although "ligament augmentation" is a term with broad definitions in the literature, the general purpose of these techniques is to allow for stronger repairs and quicker return to activity [3,4]. This may provide improved functional outcomes [5]. In medical device sales, kits intended for ligament augmentation, consisting of the necessary fixation devices and synthetic ligament, are sometimes sold with unified branding and described as a solitary technique—this article aims to break this concept down into its discrete portions for clarity of analysis.

The authors define ligament augmentation techniques (LATs) as techniques in which a ligament is repaired or reconstructed with a synthetic material, which spans from bone to bone and is fixated intra- or trans-osseously, such as with a suture anchor, suture button, or interference screw. Synthetic ligaments can possibly avoid some of the postoperative complications associated with autograft and allograft transplantation [6], and can be used as a supplement for allograft tissue. Synthetic ligaments do not lead to significant donor site morbidity and avoid persistent pain and loss of flexibility, which are common complications of autograft use [7].

Although ligament repair with various synthetic protheses has been attempted for over a century, the modern history of LATs dates back to the 1980s, when polymer devices such as polypropylene braid were first used in ACL reconstruction. Commercial ACL ligament augmentation devices were initially produced during this time, including the Kennedy LAD (3M, St. Paul, MN) and the Dacron graft (Stryker, Kalamazoo, MI) [8,9]. These first-generation devices are now less commonly used, which may be a result of relatively higher reported rates of complications with their use, such as infection, autoimmune reaction, and graft failure [9,10]. Current example techniques frequently use the Ligament Advanced Reinforcement System (LARS; LARS Company, Arc sur Tille, France), InternalBrace (Arthrex, Inc., Naples, FL, USA), and TightRope (Arthrex, Inc., Naples, FL, USA).

Historical reporting on LAT literature is important because this technique has had cyclical surges of popularity over time. In 1902, a German physician attempted an ultimately unsuccessful ACL reconstruction utilising a combined silk fibre and semitendinosus graft [10,11]. Intriguingly, in recent years, ACL reconstruction using silk fibres in animal models has been attempted, with promising results [11,12]. Examining the previous reports on this topic can help researchers understand the pitfalls of historical attempts at LATs and give inspiration for techniques which could be used to strengthen patient outcomes.

We present this current concepts review with the goal of elucidating the current publication trends in the orthopaedic literature on LAT techniques, materials, and clinical outcomes. The authors hypothesised that the quantity of ligament augmentation reports would demonstrate tremendous growth in the period between 2010 and 2022. This hypothesis was influenced by the recent explosion of the usage of LATs in clinical practice. Indeed, 75.3% of ISAKOS member orthopaedists surveyed in 2021 reported that they use the technique [13].

2. Methods

The authors conducted a systematic review, which utilised the Preferred Reporting Items for Systematic Reviews and Meta-Analyses (PRISMA) guidelines. No ethics board approval was required for this study. A keyword-based literature search, which combines a surgical term relevant to the topic of the review, such as augmentation, internal brace, or suture tape, and anatomical terms like ATFL or ACL, was created. This search strategy was executed in the PubMed, EMBASE, and Cochrane CENTRAL databases, yielding results spanning from May 1989 to May 2022. The full search terms are available in appendix A1.

After duplicate publications were removed, the studies were screened by two independent reviewers, SA and SB, for inclusion. Titles and abstracts were screened in duplicate, and studies were included if they were 1) primary literature, 2) LATs were a subject of the report, 3) if they utilised human, cadaveric, or biomechanical models, and 4) if they were published in the English language. Publications utilising animal models were excluded, as were systematic review articles. All articles in which there was a discrepancy in grading were evaluated for final inclusion by author MH. A full-text review of the articles was subsequently performed by SA. All relevant data were recorded from each full text for review. Principal summary measures include the year of publication, the LAT device used, the ligament or anatomic region to which it was applied, the fixation method, and the synthetic material applied. Data were evaluated using basic descriptive statistics.

3. Results

The results of our online literary database search and review are reported in the form of a PRISMA flow chart.

