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Introducing the Principles of Tendon Transfer for Surgical Trainees to Improve Anatomical Knowledge

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Abstract

This article reviewed the principles and outcomes of tendon transfer procedures described in the literature to restore function following injuries delivered in a workshop as a way of improving basic science and anatomical knowledge in surgical trainees preparing for surgical examinations. Post intervention surveys showed an improvement in trainees' familiarity with musculoskeletal anatomy and engagement in learning with improved readiness for surgical examinations.

Keywords

Professionalism, Tendon Transfer, Surgical Training, Surgical Trainees: Anatomical Knowledge

1. Introduction

Surgeons require procedural experience and a clear understanding of the anatomy and biomechanics of the muscles involved to execute tendon transfers effectively. Tendon transfer surgery alters the insertion of an intact, expendable, neighbouring tendon to compensate for the loss of function of another tendon but the origin of the muscle remains in the same position [1]. The aim is to temporarily or permanently rebalance the muscle power to facilitate function in those with neurological injury whether it be acquired, developmental or congenital in origin [2]. Careful patient assessment by the surgical trainee is needed to clearly understand the functional deficit arising from the musculoskeletal or neurological injury. Practising this assessment and understanding the principles of muscle and tendon function aids in surgical examination readiness for surgical trainees. The systematic literature review in the paper aimed to identify areas of insufficient knowledge regarding the common concepts for tendon transfer surgery in current practice, the effectiveness of techniques used during tendon transfer procedures and the standard of surgical skills required by trainees to understand and perform these procedures successfully.

Following this a training package consisting of a lecture and clinical workshop focussing on specific learning points was constructed to help trainees revise basic sciences in relation to tendon function but also included examples of upper limb nerve injury to help practically learn muscle and nerve evaluation. Studies suggest the shift from anatomically loaded lectures to system based learning in undergraduate medical studies has created a culture which place less emphasis on core anatomical knowledge. This deficit has also translated into the post graduate exams which also require less anatomical knowledge [3] [4]. Anatomical workshops pre and post tests have objectively shown a significant improvement in trainee knowledge. Improvement in anatomical knowledge optimises patient safety and guarantees better surgical outcomes as there is direct correlation with poor anatomical knowledge and surgical errors [5] [6].

Good knowledge of musculoskeletal anatomy is needed within the appendicular skeleton to clearly understand the motor supply, sensory supply and proprioception [7]. Inadequate anatomical knowledge can lead to misdiagnosis, increased post operative complications and poor surgical outcomes overall [4].

2. Method

1) Creating the workshop

2) Search Strategies

Eligible studies were searched on Medline, EMBASE, and PsycINFO databases using the algorithm ((exp "TENDON TRANSFER"/OR (tendon transfer* OR tendon transposition*).ti,ab) AND (exp "UPPER LIMB"/OR (upper limb* OR upper extremit*).ti,ab OR (arm OR shoulder OR elbow OR wrist OR hand).ti,ab)) [DT 2021-2021] and ((exp "TENDON TRANSFER"/OR (tendon transfer* OR tendon transposition*).ti,ab) AND (exp "LOWER EXTREMITY"/OR (lower limb OR foot OR ankle OR leg OR hip OR knee OR lower extremit*).ti,ab)) [DT 2021-2021]. This search was undertaken twice, eight months apart in 2021 by two separate experienced librarians within the hospital of the lead author to maximise sensitivity in identifying relevant articles using the following criteria.

3) Criteria

	Inclusion	Exclusion
Population	Surgeons in training (*i.e.* postgraduate surgical residents or equivalent)	Did not include medical students or programme directors

Continued

Intervention	Patients undergoing tendon transfer/basic science papers on surgical technique tendon transfer, commentary on donor tendons used patient selection, surgical approaches as well as a clear review of the advantages and disadvantages of the techniques advocated	Lacking surgical context
Environment	Accessible to trainees either in hospital, online or in a clinical workshop in an education centre or simulator	External course
Outcomes	Reported on outcomes related to tendon transfer	Described only assessment tools or definitions of professionalism
Design	Reviews, randomised trials, and single cases	Did not report empirical data Not in English
Published	Papers published between 1990 to February 2021 initially and the search was repeated on October 2021	Published before 1990

