The Meaning of Tensegrity Principles for Osteopathic Medicine

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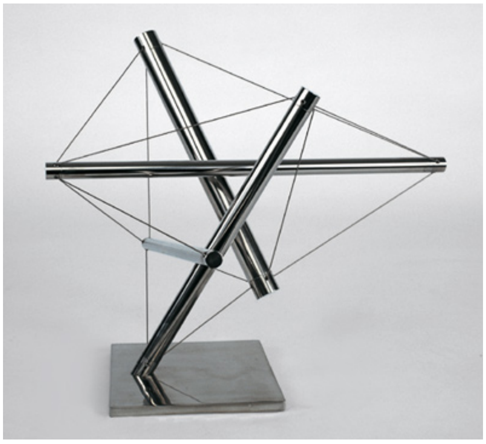

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Abstract

This study deals with the significance of tensegrity principles for osteopathic medicine. The central questions are, whether and in which way these principles can be applied in osteopathy and which scientific basis the application has.

The first part of the study, on the one hand, deals with the development of the tensegrity principles and their application in architecture as well as the transfer of these principles to biological systems in the micro- and macroscopic area with the help of basic research. The understanding of this basis is essential to assess the transfer of these principles in osteopathy. On the other hand, a literature analysis is carried out and it is investigated in which form these principles are transferred to osteopathic medicine. In doing so one concentrates on the quality of the particular sources.

In the second part of the qualitative study a critical discussion on the application of the tensegrity principles in osteopathy takes place. In the course of an expert interview, six experienced osteopaths are asked for their opinion on these principles. It is only these expert interviews that make a critical debate with the tensegrity principles possible, as in literature such a critical discussion does not take place.

Key words

Qualitative research - tensegrity - tension - compression - synergy - cytoskeleton - matrix - fascial networks - biomechanics - complex systems - models

Eidesstattliche Erklärung

Hiermit versichere ich, die vorgelegte Master These selbständig verfasst zu haben. Alle Stellen, die wörtlich oder sinngemäß aus veröffentlichten oder nicht veröffentlichten Arbeiten anderer übernommen wurden, wurden als solche gekennzeichnet. Sämtliche Quellen und Hilfsmittel, die ich für die Arbeit genützt habe, sind angegeben. Die Arbeit hat mit gleichem Inhalt noch keiner anderen Prüfungsbehörde vorgelegen.

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1. Introduction

1.1. Acknowledgements

First of all I would like to thank the people who helped me without me even being aware of the fact that they did. I am sure there is a large number of people who helped me intentionally or unintentionally through conversation and encouragement. Indeed intentionally I would like to thank my interview partners, who spent a lot of time with me despite their close timetables and supported me in every aspect. In the order of the interviews I would like to thank Patrick van Dun, Peter Sommerfeld, Georg Harrer, Claus Siemsen, Paul Klein and Max Girardin. It was a further great help and, in addition to that, a beautiful experience that all experts, who deal with the tensegrity model, reacted to my enquires per e-mail and were a great help with the understanding of often difficult issues. Many thanks go to Donald Ingber, Steven Levin, Paul Lee, Michael Patterson, Peter Schwind, Robert Schleip, Tom Myers, Phil Earnhardt, Ami Edmondson, Peter Huijing and Christian Lisdat. A large share of the success of this study is due to my scientific advisors Kathie Musil and Heidi Clementi. Their questions and comments most often meant a lot of work for me, but they always ensured to lead me back to the correct way of scientific work and finally achieve my goal. Many thanks go to Ute Amaning, who translated my work into English. Finally, and above all, I would like to thank my wife Miriam for the patience and support. Despite the huge amount of time that was necessary to complete the work, she never reacted annoyed to the term „tensegrity“.

1.2. Aim of the Study

The term tensegrity is being used increasingly in osteopathic literature. (Meert 2003, Schwind 2003, Patterson 2005, Lee 2006, Liem 2006, Koschella 2007) It is noticeable that this term is used in various ways. Whilst some authors use tensegrity as physical principle for the description of the mechanical functions of the myofascial system (Schwind 2003, Myers 2004), other authors describe tensegrity in connection with cranial concepts in osteopathy (Lee 2006), or as a partial explanation of the concept of somatic dysfunction as it is discussed in osteopathy. (Patterson 2005). Furthermore, the term tensegrity is used for various dimensions. In the micro-anatomic area, also in the dimension of cytoskeleton and extra cellular matrix, the statements were always based on reliable and sufficient sources which attempted to support the tensegrity model with experiments (Ingber 1998-2008, Chen & Ingber 1999, Stamenovic 2002-2006). The statements that the myofascial system on a mascroscopic scale behaves like a tensegrity structure were always mentioned in literature (Meert 2003, Schwind 2003, Myers 2004, Liem 2006), but never based on sources that aimed to support the model with experiments.

It is therefore the aim of this study to examine the term tensegrity and its application in biology and osteopathy. The literature analysis in part one of this study is divided into three chapters. The architectural basis and the development of tensegrity principles are described in chapter 3. Then follows a chapter on the application of tensegrity principles in biology and present research (chapter 4). The last part of the literature analysis deals with the manner in which the principles are transferred to osteopathic literature (chapter 5). In the second part of the study the application of the tensegrity model is put up for discussion by means of a guideline oriented interview. Experienced osteopaths are questioned regarding their opinion on the applicability of the tensegrity model in osteopathy (chapter 7).

1.3. Personal Background of the Study

I first heard of tensegrity in 2001 during my training at the College Sutherland. Jean Pierre Noelmans who was then my tutor, explained the principle during his lectures regarding fasciae. Since then I have come across this term, or rather the principles, every now and then. In the beginning only occasionally (Meert 2003, Schwind 2003), then more frequently in literature (Oschman 2006, Lee 2006, Liem 2006, Koschella 2007) during lectures (Patterson 2005) or seminars (Girardin 2005). I noticed then that the application of tensegrity principles in osteopathic medicine is described in different ways. On the one hand I was under the impression that only few colleagues had an exact idea what these principles are about and what their basis is. “Everything is connected in this way” or “it somehow has to do with ‘pull’ and ‘push’ ” were some of the vague ideas they expressed. Even my own notion did not reach much further at the time. Various applications of these principles and the fact that many colleagues do not have a clear understanding of the exact principles gave me the idea of analysing how the term tensegrity is used in osteopathic literature. It is my own perception that in osteopathy, terms are often discussed and used immediately without expanding them, let alone colleagues having tried to examine the applicability of these models. I therefore think it is important to analyse the basis of terms like tensegrity and the way the application of these principles can be legitimate.

2. Literature Analysis

Besides the summary and description of the examined literature it is the main aim of this study to examine the quality of the literature using categories. The analysis will show that the quality of literature in individual chapters is vastly varied. Whilst literature on the tensegrity model in the micro-anatomic area can be described as consistently good, quality in the macro-anatomic area and in the application in osteopathy is significantly suboptimal.

2.1. Literature Research

The search for literature about the tensegrity model was carried out in several steps. First of all, on 17th November, 2007, I searched for the term “tensegrity” in data banks in the internet.

Data bank	Website address	Results
Medline	www.ncbi.nlm.nih.gov/sites/entrez/	88
Osteopathic research	www.osteopathic-research.com	2
Ostmed	http://ostmed.hsc.unt.edu/ostmed/home.htm	3
Scirus	www.scirus.com	544
ScienceDirect	www.sciencedirect.com	103
JAOA	http://www.jaoa.org/	2

Afterwards, I searched for combined terms in the search machine „google“. This was necessary, as the above mentioned search machines generated only few results on the application of tensegrity models.

Tensegrity AND “Osteopathy”	756 results
Tensegrity AND “Osteopathic Medicine“	301 results
Tensegrity AND “Manual Therapy”	350 results

Entering the term “tensegrity” in the search machine „google books“ (645 results) and „Tensegrity“ AND „Osteopathy“ in „google scholar“ (65 results) was of great help. „Google scholar“ is a search machine of google, which searches in scientific publications exclusively.

The second step was a further search for articles and other sources according to the list of literature contained in articles and books found to that date. Tensegrity is a physical principle that can be applied not only in osteopathic medicine but in all manual therapies. I therefore not only searched in osteopathic literature, but in literature on manual therapy in general. A great number of studies on tensegrity was done by Rolfers, (Schwind, Myers, Schleip, Smith), but also in the area of massage therapy studies on the tensegrity concept can be found (Kassolik).

2.2. Literature Analysis

There is a large number of articles and text which I could neither find in Medline nor did they contain the word „tensegrity“ in the title. I therefore searched for each article in Medline specifically in order to be able to classify it. The classification of each article can be found in the respective chapters about the appliance of tensegrity (4.1.1., 4.2.1. und 5.1) and is structured according to the following scheme.

1st category:	Articles published in a magazine listed in a Medline (All these articles are listed in the list of references)
2nd category:	Articles based on reliable sources published in a magazine.
3rd category:	Articles based on reliable sources published in books or monographs.
4th category:	Other articles based on reliable sources (for example documents from the internet).
5th category:	All articles not based on reliable sources.

For the analysis of literature, the articles were sorted into the categories which provide a basis for the chapters of this work.

- Tensegrity basics and principles
- Tensegrity in the microscopic area
- Tensegrity in the macroscopic area
- Tensegrity in osteopathic medicine

Reading the articles of the respective subjects resulted in the categories used as sub-categories in this study (see chapters 4 and 5).

3. Basic Principles of Tensegrity

In this chapter I will show how the term tensegrity was formed, the basic principles and how these principles of tensegrity were initially used in architecture.

The term tensegrity was shaped by the American architect, engineer and philosopher Richard Buckminster Fuller (1895-1983). It is a combination of the words „tension" and „integrity". These are technical structures consisting of a continuous system of tension elements and a discontinuous system of compression elements. A decisive factor for stability is the pre-stress (Gengnagel 2002). Whilst Buckminster Fuller was the first to describe these ideas in mathematics („*islands of compression in an ocean of tension*"), Kenneth Snelson independently built structures which operated according to the principle „*continuous tension, discontinuous compression*". His structures are also built according to tensegrity. This way the two most common forms of tensegrity were created, i.e. Buckminster Fuller's Geodesic dome structures and Snelsons pre-stressed structures, for example his „X-Piece". (Motro 2003)

3.1. Definitions of Tensegrity

It is important to give a definition of the term tensegrity as accurately as possible, as precisely this definition will play an important role in the expert discussion. The problem is that an exact definition of the term is still difficult, as shown in this chapter.

Rene Motro highlights in his book „Tensegrity“ that, even though all protagonists describe identic structures, an exact definition is difficult. „*One can not define it completely. Nevertheless we can illustrate it*." (Motro 2003, p. 9)

Buckminster Fuller defines the term tensegrity in his main work "Synergetics" and describes the relation between continuous tension elements and discontinuous compression elements, which are responsible for a structure, as follows: "*The word tensegrity is an invention: it is a contraction of tensional integrity. Tensegrity describes a structural-relationship principle in which structural shape is guaranteed by the finitely closed, comprehensively continuous, tensional behaviours of the system and not by the discontinuous and exclusively local compressional member behaviours. Tensegrity provides the ability to yield increasingly without ultimately breaking or coming asunder. The integrity of the whole structure is invested in the finitely closed, tensional-embracement network, and the compressions are local islands.*" (Buckminster Fuller 1975, p. 1) In this work he also explains the balance between tension and compression. In his opinion these are only two aspects of one and the same thing. They only function in interdependence. Compression elements cause tension and vice versa.

A further definition is given by Rene Motro as follows: "*A tensegrity system is a system in a stable self-equilibrium state comprising a discontinuous set of compressed components inside a continuum of tensioned components*."(Motro 2003, p. 19) The term "stable self-equilibrium" expresses, that the system has an initial tension, even before any force -

even gravity - has an affect on it. The system is in self-balance due to its pre-stressed characteristics. „Stability“ is defined as the ability of the system to return to its original balance after an external force has had an impact on it. It is not determined of which type of „components“ the system is made of. They can be lines, surfaces or volumes, they can be cables, rods, a membrane or an air volume. The components can even be a combination of various elements combined to a component of a higher order. Moreover, it is not determined of which material these components consist. „Compression“ and „tension“ are, mechanically described, the effects of a force. This means that the material is either exposed to compression or tension effects. A component that is compressed requires rigidity in compression, however, a component that gets under tension requires rigidity in tension. It is a known fact that cables and membranes do not possess rigidity in compression. The words „discontinuous“ und „continuous“ are closely related to the words „ocean“ and „islands“ mentioned by Buckminster Fuller. Each compressed component represents an island. If a system has several compression elements, i.e. several islands, these must not be in contact otherwise the system may not be defined as tensegrity system. (Motro 2003)

3.2. History of Tensegrity

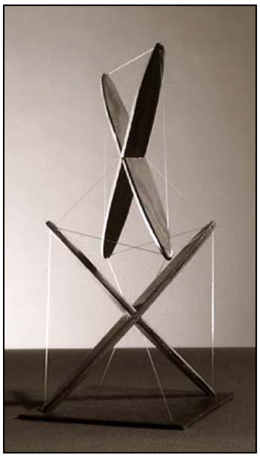

Fig.1 Kenneth Snelsons X-piece

In 1920 the Russian artist Karl Ioganson brought three compression struts into balance by means of a continuous connection with ropes. This way he created the first tensegrity structure, however, he did not use the term or describe the principles. The American architect Kenneth Snelson built smaller sculptures according to the tensegrity principle whilst he was a student. His „X-Piece" arose the interest of Buckminster Fuller. He then developed the corresponding mathematical concept. After his studies Snelson pursued an artistic orientation and implemented large-scale structures like the „needle tower" which was 30 metres high. Buckminster Fuller recognised the potential of Snelson's sculptures and developed a number of basic systems, for example the Geodesic dome structures. In 1962 Buckminster Fuller had the tensegrity principles patented, in 1964 he obtained the second patent on his „Aspension Dome" (Gengnagel 2002)

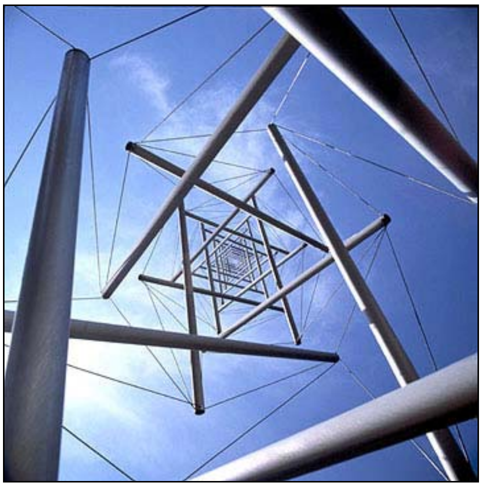

Fig. 2 Kenneth Snelsons Needle Tower

3.3. Various Tensegrity Models

In this chapter various structures built on tensegrity principles are portrayed. The following architectural or technical structures form the basis for the transfer of the principles to models in biology and osteopathy.

3.3.1. Geodesic Dome Structures

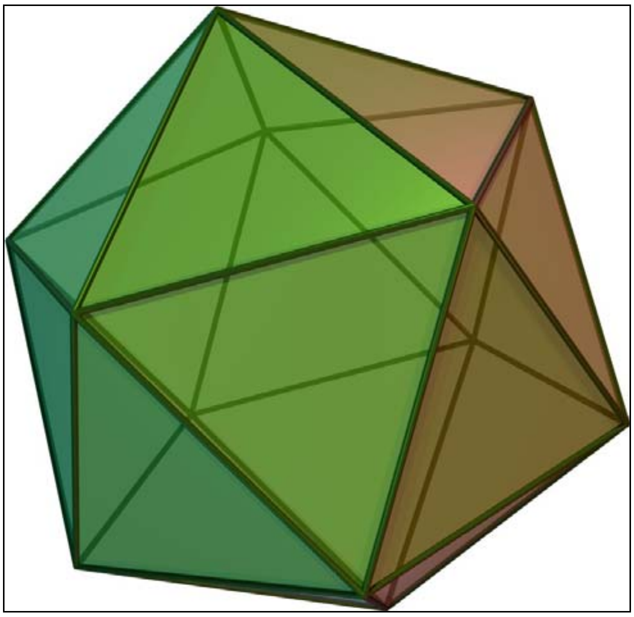

Fig. 3 Ikosahedron

Buckminster Fuller described hemispheres consisting of as many struts of the same length as possible as well as congruent surfaces. The icosahedron serves as basic structure. It is a network of equal triangles whereby the crosspoints are always situated on the surface. A further partitioning allows the formation of basic elements ever decreasing in size in a geodesic network with spherical triangles (Gengnagel 2002). Geodesy is a mathematical phenomenon. It is the most economical connection between two events, i.e. a straight line between two points. A geodesic dome structure is based on this principle. The tension elements in this tensegrity structure use the shortest path between two adjoining partners and are therefore by definition geodesic. Tension also always spreads across the shortest distance between two points and therefore the structures are well equipped to withstand strain (Buckminster Fuller 1975). A geodesic dome consists exclusively of icosahedra, which comprise equilateral triangles. This triangulation guarantees strength and rigidity of the ball-shaped structure. It differs from other tensegrity structures in as much as each strut is able to withstand either tension or compression, depending on which force acts at that moment. They act therefore neither as tension nor as compression element. There is no direct contact between the compression elements. (Parsons 2005)

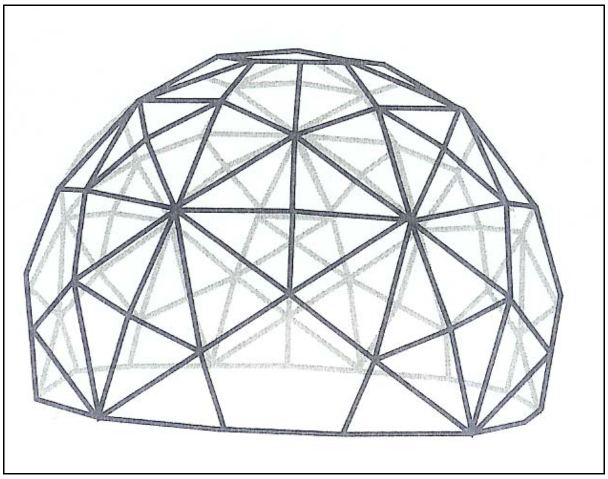

Fig. 4 Geodesic dome (Parsons)

Fig. 5 Geodesic dome

3.3.2. Pre-stressed Networks

In Snelson's pre-stressed structures the discontinued compression struts are located within a pre-stressed continuous tension network and in this way form a three-dimensional structure which is stable on all sides Snelson applied for a patent for the principles of this structure (Snelson 1965). This system works as a whole. Whatever happens at one point happens at each point of the structure simultaneously. If the system is tightened at one point, the whole system is tightened. (Buckminster Fuller 1975)

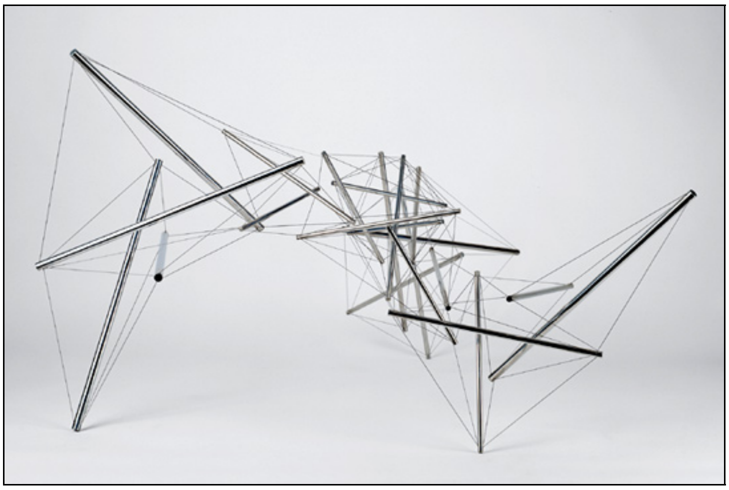

Fig. 6 pre-stressed networks

3.3.3. The Spoked Wheel

The spoked wheel was identified by Buckminster Fuller as the first tensegrity structure. It is a self-stabilising system. A pressurised ring (rim) is pre-stressed in a radial system of tension ropes (spokes) against two central hubs. Pre-stress allows the transfer of pressure through thin tension elements. The spokes are arranged continuously and give the pressure ring stability. (Gengnagel 2002)

Fig. 7 spoked wheel

3.3.4. The Balloon

For this example it is practical to replace the term „tension“ by „pull“ and „compression“ by „push“. *„The balloon consists of a continuously pulling rubber skin being discontinuously pushed by the individual air molecules in the balloon, thereby keeping it inflated*.” (Parsons 2005, p. 74)

3.4. Tensegrity in Nature

Edmondson (1992) writes in her book „A Fuller Explanation“, that the principles behind Buckminster Fullers geodesic dome structures are not new but that they are everlasting laws of nature. These principles can be found everywhere in nature, in every possible dimension. Buckminster Fuller did not copy the principles from nature but he translated them into mathematical principles and this way made them comprehensible. When these principles are transferred geodesic structures are of paramount importance. Edmondson quotes Fuller regarding this statement as follows: *„I did not copy nature's structural patterns. [...] I began to explore structure and develop it in pure mathematical principle, out of which the patterns emerged in pure principle and developed themselves in pure principle. I then [...] applied them to practical tasks. The reappearance of [geodesic] structures in scientists' findings at various levels of inquiry confirms the mathematical coordinating system employed by nature*”. According to Edmondson there is no example more suitable for the application of these principles in nature than Donald Ingber's. In her book she quotes a letter of Ingber to Buckminster Fuller from 1983: *„The beauty of life is once again that of geometry with spatial constraints as the only unifying principle. It is of interest to note that […] cancer may then be viewed as the opposite of life resulting from a breakdown of this geometric hierarchy of synergetic arrangements.”* (Edmondson 1992, p. 245-249)

Rene Motro also occupies himself with Donald Ingber's studies and regards his works as good examples for the application of tensegrity in biological systems. He especially refers to Ingber's theory of mechanotransduction via the cytoskeleton. Motro believes that it is an excellent analogy between the mechanical characteristics of both the cytoskeleton and tensegrity systems. „ *It appears that we can indeed find a limited degree of common ground. The composition of the cytoskeleton allows us to speak form a tensegrity system in this case. Moreover, the whole endothelial cell can be considered as a tensegrity system."* (Motro 2003, p. 30) However, he also says that this type of analogy still has to undergo an exact examination. Mechanotransduction mentioned by Motro will be dealt with extensively in chapter 4.3.2.