There were 1,702 studies captured by our search of the PubMed, Embase, and Cochrane CENTRAL databases after removing duplicates. Title and abstract screening yielded 720 relevant reports, and 280 articles were included in our final analysis following a full text review and application of the inclusion criteria (Fig. 1).

Although LATs are surgical techniques which have been reported in the literature as early as 1989, the majority of LAT papers have been published within the past 5 years. 60.4% of the publications captured by our search were published between 2017 and June 2022. This trend correlates to the invention and commercialisation of devices such as the InternalBrace ™ and ZipTight ™ fixation systems, both patented in 2012.

The general anatomical breakdown of publications of which LATs are a focus is reported by year (Fig. 3). Early utilisation of LATs was focused on the knee, particularly on the ACL, with first generation devices such as the Kennedy LAD [17,18]. Prior to 2005, 30 of 30 LAT publications report the use of ligament augmentation in the ACL. Following 2005, foot and ankle literature describing the usage of LATs increased following the development of techniques such as syndesmosis tightrope reconstruction and suture tape augmentation of the lateral ankle ligaments [14,15]. Increases in the shoulder body of literature are mostly related to the use of suture button constructs in reconstructing the coracoclavicular ligaments of the acromioclavicular joint [16,17]. Overall, the knee accounts for 36.8% of LAT publications, and the foot and ankle and shoulder account for 28.9% and 24.6%, respectively.

Ligament augmentation repair and reconstruction was primarily done with interference screws prior to 2005 [17,18]. Following the publication of the first journal article involving the usage of suture buttons in the fixation of ankle syndesmosis injuries [14], the usage of suture button to suture button constructs has greatly increased in the literature (Fig. 4). Many anatomical areas of LAT usage now use suture button constructs, with 56.8% of articles from 2008 to 2022 detailing the use of at least one button in LAT fixation. This can partially be explained by the expansion of LATs in the acromioclavicular joint and ankle syndesmosis, where