The first search generated 639 papers and the second search generated 450, excluding the duplicates and including screening the reference lists for eligible studies generated a total of 1089 papers. The number of studies excluded at each stage including the title, abstract and full text screening were recorded systematically with reasons (e.g., "non-surgery"). Two researchers participated in both titles, abstract and full-text screening stages (ME, NA), and where there was uncertainty in study eligibility, a consensus decision was made by at least two screeners. Endnote captured and managed the references at each stage of screening. Data extraction was undertaken using a table to facilitate assessment of the papers quality and eligibility when screening the full article, using an inductive stance rather than deductive based on previously identified themes [8] [9]. The same three researchers (ENS, IML, NA) extracted the study design, participant characteristics (number of participants, medical/surgical discipline), intervention characteristics (the main principles of tendon transfers, passively mobile joints, amplitude and excursion, straight line of pull, synergism, expendable donor) details of outcomes assessed, and the findings for each eligible outcome. The themes were synthesised into a presentation that delivered to trainees with the aim of basic science knowledge for the surgical examinations. The effectiveness of the workshop was evaluated by a questionnaire which had been developed using an iterative process to develop sensitive enough questions that reflected the familiarity of the trainees with this material and was scored using Likert scales to develop a rating of the knowledge base. Descriptors were coded to identify themes for future learning [10].

3. Results

In total 1089 articles were identified on the search and full texts were screened of these 898 were excluded at the abstract stage as not including any relevant basic science information or clinical content to facilitate training; 63 were letters, or commentaries; 128 eligible studies were identified. From these papers clinical examples were used to develop a workshop that would be effective in training surgeons about musculoskeletal anatomy.

3.1. Principles of Tendon Transfers

3.1.1. Passively Movable Joints

Joint contracture with stiffness follows the loss of innervation to muscles driving joint movement [11]. No tendon transfer will move a stiff joint so it's key that patients receive abundant hand therapy to maintain supple joints through regular passive exercises and the use of moulded splints [11]. Preventing contractures is easier than correcting them [12].

If joint stiffness does develop then capsulotomy [13] and arthrodesis [14] of certain joints can help restore function during or proceeding tendon transfer.

Maintenance wrist movement is especially important for good functional outcome in the upper limb transfers as it enables additional benefit from the tenodesis effect whilst moving the wrist [15] [16].

3.1.2. Adequate Strength

Muscles lose one grade of strength following tendon transfer and a muscle with no less than grade 4 power (MRC scale) should be used as a motor [17]. The power or strength of upper limb muscles have been calculated and these relate to the cross-sectional area and the work capacity of a muscle, which is the product of the force (absolute muscle power) and the amplitude (distance or displacement) [18] [19]. The amount of tension a muscle generates is directly proportional to the number of cross-bridges formed between Actin and Myosin filaments [20]. The optimum number of cross-bridges occurs when the muscle fibre is at its resting length [21] and at this length the maximum tension (force) is produced within the muscle. Altering a muscle's length will affect the tension a muscle can generate following transfer best described by the Blix curve (**Figure 1**) [22] [23] [24].

Practically the degree of tension in the tendon at the time of transfer is important [25]. Traditionally, surgeons over-tensioned the donor tendon expecting it to undergo stress relaxation and stretch (**Figure 2**). However, overstretching a

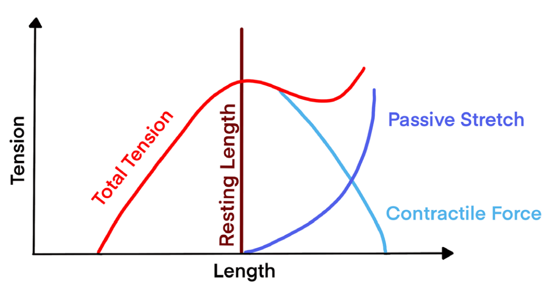

Figure 1. Blix curve (LENGTH-TENSION CURVE) relation of initial muscle length and force can generate.