3.5. Summary

In this chapter the development of tensegrity principles and their application in architectural principles is described. Furthermore it is clarified that also in technology a standard definition of the principles is difficult. Nevertheless it is important for the application of the principles in biology and osteopathy to have a standard perception of the principles. An attempt is made to summarise the principles according to Parsons (2005).

a) Tensegrity is a structural system composed of discontinuous compression elements connected by continuous tension cables.
b) There is a balance between tensional and compressive forces that maintains the stability of the structure.
c) Tensegrity structures act as "whole systems". External forces acting on them are transmitted to all elements of the structure in the same way. Vibration in one part of the structure causes vibration in all other parts.
d) The structures are efficient. They require only few materials and though the structures are very light, in fact they are very strong.

e) Tensegrity structures are self-stabilizing structures. Once the external force is removed they will return to their original shape.
f) Pre-stress and triangulation are essential elements in a tensegrity system.
g) The continuous tension elements do not have to be visible. Pneumatic and hydrostatic systems can be tensegrity, e.g. a balloon.
h) Many structures in nature seem to be tensegrity structures. They have the property of synergy. It is not possible to deduce the function of the whole by analysis of the parts.

4. Tensegrity in Biological Systems

„The book of nature may indeed be written in the characters of geometry." (Galileo Galilei)

This chapter deals with the application of tensegrity in biological systems, first in the micro-anatomic area, later on in the macroscopic area. The literature summarised and analysed in this chapter is the basis for the application of the tensegrity principles in osteopathy. This chapter is therefore of great relevance to the study. The knowledge within the studies written in this field and the present progress of research are essential to the assessment of the appliance of the tensegrity model in osteopathy.

The transfer of the tensegrity principle to biological systems is based mainly on the work of Donald Ingber. In 1998 he published a review of his work titled „The Architecture of Life" in the „Scientific American". His work became well-known through this article and at the same time the article initiated first thoughts on the applicability of the osteopathic concept, as I will show later on. Nevertheless Ingber's work reaches back to the eighties when he first presented the concept in an article.

4.1. Literature Evaluation

This chapter will give an overview over the quality of literature used. The articles used in the microscopic area were almost exclusively published in a magazine listed in Medline. One article (Guimberteau 2008) was however published in a magazine not listed in Medline, i.e. („Osteopathische Medizin“). The two books mentioned (category 3), which deal with tensegrity on this level in respective chapters are based on sources which are almost exclusively listed in Medline. All sources mentioned in the text are listed in categories as follows.

1st category (Articles published in a magazine listed in Medline)

Canadas et al (2002): A Cellular Tensegrity Model to Analyse the Structural Viscoelasticity of the Cytoskeleton. In: Journal of theoretical Biology.

Chen; Ingber (1999): Tensegrity and Mechanoregulation: from skeleton to cytoskeleton. In: Osteoarthritis and Cartilage.

Denerll et al (1988): Tension and compression in the cytoskeleton of PC-12 neurites. II. Quantitative measurements. In: Journal of Cell Biology.

Elson (1988): Cellular mechanics as an indicator of cytosekletal structure and function. In: Annual Review of Biophysics and and biophysical Chemistry.

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Heidemann (1993): A new twist on integrins and the cytoskeleton. In: Science.

Horwitz (1997): Integrins and health. In: Scientific American, Jg. 276.

Huang; Ingber (1999): The structural and mechanical complexity of cell-growth control. In: Nature Cell Biology.

Ingber (1998): The Architecture of Life. In: Scientific American.

Ingber (2000): The origin of cellular life. In: BioEssays.

Ingber (2002): Cancer as a disease of epithelial-mesenchymal interactions and extracellular matrix regulation. In: Differentiation.

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Stamenovic et al (2006): Cellular Tensegrity Models and Cell-substrate Interactions. In: Advances in Cellular Engeneering: Micromechanics at the Biomolecular Interface. Research Signpost Publishing.

Sultan et al (2004): A Computational Tensegrity Model Predicts Dynamic Rheological Behaviors in Living Cells. In: Annals of Biomedical Engineering.

2nd category (Articles based on reliable sources published in a magazine which is not listed in Medline)

Guimberteau et al (2008): Die Gleitfähigkeit subkutaner Strukturen beim Menschen - eine Einführung. In: Osteopathische Medizin.

3rd category (Articles based on reliable sources published in books)

Davies (2005): Mechanisms of Morphogenesis: the creation of biological form.
Oschman (2006): Energiemedizin. Konzepte und ihre wissenschaftliche Basis.

4th category (Other articles, for example internet documents, based on reliable sources.)

5th category (All articles not based on reliable sources)

Ingber (14.04.2008): Tensegrity. Email an Carsten Pflüger.

4.2. Self-organising Hierarchic Systems

This chapter deals with the composition of hierarchic systems. It is an attempt to explain the mechanical rules of complex systems. This is of importance to the study at the beginning as various dimensions of this chapter, i.e. micro-anatomy and macro-anatomy are connected by these rules. I will clarify in this chapter why mechanical or architectural principles are at all important to biological systems.

Ingber (1998, 2003) is of the opinion that these systems are organised through tensegrity.

To clarify how a complex systems works as a whole it is not sufficient to understand what the individual parts consist of. In addition one has to understand the rules of the system. When observing the organisation of living organisms it is noticeable that certain patterns in both microscopic and macroscopic structures repeat themselves continuously. Some of these patterns are spirals, triangles and pentagons. Also the components of organic and anorganic matter are the same, i.e. carbon, hydrogen, oxygen, nitrogen and phosphorus. The only difference between organic and anorganic materials is the three-dimensional arrangement of these substances in the space. The composition is the decisive characteristic which forms the basis for the way the structure behaves as a whole. (Ingber 1998)

When self-organisation of living organisms takes place smaller components form larger stable structures with new properties which are not predictable from the characteristics of the individual components. A body is made up of a hierarchic succession of systems: atoms form molecules. Cell organelles originate from these which join up to create cells. Cells form tissue which develops into organs which in turn form the body. Ingber applies the tensegrity principle on the self-organisation of systems in living organisms: "*I have discovered […] fundamental aspects of self-assembly. An astonishing wide variety of natural systems, including carbon atoms, water molecules, proteins, viruses, tissues and even humans, are constructions using a common form of architecture known as Tensegrity.*" (Ingber 1998, p.48) Systems that function on the tensegrity principle stabilise themselves mechanically in the way tension and compression are distributed and balanced in the structure. By understanding these principles it was possible to understand how cell forms and mechanical forces can influence the activity of genes. An explanation to why tensegrity structures are omnipresent in nature may lead to an insight of the main forces of biological organisation and perhaps even evolution as a whole. (Ingber 1998)

The principles of tensegrity can be applied to the body on every possible scale. On the macroscopic level the bones form the compression components which lean against gravity and are stabilised by the tension of muscles, tendons and ligaments. Only tensegrity can explain why an arm is moved, skin stretches, the extra cellular matrix expands , the cells including the cytoskeleton twist without causing fractures or interruptions. At the other end of the scale not only proteins stabilise themselves according to tensegrity principles but also certain carbon atoms, which, based on their architecture/structure, are called Fullerenes or "Bucky Balls" after the inventor of tensegrity. All other entities stabilise themselves three-dimensionally according to the principle of „continuous tension and local compression." (Ingber 1998)

The geodesic structures found in the cytoskeleton are examples for universal patterns found in every size in nature: carbon atoms (fullerenes), viruses, enzymes, organelles, cells, organisms. These ever recurring patterns are the visible proof for the existence of general rules of self-organisation. (Ingber 1998)

Through the work with tensegrity models it is possible to realise systems as a whole and understand how they work "throughout". Tensegrity explains how hierarchic structures consist of „systems in systems" and thereby still display interrelated mechanical characteristics. (Huang & Ingber 1999)

Ingber (2003) postulates tensegrity as a system according to which complex systems are assembled. *„The level of complexity is commonly ignored in cell biology. Fuller was the first to note that tensegrity systems can be constructed as structural hierarchies in which the tension or compression elements that comprise the structure at one level are themselves tensegrity systems composed of multiple components on a smaller scale. The tensegrity model* *of a nucleated cell, in which the entire nuclear tensegrity lattice is itself a tension element in the larger structure, illustrates this concept."* (Ingber 2003, p. 1167)

According to Chen and Ingber mechanical deformations result in a co-ordinated structural rearrangement on various scales. Chen and Ingber draw the conclusion that the reaction of the body on mechanical strain is not only caused by the quality of the material but also the architectural arrangement of microstructures. (Chen & Ingber 1999)

If, on a macroscopic scale mechanical strain is applied which distorts the extracellular matrix and the cells, the system reacts on a smaller scale. Certain molecular components change their biochemical activity. As mechanical strain is transported from the cytoskeleton to all parts of the cell, various simultaneous biochemical answers. Mechanical stability benefits from hierarchic structures which is a typical characteristic of tensegrity architecture. (Ingber 2005)

4.3. Tensegrity on the Microscopic Level

„It took a long time for me to see that some structures made of all rigid elements that touched, such as Fuller's geodesic domes, are indeed tensegrities because of how they distribute and balance forces. The key fundamental principle of tensegrity is that shape stability is governed by PRESTRESS (internal tensional stress), and this is absolutely true for living systems and our musculoskeletal system." (Ingber, 14.04.2008)

4.3.1. General Principles

The general principles of the tensegrity model are important to be able to apply it to biological systems and are essential for the understanding of their application in osteopathy.

"A tensegrity is a stress-supported mechanical network that maintains its structural stability through the agency of tensile prestress. In a tensegrity, tension is transmitted over the discrete network that comprises the structure, and these forces are balanced by a subset of structural elements that resist being compressed, thereby establishing a mechanical equilibrium." (Ingber 2008, p.54)

Mechanical stability of structures does not depend on the strength of individual parts but on how the whole structure distributes and balances mechanical strain. There are mainly two types of tensegrity structures, i.e. Buckminster Fuller's geodaesic domes and Snelson's „pre-stressed" structures. Fuller's domes have a framework of rigid struts which hold tension and compression. The struts are combined to triangles, pentagons or hexagons, whereby each strut is aligned in a way that each connection point is held in a firm position. This guarantees the stability of the whole structure. Snelson constructed tensegrity structures whereby the stability is based on pre-stress. Before an external force affects the system, all structural parts are under tension or compression. They are pre-stressed. Rigid pressure components stress the components which accommodate the flexible tension, whilst the components in turn comprise the rigid struts. This way even opposed forces are kept in balance. Both categories have in common that tension is distributed equally to all parts of the whole construction. Increased tension in one part provides increased tension in all parts. A global increase of tension is balanced by an increase of tension in various parts. Whilst tension is thus distributed evenly in the whole system, only individual parts actually balanced by compression. Those parts that accommodate tension connect the adjoining parts in the shortest, linear distance. As tension forces are distributed within the shortest distance between two points, tensegrity structures have the optimal structure to withstand strain. The construction according to the principles of tensegrity offers a maximum of load capacity and requires a minimum of construction material. It comes as no surprise that the arrangement of bones and muscles in a tyrannosaurus rex is almost equal to the arrangement in man, that animals and plants depend on pre-stress for mechanical stability in their bodies and that geodetic structures dominate in nature. (Ingber 1998)

Ingber (2003) divides tensegrity into two main categories. Firstly, pre-stressed structures which obtain their stability through their pre-stressed individual parts and secondly geodesic structures which arrange their structure elements in triangular shapes and align them in a geodesic way. Geodesic means the shortest distance between two points. Ingber points out again and again that in his opinion the main properties of tensegrity are pre-stress and the geodesic alignment of the structure elements.

According to Ingber tensegrity models use the space available in the environment in the most efficient way. It is possible that triangular tensegrity structures were chosen due to their structural efficiency, i.e. high mechanical load capacity combined with a minimum of building material. The flexibility of pre-stressed tensegrity structures may be of advantage as it permits the structures to adapt various shapes. Such structures have a longer lifespan and can react more easily with other entities. (Ingber 1998)

In 1999 Chen & Ingber summarised the main principles of the tensegrity model in biological systems in their article „Tensegrity and mechanoregulation: from skeleton to cytoskeleton“ as follows:

<u>Maximize tensile materials:</u> The human „skeleton“ is composed of tension and compression elements, whereby the tension elements dominate the system, in order to minimise the mass.

Importance of architecture: The stability, mobility and strength of a tension network is heavily dependent of the architectural arrangement of its individual parts.

Stability through pre-stress and triangulation: The presence of pre-stress in biological networks ensures the optimisation of stability of systems of each dimension. Through pre-stress it is possible that the tissue can react immediately to unexpected external forces. In areas where the body does not resort to pre-stress, the structures are stabilised geometrically, i.e. through triangulation. Triangulation is used where the maximum of stiffness is required, whereby pre-stress is used, if a larger flexibility is needed.

Structural hierarchy: Biological systems use hierarchic structures to maximise the structural efficiency. The use of multiple smaller networks that independent self-stabilize are favoured by environmental selection. The function of the whole is not necessarily comprised by the loss of a single part.

One of the most important features of the use of the tensegrity paradigm is that it permits analysis of Mechanotransduction within the complexity of living cells. This hierarchical model of biologic organisms may help to explain one of the most fundamental properties of living creatures: how the parts and the whole function as a single integrated system. (Chen & Ingber 1999)

4.3.2. Tensegrity as Model in Cytology

Formerly it was believed that the cell was a „bag of fluid solution“ and all chemical reactions take place in this solution. Firm cell components remained unconsidered. Today we „find“ more and more firm structures in cells. A network of small tubes (Tubuli), fibres and small beams (trabeculae) form the cytoskeleton. Almost the whole cell water does not move freely in the cell but is embedded in the cytoskeleton

(Cope 1967). Many enzymes are also connected to such firm cell and nuclear structures. “Chemistry of life” mainly takes place in a structural environment (Oschman 2006).

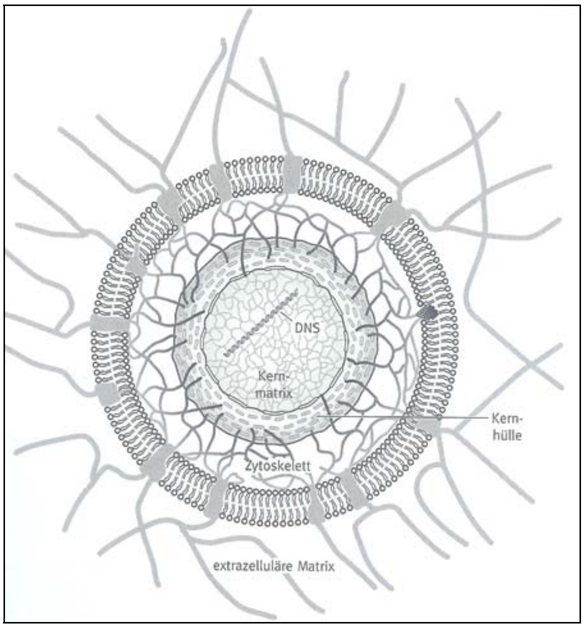

Fig. 8 A cell and its connections in a living matrix (Oschman)

“The cytoplasm is commonly viewed as viscous or viscoelastic fluid, that locally alters its stiffness as a result of changes in cytoskeletal polymerization. The reality is that living cells always retain most of their cytoskeletal filaments in a polymerized form whether the cell is round or spread. Altering the tone in this cytoskeletal network (e.g. using chemical activators or inhibitors of actomyosin filament sliding) results in immediate changes in the mechanical stiffness of the whole cell.” (Chen & Ingber 1999, p. 87)

The structure of the cytoskeleton of the cells is so complex that we still do not have a clear picture of the forces that have an effect on a simple cell. In his book „Mechanisms of morphogenesis“ Davies dedicates a whole chapter to tensegrity principles. According to him the tensegrity model with its accumulation of tension and compression elements is a very promising way of describing the transfer of forces within the cytoskeleton. (Davies 2005)

Cells have had to evolve a structural framework to transmit forces from one place to another side inside their cytoplasm. This structure, known as cytoskeleton, is a highly interconnected three-dimensional network composed of three major biopolymer systems, microfilaments, microtubules, and intermediate filaments along with their associated proteins:

Microfilaments contain polymerized actin. They can appear alone or in association with myosin filaments… which generate tension that is continuously transmitted throughout the entire actin lattice and thus, the whole cell. In living cells actin filaments almost always exhibit a highly linear form, suggesting they are continuously under tension.

Microtubules are hollow tubular polymers composed of different tubulin monomer isotypes. They commonly exhibit a highly curved or buckled morphology in living cells, suggesting that they may be experiencing local bending and/or axial compression.

Intermediate filaments are composed of different protein monomers (e.g. vimentin, desmin, cytoceratin) depending on the specific cell type. In living cells the intermediate filaments appear in a highly extended, but crenulated form, stretching from the border of the nucleus to discrete cell-cell and cell-ECM adhesion sites at the cell periphery and they also laterally interconnect with the other cytoskeletal filament systems. (Chen & Ingber 1999) This division of the cytoskeleton is also described by other authors. (Stamenovic 2006, Davies 2005, Sultan 2004, Canadas 2002) On a cautionary note however, it has to be added, that the exact machanical role has not been understood completely to date but experimental studies with living cells and measurements in vitro have allowed some insight into the function of cytoskeleton. (Stamenovic & Ingber 2002)

The network of contractile microfilaments spreads over the whole cell and serves as tension element. The force of the microfilaments is turned inwards. They pull the cell membrane and all inner parts of the cell towards the nucleus. Two compression alements work against this inwards directed tension, the extra cellular matrix on the outside and the bars of the microtubules on the inside. The intermediary filaments, a third component of the cytoskeleton, combine the microtubules and the contractile filaments with each other as well as with the nucleus and the cell membrane. They play a mediatorial role. Therefore, there is a physical connection between nucleus and other cell structures. A tension on the receptors of the cell surface will cause immediate structural changes in the depth of the cell. Tensegrity not only explains the mechanical stabilisation of cell and nucleus but also connects biomechanics and biochemistry on a cellular level. The structures of the cytoskeleton change when physical forces act on the cell. Enzymes which are responsible for the protein synthesis and energy transformation and control the cell growth are incorporated in the cytoskeleton. (Ingber 1998; Stamenovic et al 2002; Ingber 2005)

Integrins (transmembraneous proteins) combine the cytoskeleton with the extra cellular matrix and the nucleus. There is a direct mechanical connection between the surface of the cell and the genes. The borderline between cell surrounding, cell centre and genetic material are not as exact and impermeable, as was assumed to date. Integrins co-manage significantly the form and function of cells by means of these transfer functions. Horwitz established in 1997 that integrins control many body functions and play a key role in diseases like arthritis, apoplex, osteoporosis and others. The role of integrins regarding the migration of cells in defence and the healing of wounds is of great interest. (Oschman 2006)

The extra cellular matrix and the cytoskeleton are connected by integrins. Ingber (1998) prove that a force that works on integrins ensures that the cell as a whole becomes stiffer. Living cells can be made stiffer or more flexible through changes in the pre-stress of the cytoskeleton. Tissue behaves in the same way as the cells. All structural elements of the tensegrity model change their shape due to local strain and more and more elements align themselves towards the strain applied. This process is called "linear stiffening". Stamenovic and Ingber developed a mathematical model that was able to predict the stiffening and alignment characteristics of cells and tissue (Ingber 1998). Further experiments from Chen and Ingber (1999) with cultured cells confirm that mechanical stresses can directly alter many cellular processes, including signal transduction, gene expression, growth, differentiation, and survival.