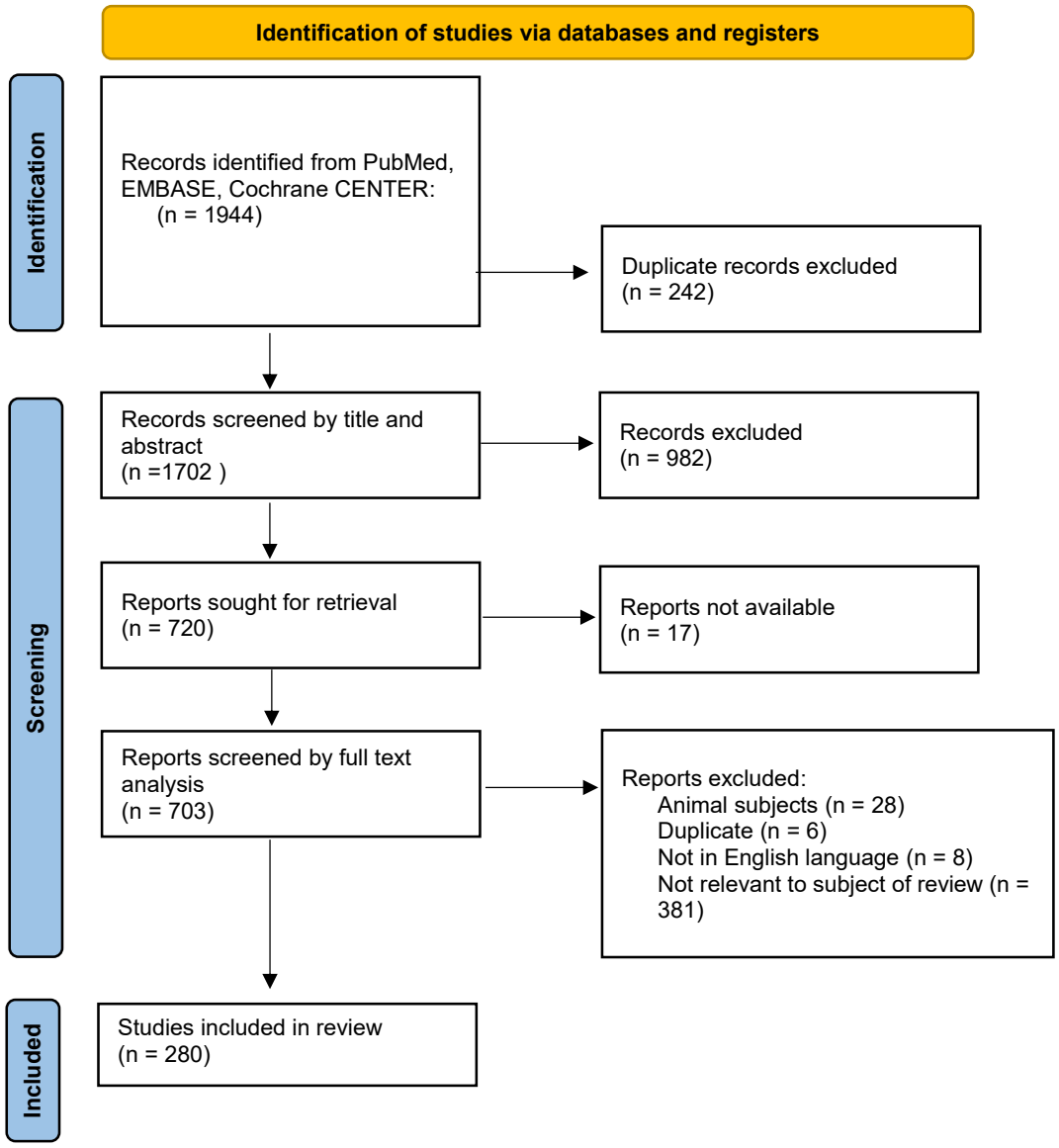

Fig. 1. The PRISMA flowchart of the database review.

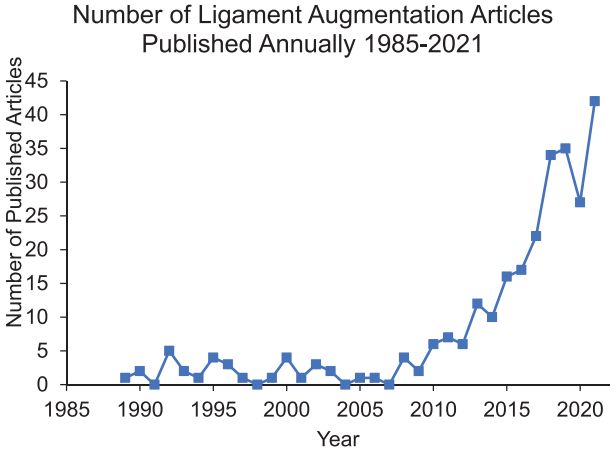

Fig. 2. The number of LAT publications per annum. LAT, ligament augmentation technique.

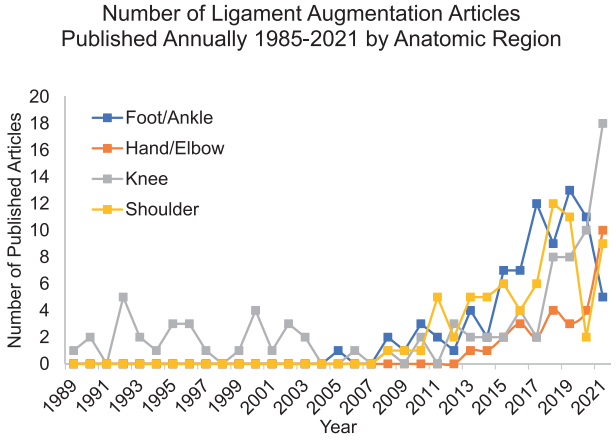

Fig. 3. Trends in LAT literature by the anatomical region. LAT, ligament augmentation technique.