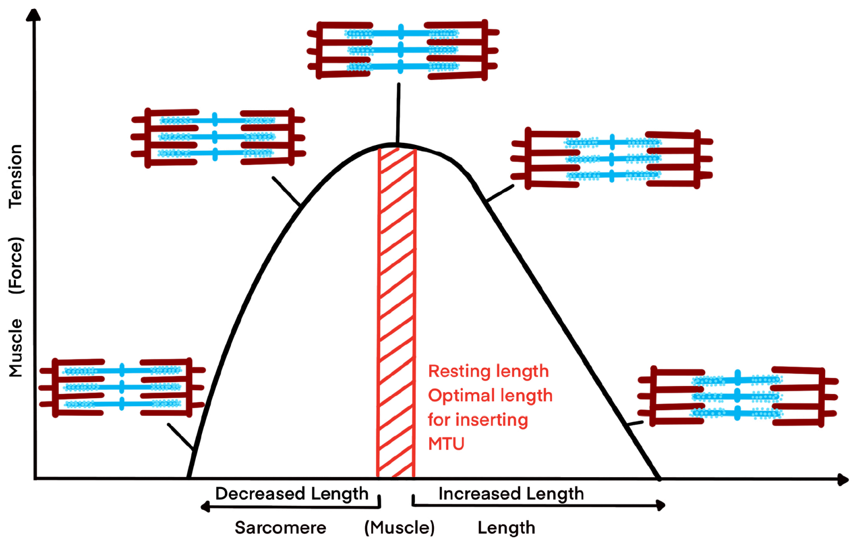

Figure 2. Relation of Sarcomere resting stretch and tension can generate by muscle.

muscle places it at a biomechanical disadvantage with an inefficient starting sarcomere length beyond the resting length on the Blix curve [26]. Studies have shown that chronic overstretching a muscle result in reduction in the overall number of sarcomeres with a resultant reduction in contraction force [25] [27]. Recently intra-operative laser diffraction technology has been used to measure fibre length to "dial-in" the tension required to achieve maximum force [28].

Performing a tendon transfer using local anaesthetics only Wide Awake Local Anaesthesia No Tourniquet allows patients to demonstrate the new function of the affected limb, post tendon transfer, allowing adjustments perioperatively of tendon transfer and muscle tensioning prior to closing the skin [29]. Patients need to be cooperative, and the techniques have found popularity especially where resources are limited [30].

3.1.3. Tendon Excursion

Excursion is the distance moved by a tendon when the muscle goes from a state of full relaxation to full contraction [31] and this affects muscle strength and joint movement. One should ensure that the muscle-tendon unit used as a donor has an adequate excursion to provide the expected range of movement across the joint(s) it is bridging (**Table 1**). A wrist flexor cannot compensate for a finger extensor although the tenodesis effect can add to the effective tendon amplitude [15] [16].

Dissection of the fascia surrounding a muscle and tendon can increase its excursion, in particular releasing the fascia around brachioradialis improves the excursion significantly [32]. The tenodesis effect is beneficial to excursion [33] since the synergies of fingers and wrist motion can improve excursion especially for transfers to tendons like flexor pollicis longus (FPL). Also transferring Flexor Carpi Ulnaris (FCU) or Flexor Carpi Radialis (FCR) to Extensor Digitorum Communis (EDC) takes advantage of the passive tenodesis effect, improving finger extension with wrist flexion compensating for lost excursion [34].

Table 1. Tendon excursion.

Tendons group	Excursion in mm
Wrist flexors and extensor	33
Finger extensors and EPL	50
Finger Flexors	70

Inserting a tendon further away from the axis of rotation increases the lever arm creating a biomechanical advantage for the muscle which then requires less force to achieve movement but less range of motion is achieved [18]. In the hand, flexor tendons are inserted very close to the axis of rotation of joints giving a low mechanical advantage but achieving a "high gear" system that achieves a wider range of movement [35]. Pulleys in the hand prevent bowstringing and maintain a constant lever arm as the joint moves from full extension to full flexion [36] (**Figure 3**).