Tensegrity helps to explain how, in living cells and tissue, the cytoskeleton transfers mechanical signals into biochemical answers. This procedure is called mechanotransduction. *„To carry out certain behaviours (crawling, spreading, division, invasion), cells must modify their cytoskeleton to become highly deformable and almost fluid-like, whereas to maintain their structural integrity when mechanically stressed, the cytoskeleton must behave like an elastic solid. Although the mechanical properties of cells govern their form and function and, when abnormal, lead to a wide range of diseases."* (Stamenovic 2003, p. 82) It is a unique characteristic of tensegrity structures that mechanical strain is passed on to the tension network over long distances. This is different from conventional models where local forces only cause local reactions. (Stamenovic et al, 2006; Ingber 2003) According to Galli too, mechanotransduction is an important property of cell and tissue functions: *„This model is a useful tool to predict cell spreading, motility and especially Mechanotransduction, i.e. the capability to transform mechanical stresses into biochemical responses, a key process in homeostasis of many tissues that must continuously withstand mechanical forces*." (Galli et al 2005, p. 5)

An important characteristic of tensegrity structures is pre-stress which is mentioned again and again. (Ingber 1998; 1999; 2003; 2008) Stamenovic et al (2006) describe these properties in detail. According to them their studies on cell cultures point to the assumption that adherend cells control their mechanical behaviour by adapting the pre-stress of their cytoskeleton. Pre-stress in this case refers to the tension already dominant in the cytoskeleton before an external force is applied. Stamenovic et al also describe that this kind of pre-stress arises actively through contractile microfilaments and is passed on by intermediary filaments. Furthermore pre-stress is passed on to the neighbouring cells through focal adhesion and the extra cellular matrix. According to them (Stamenovic et al 2006) these observations correspond with the idea that the cytoskeleton is organised like a tensegrity structure. *„Tensegrity architecture describes a class of discrete network structures that maintain their structural integrity because of pre-stress in their cable-like structural members. The hallmark that stems from this feature is that structural rigidity (stiffness) of the network is proportional to the level of pre-stress support. (*Stamenovic 2006, p. 85*)"* In conclusion they write that the pre-stress is based on the balance of forces between various kinds of molecular elements, for example the individual parts of the cytoskeleton as well as the connection to the extra cellular matrix and neighbouring cells. (Stamenovic et al 2006)

In a new article Ingber (2008) recapitulates the characters of the tensegrity model which he regards as most important. According to him it is crucial that the tensegrity model predicts, that an adjustment in the pre-stress of the cytoskeleton changes the static mechanical properties as well as the dynamic rheological properties of the cell. *„Thus, at present, tensegrity appears to be the most generalizable model of cell mechanics, in addition to being useful to describe the mechanical behaviour of living materials at multiple other size scales, from individual molecules to whole organisms."* (Ingber 2008, p. 54)

There are various opinions on the exact characteristics of the individual parts of the cytoskeleton. Stamenovic et al (2006) describe the individual parts of the cytoskeleton whereby the actin filaments and the intermediate filaments behave more like tension elements. The microtubules rather constitute compression elements. (Stamenovic 2006). In 1988 Denerell et al measured such a tensegrity system in neurons in which the microtubules serve as compression elements and the actin filaments serve as tension cables (Denerell et al, 1988). Whilst Howard states in his book „Mechanics of motor proteins and the cytoskeleton“ (2001): *„However, as we will see, polymerizing actin filaments are actually in compression, while depolymerizing microtubules are in tension. Evidently, each type of cytoskeletal filament can be in compression or tension depending on its cellular location or the activity of the cell […] and a more sophisticated model for cell structure is needed."*

Sultan and Stamenovic come to the conclusion that the tensegrity models based on the presumption that microtubules are not exclusively rigid but precisely because they are semi-flexible, they are considerably more effective when predicting the mechanical cell behaviour. (Sultan & Stamenovic 2004) Ten years have gone by since the publication of "the architecture of life" and meanwhile Ingber has adapted his idea of the tensegrity model for the cytoskeleton, at least in some small points as follows. He no longer regards the microtubules as rigid compression structure but as semi-rigid (Ingber 2008). A strictly rigid structure does not correspond to measurement results and is also challenged by other authors, as mentioned above. It can therefore be said at this point in time that the general principles of tensegrity, i.e. pre-stress, geodesic architecture and mechanotransduction can definitely be applied to the cell as a model. However, details as to the exact attribution of the individual parts of the cytoskeleton have not been clarified to date.

4.3.3. Tensegrity as a Model of the „Living Matrix“

Whilst the previous chapter deals with the application of the tensegrity model on the level of cytology, this chapter addresses the next step, i.e. the application of tensegrity on the level of histology. It is shown in which way the authors attempt to explain the mechanical properties of tissues based on the tensegrity model.

Oschman (2006) describes the connective tissue also as the „living matrix" or as tissue tensegrity matrix. It is a continuous and dynamic network that spreads into all distant corners of the body. This network is present in each size, similar to a fractal pattern. The nuclear matrix is contained in the cell matrix, which in turn is within the tissue matrix. The characteristics of the whole net depends on the activity of all incorporated parts. Affects on part of the system also affect all other parts of the whole organism. According to Oschman Heidemann (1993) proved in experiments that the cytoskeleton behaves like a tensegrity structure. (Heidemann 1993) According to Stamenovic the continuity of the cytoskeleton and the extra cellular matrix is decisive for the control of the cell functions: „*The interconnectedness of the cytoskeleton and its physical linkage to the extracellular matrix facilitates load shifts between various molecular components that are vital for control of cell mechanics, shape and function.*" (Stamenovic 2006, p. 87)

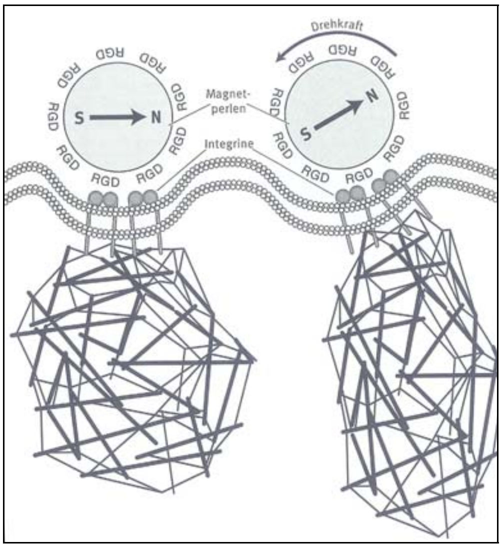

Fig. 9 Experimenteller Nachweis, dass sich das Zytoskelett wie eine Tesnegrity-Struktur verhält. An Integrienen befestigte Magnetköpfe setzten die Zelloberfläche unter Spannung, wenn sie sich in einem Magnetfeld drehen. Aus dem Verhältnis zwischen Drehkraft und Drehungsumfang lässt sich ablesen, dass das Zytoskelett eine Tensegrity Struktur hat. (Oschman)

Each component is a local domain or sub-division of a continuous net. Appearance, form, mechanical and functional characters of each cell, each tissue or organ result from the local changes in the qualities of the matrix. (Oschman 2006)

Whilst the diffusion of chemical substances from one locality to the other is an important means of communication, this process is much too slow to explain rapid and subtle aspects of processes of life. The living matrix itself is a communication net that works at high speed and connects all parts. Solid-state biochemistry examines processes which take place in the firm fibres and filaments of living cells and tissue. Chemical reactions proceed much quicker and well-regulated if they take place in a structured framework. (Oschman 2006)

The components of the cytoskeleton are connected via „cell adhesion molecules" and integrins. This way the cell structures are connected to each other and the cells as a whole with their surroundings and the neighbouring cells to one unit. The variations and patterns of the contact points which result in this manner allow an adjustment of the tensegrity matrix. This is not only done by patterns of oscillation but also the chemo mechanical transport on the surface of the tensegrity elements which serve as rail for these oscillation movements. (Pienta & Coffey 1991)

Pienta and Coffey (1991) describe the living matrix as mechanical, swinging, energetic, electronic information network and assert the following in their studies of the „swinging matrix". Cells and intra cellular elements swing in a complex and harmonious way. This can be measured and analysed with the Fourier analysis. The information on oscillation is transferred by the tissue tensegrity matrix which could act as a linked system which oscillates harmoniously and conducts impulses from the periphery to the core. This tissue tensegrity matrix system consists of the substance of the core, the cytoskeleton and the extra cellular matrix. It serves to connect cell biological oscillations with the outer surface to the point of the DNA. This system enables a specific information transfer through the cell (and even the whole body) in form of direct transmittance of vibrations of chemo mechanic energy through harmonious wave motions. The tensegrity model distributes oscillation harmoniously and thermodynamic. The nature of tensegrity tissue allows sensory perception. Moreover, it is able to act on a intra cellular and extra cellular level. It is a biological entity. Tensegrity structures may not only perceive their surroundings but also react to stimuli. It can be assumed that tensegrity systems pass information from the cell periphery to the core matrix. This information arises from the transfer of vibrational energy through harmonic wave motions. Amplitude and frequency of the wave motions define the information that spreads along a tensor.

This concept can be illustrated with help of a double pendulum system in which two compression elements (iron rings) are connected by a tension cable. If kinetic energy is applied to a compression element, this energy will be conveyed to the other element as well. The information can be tuned by touching or blocking the tension cable, which can be compared to a the string of a guitar which can be tuned to play various notes. Through the widely branched network system of the cell matrix information can be passed on quickly and directly through vibrations. (Pienta & Coffey 1991)

In this connection Oschman (2006) quotes Adolph, who describes the complex functions of the body and its entity as follows: „*The human body is in its totality a sum of thousands of physiological processes and characteristics that interact. […] A huge number of functions can be carried out simultaneously. All parts and processes in an organism are interwoven in a very complex manner. Co-ordination takes place at thousands of places. If there were no standardisation of these activities, life would consist only of accidental physical and chemical procedures. […] However, in reality each process has consequences for the whole.*“ (Adolph 1982 in Oschman, 2006, p. 42)

An ever increasing external force ensures an increased resistance in the tissue. This "linear stiffening" is an emergent mechanical quality of living tissue. (Ingber 1998) Mechanical stress applied at the macroscopic scale results in structural rearrangements at the cell and molecular level. The entire cellular response to stress may be orchestrated and tuned by altering the pre-stress in the cell, just as changing the muscular tone can alter mechanical stability and structural coordination throughout the whole musculoskeletal system. (Chen & Ingber 1999)

Oschman (2006) summarises the properties of the tissue-tensegrity matrix as follows:

- The continuum of the living matrix comprises all connective tissue and cytoskeletons of the body.
- Connective tissue forms a mechanical continuum which reaches to the marrow of the cell.
- The matrix configurates the outer form and shape of the body as well as the architecture of each part.
- Each tension, each compression and each movement causes bioelectrical signals which reflect these forces.

The surgeon Jean-Claude Gimberteau and his team regard parts of the tensegrity principles approved through their work. In their article “The conductivity of subcutaneous structure in man”, in the year 2008 they describe that in surgical dissections the total histological continuity between skin, subcutis, vessels, aponeuroses and muscles can be recognised in vivo. This is supported in their work with impressive photographs. Initially they describe the arrangement as apparently chaotic with pseudo geometric shapes. Fibrils form a framework which is filled with a type of gel. The fibre frame forms continuity and expands in all directions with no apparent logic. In this construction shock absorbing functions and absolute mobility have to be reconciled. However, the organisation cannot proceed without observing certain rules. The whole matter creates a chaotic impression, however, Gimberteau ascertains that these structures, which are mainly polygons, can be converged towards icosahedra and other geometric shapes despite their chaotic distribution. He conciliates this with the tensegrity model. These tensegrity shapes, for example the icosahedron, allow, from a mathematical point of view, filling a space under optimal conditions. The final shape is not obtained by chance and the construction is carried out according to rules and instructions. Guimberteau et al also regard the pre-stress of structures as an important factor. This is the cause for the tension of the tissue which can be observed during surgery. When opening the skin or cutting through an aponeurosis the surgical margins immediately give way by a few millimetres. There is a global tension within the tissue and this tension is distributed over all structures. In their article they (Guimberteau et al) describe, besides the shape of the icosahedron and pre-stress, other basis tensegrity principles.

"The elements have to be pre-stressed and stabilisation has to be effected by balanced opposed tension and pressure forces, whereby the shape, the firmness and the adaptability in many directions as well as the independence of gravity are maintained. Therefore, all architectural structures distributed in a given space react to the smallest increase in tension in one of the elements which is then passed on to the even most distant elements. Each local compression changes the global tension."(Guimberteau 2008, p. 10-11) In their opinion and based on these observations the importance of gravity is reduced during the growth of structures. According to Guimberteau et al this global organisation, which forms the framework of the living matrix, enspires a holistic view.

„Perhaps one could wonder whether it is a basic structural architecture of living forms. Based on this view the image of the body changes into an immense collagen tissue which is differentiated according to function, role and demands. During the phylogenetic and embryonic development the vectors of the functions have paved their way according to a predetermined genetic pattern through this collagen tissue." (Guimberteau et al, 2008, p.14)

4.3.4. Differentiation and Morphogenesis

This chapter deals with mechanical forces which play a role in the embryonic development of organisms. The findings of the authors mentioned in this chapter (Ingber 2005, Stamenovic et al 2006, Huang und Ingber 1999) correspond with the findings on embryonic development of Blechschmidt (1978). His studies are discussed more and more in osteopathy (Girardin 2005, Liem 2006).

Recently, there is a revival of interest in mechanical forces as regulators of the morphogenetic development. The question that arises is, whether the architectural shape of tissue can have an influence on the growth pattern of the cell, as a result of various mechanical forces which are passed on by the cytoskeleton. According to Ingber the various tissue forms (tubular, branched, lobular, acinar) result from local mechanical differences during the embryo genesis. The shape of a structure is determined by the dynamic balance of physical forces. (Ingber 2005)

Changes in geometry and mechanics can cause biochemical reactions and even switch genes on and off or switch back and forth between certain gene programmes: growth, differentiation, apoptosis. (Ingber 2003) By changing its shape the cell switches between various genetic programmes: if there is tension on the cells they will flatten. The cells want to divide themselves as more cells are required for the same space. Compression will cause the cells to become ever rounder. The result is an apoptosis as too many cells fight for a space that is too small. If neither tension forces nor compression forces work on the cells a tissue specific differentiation arises and the cells fulfil their normal function (Ingber 1998). According to Ingber his studies make it apparent that mechanical forces play a decisive role in the development of the tissue within embryo genesis. *„Taken together, this work confirms that mechanical forces generated in the cytoskeleton of individual cells and exerted on ECM scaffolds, play a critical role in the sculpting of the embryo."* (Ingber 2006, p. 255). The works of Erich Blechschmidt on embryology describe exactly the observation that mechanical forces play a large role on the development and differentiation of cells and tissue (Blechschmidt, 1978).

According to Stamenovic et al (2006) a mechanical deformation of the cell can cause a number of biological behavioural patterns. He makes reference especially to motility, contractility, growth, differentiation and apoptosis. He describes the behaviour of the cells under various mechanical conditions. *„Endothelial cells that spread on large islands proliferate, cells on intermediate-sized islands differentiate and cells on the smallest islands that fully prevent distortion die."* (Stamenovic et al 2006, p. 83) He carried out compatible studies on variations of cell types with the same result.

According to Huang and Ingber (1999) also in morphogenesis complexity and tensegrity play a great role. We must start to deal with the complexity of living organisms. Cells, which are the basic components of tissue, are in a position to „feel" their chemical and mechanical surroundings. They will divide themselves if they "feel" that sufficient space is available. Huang and Ingber describe this behaviour of self-organisation in morphogenesis: *"Such self-organizing behaviour that drives morphogenesis appears to be achieved by coupling cell division to cell distortion and even to changes in the balance of mechanical forces within the cell. The discovery of the importance of cell shape and cytoskeletal tension for control of cell-cycle progression requires that we place what we have learned about biochemical mechanisms of cell-growth regulation within a larger frame of reference that also takes into account cellular architecture, micromechanics and structural complexity."* (Huang & Ingber 1999, p. 136) They regard it as necessary not to use only models based on a change of molecular bindings. It is rather necessary to study in addition the architectural principles of these structures to clarify the reasons for their mechanical behaviour. *„Use of tensegrity architecture by cells, which provides an engineering basis for integrating cell tension and cytoskeletal structure may offer a mechanism by which changes in mechanical forces can influence thermodynamics and kinetics* *within load-bearing structures within the cell, and hence regulate specific molecular biochemistry."* (Huang & Ingber 1999, p. 136) They demand that cell biology has to manage the step from „molecular reductionism" to "cellular realism". Only then the fundamental questions regarding the behaviour of cells and tissue can be answered.

4.3.5. Mathematical Tensegrity Models

In this chapter studies on mathematical models of tensegrity are briefly introduced. Although research on the basis of cell biology increasingly shifts to the prediction of cell behaviour of these models, the development of these models goes beyond the scope of a study on the significance of tensegrity principles in osteopathy.

The development of the tensegrity model and its translation into mathematical formulas makes it possible to define the connection between mechanics and bio chemistry on a molecular level. (Ingber 2003) The mathematician Robert Conelly developed a simple method to describe pre-stressed tensegrity configurations. (Conelly & Back, 1998)

Physical and mathematical tensegrity models can describe successfully various mechanical properties of living cells. All these results were obtained by application of the tensegrity model with idealised geometry and a limited number of cables and struts. (Stamenovic et al, 2006), for example „prestress induced stiffening" and „viscoelastic transient and oscillatory behaviours of cultured cells" (Canadas 2002; Sultan & Stamenovic 2004). With his mathematical models Sultan comes to the conclusion that a tensegrity model of the cytoskeleton, which contains a pre-stressed network of connected parts, can effectively predict the dynamic, mechanical behaviour of living cells. He restricts, however, the validity of this model as to whether it is able to describe all facets of cell dynamics. „*Despite its limitations, this* *highly simplified architecture apparently embodies the fundamental features of cell mechanics."* (Sultan & Stamenovic 2004, p. 528)

The simple tensegrity models were criticised because, if one or two cables or struts are destroyed, the whole system would collapse immediately. However, in a cell it can be observed that even though the disruption of individual filaments or tubules has an effect, it does not revoke stability as a whole. It is possible in very simple models but not in more complex, hierarchic tensegrity structures where individual damage to the structure can be compensated. (Stamenovic et al, 2006) They summarise that a multitude of experimental studies support the idea that living cells use tensegrity mechanisms to react to their surroundings and adapt to them. According to them (Stamenovic et al) these models show how the mechanical interaction/co-operation of cytoskeleton and extra cellular matrix control the various cell functions. The tensegrity model forms the theoretic framework for research in this area. *"The cellular tensegrity model provides a good theoretical framework for such research because it provides a way to channel mechanical forces in distinct patterns, to shift them between different load-bearing elements in the CSK and ECM, and to focus them on particular sites where biochemical remodelling may take place."* (Stamenovic et al 2006, p. 97)

4.4. Tensegrity on the Macroscopic Scale

Having dealt with the application of tensegrity principles in the microanatomic area, i.e. cytology and histology, in the previous chapters, this chapter is about the next higher dimension, the application of tensegrity in the macroanatomic area on the level of organ systems and especially the myofascial system.

4.4.1. Literature Assessment

Both quality and quantity of literature on the application of the tensegrity model in the macroscopic area are inferior than on the microscopic level. Only two articles appeared in magazines listed in Medline (Chen & Ingber 1999) und Levin (1997, Putting the shoulder to a wheel). The other articles listed in Medline (Gupta, Jones, Levin) refer to a controversial discussion of the tensegrity model in magazines listed in Medline. The analysis of literature shows that the application of tensegrity models in the macroscopic area is not described sufficiently in articles.

1st category: (Articles published in a magazine listed in Medline)

Chen; Ingber (1999): Tensegrity and Mechanoregulation: from skeleton to cytoskeleton. In: Osteoarthritis and Cartilage.

Gupta; van der Helm (2004): Load transfer across the scapula during humeral abduction. In: Journal of Biomechanics.

Gupta; van der Helm (2005): Letter to the Editor. Reply to "The scapula is a sesamoid bone". In: Journal of Biomechanics.

Jones et al (1999): Alterations in the Young's modulus and volumetric properties of chondrocytes from normal and osteoarthritic human cartilage. In: Journal of Biomechanics.

Levin (1997): Putting the shoulder to the wheel. a new biomechanical model for the shoulder girdle. In: Biomedical Sience Instrumentum.

Levin (2005): Letter to the Editor: The scapula is a sesamoid bone. In: Journal of Biomechanics.

2nd category: (Articles based on reliable sources published in a magazine not listed in Medline)

Levin (2002): The Tensegrity-Truss as a Model for Spine Mechanics. Biotensegrity. In: Journal of Mechanics in Medicine and Biology.

3rd category: (Articles based on reliable sources published in books)

Oschman (2006): Energiemedizin. Konzepte und ihre wissenschaftliche Basis.

4th category: (Other articles, for example internet documents based on reliable sources)

Levin (1980): Continuous Tension, Discontinuous Compression. A Model for Biomechanical Support of the Body. Available on http://www.biotensegrity.com.

Levin (1998): The Tensegrity System And Pelvic Pain Syndrome. 3rd. Interdisciplinary World Congress On Low Back Pain & Pelvic Pain.

5th category: (All articles not based on reliable sources)

Levin (14.04.2008): Biotensegrity. Email to Carsten Pflüger.

Levin; Madden (2005): In Vivo Observation of Articular Surface Contact in Knee Joints. Available on www.biotensegrity.com

4.4.2. Tensegrity as Model in the Musculo-Skeletal Area

Most of the studies in the macro anatomic area were carried out by Stephen Levin. He describes the architecture and the behaviour of the musculo-skeletal system as that of icosahedra. According to Buckminster Fuller the icosahedron is a basic tensegrity structure (Buckminster Fuller 1975).

