Biomechanics of Tendon Transfers

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KEYWORDS

• Biomechanics • Tendon transfer • Sarcomere • Excursion • Tendon coaptation

KEY POINTS

- Tendon transfers depend on the tension and excursion capabilities of the transferred muscle.
- Anatomic charts have been created allowing comparison of potential donor-recipient muscle pairs.
- Tensioning the transferred muscle determines its functional capacity for force generation. Although work is being done to quantitate this, it remains poorly understood.
- A single transferred muscle controlling multiple tendons, either in parallel or series, presents unique challenges to the surgeon and patient.
- Multiple coaptation methods have been shown to be similar to the standard Pulvertaft weave.

INTRODUCTION

This article explores the biomechanical principles governing tendon transfers in the upper extremity. The intricate mechanics of the hand are often taken for granted in health, but even slight aberrations can greatly impair function. In the devastating setting of a partially paralyzed hand, a firm understanding of these mechanics can allow the surgeon to redirect forces from uninjured areas to restore function of the hand. Although many of the mechanical principles remain as first described by the founders of tendon transfer, such as Bunnell and Boyes, vast improvements in the understanding of anatomic and biochemical properties of upper extremity muscles by the likes of Brand and Lieber have pushed the field to exciting new places and uncovered new areas for research.

BIOMECHANICS FUNDAMENTALS

Balance and Synergy

When function has been compromised in a hand due to acquired or congenital neuromuscular deficits, various surgical options may exist for functional restoration, including early reestablishment of nerve function (nerve transfer or reconstruction) or subsequent substitution for muscle weakness via tendon transfer. The former is beyond the scope of this article and is not addressed here. In the absence of reversing paralysis, the hand surgeon is tasked with redistributing the remaining strength in the limb.

Achieving balance is the ultimate goal of tendon transfer surgery. Balance does not imply equal strength on either side of a joint, but rather sufficient strength to ensure stability. For example, in restoring wrist extension following a radial nerve palsy, the extension moment created must be adequate to balance the flexion moment created by the finger flexors. This creates a stable wrist joint, maximizing the hand's ability for more distal activity.

The concept of synergism is integrally related to balance. It denotes 2 or more muscle functions that amplify the effect of the others, whether simultaneously or sequentially. Active synergism involves 2 concurrent actions. A natural pairing in the upper extremity is that of wrist extension with finger flexion,

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as well as wrist flexion and finger extension. Maintaining synergistic relationships during tendon transfer, such as wrist flexors to finger extensors for radial nerve palsy, facilitates retraining in the postoperative period, as these muscle groups are typically fired together. This is especially relevant in older patients, and less so in children, whose neuroplasticity allows rapid adaptation to new muscle function.[1]

Sequential synergism relates to the passive stretch placed into a muscle by the active contraction of a complementary muscle. This storing of potential energy in a muscle places it in a more mechanically advantageous position to effect strong contraction and is essential in efficient function of skeletal muscle (**Fig. 1**). We explore this further in the next section.

Muscle Mechanics

Fundamental to understanding tendon transfers is an understanding of the mechanics of the native musculotendinous unit. Brand[2] pointed out that each muscle can be described by just 2 parameters, its potential for generating tension, and its excursion, or the distance and direction over which this tension is exerted.

Tension

Tension in skeletal muscle comes from 2 primary sources. Most commonly considered is active contraction, though equally important is passive elastic recoil of a stretched muscle. The functional unit of active contraction is the sarcomere, which is under voluntary nervous control (**Fig. 2**). It is composed of filaments of actin emanating from adjacent Z plates and interweaving with the intervening myosin filaments. When activated, the myosin filaments pull the actin filaments and subsequently the attached Z plates closer together, causing contraction and, therefore, tension. Sarcomeres are arranged in series to form fibers on a macroscopic level, and the

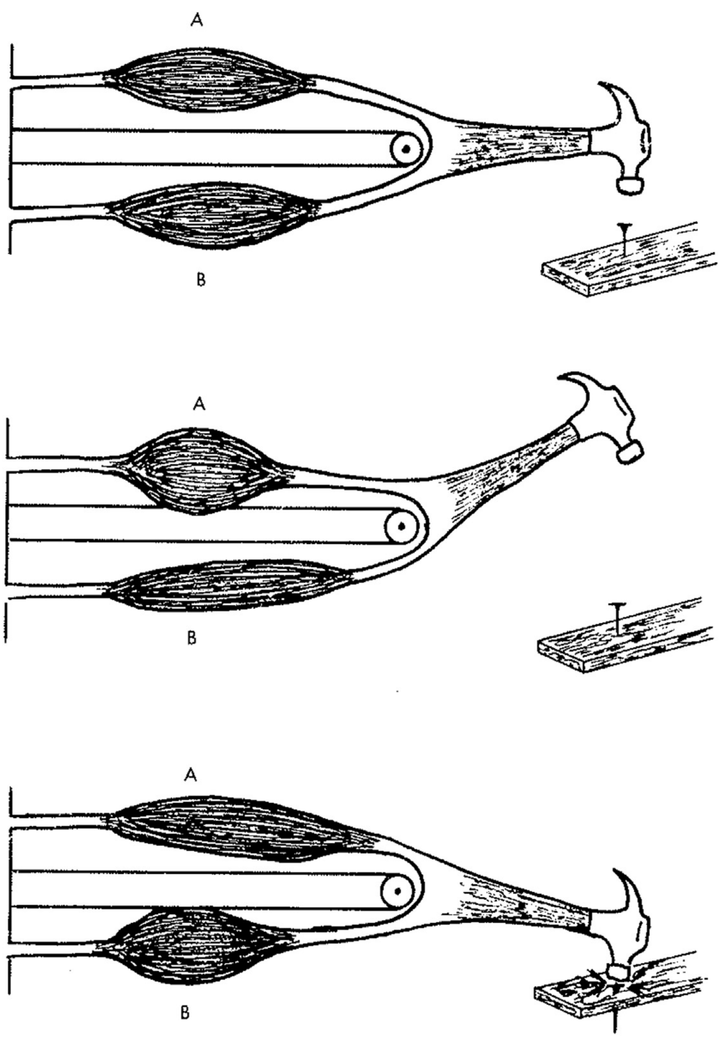

Fig. 1. When the hammer strikes, it is using both the active contraction of B plus the elastic recoil in B that has been put into it by A. (*From* Brand PW, Hollister A. Clinical mechanics of the hand. Second edition. St Louis (MO): Mosby Year Book; 1993. p. 19; with permission.)