3.1.4. Straight Line of Pull

To achieve a straight line of pull requires extensive dissection to allow the tendon to pass through a straight course between its origin and its new insertion [7]. This improves excursion and improves efficiency and strength, as less energy is dissipated from forces that do not move a joint [15] [16]. This is not possible to achieve in all transfers such as opponensplasty for median nerve injury [37], but is crucial in others, for example FCU to EDC [38]. Studies suggest a change in tendon pull direction up to and greater than 40 degrees can reduce muscle power, as it increases tension and other opposing forces [7]. If a direction change is necessary for achieving a desired outcome, creating a pulley system may be beneficial. An unsuccessful pulley system will lead to bowstringing of the tendon hence decrease amplitude and power in the effected muscles [15].

3.1.5. One Tendon One Transfer

A tendon cannot perform two opposing functions simultaneously [11]. The amplitude and force is shared between two tendons and this results in a less efficient transfer than when a single tendon is used to motor a single function [15] [16] [22] [39].

3.1.6. Synergism

Synergistic muscles are those with interdependent cortical control a principle first described by Littler [40] [41] and includes wrist and finger flexors as well as extensors. The use of synergistic tendons for transfer preserves muscle function. An exception to this rule is the FDS tendon which seems to have independent cortical control [42].

3.1.7. Expendable Donor

The tendon used to restore a particular function must not result in loss of function elsewhere [43]. It is important to ensure that the remaining tendons have

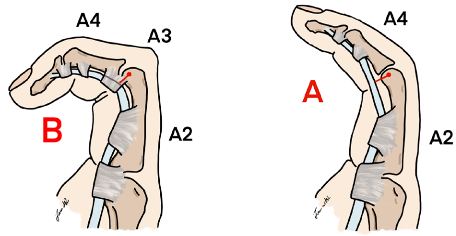

Figure 3. Increase lever arm of tendon decrease required force (A), however, decrease range of movement (B).

sufficient power to produce the "donor function". For example, leaving Palmaris longus as a sole wrist flexor is not sufficient [15] [39].

3.1.8. Tissue Equilibrium

Tendon transfers work best when the donor's tendon is passed between the subcutaneous fat and the deep fascial layer [19]. Therefore, any induration or scarring at the surgical site will result in future adhesions and failure. Steindler introduced the principle of "tissue equilibrium" when all induration has settled, all wounds and scars have healed and matured and all contractures are constant prior to attempting a tendon transfer [19].

3.2. Rehabilitation

Post-operative rehabilitation is crucial for returning function to the limb following a tendon transfer [44]. Mobilisation is reintroduced in stages, starting with immobilising the joint with splints and plasters to prevent damaged to the transferred tendon [45]. Patients should engage in static exercises during this phase. It is essential to achieve adequate pain control and introduce precautionary measures to reduced post-operative oedema as both factors can lead to increase joint stiffness hence increasing recovery time. Regaining maximum limb function is an active and continual process.

3.3. Technique

Good technique increases the chance of post operative function while decreasing post operative complications and secondary joint contractures [46]. The Pulvertaft developed in the 1950's [47] allows tendons of different diameter sizes to be joined together as smaller tendons are threaded through larger tendons and sutured together. This technique may create bulking at the suture site which can hinder the smooth gliding motion can decrease resistance so has to be done carefully [18].

3.4. Limitations of Tendon Transfer

There is a degree of risk in all surgical procedures [48]. Intraoperative risk in tendon transfer surgery includes bleeding, infection, further damage to surrounding tissue including nerves and failure of the procedure. Post operatively contractures and joint stiffness may occur, weakness in muscle group with previous grade 5 power, under or over tensioning of donor tendon leading to poor muscle function and lastly injury to the donor tendon. Cast and splints immobilise the joint and protect the donor tendon if tolerated, but these can also cause damage by not accommodating for postoperative oedema hence producing a torniquet effect that causes further neuropathy. Tendon transfer requires a phasic return to full function through physio hence lack of patient engagement with rehab services or exercise plan may diminish surgical outcome [19] [22].

3.5. Survey

There was a total of 23 responses from a survey sent to 35 participants a response rate close to 66% for a workshop run annually from 2021 for surgeons in training. There were 11 core trainee equivalents (foundation doctors with an interest in surgery) and 12 speciality doctors revising for further examinations with an average experience of 3.9 years (1 to 14). All recognised the need to have a firm understanding of anatomy and felt training on clinical cases was important for examination preparation.