4.4.2.1. The Basic Principles

Levin (1980) postulates that the tensegrity model and its principles demonstrates the structural integrity of the body on the basis of the icosahedron. He requests to check all previous biomechanical concepts regarding this concept. *„A model based on Buckminster Fuller's Tensegrity icosahedron, which demonstrates the principle of continuous tension, discontinuous compression, may also be utilized to demonstrate the structural integration of the body. All our previous concepts of biomechanics of the body will have to reassessed in relation to the model and our therapeutic approaches to the musculo-skeletal system will have to revised*." (Levin 1980, p.4)

The tensegrity system developed by Buckminster Fuller can be regarded as physiological support system for the body. The tensegrity model has several advantages when applied to biological systems. These structures are omnidirectional and they are stable in all directions and independent from gravity. The tensegrity model can be applied, regardless of which way we move or function, on two or four feet, on earth, under water or in space. Forces applied on the outside are passed on through the whole structure and in this way even the weakest element is supported. One of the principles of tensegrity is the synergy, i.e. the co-operation of structures and forces to boost each other. Buckminster Fuller defines them as the behaviour of composed systems, whereby if the behaviour of individual parts regarded separately no conclusions can be drawn to the behaviour of the system as a whole. Therefore all studies that deal exclusively with individual parts, for example vertebrae or intervertebral discs, have to be re-assessed. (Levin 1980)

In Newton's biomechanics the skeleton and the joints are regarded as the frame from which the soft parts are suspended. The concept of pathology is based on anatomic changes or injuries, respectively. Tensegrity stresses that bones are compression elements which swim in a network of tension integrated soft parts. The soft parts obtain a new importance and the mechanics of the joints becomes the mechanics of soft tissue. Tensegrity and Newton's mechanics are mutually exclusive. (Levin 1998). Levin states that the body cannot function according to Newton's biomechanics and quotes the following examples: *„If the present paradigms of Newtonian based biomechanics hold true, then the calculated forces needed for a grandfather to lift his three year old grandchild would crush his spine. The truth is that grandfathers hoist their grandchildren and often toss them in the air. The calculations are correct but the paradigm is faulty and ignores the realities of biological functions."* (Levin 2002, p. 375). Levin does not want to state that Newton's biomechanics are wrong. He rather regards the presupposition as incorrect. He compares this fact with problems in Euclid's geometry. According to this geometry parallel lines never meet. However, the longitudes on the earth's surface, which are parallel, meet at the north and south pole. Therefore, Euclid's geometry is not wrong, it is however necessary to make different basic assumptions to describe the geometry of the earth. It appears to him, that „bio architecture" also requires a different perception than Newton's mechanics. *„It appears that bio-architecture requires non-Newtonian mechanical thinking that is more adaptable to life forms."* (Levin 2002, p. 376)

Levin regards biotensegrity, the application of Buckminster Fullers' tensegrity principle to the body as a model that can be applied successfully to the sceletal system and other organ systems. *„This system of total body modelling, the limbs are not an assemblage of rigid body segments. They are semi-rigid non-linear, viscoelastic bony* *segments, interconnected by non-linear, viscoelastic connectors, the cartilage, joint capsules and ligaments and with an integrated non-linear, viscoelastic active motor system, the muscles and tendons and connective tissue. The visceral organs integrate structurally and physiologically into the same system."* (Levin 2002, p. 387)

In the macroanatomic area according to Levin the sceleton system forms the discontinuous tension element suspended in a continuous tension network. He goes further to say that tension does not serve as a support system for compression elements, but in fact forms/constitutes the only support system for the joints. (Levin 1980). Oschman regards the bone in itself already as a tensegrity structure as it consists of expandable and compressible fibres. Together with/in conjunction with the myofascial system the bones form a three-dimensional network that serves as support and musculoskeletal system. This way shocks can be absorbed without damage to the body. Due to the tensegrity properties of the tissue mechanical energy can flow off the area of impact. The better the integrity of tension forces, the easier shocks are absorbed and transformed to information instead of damage to the tissue. Due to these properties the body is less prone to injuries (Oschman 2006).

According to Chen und Ingber (1999) the construction of a tension network has many advantages. This network construction features a framework that supports the weight of our body and allows us at the same time to react quickly to external force and move freely in our surroundings. These stable and yet very dynamic structures offer a large advantage for selection during the evolution. A structure that has little mass but offers a lot of stability and flexibility. A light framework can move faster and search a larger area for food with significantly less metabolic energy. According to them (Chen and Ingber) this reduction of mass and consequently the reduction of metabolic costs is due to the fact that systems maximise their tension elements and minimise the compression elements. They describe the human body as such a tensegrity structure. They regard the bones as small compressive subunits in the large tension network of myofascial systems. *"Examining the construction of the human body, we find that Nature has discovered the same solution to this optimization problem of maximizing strength per mass. The compression-resistant bones of the "skeleton" are smaller subunits within a larger supporting framework, or "musculoskeletal system", that is comprised of an interconnected network of bones, ligaments, tendons, and cartilage*." (Chen & Ingber 1999, p. 82)

An important aspect which Ingber mentions over and over again is pre-stress (Ingber 2008). Levin too regards this as an important aspect of tensegrity structures. Ligaments are pre-stressed. Levin refers to Nachemson's studies who described that the Ligg. flava und die Ligg. longitudinale anterior and posterior are even under tension if the spine is in a neutral position. They are not relaxed at any point in time. The skeletal muscles are also under continuous strain and are never relaxed completely (Levin 1980).

4.4.2.2. The Icosahedron

The icosahedron is the basic element of the tensegrity system. It is a three-dimensional structure consisting of twenty triangle surfaces. The arrangement is of advantage to biological systems as it has the largest volume in relation to the surface and this way can fill out the space to an optimum by „close packing". 12 icosahedra can be arranged around a central core to form a new, large icosahedron. These self-similar structures develop to an ever larger complexity to the point of a geodesic architecture like Buckminster Fuller's domes. Levin describes the functionality of these structures as follows: *„The entire structure is a rigid, sphere-like geodesic, a tensegrity icosahedron, with a skin under tension and the endoskeletal compression elements enmeshed in the interstices but not compressing one another. The internally vectored endoskeletal icosahedrons have a non-linear stress-strain curve, which is an essential element of biological material*." (Levin 2002, p. 379) According to him it is of central importance that under strain these structures always react as a whole. They expand and contract or become firmer or softer in a non-linear way.

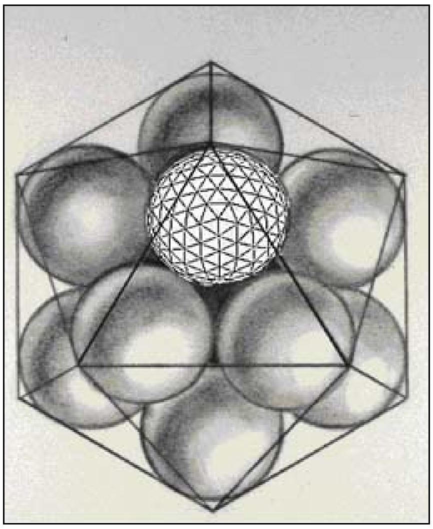

Fig. 10 “close packing” icosahedron

This framework construction is stable in itself and independent from gravity. Trusses have flexible hinges with zero moments about the joint. Loads applied at any point distribute about the truss as tension or compression. There are no levers within the truss. Only trusses are inherently stable with freely moving hinges. Vertebrates are stable, with flexible joints and, therefore, constructed as trusses if they are to stand upright. (Levin 2002)

4.4.2.3. Hierarchic Systems in the musculo-skeletal System

The large components of the musculo-skeletal system have a wide spectrum of mechanical qualities without having to resort to very varied material. This is possible due to the use of a structural hierarchic organisation. The existence of networks in bones, cartilage, tendons and ligaments optimises the structural efficiency and enables an optimal energy absorption. In a living organism the tension in the extra cellular matrix of a bone is influenced by the shape of the whole bone and the tensions of the surrounding soft parts. Contractile fibroblasts also pre-stress the collagenous network during the development of tissue before the calcification of the extra cellular matrix sets in. (Chen & Ingber 1999)

Levin also regards biological constructions as evolutionary, hierarchic systems. During the development these constructions are mechanically stable. Tensegrity is an evolutionary system based on the development of micro, macro and meta structures (Levin 1998).

4.4.2.4. The Spine

To date mechanical models of the spine were based on the model of an axial compression system. As this concept is unidirectional according to Levin it can only be applied on/to a perfectly balanced and immobile spine. According to this model, in any other position injuries to muscles or bone fractures would result. If the tensegrity model is applied, the spine can function in every position. According to Levin the spine never acts as a column. In the phylogentic and ontogenetic development the spine is at no point in time a column. It is a supporting structure of semi rigid segments connected by flexible connective tissue. He postulates that the spine behaves like a tensegrity system in which all other parts of the body, like the limbs, the head and the organs, are integrated (Levin 2002). Chen and Ingber (1999) also come to the conclusion that the spine cannot behave like a mere compression system. Without the stabilising influence of the surrounding tension elements the bones of the curved spine would fall to pieces. Furthermore they assume that, if the spine were a mere compression column, it would have to be much larger and heavier to withstand gravitation.

4.4.2.5. The Pelvis

Levin imagines/envisages the pelvis as a bicycle wheel. This wheel is also a tensegrity structure described by Buckminster Fuller. If the difference of the wheel of a vehicle and the wheel of a bicycle is observed, according to Levin the difference between Newton's mechanics and tensegrity mechanics can be seen clearly. The wheel of a vehicle distributes the load onto compression elements which are directly connected. The wheel of a bicycle however transfers the weight of the frame onto the hub which is suspended in the network of the spokes. These spokes are under continuous tension (they are pre-stressed), the compression elements are discontinuous and the compression forces are distributed around the rim. The rim is comprised by the tension of the spokes.

Levin regards the pelvis as such a construction whereby the pelvic ring forms the rim and the sacrum forms the hub. The surrounding myfascial structures are pre-stressed spokes. The sacrum is suspended in a myofascial shell as compression element and divides its load in this network. Thereby an omnidirectional stability is achieved whilst simultaneously mobility is allowed. The coccyx and the pelvic floor form the hub in this structure and are important for the stand and stability during everyday functions. (Levin 1998)

4.4.2.6. The Shoulder Girdle

The total/whole support system of the upper extremities is a tension system that is supported by the skeletal muscles which interweave the spine, the thorax and the arm. The scapula is not pressed to the thorax. Traditionally the clavicles are regarded as compression struts. According to Levin the system therefore behaves like a tensegrity system (Levin 1980). According to him the model for the shoulder girdle is based on the tension elements of an icosahedron. In his model the scapula moves freely in a tension network of the musculature of the shoulder girdle, exactly in the way the hub of a bicycle is suspended in a tension network of the spokes. These "swimming" bones are exposed only to compression forces. Furthermore Levin assumes that above all the arrangement of the elements ensure the stability of the whole structure: „*There are no moments at the joints because the structure is fully triangulated […] the scapula suspended in the "spokes" of the attached muscles and soft tissue, could function as a stable base for the arm. It could also transfer loads to the "rim" of vertebrae through these same spokes*." (Levin 1997, p. 2) According to Levin the shoulder girdle is in a position to withstand omnidirectional forces due to the tensegrity system. The tensegrity system explains forces that for example occur in weight lifting.

Just this model was discussed very intensely. Gupta and van der Helm carried out measurings of the tension transmittance of the scapula during abduction. One of the results showed that the scapula transmits compressive forces (Gupta & van der Helm 2004). In a „Letter to Editor" Levin challenges the transferability of these measurings to all functions of the shoulder. According to him the head of the humerus can only transfer direct compression forces to the glenoid in the abduction position. However, in his opinion, in most positions it is mathematically impossible to transfer compression forces on the gleno-humeral junction. He stresses that the scapula behaves like a sesamoid bone. „*In a scapula-hub model, there is no fulcrum since the scapula is enmeshed in a spider-web of muscles. Without a fulcrum, there are no leavers. Without leavers, there are only compression and tension forces. Loads are transmitted to the axial skeleton by tension just as in a bicycle wheel, where the compression load of the rim and hub interface through the tension spokes*." (Levin 2005, p. 1733) Gupta replies in the same "Letter to Editor" that their measuring clearly result in the fact that not only compression forces but also bending tensions occur in the scapula. "*One obvious result was that the scapula does not only sustain a compressive loading, but also bending loading, resulting in a combination of tensile and compressive stresses in the bone*" (Gupta 2005, p.

1734) Furthermore Gupta does not regard the scapula per definition as a tensegrity structure as it is embedded in the musculature as a whole and not only at its end points. Gupta accuses Levin that he does not support his hypothesis based on measuring. Therefore, according to Gupta, Levin's model is not a model but only a hypothesis. *„The scapulothoracic gliding plane acts as a "fulcrum", and also the clavicle acts as a "fulcrum". Therefore, the concept of regarding the scapula as a tensegrity structure or a sesamoid bone is not correct."* (Gupta & van Helm 2005, p.1736)

4.4.2.7. The Femur

The femur functions like a compression bar on the macroscopic level of the whole body. The shape is formed by the hierarchic construction and the adaption to the function. Chen and Ingber (1999) describe the shape and the distribution of force within the femur: *„The long bones have actually evolved a hollow centre to increase their second moment of inertia and thereby, maintain their strength in bending and twisting, while minimizing mass. Because of the bowed out shape of the femur and its vertical orientation when loaded, different regions of the same bone will experience very different mechanical loads on a smaller size scale*." (Chen & Ingber 1999, p. 83)

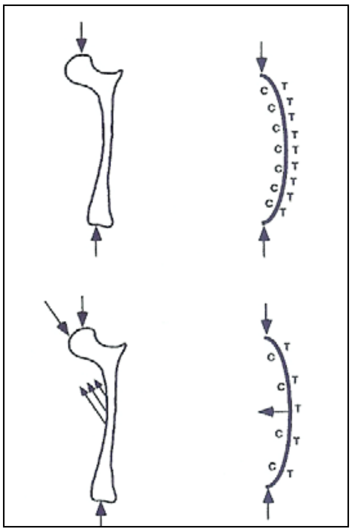

Fig. 11 Diagram showing the loading of a femur in standing position. The primary compressive forces generated by standing (top left) causes bending of the bone that results in local internal tension and compression (top right). With the stabilizing force of medial muscular tension on the bone shaft (bottom) the internal compression and tension felt by the medial and lateral aspects of the diaphysis are reduced. (Chen & Ingber)

Muscles that pull the femur medially would function like tensile guy wires to resist buckling. This effectively decrease the level of tension and compression experienced in the lateral and medial walls of the femur. The local stress patterns are clearly visualized in gross sections of the femur which demonstrate that the network of trabeculae is organized to approximate the principle stress directions. (Chen & Ingber 1999).

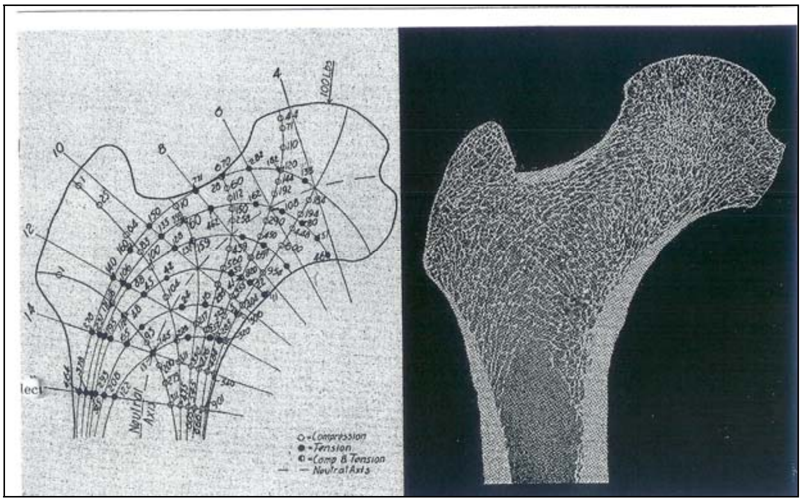

Fig. 12 Approximate principal axes of stress (predicted from a homogeneous, isotropic elastic model for the bone) shown as field lines in a loaded femural head (left) and the corresponding trabecular structure within it (right), indicating reasonable alignment of trabecular structures with stress field lines. Note that the lateral portion of the femur is primarily in tension while the medial aspect experiences pure compression. (Chen & Ingber)

4.4.2.8. Levin's Studies on the Knee

In an internet document „In vivo observation of articular surface contact in knee joints" Levin describes a self test whereby his knee was operated with arthroscopic surgery and weighted simultaneously. „Arthroscopic knee surgery was performed with local anesthesia with the patient fully awake and cooperative. Manoeuvres were performed to stimulate loading the joint and weight bearing. The experiment showed that it was not possible to coapt the surfaces of the joint. In all cases a gap/opening of at least 1 millimetre appeared. Levin concludes from these studies that the concept of transfer of compression forces through a joint has to be reconsidered, neither can hydrostatic forces explain the separation of the joint surfaces. In conclusion he puts up for discussion whether the joints are not exposed to any compression: "*The observation that the articular surfaces of the knee joint do not compress each other when the* *joint is loaded has since been reproduced several times, in different patients, and clearly is not an isolated finding […] a simple and readily reproducible in vivo observation challenges the long held belief that joints of vertebrates are compression loaded.*" (Levin & Madden 2005, p. 6) Levin submitted his work to the "Journal of Biomechanics" for publication. It was however rejected, as Levin wrote on his internet site.

4.5. Discussion

After assessing the literature it appears that the application of tensegrity principles on a microscopic level and as organisation principle for hierarchic systems is scientifically based. There is evidence to suggest the accuracy of the application of general tensegrity principles on cells and tissue, i.e. the balance between compression and tension forces as well as pre-stress in biological structures. (Ingber, Stamenovic, Guimberteau). The function of individual parts in a tensegrity model of the cytoskeleton remains remains subject to further research. An example is the role of microtubules (Ingber, Stamenovic, Denerll, Howard).

The application of the tensegrity model on the human body on the macroscopic level remains under discussion. According to the present state of affairs it is difficult to judge how the tensegrity model can be applied. Whilst some authors regard their studies on the Young modulus as confirmation of the thesis that the body does not function according to tensegrity principles (Jones et al 1999), other scientists regard this modulus as a confirmation for a load transmission in the tissue following the tensegrity principles (Siemsen 2008). Levin also considers the difficulties of proving such a theory scientifically: „*It is often hard, even impossible, to prove a theory, but […] I have certainly falsified the accepted theory of compressive loaded joints and given an alternative theory that is consistent with known anatomy and biology.*" (Levin 14.04.2008) In this connection Levin mentions the studies of Hujjing (1999), which, according to him, prove the mechanical connection of all fascial structures as well as a continuous tension in these systems (Levin 2008).

5. Tensegrity in Osteopathy

After the application of the tensegrity principles in various fields (cytology, histology and organ systems) was discussed in previous chapters, this chapter now deals with the transfer of these principles to osteopathic medicine. After studying the literature, various applications of the tensegrity model arose which form the individual subchapters of this chapter. These various applications will be presented. Then follows an analysis of the way the principles of tensegrity are applied. Most importantly it deals with the application of the principles in the myofascial system, in the concept of somatic dysfunction, cranial osteopathy, the consideration of hierarchic systems and tensegrity as a didactic model. In some parts an exact description and interpretation is difficult as certain concepts within osteopathy have not yet reached the status of a scientific theory. This is highlighted at the respective parts of the text.

5.1. Assessment of Literature

Only a few authors have published articles on tensegrity in osteopathy in magazines listed in Medline. The only listed magazine is the „Journal of American Osteopathic Association“. Nevertheless, I found many articles in other magazines which were based on sufficient sources (categoriy 2). I have also integrated a few articles in this study which are not based on reliable or sufficient sources (category 5). Therefore, these studies can only be used as a subjective opinion of the author mentioned. However, I regard these opinions in this context for quite useful for this study as it is partly the aim of this study to discuss possible applications of the tensegrity model. The following articles are used in this study.

1st category (Articles published in a magazine listed in Medline)

Kuchera (2005): Osteopathic Manipulative Medicine Considerations in Patients With Chronic Pain. In: Journal American Osteopthic Association.

Kuchera (2007): Applying Osteopathic Principles to Formulate Treatment for Patients With Chronic Pain. In: Journal American Osteopthic Association.

Magoun (2002): Structure and function reexamined. In: Journal American Osteopthic Association.

2nd category (Articles based on reliable sources published in a magazine which is not listed in Medline)

Cummings (1994): A Tensegrity Model for Osteopathy in the Cranial Field. In: AAO Journal.

Cummings (2001): Letter to the Editor. In: AAO Journal.

Eckardt (2007): Neurologisches Integrationssystem (NIS) nach Dr. A.K. Phillips D.O. In: Naturheilpraxis.

Kassolik et al (2007): Anatomical grounds for the use of the tensegrity principle in massage. In: Fizjoterapia Polska.

Kassoliket al (2007): Role of the tensegrity rule in theoretical basis of massage therapy. In: Journal of Back and Musculoskeletal Rehabilitation.

Kassolik et al (2007): Tensegrity principle in massage demonstrated by electro- and mechanomyography. In: Journal of Bodywork and Movement.

Koschella (2007): Ist eine funktionelle Verbindung zwischen Diaphragma und Cranium palpierbar? Versuch der Deutung mittels des Tensegrity-Modells. Diplomarbeit.

Lee (2000): Tensegrity. In: The Cranial Letter.

Lee (2001): Letter to the Editor. In: AAO Journal.

Lee (2001): The primary respiratory mechanism beyond the craniospinal axis. In: AAO Journal.

Myers (2004): Structural integration. developments in Ida Rolf's Recipe 1. In: Journal of Bodywork and Movement.

Schleip (2004): Die Bedeutung der Faszie in der Manuellen Therapie. In: Deutsche Zeitschrift für Osteopathie.

Siemsen (2006): Tensegrity. Theoretisches Gesundheits- und Krankheitsmodell. In: Manuelle Medizin.

Smith (2006): The Oscillatory Properties of the Structural Body. In: IASI Yearbook.

3rd category (Articles based on reliable sources published in books)

Lee (2006): Interface. Mechanisms of Spirit in the Osteopathy.

Liem (Hg.) (2006): Morphodynamik in der Osteopathie.

Myers (2004): Anatomy Trains. Myofasziale Meridiane.

Parsons; Marcer (2005): Osteopathy. Models for Diagnosis, Treatment and Practice.

Patterson (2006): Das Konzept der somatischen Dysfunktion. In: Liem (Hg.): Morphodynamik in der Osteopathie.

Schwind (2003): Faszien- und Membrantechnik.

4th category (Other articles, for example internet documents, based on reliable sources.)

Girardin (2005): Evolutionary Medicine in the Osteopathic Field. Part 2: Review of system, tissue and organ specialisation. Kursskript.

5th category (All articles not based on reliable sources)

Davies (2004): The Intelligent Body. Tensegrity - its relevance to the human body. The Sutherland Cranial College. Onlinedokument

Davies (2005): The Intelligent Body: Bones are the Prime Movers.