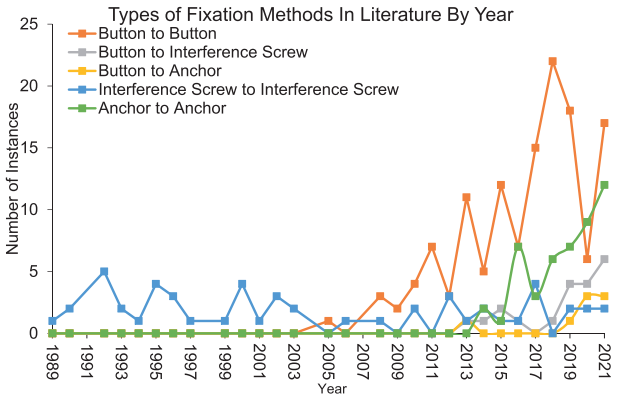

Fig. 4. Fixation method trends by year.

suture buttons are overwhelmingly used.

Fig. 5 demonstrates the distribution of ligaments which are repaired or reconstructed in the publications included in the literature. Articles in which multiple ligaments are augmented with LATs are counted for all ligaments. In this figure, the broad nature of the usage of this technique in clinical practice is evident and the adaptable nature of LATs is shown. However, it should be noted that the largest bodies of information in the literature describe the ACL, ankle syndesmosis, ATFL, and the AC joint, with 80% of 280 inclusions of LATs falling into one of these anatomical subsets. Numerous articles describe the use of LATs in multiple ligaments, such as the ACL and PCL, concurrently [19,20].

Abbreviations: LAT, ligament augmentation technique

The 15 journals with the most publications on this topic are listed (Table 1). The highest number of LAT publications are in the *Orthopaedic Journal of Sports Medicine* (24, 8.6%), *American Journal of Sports Medicine* (19, 6.8%), *Foot & Ankle International* (18, 6.4%) and *Knee Surgery, Sports Traumatology, and Arthroscopy* (16, 5.7%). Although it has been demonstrated that the number of ligament augmentation articles has greatly increased with time (Fig. 2), there is no correlation between the self-reported level of evidence of articles included in this study and the year of publication ($r^2 = .001$).

There are three primary fixation methods used in securing synthetic connecting materials to bone in LATs: interference screws, suture anchors, and suture buttons. We present a breakdown of the devices used for fixation and ligament repair [Table 2]. 70.3% of articles included in this review stated the specific fixation devices used in the augmentation, and 79.3% listed the bridging material which was used. Some articles listed only the fixation devices or the connecting material used in their technique. As demonstrated in Table 2, some ligament augmentation constructs use disparate types of devices at either end of their fixation, e.g., a suture button at one end and an interference screw at the other. Suture anchor to suture button constructs and suture button to interference screw concepts are described in the literature, but interestingly, to our knowledge, there is no literature which describes the usage of both a suture anchor and an interference screw in ligament augmentation fixation. Suture button to suture button fixation is the most common form of ligament augmentation, with over half of all included articles using this method. Ten articles captured describe ligament augmentation constructs which use staples as fixation devices for synthetic ligaments; these are excluded from this chart.

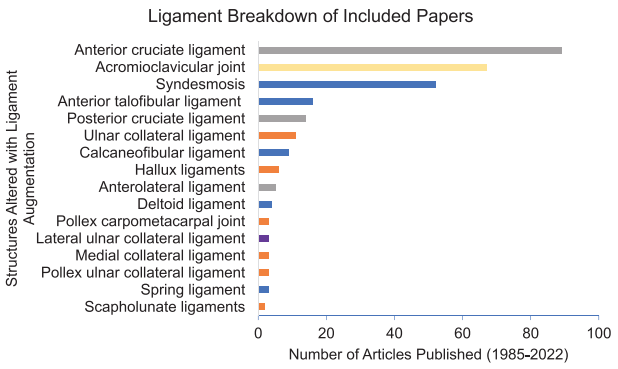

Fig. 5. The breakdown of LAT articles by ligaments involved (minimum n = 2). LAT, ligament augmentation technique.

Table 1
Journals by LAT publication count.

