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Fascial hierarchies and the relevance of crossed-helical arrangements of collagen to changes in shape; part II: The proposed effect of blood pressure (Traube-Hering-Mayer) waves on the fascia☆

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Summary Periodic changes in arterial pressure and volume have long been related to respiratory and sympathetic nerve activity (Traube-Hering-Mayer waves) but their origins and nomenclature have caused considerable confusion since they were first discovered in the eighteenth century. However, although they remain poorly understood and the underlying details of their control are complicated, these waves do provide valuable clinical information on the state of blood pressure regulation in both normal and pathological conditions; and a correlation with oscillatory motions observed by certain practitioners suggests that they may also have some physiological value that relates to changes in the volume of fascial 'tubes'.

Part I of this paper (Scarr, 2016) described a complex fascial network of collagen-reinforced tubular sheaths that are an integral part of muscle structure and function, and continuous with 'higher-level' fascial tubes surrounding groups of muscles, the limbs and entire body. The anisotropic arrangements of collagen fibres within the walls of these tubes reflect the most efficient distribution of mechanical stresses and have been considered to coordinate changes in shape, and a proposed link between cyclic variations in arterial pressure and volume, and the behaviour of these fascial compartments is now described.

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Introduction

The fascia

Once dismissed as a packing tissue of little consequence, the fascia is now recognized as a continuous and interconnected structural network that permeates and envelops almost every part of the body, and it has many diverse and important functional roles (Schleip et al., 2012; Tozzi, 2015a,b). Part I of this paper (Scarr, 2016) described the hierarchical structure of muscles as a complex network of collagen-reinforced tubular sheaths, which enclose the myofibres and are continuous with 'higher-level' fascial tubes (compartments) surrounding groups of muscles, the limbs and entire body (Benjamin, 2009); and this description of fascial tissues as 'tubes' naturally follows from their cross-sectional appearances (Fig. 1).

The crossed-helical tube

In 1958, Clarke and Cowey showed that changes in the relative length and diameter of nemertean and turbellarian worms were controlled by the particular alignment of tensioned fibres within their body walls, where the fibres were constrained by the crossed-helical geometry surrounding the pressurized body tube and enabled it to maintain a constant volume throughout changes in shape (Fig. 2); and this basic model has now become entrenched as a design principle in biomechanics (Wainwright, 1988; Shadwick, 2008; Kier, 2012).

A crossed-helical tube that is shortened will cause the fibre angles to increase (relative to the tube axis) while one that is extended in length will cause them to decrease; and in both cases, the tension within the fibres becomes greater as the tube shape moves away from its central resting position (Purslow, 1989; Goriely and Tabor, 2013). The shape that optimally balances both longitudinal and circumferential stresses is when the fibres are at an angle of 54.44°, i.e. the fibre orientations are reflecting the most efficient

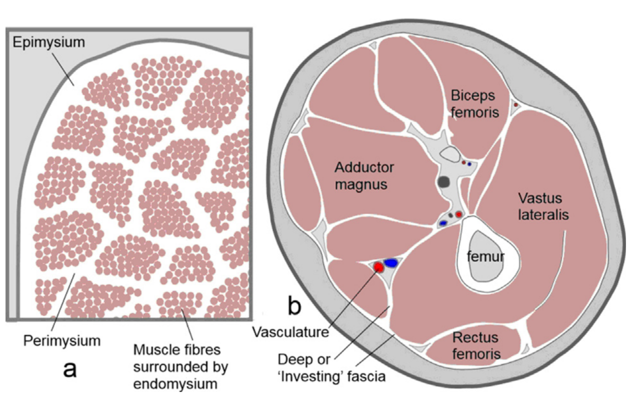

Figure 1 Schematic diagrams of (a) a transverse section of muscle showing the general hierarchical arrangement of myofascial 'tubes' surrounding the myofibres (not to scale); (b) transverse section of the human thigh showing the 'higher-level' fascial tubes consisting of muscle septa and the deep 'investing' fascia surrounding individual muscles and the entire limb. Reproduced with modifications from Scarr (2014) Handspring.

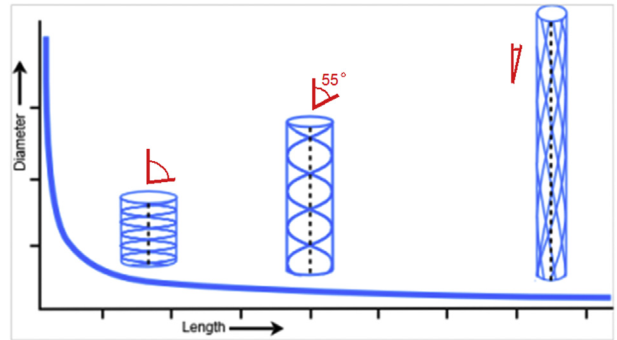

Figure 2 Graph showing the relationship between changes in length, diameter and fibre angles for a constant volume tube with crossed-helical fibres, where a 'resting' tube with fibre angles of ~55° balances both longitudinal and circumferential fibre stresses (helixes not to scale). Re-drawn with modifications from Kier and Smith (1985).

distribution of mechanical stresses and coordinating the changes in shape of the tube, as well as providing a system of elastic energy storage that assists in returning the tube to its resting state (Clark and Cowey, 1958).

Although the functional significance of this particular arrangement is now well established in many species and in different parts of the body, it has received relatively little attention within the fascia of humans, and the theory and relevance of this pattern to changes in the shape of muscles was described in Part I (Scarr, 2016). The formation of a crossed-helical pattern is based on simple geometric principles (Pickett et al., 2000; Scarr, 2011) and its persistence is ensured because it is one of the most stable of structural configurations; and it is not surprising that such a system should predominate in compliant biological tissues because this is one of the most efficient ways of optimizing the stresses within their walls (Clark and Cowey, 1958; Wainwright, 1988; Kier, 2012).

Anecdotally, certain practitioners routinely observe an oscillatory tissue motion that is palpable on the surface of the body and provides qualitative information that contributes to the diagnosis and treatment of a wide variety of conditions (Parsons and Marcer, 2006 p 201–218; Sergueef et al., 2011) and Scarr (2013) described a potential link with crossed-helical arrangements of collagen. Nelson et al. (2001, 2006) also found a correlation with cyclic changes in arterial blood flow and it is now proposed that all these factors relate to changes in the volume of tubular fascial sheaths.

Traube-Hering-Mayer waves

While periodic changes in arterial pressure and volume have long been recognized, their physiological origins and nomenclature have caused considerable confusion since they were first described in the eighteenth century (Koepchen, 1984; Larsen et al., 2010), but they do provide valuable clinical information through the real-time monitoring of haemodynamic parameters and contribute to the decision making process within intensive care units (Lamia et al., 2005). They are also useful to research in