Lee (11.04.2008): Use of Tensegrity in Osteopathy. Email an Carsten Pflüger.

Meert (2003): Das Becken aus osteopathischer Sicht. Funktionelle Zusammenhänge nach dem Tensegrity-Modell

Myers: Fascia and Tensegrity. Onlinedokument verfügbar unter http://www.anatomytrains.com/explore/tensegrity/explained.

Noelmans (2001): The architectural Tensegrity theory applied to Osteopathy. VOD-Kongress 2001

Patterson (2005): Beyond Tensegrity. A Glimpse of the System. Veranstaltung vom 2005. Freiburg.

5.2. Force Distribution in the Fascial Network

Based on the sequence of the 4th chapter where the tensegrity model is applied in basic science in various dimensions, in this chapter I will first of all examine the adoption of the principles in a micro anatomic dimension and their implications for osteopathy. The following chapter deals with the application in the macro anatomic area, i.e. the myofascial system. I would like to emphasize again that the implications for osteopathy mentioned there are in the accordance to the opinion of the respective experts which are put up for discussion.

For many authors the image of the tensegrity model on the microscopic level, as described in chapter 4, is a central point of application of the tensegrity concept in osteopathy or manual therapies, respectively. (Schwind 2003, Myers 2004, Patterson 2005, Davies 2005, Parsons 2005, Siemsen 2006, Liem 2006, Oschman 2006, Eckhardt 2007)

The tensegrity network is a stable, at the same time an adaptable construction. The whole system reacts to an outside force with an adaptive tension distribution. According to Schwind (2003) this happens due to the arrangement of the stable and elastic elements. Pressure and tension are distributed evenly in this arrangement. Then follows a self-stabilisation through the distribution of tension and pressure forces in the whole construction (Siemsen 2006). As a response to a locally working force all structures of the tensegrity model re-arrange themselves. The elements arrange themselves towards the tension force. This causes a linear stiffening of the tissue in this direction (Myers 2004). This three-dimensional arrangement and the even distribution of force cause the largest possible strength with as little input of energy and material as possible (Patterson 2005). Up to this point the information corresponds with the studies described in chapter 4.

Eckhardt (2007) concludes from these principles that the structural integrity of the body is guaranteed by the permanent maintenance of the balance of these forces as well as a constant passing on of forces. Patterson (2005) therefore proposes that the fascial system constitutes a tunable biotensegrity network controlled by primitive neuro modulators and extrinsic and intrinsic mechanical forces.

The ability of tensegrity structures to withstand omnidirectial forces implies a dynamic balance with constant integrity for our body. In doing so the tensegrity system works in every position: standing, lying down, doing a headstand, as well as in space and the deep sea. Gravity plays an interesting role in the process: it increases the pre-stress of our ligaments and fasciae by giving us weight (Davies 2005).

According to Liem (2006) one can assume that the extracellular matrix produces a continuum, a type of communication network, where not only the parietal system but also the inner organs are embedded. According to this, the tensegrity principle emphasizes the significance of fascia in osteopathy. Liem contributes practical relevance to this fact: *„The osteopathic approach to these tension conditions, to the attracting and rejecting forces and the therapeutically induced normalisation of this tension with the aim to achieve a higher order – to me that is applied tensegrity"* (Liem 2006, p. 178). Oschman (2006) also believes that the application of this model has consequences for the practice. According to him, therapists not only touch the skin but they can come into contact with the continued tissue of the whole body via the tensegrity matrix. *„In principle, by touching the body, direct contact with this continuous system of crosslinks is made, in which all molecules of the body are embedded and combined to a complex and non-detachable network.*" (Oschman 2006, p. 40). Via this network the therapist makes contact with the whole body and therefore applies tensegrity as a model. There is no doubt that the assumption that it is possible to make contact with the whole body through this system has not been confirmed in an experiment. But Parsons (2005) also recognises the potential of such a model in the same way when he writes that the tensegrity network makes it possible to touch the body and to know, that we are in contact with the whole "living matrix". By changing part of the matrix he believes that effects in the whole matrix occur, with possible consequences for the cellular level as well. According to Davies (2005) this communication network offers a possible explanation for the fast and global answer of the body to a slight correction of the tension elements as well as the often described ability of us osteopaths to feel what happens in the whole body.

Tom Myers compares various models of force distribution (tensegrity and a mere compression model) with the analogy with which a tree falls into a house. The brickwall of a house is based purely on compression. If a tree falls onto the house, only that part of the wall will collapse on which the force acts. In a tensegrity structure these forces are distributed evenly on the whole system and therefore the overall stability is higher. Tom Myers also transfers this analogy to various approaches in the medical field. "Modern treatments" work? are processed according to the principle, that a local injury is caused by local forces and consequently local treatment is required. If the tensegrity model is however applied, a different outlook arises, i.e. if a tensegrity structure is exposed to excessive strain at some stage, damage will result but not necessarily there where an external force takes effect. Because the strain was distributed, it is also possible that a more distant weak point is damaged (Myers 2004).

5.3. The Myofascial System

Here follows the transfer of the tensegrity principles from osteopathy to the macroscopic field, analog to the sequence in chapter 4, where these two dimensions are described. This chapter deals with the myofascial system in the macroscopic field, where the boundaries between the macroscopic and microscopic area rather merge into each other. It is interesting, that the rolfers (Schwind 2003, Schleip 2004, Myers 2004, Smith 2006) dealt with this approach more intensely in their articles than the osteopaths (Noelmans 2001, Parsons 2005, Patterson 2005, Davies 2005, Siemsen 2006, Kuchera 2007), who laid more emphasis on other concepts. Furthermore, there are a few more articles that deal with the myofascial component of the tensegrity model in the area of the massage therapy. (Kassolik 2007)

„The tensegrity model offers a pleasant alternative or supplement to the traditional way of thinking regarding the supporting spine and the skeleton as support system." (Schleip 2004, p. 11) A point of criticism of a mere compression model is the unidirectionality. If the orientation of the structure changes it becomes instable. The tensegrity model changes this view and considers the bones of the skeleton as discontinuous compression elements, which are suspended, or swim, in a continuous tension network of soft part tissue (Parsons 2005). The soft part tissue acts as tension element and the bones and other hard structures serve as compression elements (Patterson 2005). The compression elements (206 bones) are held in balance by the elastic

myofascial system (Siemsen 2006). This view is probably based on the studies of Stephen Levin and is shared by all authors mentioned at the beginning of this chapter. Whilst Ida Rolf treated the body as a tensegrity structure at an early stage, i.e. used tensegrity as a model, Levin went a step further and said that the body is a tensegrity structure and its tension is formed by a matrix of connective tissue, ligaments, muscles, nerves, fasciae and blood vessels. As described in chapter 4.4., this approach has a model character for the myofascial system. Davies (2005) uses this model and describes the matrix as a system, that gives the body strength, integrity and the necessary pre-stress. The compression components are represented by bones and the incompressible fluids in certain compartments. According to him these compression elements work as separators which are necessary to keep the space open (Davies 2005).

According to Meyers (2004) the tonus in the myofascial system is the decisive factor for the balance in the whole structure. If the tonus is balanced, both bones and muscles can move in a balanced posture. He believes that this has consequences for the treatment as he thinks that the treatment of bone structures should really happen through the fascial system:

„If you want to change the correlation of the bones, you should change the balance of the tension forces in the connective tissue. The bones will the re-arrange themselves. (Myers 2004, p. 51). Noelmans (2001) also believes that the balance in this system is of high interest for osteopathy. According to him, each dysbalance in tension influences the quality of compression whereby each dysbalance in compression influences the tension elements. That way an influence on all connected structures always results. He believes that "balanced tension" is essential for a normal physiology: *„As an osteopath I had already sense that the body structures respond as one unit to any stress imposed on it."*(Noelmans 2001, p. 40) Davies (2005) also seems to be of the opinion that the balance of these structures is necessary, for us to be in a position to absorb

forces better and process these forces and not transform them into injuries. If one property dominates, for example compression, the body would be exposed to higher forces which could result in wear and tear like a degeneration of the spinal column or arthrosis.

As the transduction of pressure in the joints is always cushioned by elastic elements and liquids, one can conclude that, one has to direct only part of the attention to the bones, according to Schwind (2003). Therefore, in his opinion, the differentiated structure according to the tensegrity model has lasting consequences. He believes that the model underlines why it is possible to treat one section of the body without touching it directly. Through the endless myofascial system adjustments can be made which have effects in other sections. *„If all elements are actually connected and even intensely rigid relations are embedded in an elastic network, it must be possible to treat these rigidities using little or relatively little force. A procedure that deals with the „great landscape“ of fasciae and ligaments has effects on a larger morphological relation and we can therefore expect a longer lasting result.“* (Schwind 2003, p. 7-9). Respiration creates movement in all 136 joints and in the whole tissue. Kuchera (2005, 2007) uses this fact for the treatment: *„The act of deep breathing creates obvious motion in 136 joints and is palpable into all body tissues. It is a continuous motion with active and passive components. Through Tensegrity relationships, the patient or physician can focus deep breathing to remove motion restrictions or engage neuromuscular reflexes to achieve tightening or relaxation of selected tissues.”* (Kuchera 2005, p.35, 2007)

Smith (2006) occupies himself very intensely with the tensegrity concept in the myofascial area. In his opinion, only the combined properties of the fascial and sceletal systems form a tensegrity structure. Furthermore, he assumes that the tension in the fasciae ensures an adequate relationship of the skeletal elements. However, it would remain a static system and could not become active on its own accord, if there were no neuromuscular system. Furthermore, Smith writes that the body consists mainly of water and most of the structures are composed of balloons filled with water, i.e. fascial bags filled with a type of gel. These are muscles in their endomysial shells the abdominal organs in the peritoneum. We are bags within bags. According to him, the structural integrity of these bags arises through the opposite influence of the compression tendency of the surrounding shell and the tendency of liquids to withstand this compression. In his opinion it appears to be as if these hydraulic bags are only a type of tensegrity structure, as they combine compression and tension elements. Buckminster Fuller also considered a balloon to be a mathematical tensegrity structure. Smith however states that these bags do not behave as absolute tensegrity structures. An external pressure ensures the liquid contents to distance themselves from the pressure. The abdominal cavity is then newly formed through a contraction of the M. transversus abdominis and simultaneously supported, so that the thorax and the spine are stiffened. Therefore, it is necessary to always integrate the neuromuscular system. (Smith 2006)

Kassolik (2007) postulates, that the tensegrity concept can also be applied to massage therapy and thereby it can be explained that due to treatment of one area also other areas, which stand in fascial relation, react. „*Based on the tensegrity principle, direct or indirect connections between fascia or muscle which stretch the aponeurosis or intermuscular septum may allow the transfer of tension over long distances*." (Kassolik 2007, p. 1) In one of his studies Kassolik tries to prove these principles. He puts the effects of a massage on the EMG and MMG activities of muscles to the test. The muscles are further away from the massaged muscle but are still in fascial continuity with it. He measured a significant increase of the EMG and MMG activities in these muscles and drew the conclusion that his results are in line with the tensegrity model. Indeed, Kassolik was doubtlessly able to prove an effect of massage on distant parts of the body, however, the explanation remains speculative. He was unable to prove whether the therapeutic effects can be explained with tensegrity.

5.4. The Somatic Dysfunction

In osteopathic medicine there is the concept of somatic dysfunction which is based mainly on neurophysiologic explanations (Willard 2003). Some authors (Myers 2004, Parsons 2005, Patterson 2006, Liem 2006, Siemsen 2006) describe the mechanical tensegrity principles in micro and macro-anatomic structures as a model in order to describe one aspect among others of this concept mechanically.

Siemsen (2006) applies the tensegrity model to explain that somatic dysfunctions influence the movements of the whole body, also on a cellular level. According to him this can only be explained by the application of tensegrity principles. Patterson (2006) writes about the concept of somatic dysfunction and the influence on such a dysfunction. He believes that neurophysiologic models are in the centre but he also emphasizes that some characteristics of dysfunctions cannot be explained on a neuronal basis. He describes the observations of osteopaths which state that that local treatment of a somatic dysfunction leads to an apparently immediate change in somatic and visceral mobility, which can be even farther away from the point of treatment. If the fasciae were part of a tensegrity structure, it would be in a position to distribute extrinsic and intrinsic forces on the whole construction.

Therefore, he considers such a structure which distributes energy in the whole system as very stable, regardless whether appealing appear or disappear. If mobility is improved through treatment in one area, according to him this leads to an immediate transmission to other areas which may then also return to normal mobility. He predicts an enormous potential in the tensegrity model as to somatic dysfunction and postulates: *„The tensegrity concept will probably become more and more important in osteopathic thinking in the near future."* (Patterson 2006, p. 169-170)

A change in the balance of the myofascial tensegrity system may be based on a somatic dysfunction. Liem (2006) writes as follows: „*Somatic dysfunctions arise when alterations occur either to the bones acting as compression elements or the soft parts acting as tension elements or if the balance between both is altered.*" (Liem 2006, p. 178) Thereby, the occurence of compensation in this system is decisive whether symptoms arise or not.

According to Parsons (2005) the treatment of a primary dysfunction should result in a solution to all problems within the system. However, he restricts the tensegrity structures to only distribute all forces within the whole system if there is no disruption. If only one element is in dysfunction, the whole structure is disrupted and consequently the tensegrity structure as well. If many of these procedures occur it is possible, that the tensegrity pattern and classical biomechanical patterns are present simultaneously.

5.5. Cranial Osteopathy

This chapter deals with the attempts of osteopaths to transfer the tensegrity principles as a model on cranial osteopathy. This is difficult as cranial osteopathy is a model in itself. The authors of studies in this area try to establish a connection between these models. On the one hand there is tensegrity which is applied in biological systems at least on the macroscopic level on the basis of experimental data. On the other hand one finds the model of cranial osteopathy which is designed to supply a theoretical background for osteopaths' experience in palpation. In chapter 7 of this study I will describe in detail to which extent such models can be useful.

Lee (2006) depicts a new picture of Sutherland's concept of the reciprocal tension membrane. In his book he tries to create an "interface" between the basic philosophies of osteopathy and newer scientific concepts. This way he combines Sutherland's concept of the reciprocal tension membrane with the tensegrity principles. Sutherland (1990) describes that, according to his experience, there were alternating oscillation in the cranium in all dimensions and a co-ordinated movement which reaches all the way down the spine to the tail bone. In his opinion, the structures surrounding the CNS (central nervous system) act as a functional unit which is controlled by the connective tissue of the region. He called this behaviour „reciprocal tension." Lee (2000, 2006) is convinced that the membrane system behaves like a tensegrity structure and that Sutherland described exactly this function, even though he used a different name. Lee believes that the bones of the skull and the spine, according to the tensegrity principles, are the discontinuous compression elements, whereby the dura mater serves as the continuous tension system. Sutherland also concluded from the continuous design of the membrane system that it is responsible for the co-ordination of the bone movement. Lee emphasizes additionally, that not only the cranial and spinal dura mater form a unit but that the whole body forms a unit through the connective tissue, as it acts as a tensegrity structure. He then transfers this thought to the PRM (primary respiratory mechanism), a further basic assumption in the concept of cranial osteopathy. *„Biochemical, hydraulic and thermodynamic activity is the active component of the Primary Respiratory Mechanism; the tensegrity aspect the restraining, guiding, coordinating and controlling component. Sutherland indicated that the reciprocal tension membranes are the restraining, guiding, coordinating and controlling components of the primary respiratory mechanism on a gross scale. We now can see that the tissue matrix system serves the same function on a biochemical / microscopic scale."* (Lee 2000, p. 10) Thus Lee visualises in the tensegrity model the interface between the principle of the reciprocal tension membrane on the macroscopic level and the function of the tissue matrix system on the microscopic level. On this level he also visualises for example also the effects of the CV4 for example, which is said to lead to an exchange of liquids throughout the whole body (Lee 2000, 2006). In another part of his study Lee emphasizes again that such a reciprocal tension is a universal phenomenon of the whole human connective tissue and does not just occur in the cranium or the dural membrane. Tensegrity and the mobility of the whole connective tissue of the body play a central role in his cranial concept (Lee 2001). He goes as far as to define the five elements of the PRM in an untypical way. He replaces the term „mobility of the dural membranes“ by „tensegrity of the dural membranes“.

- Cranial bone mobility
- Inherent CNS motility
- CSF fluctuation
- Tensegrity of the dural membranes
- Mobility of the sacrum in a respiratory motion (Lee 2001)

Noelmans (2001) and Parsons (2005) also use the tensegrity model to describe the concept of the reciprocal tension membrane. The dura mater as continuous tension element maintains the dynamic balance between the cranial bones and the sacrum. Noelmans (2001) states that in the system of the reciprocal tension membranes control the tension. In a system that works normally, shearing and bending forces are eliminated to obtain a balance in the various structures. From his point of view, it is possible to bring the body back into its balance by balancing these tensions in an osteopathic treatment.

Another American osteopath who has written about the tensegrity principle is Cummings (1994). To my knowledge, his article „Tensegrity in the cranial field“ is the first published article of an osteopath on the tensegrity model. In his article, Cummings proposes the tensegrity model as model for the CRI (cranial rhythmic impulse) as he believes a theoretic basis is necessary for these clinical observations. According to him, the tensegrity model is suitable to explain the clinical efficiency of a cranial treatment. Furthermore, he believes that the tensegrity model can be adjusted to the current knowledge of anatomy and biophysics. He regards it as an alternative paradigm, which rests on a scientific foundation. Cummings (2001) believes that, on closer examination, the shape and function of the icosahedron plays a central role. He regards the cranial system as a tensegrity model, whereby the CSF (cerebro spinal fluid), which is not compressible, functions as compression element of the icosahedron. In this context he describes the qualities of an icosahedron in the same way as Gengnagel (2002) described them in chapter 3.3.1. and Levin (2002) in chapter 4.4.2.2.. Icosahedra can connect in a way that each subunit can work as an independent icosahedron or as part of a icosahedron which increases steadily in size according to a hierarchic pattern.

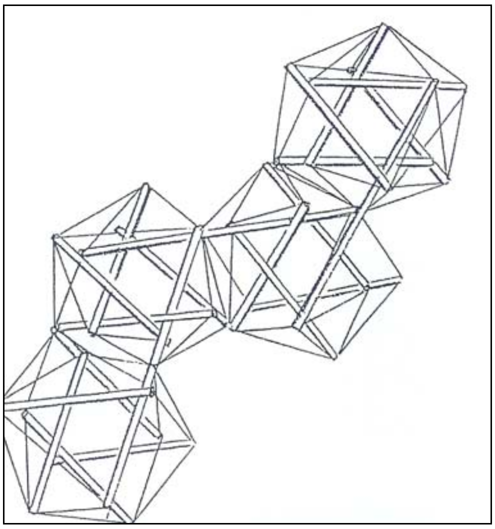

Fig. 13 linked icosahedra - high stability with added flexibility

These structures guarantee the stability of a tensegrity network. Cummings (1994) regards the DNA Helix and the very cranial system as an example for such complex structures. He applies the tensegrity model with help of the cranial concept by claiming that the mechanical function of the icosahedron is the transmittance of energy in a helical manner. Moreover, he states that this procedure can be compared to the transmittance of energy through the neural tube from occiput to sacrum.

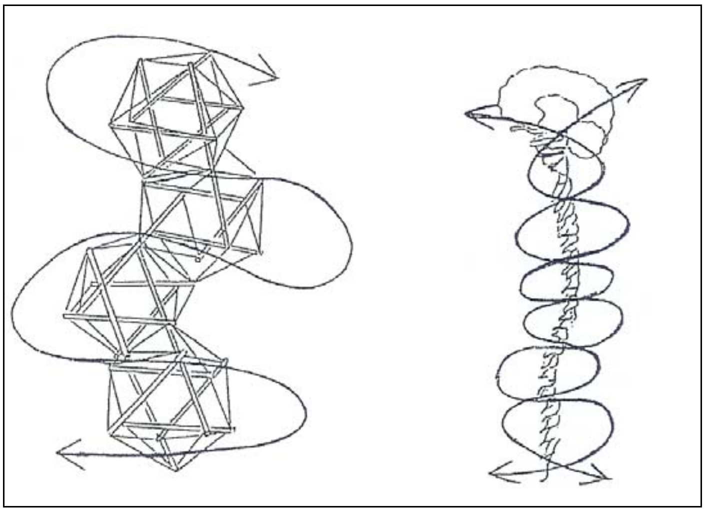

Fig. 14 linked icosahedra compress in a helical fashion. Similarly, motion is conducted along the dural tube from the occiput to the sacrum in a helical fashion.

Furthermore, he describes the cranial movement as a reflexion of extrinsic and intrinsic movements on the basis of such a complex network. He therefore regards the CRI as an interactive movement which involves both the patient and the therapist. The perceived movement patterns only exist, when they are perceived by the examiner. Therefore, he assumes that the CRI of a patient is not identical when it is palpated by various osteopaths. Moreover, he believes, that we (the osteopaths) do not palpate the continuous tension system of the patient directly but an indirect phenomena, a cumulative movement of the tension network, whereby the therapist admittedly plays an important part. According to him, the therapist can use these movements to boost a change in the tension network of the patient. Cummings (1994) concludes that he is convinced that the idea, that the CRI is rather the manifestation of a complex system than just a type of energy, is the key to an understanding of the tensegrity model. He describes the CRI as a manifestation of an interactive cumulative system between patient and osteopath. *„The Tensegrity Model for understanding the interconnectedness not only within the craniosacral system but the entire musculoskeletal system may be one unifying theory to understand the concurrent effectiveness of different treatment modalities.“* (Cummings 1994, p. 27). Later on Cummings again emphasizes again the holistic basic idea of the tensegrity model. All parts appear to be integrated in a tensegrity in a way that it always reacts as a

SYSTEM and not only in some parts. „*With the tensegrity model, we are oriented to biologic organism not as individual yet connected components, but as a SYSTEM. With further research, I feel that the tensegrity model will be one of the most valuable concepts in osteopathic medicine and how we understand the musculoskeletal system.*" (Cummings 2001, p. 8)

5.6. Hierarchic Systems

The connection and the correlation of the individual dimensions (microanatomic and macroanatomic) are described in chapter 4.2.. In this chapter I describe the opinions of osteopaths who apply the tensegrity model based on this connection.