Title of Journal	Number of LAT Publications
Orthopaedic Journal of Sports Medicine	24
American Journal of Sports Medicine	19
Foot and Ankle International	18
Knee Surgery, Sports Traumatology, and Arthroscopy	16
Foot and Ankle Surgery	15
Arthroscopy	10
Arthroscopy Techniques	9
Archives of Orthopaedics and Trauma Surgery	9
Injury	7
Journal of Shoulder and Elbow Surgery	6
European Journal of Orthopaedic Surgery and Traumatology	6
Orthopaedics	5
Journal of Orthopaedic Trauma	5
Journal of Bone and Joint Surgery	5
Acta Orthopaedica Belgica	4

4. Discussion

Analysis of LAT publications demonstrates that there have been increases in the number of publications, anatomical scope, and diversity of materials used. The usage of the Dacron synthetic ligament to replace the ACL by Lukianov et al., in 1989, was the first report of an LAT [21,22]. Subsequently, the usage of synthetic materials, such as the Kennedy LAD, in ACL reconstruction was the only area of focus of LATs in the literature prior to 2005 [22,23]. Thornes et al. then reported on the use of suture button fixation in patients with syndesmotic injuries, leading to superior outcomes as compared to syndesmotic screw fixation [14]. Baumgarten et al. reported the first use of ligament augmentation reconstruction of the acromioclavicular joint by using a dual suture button construct in 2008 [16]. This period of literature was a germination point for the spread of this technique to other ligaments, resulting in the diverse distribution of reports currently available (Fig. 4). In the past decade, the repository of LAT literature has expanded almost exponentially, and further year-to-year growth in publication numbers can be anticipated. Additionally, this technique has reached wide popularity, with a plurality of orthopaedic surgeons surveyed in 2021 using LATs in their practice [13].

Devices are central to the concept of LATs, and it is important to recognise the historical trends of device use when considering synthetic augmentation. First generation ligament augmentation devices, such as the Kennedy LAD, are generally not used in the present day, partially because of poor outcomes associated with their implantation [24,25]. These devices differ from the modern constructs in significant ways. Firstly, these historical devices were typically fixed to bone through the usage of relatively large titanium interference screws, as compared to modern bioabsorable anchors and minimally invasive suture buttons. Secondly, the assembly of the suture materials used in LATs has evolved over time. Although all devices listed in this study use similar polymers for the braided suture involved in tensioning, typically high density polyethylene or polypropylene, the construction of suture materials such as FiberWire and FiberTape is two-layered, with an inner core and an outer sheath, whereas the Kennedy LAD is one-layered.

Table 2
Branded ligament augmentation devices in the literature.

Type of Construct (# in review)	Button to Button 154	Button to Interference Screw 22	Button to Anchor 8	Anchor to Anchor 48	Interference Screw to Interference Screw 42
Fixation Systems	TightRope[a] to TightRope **128** DogBone[a] to DogBone **7** Endobutton[b] to Endobutton **5** ZipTight[c] to ZipTight **4** Fliptack[d] to Fliptack Dogbone[a] to TightRope[a] **1** Retrobutton[a] to Retrobutton **1** Ultrabutton[b] to Ultrabutton **1** ToggleLoc[c] to ToggleLoc **1** Procinch[e] to Procinch **1** TightRope[a] to EndoButton[b] **1** Not listed **2**	TightRope[a] to unnamed screw **8** Endobutton[b] to unnamed screw **3** Endobutton[b] to Intrafix Screw[f] **2** TightRope[a] to BioComposite screw[a] **1** DogBone[a] to unnamed screw **1** Not listed **5**	TightRope[1] to SwiveLock[a]**8**	SwiveLock[a] to SwiveLock **27** SutureTak[a] to SutureTak **2** PushLock[a] to SwiveLock[a] **2** PushLock[a] to Anchor[f] **1** FiberTack[a] to SwiveLock[a] **1** Not listed **15**	Dual titanium screw[g] **3** Dual Bio-Tenodesis Screw[a] **2** Dual cannulated screw[h] **1** Not listed **36**
Connecting material	FiberWire[a] **81** FiberTape[a] **21** InternalBrace FiberTape **4** Ethibond[i] **2** Ethicon suture[j] **2** FiberTag[a] **1** Artelon tissue reinforcement[k] **1** Ultrabraid #2[b] **1** MaxBraid[c] **1** Not listed **40**	FiberTape[a] **6** FiberWire[a] **4** LARS ligament[h] **4** InternalBrace FiberTape[a] **2** Ethicon #5[j] **1** Not listed **6**	FiberTape[a] **6** InternalBrace FiberTape **1**	InternalBrace FiberTape[a] **20** FiberTape[a] **17** LabralTape[a] **2** LARS ligament[h] **2** FiberWire[a] **2** Not listed **5**	Kennedy LAD[l] **16** LARS ligament[h] **17** Dacron ligament[m] **2** FiberWire[a] **1** Artelon ligament[k] **1** Leeds-Keio ligament[n] **1** Ethicon PDS II[j] **1** Ultrabraid #2[b] **1** Not listed **2**