1) Surgical trainee

		Response Percent
1	Foundation Doctor	40%
2	Speciality Doctor	40%
4	Core Trainee	15%
5	Locum Surgeon	5%

2) Impact of tendon transfer training on basic science knowledge

Adversely	0%
Not at all	30%
Positively	70%

Trainees understanding of tendon anatomy and healing was poor prior to the teaching from the comments made on their questionnaires. There was a firm grasp of the clinical need for transfers to compensate for functional deficit. However, the practicalities of how to achieve this and how tendons behave was improved by the workshop with most trainees (70%) noting an improvement in basic science and anatomical knowledge (90%). Although one trainee felt the anatomical knowledge required was too much despite the clinical examples being taken from the medical school syllabus for what a qualified doctor should know. The confusion arising in understanding brachial plexus anatomy. Similarly, one senior trainee felt the training had not improved their anatomical basic knowledge.

3) Did anatomical knowledge improve?

In a similar way many of the trainees (90%) felt that the training improved the chance of passing the examinations of those that had taken a surgical examination since (5) all passed. The same number (90%) would recommend the training with more clinical examples being requested to improve the impact of the training package. It was felt that face to face training in bespoke packages like this could help understanding of other areas within the surgical syllabus.

4. Discussion

Tendon transfer provides a surgical solution to correcting muscle weakness and imbalance [43] [46]. Using a donor tendon with similar qualities to the damaged tendon that achieves the required biomechanics to facilitate function [48]. Understanding musculoskeletal anatomy helps surgeons treat their patients effectively especially where there is an obvious functional deficit [49]. There is a particular need to be familiar with the relevant anatomy in tendon transfers as further functional deficit other muscle groups in the process [43]. The success of tendon transfer procedures depends on accurate assessment of muscle power, available tendon length and flexibility, synergism as well as surgical precision and rehabilitation [50].

Trainees should understand preoperative assessment of the anatomical functional deficit enables the optimum post operative outcome in terms of morbidity, mortality, and functional outcomes [51]. Preparation for tendon transfer procedures involves careful appropriate patient selection [52] and identifying a suitable donor tendon [43]. The affected joint needs a good range of passive movement prior to surgery and assessing this accurately needs to be performed in a logical and methodical manner to achieve good functional results [53]. Training requires exposure to these types of clinical problems, and this has been difficult to achieve in recent years.

Surgical training opportunities remain limited with issues relating to European Working Directives [54] and the impact of the COVID-19 pandemic [55]. Novel ways of improving training using virtual means are being advocated [56] or simulation especially when learning clinically relevant anatomy [57]. Trainers in particular feel more time is required to learn surgically relevant anatomy [58] and as shown in this study trainees relish the opportunity for more exposure to clinical anatomy. Tendon or nerve injury cases provide good material to test a clinicians assessment skills and ability to develop a treatment pathway [59]. Developing a training package that gives trainees access at their convenience increases its acceptability and provides more equality to training opportunities for those with restricted access to cases [60]. Blended learning offering both face to face and on line may offer the best of both worlds [61] and appears to be gathering popularity with trainees and trainers alike. This training package had good acceptability and engagement from the trainees and helped revise anatomy that all surgeons should be familiar. The trainees particularly liked the refresher of brachial plexus anatomy and testing. Assessment of this plexus remains a core skill for budding orthopaedic, plastic and neurosurgical trainees [62] [63]. Undertaking the training helped with trainee confidence in taking the surgical examinations despite the topic being complex and relatively rare. The senior authors plan similar blended learning opportunities using clinical cases and online material or lectures for patients with functional deficits and surgical solutions to remedy these to help patients rehabilitate.

5. Conclusion

Patients with significant functional deficits following tendon or nerve injury benefit from reconstruction or transfers. A clear understanding of the anatomy in these circumstances helps trainees and surgeons with patient assessment and treatment. Discussing these cases online or face to face helps trainees with preparation for surgical examinations.

Conflicts of Interest

The authors declare no conflicts of interest regarding the publication of this paper.

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