The body is a hierarchic structure. Each dimension from the microscopic to the macroscopic area is connected with all other dimensions. The body always reacts to a change with his entire hierarchic system. This view plays a great role in Ingber's studies (1998, 2005, 2006). Some authors consider implications for osteopathy in the hierarchic systems of the body (Lee 2001, Noelmans 2001, Magoun 2002, Davies 2005, Girardin 2005, Parsons 2005, Oschman 2006).

Noelmans (2001) regards our body as a fractal unit. In his opinion, patterns which repeat themselves on the level of microscopic and macroscopic structures form the basis of geometry in nature. Oschman (2006) also describes such a structure when he writes that the dynamic tissue tensegrity matrix is a dynamic network and resembles a fractal pattern that is present in each dimension. He describes hereby the core matrix which is situated within the cell matrix, which in turn is in the tissue matrix. According to Oschman (2006) the properties of the whole network depend on the activities of all integrated individual parts. Davies (2005) describes the unpredictability of new properties („Emergent Behaviour") in this self-organisation. These properties cannot be determined by the observation of the individual parts.

Buckminster Fuller (1975) called this circumstance "synergy". According to Magoun (2002), a system stabilises itself during its self-development by the way tension and compression forces are distributed and balanced, precisely through tensegrity. When a cell develops into tissue the phenomena of linear stiffening occurs, a situation that was already described by Ingber (1999, 2005). Magoun (2002) adds that via resistance the tissue re-arranges itself towards the strain and he claims that this way lines of stress arise which we can see and ascertain as osteopaths. According to Girardin (2005) this self-organisation becomes also apparent in the development of tissue in embryology. He believes that tensegrity plays a direct role in the regulation of tissue development and the resulting development of organs and organisms. He believes that the development of the embryo goes through these stages following the tensegrity principle. He quotes as example the muscles that grow, according to Blechschmidt (1975) in connection with tension in a dilationfield[1] and that the growth direction later on determines the contraction. Girardin (2005) finalises that embryology demonstrates tensegrity principles in abundance.

Parsons (2005) believes that the connection of various dimensions are of relevance in practice, when he writes, that tensegrity allows us to realise that we can have an effect on basic microscopic structures (molecular and cellular) and therefore on physiology by creating changes in macroanatomic structures. Davies (2005) argues that, as a result of mechanotransduction, the tissue matrix system controls and coordinates the cellular respiration. According to him this would have a great influence on osteopathic treatments as it would make us sense how far reaching the consequences may be if we bring the body into balance, an interaction of geometry and chemistry, between structures and function (Davies 2005). Lee (2001) describes this connection between structure and function in such systems as follows: "*If one sees the behaviour of various enzymes and substrates as structural, if one understand that the*

[1] According to Erich Blechschmidt (1975) a dilationfield is a metabolic field in which cells are strained under tension. They ease up and are then dilated. During the embryogenesis the muscle cells are formed in such a metabolic field.

matrix and the cytoskeleton together mechanically control the activity of enzymes, if fluxes of Calcium ions triggering enzymatic events are visualized as electromechanical waves, everything becomes structure, form, or anatomy playing itself out in a unified system of function. The "anatomy" of biochemical activity describes tensegrity in action." (Lee 2001, p. 8-9)

5.7. Tensegrity as a Model

In the previous chapters tensegrity was described as a physical principle that can be applied in various areas of osteopathy. Many authors use tensegrity as a model to illustrate certain ideas and pictures, partly for didactic reasons, partly in order to demonstrate the holistic concept of osteopathy in a plausible way. It is hereby not important whether this model is true or not. The point is merely to use an analogy to make certain circumstances more comprehensible.(Noelmans 2001, Myers 2004, Parsons 2005, Davies 2005, Oschman 2006, Siemsen 2006)

Parsons (2005) declares that in osteopathy many vitalistic expressions are used, for example, „the breath of life" or „the body's inherent wisdom" and it is more practicable for students and practicioners, who do not believe these things without any reservation, to search for a more rational explanation. Many mechanical models have been developed but none of these models are suitable to demonstrate the holistic way of thinking of osteopathy in a plausible way. Here tensegrity opens a new possibility. This model forms a logic analogy for the ability of the body of self-regulation. For the tensegrity model is does not matter to the body, which treatment method is used, i.e. structural, fascial, or cranial. As long as the normal function is restored, the body will regain its structural, physiologic and perhaps even its psychological homeostasis. (Parsons 2005) The tensegrity model opens a holistic view on the way the body functions, compensates and acts as a whole (Myers 2004).

Oschman (2006) considers pictures like the tissue tensegrity matrix to be important. *"According to our pictures we achieve success in therapy, from our pictures special intentions result. They are not trivial, as they generate specific electric and magnetic activity patterns in the nervous system of the therapist which can spread from his body to the body of the patient."* (Oschman 2006, p. 40). Lee (2008) also regards such pictures besides physical principles as important. He describes the necessity of visualisation as demanded by Dr. Still again and again: "*Dr Still counselled his students to "hold in your mind the image of the normal anatomy as an artist holds the image of a scene or beast he wishes to represent with his brush."* And he describes furthermore, that in his opinion the tensegrity model is a possibility of visualisation: *"Your image of the normal anatomy (tensegrity) - or as I like to call it 'long fascial relationships' - will help your mind create the desired therapeutic conformation of your hands."* In his opinion, the ability of visualisation results in the success in therapeutic success: *"Your hands respond to the neurological input from your brain (even unconsciously) to shape them and push or pull in such a way that you recreate the normal anatomy - the ultimate goal of treatment."* (Lee 11.04. 2008)

Siemsen (2006) describes the tensegrity model as a general model of health and disease. The distortion of the model through a force that remains within the reset position can be cancelled by the system itself. This self-stabilisation of tensegrity systems corresponds to the self-healing power of the body. A strong distortion that is situated outside the reset position cannot revert to the original shape on its own and leads therefore to disease. Through manual intervention the „exhausted" model can be brought back into the flexible reset position and the self-healing power can restart work. That way he regards the background of the treatment as explainable.

Noelmans (2001) regards the tensegrity model as a didactic model, which he found when looking for a didactic model to explain fascial treatments, listening techniques and biodynamic basic knowledge. He is of the opinion that this model may form a plausible basis for a topic that is normally very subjective. He simply regards it as very practical to consider the body as a tensegrity structure. Furthermore he points out that such a didactic model is only an aid to reach a certain goal. In his opinion such concepts are useful for a better comprehension of subjective and abstract things. However, once the image is integrated in the knowledge and thus the aim of the model has been achieved, one should better forget the model and concentrate on one's own experience. Otherwise, the risk arises that new dogmas are added to osteopathy. (Noelmans 2001)

6. Guideline Focussed Expert Interview

To date no indication of a critical examination of the tensegrity model can be found in osteopathic literature. None of the authors who occupy themselves with the topic, query the tensegrity model. No discussions take place. For this reason experienced osteopaths were asked for their opinion on the tensegrity model in an expert interview.

In this chapter the methodology of the expert interview and the consequent content analysis is described.

6.1. Qualitative Research

Qualitative research involves the description, interpretation and understanding of connections, the set-up of classifications and the formation of hypotheses. The outstanding feature is an undistorted approach that supplies undistorted and comprehensive information and is therefore suitable, whenever a differentiated and detailed description of individual opinions and impressions is required. *„Qualitative research claims to describe living conditions „from within" from the point of view of acting* *people. The aim is to contribute to a better understanding of social reality and draw attention to activities, interpretation patterns and structure characteristics.*"(Flick et al 2007, p. 14)

6.2. Selection of Experts

Initially I chose the experts from my personal environment. I tried to memorise who had talked about tensegrity and who is an expert in an area that has to do with tensegrity, for example histology (Van Dun, Girardin), biomechanics (Sommerfeld) or fascia (Harrer). I contacted one conversation partner due to a paper he had published (Siemsen). He is the only one who does concrete research in the field of „tensegrity". Another conversation partner (Klein) was contacted on recommendation (Sommerfeld). All experts had to fulfil the following requirements:

- Completed studies of osteopathy and D.O. qualification
- A minimum of 5 years of experience as an osteopath
- Occupation as lecturer in an area relevant to tensegrity (histology, biomechanics, fascia)
- Known occupation with the tensegrity model

According to these criteria the following experts were selected and interviewed (listed in chronological order of the interviews):

- Patrick van Dun, D.O. in January, 2008, in Kassel, Germany
- Peter Sommerfeld, MSc D.O. in January, 2008, in Vienna, Austria
- Dr. Georg Harrer, D.O. in January 2008 in Vienna, Austria
- Prof. Dr. Claus Siemsen, D.O. in February 2008 in Buxtehude, Germany
- Prof. Paul Klein, PhD D.O. in February 2008 in Brüssels, Belgium
- Max Girardin, D.O. in March 2008 in Masseik, Belgium

6.3. Guideline Focussed Interview

In an understanding interview the guidelines are a flexible aid to orientation to encourage the informants to talk about a certain topic. In an ideal case a dynamism develops in the talk which, as long as one sticks to the topic, is much more valuable than simple answers to the questions. The questions should be asked in logical order and it makes sense to arrange them according to the topic so that they form a coherent discussion. Abrupt mental leaps or a pot-pourri of questions have to be avoided systematically for a reason that is rarely considered: the informant decides how far he gets involved in an interview and that depends mainly on the confidence he has in the interviewing person. Questions taken out of context, strange or unjustified questions immediately create a negative impression. (Kaufmann 1999)

As shown in chapter 8, the experts often had very different access to and opinions on the tensegrity model, so that the guidelines had to be „adapted" quite a bit as the interview dynamics would otherwise have been affected. Some experts had a lot to say to certain topics, but on the other hand said nothing about others, so that even though the guidelines were partially adhered to, some questions appeared no longer appropriate.

The guidelines of the expert interviews regarding tensegrity in osteopathic medicine comprise the following questions:

1. When did you first hear of tensegrity and in which connection?
2. What do you consider are the core messages/core statements of tensegrity?
3. What is the significance of tensegrity in osteopathy?
4. Which level is important? (micro-anatomic / macro-anatomic)
5. What is the significance of models in general?
6. How about scientific studies regarding the application of the tensegrity model?

7. Were you able to benefit personally from the knowledge about tensegrity?
8. Can students of osteopathy benefit from tensegrity?
9. Why is tensegrity mainly discussed in osteopathy?
10. What are the weaknesses of the application of the model?
11. Do you think that the tensegrity model will establish itself in osteopathic medicine?

The interviews were held in German and recorded with a tape recorder. The experts were asked before the interview whether they were agreeable with the publication of their names together with the thesis. All persons interviewed agreed.

The interview had a total of 13,884 words and 90,004 characters.

6.4. Qualitative Content Analysis (according to Mayring)

The analysis of the interview was carried out in several steps. First of all the interviews were transcribed. When the spoken word is transferred into writing and structured, reality is necessarily reduced. Then each interview was dealt with individually and categorised. The categories arose either from the guidelines or the content which occurred during the interview. Finally, the actual work of the qualitative content analysis (Mayring 2003) was carried out and the interview material was dealt with systematically. All interviews were put into relation with each other and common points or differences were extracted.

6.4.1. Aim of Qualitative Content Analysis

The object of content analysis is a systematic processing of the interview material, which was recorded with a tape recorder. The fundamental idea of qualitative content analysis is to maintain the rules of content analysis (strict adherence to systematic analytical procedure, fitting the material into a model of communication, quality factors) for qualitative analysis steps without making premature quantifications.

6.4.2. Theoretical Background of Qualitative Content Analysis

Qualitative content analysis is based on the following basic principles. The material is perceived in the context of the talks: Who is the author? What are his sources, who is his recipient or his target group? The specific systematic consists of the adherence to systematic analytical procedure (approaching in accordance with stipulated processes, in the adherence to theoretical procedure (following theoretically verified formulations of questions) and in the step by step procedure to dissect the text in individual units of analysis. The procedure is oriented towards categories. The aim of a content analysis is for several analysts to obtain similar results.

6.4.3. Techniques of the Qualitative Content Analysis

In a recapitulatory contents analysis the material is reduced to the relevant content and a clear and manageable text remains. It presents itself when you are only interested in the contents of the material and a compression to a short text is required. The fundamental idea of the formation of categories is the use of methods of a summarised content analysis to develop categories from the material step by step.

6.4.4. Benefits and Limits of Qualitative Content Analysis

The system of qualitative content analysis normally follows procedures that are laid down beforehand. This way procedures are transparent, comprehensible, easy to learn and transferable to new formulations of questions. Although a category system normally forms the central point of the analysis, this is revised during the analysis in feed-back loops and the material is adjusted flexibly. The qualitative content analysis reaches its limits when formulations of questions are very open, so that an inductive formation of categories is too restrictive or cannot be theoretically substantiated in a conclusive manner. (Mayring in Flick et al 2007)

7. Views of the Experts on the Application of the Tensegrity Model

The experts' statements on the tensegrity model reflect only a small part of their work, opinions and knowledge. Each one of them has his own access to osteopathy and probably to a specific topic such as tensegrity. Therefore it is possible that, when categories were formed, these statements appear to have been taken out of context of the daily work of the interview partners. I have made every effort to avoid taking statements out of context, however, that cannot be ruled out completely.

7.1. Access to the Tensegrity Model

Literature research showed that Donald Ingber and Stephen Levin are the ones who have done the most research and written work on the application of the tensegrity model in biological systems. Therefore it did not come as a surprise that their work was the introduction for experts, to occupy themselves with the tensegrity principles. HARRER, KLEIN and SOMMERFELD mention that they had access to the tensegrity model through the congress at the "Osteopathieschule Deutschland" (School of Osteopathy, Germany) in 2004, however, they emphasize, that they had previously heard of the application of tensegrity principles in biology.

„I know of tensegrity as architectural principle from Buckminster Fuller. I read about it about 10 years ago. I found the fullerenes quite interesting. They might be of interest in pharmacology in future. Pure carbon compounds made from equable polygons: the only form of pure carbon compounds apart from the diamond is the fullerene. However, I did not think it had anything to do with medicine. In 2004, on a congress organised by Torsten Liem, I was a speaker previous to Stephen Levin and that is when I first got to know of biotensegrity. That was my introduction.“ (HARRER 1/3-10)

„First of all from the congress, where Levin took part, however, I was not able to attend myself. I knew it before then from mechanics and cell biology, I had known about it for about ten years." (KLEIN 1/3-4)

„…that might have been in 2004. There was a small congress in Hamburg organised by Torsten Liem from the first school of osteopathy in Germany, where he had invited Dr. Levin.“ (SOMMERFELD 1/17-18). Peter Sommerfeld noticed that at that time many students suddenly occupied themselves with the tensegrity model in Germany, whilst nobody in Austria knew about this principle. He believes that it is because Liem mentioned this model in his „Leitfaden Osteopathie“ (Compendium of Osteopathy). (SOMMERFELD 1/19-28).

Max Girardin and Patrick van Dun first obtained access to the tensegrity model through the studies of Donald Ingber. *„… about 6 years ago I wrote a script about biomolecules and cytology together with a biotechnologist. When writing the script we encountered the internet page of Donald Ingber, who applies tensegrity on the level of cell biology.“* (VAN DUN 1/3-5)

„The first time I read an article in „The Scientific American“, an article Donald Ingber „The Architecture of Life“, about the end of the nineties. I have a number of journals on the areas of physics, chemistry, physiology, anatomy, archaeology and biology, from time to time also on

astronomy which I try to go through systematically. That is my field of interest.“ (GIRARDIN 1/3-8)

Claus Siemsen heard of the tensegrity model for the first time during his osteopathic training. *„It was during my osteopathic training, which is already a few years back. I cannot give the exact date but it must have been between the years 2000 and 2002. It was introduced as a model, an abstract explanatory model for many phenomena in osteopathy.“* (SIEMSEN 1/3-5)

In conclusion, it can be said that four out of six experts obtained access to the tensegrity model not through osteopathy but through their occupation with biologic systems (HARRER, KLEIN, VAN DUN, GIRARDIN). Two experts heard of the principles for the first time from other osteopaths (SOMMERFELD, SIEMSEN).

7.2. The Core Statement of the Tensegrity Model

All experts regard the tensegrity model as a mechanical model, where both tension and pressure forces take effect and certain properties result from the interaction of these forces. Regarding the core statement, three experts mention the transfer of the principles to biological systems (HARRER, GIRARDIN, SIEMSEN), whilst two experts confine themselves to the architectural, mechanical principle (KLEIN, SOMMERFELD).

Max Girardin regards the phrase coined by Kenneth Snelson „continuous pull, discontinuous push“ as the core statement of the tensegrity principle. *„In order to obtain a tensegrity system, you have to have a power system which maintains continuous tension on the structure and that actually the "pull"- the counterpressure - emerge as a reaction to this tension. The combination of both means a maximum in strength with a* *minimum of material. It is an optional form from a mechanical point of view.“* (GIRARDIN 1/16-23)

Two experts describe the mechanical principles according to the models developed by Kenneth Snelson, i.e. sculptures like the „needle-tower“ (SOMMERFELD, KLEIN). Two experts describe the principles from the view of Buckminster Fuller’s geodesic domes (HARRER, SIEMSEN). This is interesting, as the experts, who approached the principles through Snelson’s sculptures are rather sceptical towards the tensegrity model in biological systems, whilst the experts, who base their ideas on the geodesic framework principle, approve of the model. As described in chapter 4 Donald Ingber describes the mechanical characteristics of the cytoskeleton using Buckminster Fuller’s model of geodesic domes (Ingber 1998, 2008).

According to Peter Sommerfeld the tensegrity system is a system whereby only tension and pressure forces work and not shear forces. For him as bio technologist the elimination of shear forces is the main aspect. The geometric principles are partly based on triangle shapes. He regards the „needle-tower“, which is held only by tension and pressure and tension elements and nothing else, as a beautiful example. (SOMMERFELD 1/33-48) Paul Klein also believes that architectural aspects are in the foreground. *„In my understanding, tensegrity is something used when building something, for example a tower, like Snelson’s needle tower. If you build a tower, compression forces have to be transferred. In a tensegrity model the compression bars do not lie on top of each other, they do not touch each other. The only elements to connect them are elastic bands or ropes, i.e. elements which can convey tension. That creates a paradox situation: How can you build a tower whereby the compression elements are connected by tension elements? Snelson found out how it works and built the needle tower. …. The beauty of tensegrity is the architecture, like the needle tower. I regard tensegrity as a connection between architecture and art. Whether it can be applied in biology, is another matter.“* (KLEIN 1/8-19)

According to Claus Siemsen the framework principle of tensegrity remains paramount. He believes that according to the framework principle many phenomena in the body can be explained: *„The core statements are, that we have structures, static and elastic elements, i.e. bones as static, fasciae and ligaments as elastic elements. They co-operate in a way that we are able to achieve a level of power which goes beyond the normal degree of comprehension. We can introduce forces to the body which cannot be explained with normal explanatory models. Through this model we have static-dynamic balance in micro structures and macro structures as well as a synergy effect*." (SIEMSEN 1/9-14) The work of Ingber was the basis for him to occupy himself further with these principles, as, due to this, they were transferable to microstructures. *„At long last we have micro structures. Architects and engineers have been working on macro structures for a long time, for example Buckminster Fuller, who realised domes and halls with these structures. The principle is the framework principle. This framework principle is becomes part of tensegrity. The most important characteristic of these things is the three-dimensional framework principle*." (SIEMSEN 1/47-51)

Georg Harrer describes tensegrity as a possibility to build things which are omnidirectionally stable and are based on tension and pressure resistant elements. Some elements are only tension resistant, the others only pressure resistant. In conventional architecture all parts must be resistant to both tension and pressure. Tensegrity makes a different construction method possible. *„In a car for example all structures must be both tension and pressure resistant, otherwise it cannot work. If you built a tensegrity car, it would be a much lighter construction, however, it would be flexible – like every living thing – and it would be very airy."* (HARRER 1/18-22). He does not regard the application of such principles in biological systems as a problem. *„Based on their bioqualities biological structures are well suited. Because of their non-linear interrelation between pressure and form, biological structures are suitable to produce tensegrity structures. That means, with a biological membrane I can build such a Fuller dome."* (HARRER 1/29-32)

7.3. The General Significance of Tensegrity to Osteopathy

Four out of six experts consider the tensegrity model significant for osteopathy (GIRARDIN, HARRER, SIEMSEN, VAN DUN). One expert regards the application of the principle very critically (KLEIN) and one experts does not see any significance of the tensegrity model for osteopathy (SOMMERFELD). However, this is only a rough summary as the experts base their opinion on very varied incidences, as I will describe as follows.