Abbreviation: LARS, Ligament Advanced Reinforcement System
[a] Arthrex, Naples, FL, USA.
[b] Smith & Nephew, Andover, MA, USA.
[c] Zimmer Biomet, Atlanta, GA, USA.
[d] Karl Stolz, Tuttlingen, Germany.
[e] Stryker, Kalamazoo, MI, USA.
[f] DePuy Mitek, Raynham, MA, USA.
[g] Surgical Implants and Devices, Arc-sur-Tille, France.
[h] LARS Company, Arc-sur-Tille, France.
[i] Johnson & Johnson, New Brunswick, NJ, USA.
[j] Ethicon, Raritan, NJ, USA.
[k] Artelon, Marietta, GA, USA.
[l] 3M, St. Paul, MN, USA.
[m] E.I. Du Pont de Nemours and Co, Wilmington, DE, USA.
[n] Xiros Ltd., Leeds, UK.

One striking detail reported in this review is the expansion of suture button fixation over time. The greater adoption of these fixation methods could be related to the expansion in the anatomical scope of LATs—as the number of papers which examine LATs in ligaments, which are best repaired through this fixation method, increases, the number of papers using them will increase as well. In addition to this consideration, there are clear indications for the use of suture button fixation methods in specific situations, e.g., double TightRope fixation has been demonstrated to be stronger than anchor to button fixation in the setting of acromioclavicular joint reduction [26]. Few studies compare the benefits of any type of ligament augmentation fixation over another, and this area of technique literature may be a fruitful area of future investigation. In using suture button fixation, physicians should consider the possibility of button migration, loss of reduction, infection, and osteomyelitis as possible complications in choosing whether to pursue suture button fixation over other methods [27,28].

Another interesting finding is the near linear increase in publications since 2005 in all relevant subspeciality areas. The first usage of LAT devices outside of the knee was in 2005, in usage for reduction of the ankle syndesmosis. This was followed by significant increases in technique and clinical papers describing LATs in the foot and ankle, followed by a resurgence in the knee, shoulder, and eventually the hand and wrist around 2013. This correlates well with our survey data which indicated that the majority of foot and ankle, knee, and shoulder surgeons surveyed use LATs, and that just under 50% of hand surgeons utilise LATs [13]. A purported advantage of LATs is an accelerated return to sports participation with a mitigated risk of ligament stretching [2,5,29]. To date, there is no high level evidence to support more aggressive rehabilitation techniques with the use of LATs. However, given the surge in use, volumes, and literature, such comparisons and guidelines are inevitably forthcoming.

Although modern LAT devices have not had as many reports of synovitis and adverse reactions, physicians should be vigilant in recognising these issues due to the relative similarities between these synthetic grafts and those which have previously caused pathology in patients. This is especially important to consider in the longitudinal evaluation of the safety of new generation devices because severe complications, such as synovitis, in devices like the LARS ligament have been observed many years after implantation [30]. Recent attempts to achieve further biocompatibility, and thereby reduce reactivity, have involved the use of a collagen-coated suture material in order to reduce complications [31,32]. Research in creating more biocompatible ligament augmentation devices is ongoing—innovation in these devices could eventually avoid acute and chronic immunologic reactions and confer less chance for

postoperative infection as compared to allograft ligament transplantation, although such advancements have not been demonstrated thus far [8,32]. Further development of the materials involved in LATs may lead to fewer instances of adverse outcomes and improved healing.