If the tensegrity model is applied to the level of cytology as done by Ingber, then Patrick van Dun regards this as theoretic support of the first principle of osteopathy. It emphasises holism. *„If an impulse is given to the cell, this impulse is distributed through this model in the whole cell. If this model could be applied on all levels, it would be a theoretical support for the principles of osteopathy, i.e. holism."* (VAN DUN 1/13-16). Claus Siemsen also believes that the basic principles of osteopathy are explained with the application of the tensegrity model: *„Think of the predecessors, think of Still. Those are the osteopaths who have really already molded the model. The basic principle: „Form determines function". We can now understand this sentence based on the theoretic perception of tensegrity and the mechanics. Form determines function. You can understand it when looking at a three dimensional tensegrity model. If you regard it as a cell or a chaining of many cells lying in each other, then focus on a point and alter the tension there, and the whole model changes. In each point, in each strut we have obtained a different tension. „The form results from moving structures", we can see that here and that was also one of Still's core statements. Function is responsible for everything, that we observe in structural elements."* (SIEMSEN 2/32-43)

Siemsen regards these principles as comprehensible in each area, also in the visceral area. At the same time, however, he points out that not everything can be explained with tensegrity: *„If one goes much further and asks, how everything is connected – surely biochemistry plays a great role, also electrophysics. Psychological mechanisms play a role too. I don't know whether you can explain everything with tensegrity – as some people do. I don't want to commit myself."* (SIEMSEN 3/19-22)

Max Girardin regards tensegrity as a physical principle and not as a model. According to him it is an essential basic principle and therefore important to osteopathy. *„In practice, I think that tensegrity is a fundamental principle that you can find on each dimension measurable by man. To me it is a principle just as important as other principles from physics or chemistry, as for example the principles of flow or the piezoelectric effects in crystals. They are fundamental principles. In osteopathic studies you should start with these things, they are basic principles."* (GIRARDIN 1/27-31). According to Girardin it plays an important role to integrate such principles into the way an osteopath acts and thinks. He believes it is important to know about these principles of nature. *„…I am convinced that an osteopath in the real sense of the term should be someone who understands the principles of nature, and tensegrity is one of these principles. Moreover, he should have scientific knowledge of the shape of the human body. What is shape? The structure, i.e. the anatomy with embryology, histology and everything around it. And the behaviour and the function, that means physiology as a whole. If he knows the principles, he has quite a wide basis for shape. And then the third aspect comes into it, that he manages to recognise science and the principles of the shape of the human body. That is what we work with in practice and that is why I believe it is important."* (GIRARDIN 2/27-36). However, Girardin also mentions, that these principles are no longer important in practice as the osteopath is not aware of them. They are integrated in the system and the osteopath does not think about them any more (GIRARDIN 2/26-27).

Georg Harrer on the other hand regards tensegrity in osteopathy mainly as a model. Such a model or image is practical and useful. For osteopathy however it is only useful as he considers osteopathy not as a method but as a school. *„In my opinion* *osteopathy is neither a method nor a theoretical concept, something that many osteopaths do not realise, but in my opinion it is so. Osteopathy is a school. An osteopath is someone who has graduated from a school of osteopathy. All over the world it is managed in this way – also in Germany, for example. A school can indeed benefit from an expanded consciousness through the tensegrity model. It creates a different image of human beings, of joints, of structures, if you were to imagine it. For an osteopathic school it is enriching. For the osteopathic method I do not think it is enriching, but that doesn't matter, as it is not a method as such.*" (HARRER 1/40-48). It is above all the imagination which Harrer mentions again and again, seeing it as important. By imagining tensegrity it is possible to visualise especially the omnidirectional stability of the human body very well. „*You can expand your imagination,, when you look at tensegrity structures and perhaps build something like that. The first thing I did after returning from the congress – I built a tensegrity icosahedron made of wooden sticks and surgical thread in the operating theatre. It had astonishing qualities. That is four years ago and my children still play with it today. It doesn't break, even though I just quickly made it in the operation theatre. Due to the tensegrity qualities it is so strong, that my children have up until now not managed to destroy it. This is an interesting experience and one gets an idea of how solid the human body is and why it is so strong. The stability of the human body and its omnidirectionality cannot be explained with conventional models.*" (HARRER 1/52-61).

Paul Klein sees the idea of tensegrity principles as interesting. „*If you build a tensegrity model and alter the tension in only one tension element, for example an elastic band, this change in tension is transferred to all other elements. This is interesting. There is too much tension in a muscle and it can be assumed that this has an influence on other muscles, ligaments and fasciae. Therefore, it could be of interest to osteopathy.*" (KLEIN 1/28-31). However, he notes that, according to the actual standard of knowledge it cannot be determined whether the body uses tensegrity principles. Therefore, he regards the examination of the body as a tensegrity system as an epistemological mistake: „*Assuming a muscle is hypertonic. That possibly influences other elements. But to know* *exactly in a patient: What is the influence on other elements which are further away? We just don't know. Why does it happen? How is it transferred? You don't know it. You can assume that the tension in one element has an influence on other elements, but it cannot be explained. That cannot be explained by tensegrity either. I believe that, we go too far, too quickly. One has a nice theoretical model and tries to adjust nature to the model somehow. That is a big risk from an epistemological point of view. That will go wrong. The models have to be adjusted to nature and not vice versa. That is an epistemological mistake*." (KLEIN 1/35-44). In this connection, Klein mentions that it is doubtful to claim that by treating one part of the body, effects in the whole system can be achieved. „*Okay, we have some influence on the body as osteopaths. But first of all there is the influence on the brain of the osteopath. It is his imagination. The patient feels better and the osteopath says: Yes, I had an influence on the whole body. I believe one acts too quickly in osteopathy.* (KLEIN 1/55-58)

Even though Dun regards the tensegrity model as a useful model for osteopathy (VAN DUN 1/45) he remarks that in osteopathy something is adapted prematurely, without a deeper knowledge of it. „*I am afraid that too many osteopaths just simply try to use it. One sees something or hears something and without looking into the topic further it is applied, even though one does not know all characteristics.*" (VAN DUN 2/8-12).

Sommerfeld does not believe that the human body applies tensegrity principles.. „Well, I do not believe it." (SOMMERFELD 1/59)

Claus Siemsen not only sees the tensegrity model as a good possibility for explaining the somatic dysfunction, but also for its treatment. „*The somatic dysfunction in which we are interested as therapists, can be proven and explained with the model and we are able to bring back the function with our hands in an elastic reset position* " (SIEMSEN 2/41-43). According to Siemsen the somatic dysfunction influences the movements of our whole body, from the cellular level to the macrostructure. He describes the possible treatment and regards the tensegrity model as mechanical supplement to existing neurophysiological explanations. *„If there are chainings and a decompensated system exists, we can treat a certain body part and influence and bring back the whole system. That means, we can adjust to a considerable degree with soft part or release techniques. Thereby, the tensegrity model is a mechanical supplement of existing neurophysiological explanations. Upledger talks about scars and micro injuries in the connective tissue causing somatic dysfunctions. They cause a lasting dysfunction which can be recovered with our hands. That is very fascinating. This mechanical basic model can be introduced very well and is therefore of interest to us.“* (SIEMSEN 3/56-61 and 4/1-2)

Girardin however, does not agree with such models at all. According to him tensegrity is, as described earlier, a physical principle and not a model to explain „this“ or „that“. *„I believe tensegrity is a principle and not a model. A model to my mind is when you say: The dysfunction can be explained by tensegrity, it can explain the reasons why the dysfunction has been established. That is a model.“* (GIRARDIN 3/39-41). According to him, somatic dysfunction does not exist and therefore you do not need a model for it. *„First of all in my osteopathic concept there is no somatic dysfunction, but that is another matter. There are only functions. The system behaves in the best way it can. That is not a dysfunction, that is a function.“* (GIRARDIN 3/8-12). Girardin regards the behaviour of connective tissue also as a system which is not in the tensegrity system, but rather in physiological regulation systems, for example the one developed by Alfred Pischinger. *„If you want to say that the whole connective tissue reacts as one system, I completely agree with you, but not when you say it does this through the tensegrity principle. The first to describe this was Pischinger with his bio regulation system; and I would not give it a name straight away but I think it is located in the dimensions of light-communication, i.e. biophotons, or really electricity. “* (GIRARDIN 3/11-18). Van Dun too sees possibilities to explain the development of dysfunctions rather on the level of regulation and communication. (VAN DUN 3/8-10).

Four experts definitely see a significance of the tensegrity model in osteopathy, even though under very different conditions (Girardin, Harrer, Siemsen, Van Dun). Two experts agree, that tensegrity is not likely to play a role for osteopathy (Klein, Sommerfeld).

7.4. The Microanatomic Area

Sommerfeld and Van Dun ask themselves, whether one can still speak of tensegrity principles, when looking at the level of cytology and histology. *„The problem is, that this tensegrity model is described for structures, which are shown in a space. Looking at a cell or connecting tissue you can see that they are not shown in an empty space. If you look at the cytoskeleton of a cell and assume that the actin filaments represent the bars and the other filaments represent the cables, you will find that they are not situated in an empty space. There is liquid and other cell structures for example in between. And then I really don't know whether you can still call it a tensegrity construction.*" (VAN DUN 1/26-33). Sommerfeld says about the application of the tensegrity principle in the microanatomic area: *„There are models like the „needle tower", a definite tensegrity model, or these wire rope hoists with rods and gum … there must be an algorithm for the building principle. And then I ask myself, whether the connecting tissue has this construction principle and I think, if we look at micro anatomic articles about what this Frenchman is doing, the one who had an article in the last issue of the „Osteopathischen Medizin", I don't know his name, that is very chaotic. Whether to introduce such a model, that would be my first question.*" (SOMMERFELD 2/20-27) It is interesting that Siemsen quotes exactly this article in the „Osteopathischen Medizin" (by Guimberteau et al) as evidence for the tensegrity model: *„In the last issue of the „OM" a Frenchman published fantastic pictures, both of microscopic and macroscopic structures. This lattice work in the microscopic area has an influence on the macrostructures. One can explain this with help of the principles of technical* *mechanics, they reflect this*." (SIEMSEN 1/23-27). For that reason Siemsen regards the work of Ingber, which is done according to the tensegrity model and Buckminster Fuller's domes as the basis for the functioning of connective tissue in a three-dimensional framework principle (SIEMSEN 1/47-51). According to Van Dun it remains questionable whether the connective tissue really communicates via this lattice work of the cytoskeleton and extra cellular matrix: „*That may be true. As far as I know, there is no proof for this. Therefore up until now it is only a model*." (VAN DUN 1/22). However, Van Dun reports on the work of Ingber and his team: „*They set a cell on a certain floor. Either a very stable floor or a rubber floor, which undulates. And the cell reacted in various ways. If you enlarge this on other levels then you can see that certain organs, or cells, or tissue structures, depending on their surroundings, react in various ways and may change their physiology*." (VAN DUN 4/13-17)

Klein considers the tensegrity model on the level of cell biology as proven wrong, according to the actual standard of knowledge. „*Ingber proposed this in the nineties. But in most studies on cell motility the authors claim that cell motility is not based on tensegrity.*" (KLEIN 1/23-24). Regarding the components of the connective tissue he asks himself: „*Where are the elements that work with pressure? We have so many elements which transfer tension but where are the elements that transfer pressure? I can't find them. Collagen is made for tension*." (KLEIN 2/40-42) According to him, fasciae are built in such a complicated way that it does not make sense to look there, when searching for explanations how changes in tension can become noticeable in other areas. „*…if we keep on looking there, we are not getting any further. But we should not give up, we should be optimistic. We have to continue with our research. But to say today: Now we have understood, is not correct. Up until now we have not understood anything at all*." (KLEIN 2/2-4). Whilst he rules out the significance of tensegrity in the macro-anatomic area completely, he does not want to do that categorically in the micro-anatomic area: „*I don't want to close all doors, but in macro anatomy you cannot talk of tensegrity. In the* *micro anatomic area it is difficult to say: Where should I find something in all these fibres?"* (KLEIN 2/32-34).

Sommerfeld thinks that it is speculative to assume that the connective tissue works as a unit. He does not believe that such completely coupled systems can function. *„It is speculative to assume that you do something and the whole connective tissue reacts. It may well be, that it reacts, but this reminds me a bit of the time when dynamic system theories were very modern. You have totally coupled systems. The butterfly effect for example: A wing beat in China causes a tornado in Jamaica. One knows now from empirical research and also from the system theory itself that systems that function in this way do not function at all. A system, that is completely coupled, where everything is always in connection with everything else, really is not functional. The more subsystems can be decoupled, the better. Whereby there are certainly limitations when a complete decoupling leads to a problem, the problem of particularism and freedom. But I would say, these are assumptions, which one develops where one attempts to support osteopathic models. "* (SOMMERFELD 2/27-37). He summarises the tensegrity model as follows: *„I regard the tensegrity model rather as a physical model. A physical model which has phantastic properties and can be illustrated beautifully in a model … but to bring it into correlation with biology and the functionality of organisms – I would be very careful. I have a problem with that."* (SOMMERFELD 2/39-44). Furthermore, Sommerfeld mentions, that the well-known cytologist Bruce Alberts mentions the tensegrity model only lapidary in his works and he is rather of the opinion, that all this has not been confirmed. According to him this model is not mainstream amongst cytologists. *„It is not mainstraim. You also have to consider, also when evaluating phenomenons that everything that is not mainstream is interesting. But just because it is interesting, you don't have to construct a whole building on it."* (SOMMERFELD 5/1-9)

Girardin on the contrary regards the combination of tensegrity with the complex system theory as an advantage. According to him, the principles of tensegrity appear in every complex level. *„Looking at a bone for example, the push-pull principle is also* *present in the micro structure. If I move on to the level of a cell, I find that again. That means, tensegrity is just a principle, that you can zoom in or out in various dimensions.“* (GIRARDIN 1/52-57)

7.5. The Macro Anatomic Area

Only few experts can do anything with the application of the tensegrity principles in the macro anatomic area, where the bones are regarded as discontinuous compression elements and the fascial system as the continuous tension element. Somerfeld and Klein rule out the application of the tensegrity principles in biomechanics in this dimension. Girardin and Van Dun are sceptical, whilst Siemsen and Harrer regard the tensegrity principles as a substantial biomechanical model.

According to Sommerfeld you may not, at least according to today’s state of knowledge, talk about the body applying tensegrity principles in its skeletal system. *„It would be nice, but obviously nature isn’t as perfect, as we wish it to be*.“ He doesn’t believe that joints are put under pressure primarily and that first of all force is required to bring the articular surfaces into contact. According to him, you find in all joints extremely high pressure forces. *„At one time one thought this is the case in the scapulo-thoracal joint but there are good studies which disprove that.“* (SOMMERFELD 2/1-10). Klein also regards the explanations of the muscle-sceletal area as interesting, but not correct. *„It is interesting. I am interested in it too – you can see the tensegrity model here in my office – but the explanations in the fascial and the musculo-skeletal area are not correct. Levin himself described the scapula as tensegrity. That is not correct. The scapula transfers compression to the thorax and is connected directly with the clavicle. Therefore the shoulder* *girdle is not a tensegrity model.*“ (KLEIN 2/9-13). Klein also regards the other examples given by Levin as examples for tensegrity principles as wrong: the thoracic vertebrae and the upper ankle joint. He summarises the application of the tensegrity principle in biomechanics as follows: „*In biomechanics, tensegrity is mentioned on and off, but then it is stated: Alas, / Oh, it really isn't important. Thus I can say that in the musculo-skeletal field, which is my area of expertise, tensegrity is not mentioned.*“ (KLEIN 2/14-27)

According to Siemsen, tensegrity is a significant biomechanical principle. However, you must not regard the bone as mere compression structure and the fasciae as mere tension structure. „*The bone is not a mere static element. All elements have static functions, only fasciae are more elastic than bones. Bones have a tension gradient downward. That can be explained with Young's moduli. Bones are more suited to absorb compression stress, fasciae can absorb tension stress*.“ In this connection he explains: „*We have just made calculations with weight lifters. We make calculations based on various Young's moduli. You can either work with bones, fasciae or ligaments, you simply have to alter the moduli. If you use these in your calculations, you can achieve a nice homogenous result.*“ (SIEMSEN 1/31-37). Siemsen sees the advantage in the tensegrity model that the body can absorb forces, which can otherwise not be explained. „*When lifting weights of 250 kilos the intervertebral discs would disrupt in a pure mechanical sense. The material of the intervertebral discs cannot absorb these forces. Therefore, there must be structures in the body that reduce these extreme forces.*“ According to him, the distribution of force of all structures can be explained perfectly with tensegrity. (SIEMSEN 1/55-59).

At this point it became clear to me how varied the conceptions of the experts in this field were. Whilst Sommerfeld and Klein apply the tensegrity principle to large structures and regard a bone as a mere discontinuous compression structure, Siemsen regards the bone in itself already as a tensegrity structure.

Harrer also regards the tensegrity model as a significant biomechanical model, which explains the enormous resilience of the body (HARRER 2/3-5). Generally, Harrer regards the whole of biomechanics as fundamental science which is not of direct use to the patient. *„I believe it is mainly something for fundamental science, i.e. biomechanics. The same applies to biomechanics. During my career I have never restored a patient to good health using biomechanics. All these lectures on biomechanics that I attended, all these hours I spent with the Kapandji, did not help any of my patients.“* (HARRER 4/32-36). Harrer regards this as the weakness of the tensegrity model, a lack of applicability in osteopathy: *„It is of no therapeutic use. I regret this as medical practitioner. I therefore have little use of it. It is merely a describing model. I can hardly imagine a therapeutic use at the moment. Stephen Levin also could not tell me much about it. Possibly the consideration as tensegrity model helps in medical decisions, but I cannot think of any concrete decision, which I would alter based on the tensegrity information available to me. Because I am a practitioner and have to restore patients to health. I believe it is something for the study.“* (HARRER 4/21-27)

According to Van Dun the transfer of the tensegrity principle on the anatomic area is a critical one, as in his opinion the space between muscles and bones is not an empty space, as for example in Snelson's „needle-tower“. Due to the structures in our body between muscles and bones, the resistance in our body is different to the resistance in such sculptures. Durch die Strukturen, die in unserem Körper dazwischen anwesend sind, gibt es einen anderen Widerstand als in solchen Skulpturen. *„Then the tensegrity model has to be adapted, and then we are dealing with the normal biomecanics.“* (VAN DUN 1/56-60 und 2/1-2). From Girardin's point of view one can already see, by the form of the bone, that it is not a compression structure through and through. *„If the bone were to be a continuous structure, it would not be formed this way."* He can imagine that this is the case in certain movements, however he does not believe that the whole body works this way.(GIRARDIN 1/49-51)

7.6. Models in Osteopathy

The application of the tensegrity principles as model was described in chapter 5. In this chapter first of all the definition of a model and the tasks of a model will be explained. Then the experts are asked for their opinion on the usefulness of such models in osteopathy. Even if although this chapter is not explicitly about tensegrity, it is of interest, as the tensegrity principles are most often used as such a model.

7.6.1. Definition of the Concept "Model"

Stachowiak (1973) formulated his generally accepted model theory. Hereby the term model is identified by three characteristics:

1. Image: A model is always an image of something, a representation of natural or artificial originals, which in themselves can be models.

2. Abbreviation: A model does not comprise all attributes of the original but only those which appear relevant to the model creator or the model user.

3. Pragmatism: Pragmatism means orientation according to the usefulness. A model is not attributed to an original on its own accord. The attribution is put into perspective by the questions "For whom? Why? For what?". A model is used by the creator or user to replace an original within a certain period and for a certain purpose. Thus, the model is interpreted.

7.6.2. The Experts' Opinions on Models

Models are useful in osteopathy to make certain aspects in nature understandable (SOMMERFELD, KLEIN, HARRER, SIEMSEN, VAN DUN). It is however extremely important to clarify under which conditions a model may be used (SOMMERFELD, KLEIN, VAN DUN). One expert has difficulties with models in general (GIRARDIN).

Harrer, Klein and Sommerfeld regard models as necessary to describe reality to it's best. Harrer describes the importance of models as follows: „*Models are of great importance when we deal with nature. We can understand everything made by man. Everything that is created by nature, however, we cannot understand. Therefore, we have to develop models to describe and predict nature. The point is, something made by man, can be described without using a model, but everything that is created by nature, must be described and explained in a model. That is the only way to progress. That is the only way to obtain solutions. We do not have access to the truth, the truth is not in our reach. We are not in a position to understand the truth, we are too daft, too small, too dumb and too short is our "one-day existence" to get closer to the truth. Models allow us, however, to advance into spheres, which we never thought we would be able to enter. Quantum mechanics, the Bohr model. Chemistry as a whole is based on the Bohr model. This is not true. The Bohr model is an idea of Niels Bohr. It is not true, but it works and chemistry ...is based on it. A few things cannot be explained with it, but most others can."* He believes that the tensegrity model is such a model through which many things become more comprehensible (HARRER 2/20-35).

Sommerfeld also visualises a possible access to reality through models. „*We probably just manage to scrape through with models … The actual physics, where very good precalculations are made, ultimately only exist as a model. The question is, what is reality. I believe that models are incredibly useful for such problems in natural science.*" (SOMMERFELD 3/36-41) Sommerfeld elaborates as to what a model should represent: „*The most beautiful models are the simple models. And I am under the impression that in osteopathy, people think, the more complicated, the better. And one becomes rather speculative and often contradicting due to complexity. That is something I also see in my lessons. In the classic biomechanics often very simple models are used, very banal, but* *banality also has something to it. I have a problem with models, that are extremely complex and that give the impression they could explain complexity, because they themselves are complex. To me these are false conclusions.*“ (SOMMERFELD 3/42-49). Sommerfeld concludes that models are quite useful. To him it is very important to formalise things sometimes. But things must become easier that way. A model that becomes unclear and claims to explain everything, is useless to him (SOMMERFELD 4/1-5).