In conducting this current concepts review, we encountered multiple challenges and thus faced certain limitations. Numerous articles in this sector of orthopaedic literature describe ligament augmentation techniques but do not provide sufficient reporting of the materials and methods used in their procedures, and thus, these variables could not be collected for data analysis. Our study lacks coverage of the orthopaedic literature outside of theEnglish language. Because this review aimed to describe the trends in these techniques relating to human subjects, veterinary literature, and literature which attempted to model the human anatomy through the use of animal models, was not considered for inclusion. Additionally, certain articles were unable to be accessed due to paywalls and lack of open-access. Moreover, our review only considers reports archived in major literature databases—PubMed, EMBASE, and Cochrane CENTRAL and thereby excludes publications in journals which are not indexed in these services.

5. Conclusion

This current concepts review clarifies the term ligament augmentation techniques and describes the growth of this up-and-coming topic in the orthopedic surgical literature over time. Based on previous trends, we can expect LATs to become more prevalent in orthopedic publications, as well as in clinical practice, in the future. This trend can be explained by innovation in materials and methods used in these techniques, as well as through the clinical outcomes demonstrated by several landmark publications. Research providing clarity on the longitudinal effectiveness of ligament augmentation techniques would improve the body of literature.

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Declaration of interests

The authors declare that they have no known competing financial interests or personal relationships that could have appeared to influence the work reported in this paper.

Appendix A1

Combined search format: (concept 1) AND (concept 2 (all anatomical terms combined))

("augmentation"[tw] OR "internal brac*"[tw] OR "suture tape"[tw] OR "suture-tape"[tw] OR "reinforcement"[tw] OR "suture button"[tw] OR "suture-button"[tw] OR "tightrope"[tw] OR "internalbrace"[tw] OR "fiberwire"[tw]) **AND** ("ATFL"[tw] OR "Anterior Talofibular"[tw] OR "Brostrom"[tw] OR "Achilles"[tw] OR "Calcaneal"[tw] OR "Calcaneofibular"[tw] OR "CFL"[tw] OR "Deltoid"[tw] OR "Spring"[tw] OR "Calcaneonavicular"[tw] OR "Plantar calcaneonavicular"[tw] OR "Anterior inferior tibiofibular"[tw] OR "Anterior tibiofibular"[tw] OR "AITFL"[tw] OR "Liscfranc"[tw] OR "Tarsometatarsal"[tw] OR "Peroneal"[tw] OR "Peroneus"[tw] OR "Fibularis brevis"[tw] OR "Fibularis longus"[tw] OR "interosseus"[tw] OR "syndesmosis"[tw] OR "syndesmotic"[tw] OR "total talus"[tw] OR "hallux"[tw] OR "Acromioclavicular"[tw] OR "AC"[tw] OR "Rotator cuff"[tw] OR "sternoclavicular"[tw] OR "SC"[tw] OR "SCJ"[tw] OR "coracoclavicular"[tw] OR "Lateral ulnar collateral"[tw] OR "LUCL"[tw] OR "Ulnar collateral"[tw] OR "UCL"[tw] OR "Ulnar"[tw] OR "Triangular fibrocartilage"[tw] OR "Scapholunate"[tw] OR "Carpometacarpal"[tw] OR "CMC"[tw] OR "Annular"[tw] OR "RCL"[tw] OR "medial epicondyle"[tw] OR "ACL"[tw] OR "anterior cruciate"[tw] OR "PCL"[tw] OR "Posterior cruciate" OR "MCL"[tw] OR "Medial collateral"[tw] OR "LCL"[tw] OR "lateral collateral"[tw] OR "popliteofibular"[tw] OR "popliteal"[tw] OR "patellar"[tw] OR "quadriceps tendon"[tw] OR "patellofemoral"[tw] OR "anterolateral"[tw] OR "posteromedial"[tw])

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