Klein also talks about the model as an attempt, to describe nature as well as possible. He mentions that in his book, for example, he described eight models of feet. None of them, he says, is true, but they all fulfil a pedagogical purpose. „*It helps to explain one or two aspects to other people, or students. It is both pedagogically and didactically important.*“ For that reason he visualises the possibility to obtain psychological certainty in a model in certain areas. (KLEIN 2/44-48). Klein thinks it is of great importance to point out again and again that a model is not reality. Something, that in his opinion is not done enough in osteopathy. „*One must be conscious of the fact that no model corresponds to reality. Therefore, a model can only be wrong. In osteopathy, this word is not used very well. You give your student a model and say, this is only a model, we do not know how to explain it. But only a short time goes by and he thinks it is reality. He continues to work according to this model, the patient may feel better, and the practitioner thinks, o.k., the model is correct. No, that is an epistemological error. There might be a thousand reasons and possibilities why the patient feels better.*“ (KLEIN 2/48-56). According to Klein the greatest problem with models in osteopathy is, that models are used, which are known to be false. „*What I think is worst is that models are still used that are known to be false. That is obscurantism. I don’t agree with that. There is too much obscurantism in osteopathy.*“ (KLEIN 2/56-59) It is not easy to determine, whether a model is of use or not. Klein is of the same opinion: „*As long as it is not disproven ...disproven is a big word. Let’s rather say, if there are not too many arguments against it.*“ (KLEIN 3/48-49)

Van Dun also considers it important to use models only when working or studying with them. *„It does not make sense to neglect working continuously with these models. This is the task set for osteopathy. Theoretical models are important if we try to not only use them but also try to research whether this model is true and whether we can progress within osteopathy. Then it is justified.*" (VAN DUN 2/45-49)

Girardin merely considers the application of models as an attempt to reduce one's own insecurity. *„I think that a model is a backup for the therapist who feels insecure. In that sense I would even say that I find the use of models abnormal, and that you have to be extremely careful with models.*" (GIRARDIN 3/28-30). For Girardin the principles of nature are important, they could perhaps be studied based on models. But to him a model remains a model and you have to be very careful with it. However, according to him tensegrity is not a model, only a principle: *„In my opinion tensegrity is a principle that I recover in wood, in the growth of plants, I find it everywhere in nature. To me it is not a model, but it is rather a principle.* " (GIRARDIN 3/59-60 und 4/1-2)

According to Siemsen tensegrity is a model that has a scientific basis. With this model, gaps in one's knowledge can be closed. You understand better what you do with your hands: *„That is the essence of science. To discover common basic phenomena, to know that I am not treating something imaginary, I am treating a structure, that is technically imaginary.*" For Siemsen it is a step from paramedicine to real medicine. (SIEMSEN 2/56-58) He has up until now regarded medicine as an unclear structure rather than a real science that is based on definite laws. (SIEMSEN 2/48-51).

7.6.3. Georg Harrer's „Tunnel allegory"

During our interview, Georg Harrer stated an interesting example for the reason why he regards the way to deal with models as very important for his work. He regards the imagination of the therapist as the key to success in treatment.

„There is the Austrian tunnelling method. There was a Hungarian, I don't remember his name right now, a professor at the Technical University in Vienna, who said: We build tunnels by drilling a hole in the mountain and we believe the mountain crushes us. Therefore, we need tons of concrete for each tunnel to support the mountain, in order to hold it's weight. I think, he said, the mountain is a vault and keeps the tunnel open. It is only a question of approach. And he started building tunnels with less than a tenth of the building material in a quarter of the time, by simply drilling holes in the mountain, casting in steel anchors and connecting these steel anchors with a thin reinforcement. This way he created a vault ten metres thick which consisted of the mountain, which was already there. Drilling had been invented already, steel was already available earlier, anchors as well and tunnels had also been built before. Only the model was different. Before then, the mountain had been a burden, that had to be supported. Suddenly, with this approach, the mountain had become the vault that keeps the tunnel open. It is not a question of technology, as we humans always think. Progress is not a question of technology, progress occurs thanks to a model. If I regard something from a different angle, I can suddenly build a wonderful tunnel in a quarter of the time using a tenth of the material. Not because I have a better machine or because my engineers are better, but because I have a different idea in my head. Because I look at it from a different angle. And that changed my life as a doctor, because I came to the conclusion that, a new tablet or a new machine for the theatre, that's not the issue, the issue is a different point of view. What is my idea of the problem? Suddenly I can fix a shoulder with minimal effort, for which I normally would have had to spend, I don't know how many Euro, in the health system. I have also learnt from the tunnelling method. And when I think about it in retrospect, I believe that the Austrian tunnel is a tensegrity model, in which pressure elements were replaced by tension elements. What you need for it are these anchors and the connection between them and just a little shotcrete, so that the chunks of rock or stone do not fall on your head. Apart from that it would hold. I would think that is a tensegrity model." (HARRER 4/48-61 and 5/1-12)

7.7. The Cranial Model

According to Klein one example for obscurantism is the cranio-sacral system, where it is mentioned that the bones of the skull move like gear wheels. „*That is ridiculous, that is not possible at all. And it is taught a lot and the student actually believes that the temporal bone turns so and so and does this and that. Those are models, obscure models. If it is still taught, then this is even dogmatism.*“ (KLEIN 3/1-5). The fact that one increasingly tries to establish the tensegrity model in the cranial area, for example as principle of function in the reciprocal tension membrane is considered by Klein as sign that the basic model is already regarded as not true. „*People are looking in a different direction because they know that the basic model cannot be maintained this way. Sutherland and Magoun were the first to think that it works that way. The situation is different now.*“ (KLEIN 3/13-15). Klein however is glad, that he does not have to answer the question as to how the cranio sacral system can be taught instead (KLEIN 3/19).

Sommerfeld is of the opinion, that it does not make sense to replace an existing model with another model. „*. I do not understand why Sutherland's model should not suffice. I would consider the tensegrity model as overcomplication.*“ (SOMMERFELD 2/51-56)

7.8. Complexity

The complexity of structures and the hierarchic construction method, which are also described by Ingber and his team, are of great significance to Girardin. It is important to understand that in each dimension, the other dimensions are included. „*Taking a bone for example, there the push-pull principle is also present in the microstructure. When I betake to the level of a cell, I find the same thing. That means, tensegrity is simply a principle that you can zoom in or out in various dimensions. Complexity, that is the point where I* *believe that many osteopaths have a problem with comprehension. You have a form of tensegrity in the next dimension, and the next dimension is again situated within, and so on. What is the final effect? It is tensegrity in each dimension. As a whole it is a form of tensegrity and you deal with unbelievable complexity. In my opinion, that is where it goes wrong, because they do not understand that tensegrity is only a principle that can be found in nature. On a molecular level, on a cell level, in organelles, on all possible levels. The way a tree is formed– that is tensegrity. As a whole and if you take a small piece out, it still remains the same. If you remove a molecule from the fibres of cellulose, it still remains cellulose which is formed according to the tensegrity principle. That means, if you try to describe such a principle, you must at the same time be aware that, whatever you talk about, has a multidimensional aspect. And not only that it is multidimensional, but that the various dimensions are situated in each other, like an onion, that is cut into half. That means, whatever you talk about, it is very complex as it is multidimensional."* (GIRARDIN 1/54-61 and 2/1-14)

Harrer also thinks that various stages of complexity can be examined if they show a self-similarity. However, he states that on each level other regularities/laws exist. *„I can draw conclusions from the family to the village, from the village to the town, from the town to the country and from the country to the human race. But I believe, that on each level the regularities are slightly varied. It is probably easier to draw conclusions from one family to another, rather than from a family to the town – as then many forces do not work here any more. In physics it is similar where different forces work on each level. Subatomic forces do not work in mechanics, whilst gravitation is neglected in the subatomic area. That means, on each level different forces work. You have to understand these forces, then you understand the coherence. I could imagine that on certain levels tensegrity forces may be able to explain sociological or epidemiological models."* (HARRER 3/30-39)

According to Sommerfeld the examination of subsystems does not lead to a reliable statement regarding the function of the system as a whole. He regards this as a problem of reductionism. However, he says:: „*That is the problem of reductionism. But another problem is of course, that reductionism may be "talked to death". To behave, as if you have something better and then get lost in total speculation. I also have a problem with that. … We proceed in a very analytic manner, we analyse, look at the individual parts, but we also know in science, ... that this is a problem, that you cannot draw conclusions from individual parts to the whole. Everybody is aware of that, except some, who are perhaps a bit stubborn. I believe, it is a bit of a misjudgement that the so-called holists believe, that the reductionistical natural scientists do not know that. They do know that. But in classical science we do not yet have the methodological skills. One always tries to unite everything anyway, but we only succeed to a certain extent."* (SOMMERFELD 3/16-27)

Van Dun especially regards the tensegrity model as a possibility to explore new ways in scientific research in osteopathy: „*The beauty of it is that you can apply it on a mathematical level as computer model and even make predictions with it. When you occupy yourself with these computer models you enter into complex systems theory, which is very useful for osteopathy. That could be a possibility to break new ground via these complex systems theories and based on these types of models. Osteopaths have always been looking for a way of doing scientific research. But science today is still regarded too analytically, too reductionistically and that could be a possibility that one could examine.*" (VAN DUN 2/33-40). He therefore believes that the tensegrity model is rather a model for research than for practical use. „*It is a model for further research, on a level that is not so reductionistic and analytical, a more global level."* (VAN DUN 3/23-25)

Siemsen sees the possibility to examine the tensegrity model in its entirety by all means, and not only the individual subsystems, also in biomechanics. „*If you have sufficient means and time then this can be proven. We are going in this direction.*" (SIEMSEN 2/27-28)

7.9. Research with the Tensegrity Model

Claus Siemens is a professor for biomechanics at the Hamburg University of Applied Sciences. I first heard of him when I read his article in the magazine „Manuelle Medizin“ (Siemsen 2006). He is the only expert who carries out direct research with the tensegrity model. He reported on his work and his results during the interview.

Siemsen makes calculations of force distribution in the body together with a colleague, a mechanical engineer (SIEMSEN 2/1-3) The calculations are carried out with various of Young's moduli. *„A Young's modulus is a material characteristic parameter. Each material has a specific parameter. It describes how elastic or non-elastic this substance is, this applies to metals as well as all biomaterial.* “ (SIEMSEN 1/41-43). Siemsen regards the tensegrity model as absolutely confirmed in his work. He summarises the results of his work as follows: *„We carried out measurings that confirm this model. And we know from the measurings of the researchers – for example the group Bergmann and Rohlmann in Berlin, who inserted small micro sensors into the spinal discs and measured the forces that work there. The studies of mechanics can be found in reality due to measuring techniques and are confirmed by these. Therefore, it is not only a theory but we can measure it exactly. With our calculations of tensegrity we lie within the measuring range established by experimental researchers regarding tension and material. That is the proof that not as much tension arrives for example at the spinal disc as we assumed to date.*“ (SIEMSEN 2/9-16). At the time of the interview the study had not yet been published. The exact time of publication was not set, however it will probably be published soon in the magazine „Sportmedizin“. (SIEMSEN 2/1-5 und 2/20-21)

7.10. Practical and Personal Benefit

Four experts say that they have had a personal benefit from the knowledge of the tensegrity model (GIRARDIN, HARRER, SIEMSEN, VAN DUN), two did not have any benefit from it (KLEIN, SOMMERFELD).

When asked about their personal benefit, Sommerfeld and Klein are of the same opinion. *„For my practical work: None.“* (KLEIN 3/37). *„None. And I still do not understand why it had such a boom, which, however, I think is over. If I ask students in Germany now whether they know tensegrity, none of them do. It lasted only two years…“* (SOMMERFELD 4/18-20)

Siemsen, who is not only a medical practitioner but also a graduate engineer, regards the bridging of technique and medicine through the tensegrity model as especially interesting (SIEMSEN 3/45-47). *„Technique and medicine are not very far apart from each other. We have a connection between the technical and the biological structure in the construction and the function. It is an elementary part, to be able to explain medicine technically as well as scientifically, the micro- and macro structures."* (SIEMSEN 3/1-4). Siemsen regrets that most of his colleagues are not very interested in the theoretical background: *„I introduced the model to orthopaedists and manual therapists on our congresses. However, there was little interest. The practitioners are not very interested in theory. That is my perception. Unfortunately, that's how it is, even though it is necessary to know the theory. The practitioners do something and are pleased when it works but they are not very interested in the theoretical background.“* (SIEMSEN 3/40-45)

For Girardin it is important to integrate principles like tensegrity in his work. *„When I read about it for the first time, I thought, that is exactly what I have not been able to name for the last years. I have tried to explain this to the students using the elasto-collagen complex. After I had integrated the principle and the word tensegrity, and that did not take long, I did not think about tensegrity much, but I just integrated it.“* (GIRARDIN 2/47-51)

For his practical work such principles are also useful: „*On the practical level I rather react to tension in the body of the patient intuitively, it is automatic. In the beginning, when I occupied myself with the elasto-collagen complex and Sutherland's reciprocal tension, I was more aware of it, but in the long term, it is integrated into the automatism of acting. Theoretically it is also of use, as it feeds information into and occupies the left cerebral hemisphere, that way we can understand things and, with our right cerebral hemisphere, work with the patient or the situation, without thinking, only feel and react to the general information.*“ (GIRARDIN 4/6-13). Girardin also describes a practical application during the interview. During a holiday in Ireland he experienced a severe storm and with his poncho and a few twigs he built a tent according to the tensegrity principles. This tent endured the very heavy storm without damage (GIRARDIN 2/55-61).

Harrer had a personal use for the tensegrity model, based on it, he understood the interfolding distortion of the fascial distortion model better: „*In the beginning I thought that it is an interesting observation but there are no practical benefits, except for builders. I do not have to form the human body, it is already there. I always had a problem with the interfolding distortion according to the fascial distortion model. The analogy of the unfolded map in the unfold distortion works theoretically as well as practically, the interfolding distortion is poor in comparison. During lectures I always manage to bluff that this analogy is not logic. It does not work. Many aspects were a problem to me, as I did not understand what happens in the human body during interfolding distortion. How can exceeded crushing destroy the folds? I do not understand it. Through the bio tensegrity model I understood that interfolding and unfolding distortions are one and the same thing. They only relate to a different fascia. There is a fascia that holds us together and a fascia that keep us apart. If the fascia, that holds us together has a folding distortion, I call it unfolding distortion.*“ (HARRER 2/39-52). However, he remarks in this context that it is often not very clever to mix various models. „*In this case one would have to integrate the tensegrity model into the fascial distortion model. However, that does not appear to be logical either...both didactic nor regarding the content, as it would complicate things and one would think that somehow it is similar to tensegrity, but it really has nothing to do with it. But it* *still helps with the understanding. I think for the advanced user of the fascial distortion model the tensegrity model is a possibility to eliminate basic doubts on the fascial distortion model, they are empirically retrievable and can be eliminated easily. That is quite easy to imagine with the biotensegrity model."* (HARRER 2/52-60) According to Harrer, the clear picture, that one obtains through such models, is also their greatest practical use: *„We need it for our determination. Humans need a clear model to be able to act decisively. It goes so far, that people blow up other people for a religious model – a determination that cannot be achieved with money. That is the key, that is how people function. Everything is based on models. Whether it is communism, Islam or the fascial distortion model, that is interchangeable. Determination is only possible in a model. It is the model that guides us. The truth itself would be the best model, only it is too indigestive, too large. Therefore the models, which are easy to digest, are very useful. The tensegrity model has improved my work with the interfolding distortions."* (HARRER 3/7-15)

Van Dun regards the theoretical aspect of the tensegrity model as more important than the practical use: *„I regard it as a topic for research. I personally do not use it in my surgery.....as I have been convinced for some time, critically convinced of the first principle. Therefore, it was more a moment of realisation to carry on research on a different level, not a reductionistical, analytical level, but a more global level.*

7.11. Didactic Benefit

The opinion of the experts regarding the use of the tensegrity model for osteopathic students corresponds with their attitudes towards the general significance of the tensegrity model for osteopathic medicine and the personal and practical use. Whilst four experts regard this model as useful for osteopathic studies (GIRARDIN, HARRER, SIEMSEN, VAN DUN) two experts do not see a didactic use. (KLEIN, SOMMERFELD)

Girardin regards tensegrity as a physical base principle, that belongs into every osteopathic training. „*They are fundamental principles. In an osteopathic training one should start with these things as they are basic principles. Just like evolution and the complex system theory. These are basics that should be taught at the beginning and in regular repetition lessons during the whole training, so that the students can reintegrate themselves in the topic. And at the end of the training it should be summarised again..*" (GIRARDIN 1/30-35). In this connection Girardin mentions again, that it is important to really understand such basic principles and not to merely apply them as models. He describes his experience with students with whom he talked about tensegrity as follows: „*What sort of answers did I get? I got the same reaction as with biodynamics: very interesting, really cool, but nobody knows what it is all about .... And I am afraid, it is like that with many things, not only tensegrity in osteopathy.*" (GIRARDIN 2/19-22). He regards exactly this as a problem in osteopathic training as a whole. „*What is the reality like in osteopathic training? There are a few lessons on structure, a little on function, the philosophy and the principles are discarded. And what is the result? Exactly as it happened with Still's first students: you create a group of „parrots", who take over a certain handling and tradition – without asking questions, which is a shame. In that sense principles are very important. They have to be integrated at the beginning, during the training and even after the training.*" (GIRARDIN 2/36-42)

Harrer has a different opinion. He regards didactic models as very important for education, even if they do not have a scientific basis. „*Because I am a teacher, I enjoy working with analogies. They are essential for didactics. But an analogy does not really have a scientific basis, as it is only a chain of associations.*" (HARRER 2/13-15)

Siemsen and Van Dun regard the tensegrity model as useful for osteopathic training.. „If we can explain things on a simple and perhaps superficial level to students, explain to them that this is a possible way, how certain things are, why should we not use this as a model?" (VAN DUN 2/54-56). „*Everybody who trains as osteopath* *should know more about it and should know the basic principles of the models. That is the new and fascinating aspect of tensegrity.*“ (SIEMSEN 4/2-4)

Klein and Sommerfeld think that tensegrity is not suitable for training. „*No.*“ (SOMMERFELD 4/26). Klein also clearly says „no“, however, he explains: „*If tensegrity cannot be used on the macro anatomic level, it cannot be used* (in tensegrity). *We must not describe a model if we don't know how it can be used. If it can be used in the micro anatomic area, perhaps we could use it, but I would not know how.*“ (KLEIN 3/42-44)

7.12. Why does just osteopathy deal with the tensegrity model?

The answers to this question couldn't have been more varied, but I find such questions interesting, as they do not only reflect the tensegrity model but also the general opinions of experts in this connection.

Van Dun believes that the tensegrity model is an attempt for osteopaths to substantiate their principles more or less scientifically. „*It could offer an explanation for the first principle of osteopathy on a more or less scientific level. There has never been such a general model, that supports this first principle on all levels. Therefore, we were always looking for such a model, then a new model falls into your lap and you examine whether you can use it to support the first principle scientifically.*“ (VAN DUN 2/23-28). We are „longing for“ a model that can support the principles of osteopathy as we are often in a position where we have to justify ourselves. „*Because we always have to justify what we do and who we are, it is nice for osteopaths, that a model is on its way that can give an explanation for it..*“ (VAN DUN 3/44-45). At the same time the tensegrity model is a mainly mechanical model and therefore Van Dun thinks it is in the nature of things that mainly osteopaths occupy themselves with it. „*Furthermore, tensegrity is also a* *mechanical model, and we osteopaths work a lot with biomechanics. There are not many professions that occupy themselves with it. Allopaths occupy themselves rather with chemical components and osteopaths still have a mechanical approach*." (VAN DUN 3/45-49)

According to Sommerfeld the osteopaths' occupation with the tensegrity model is a secret search for harmony within biology which goes back to the founding fathers. *„I believe it is a secret search for harmony within biology by osteopathic medicine which is proclaimed profoundly by the work of the founding father: that nature is created by God in a perfect way. And that is a model, in which no shear forces are mentioned, if I examine it purely from a physical point of view, a completely harmonious model. All kinds of tissue have a problem with shear forces, it doesn't matter whether they are bones, connective tissue or a discus, they all have problems with shear forces. The world just isn't all harmony. That is my problem with osteopathy, that one feels an unbelievable need for harmony … also in the approach of problems and how a discussion (a discourse) is held. There are hardly any debates. On some congresses I feel really sick when I listen to all the adulation. But in the background you hear that there are other opinions. A culture of constructive debate is missing in osteopathy. We do not really have discussions, we do not even practice self-criticism. And I think that for me it is a symptom of the lack of a self-critical discussion, which we desperately need*." (SOMMERFELD 4/30-47). Sommerfeld does not understand it as if the tensegrity model could substantiate osteopathy scientifically in any way. *„I think it is rather „playing around", just like quantum physics. Osteopaths have a certain trend to playfulness, which is present in all complementary medical subjects. … I would not classify tensegrity as supportive for the scientific aspect of osteopathy.* " (SOMMERFELD 4/52-57)

According to Georg Harrer it is mainly due to professional policy, why osteopathy is so very interested in models like tensegrity. *„On the one hand I believe that osteopathy is open for new things. Mainly because osteopathy, especially in the German speaking countries, has been taken over by physiotherapists. Meanwhile osteopathy, especially in Germany, is a physiotherapeutical matter. Physiotherapists naturally tend to obey a delusion of advanced* *training, that means, they visit significantly more advanced education than any professional group that I know of. ... They are very keen to collect certificates for advanced education. Medical practitioners have to be allured with buffets, skiing in the afternoon, free flights and points for advanced education, otherwise they will not visit such events. Physiotherapists do this because of their motivation. I think, they do it because they believe that based on their training they should have a higher social status than they actually have in the health system. They think they are inferior and disadvantaged compared to medical practitioners and try to compensate this with more advanced education and more knowledge, but that doesn't work. Therefore, it drives them to delusion but it is of no use, as they do not rise to a higher position in the hierarchy. Therefore, they are much more open to new things and stimulate osteopathy with their advanced education. In America this delusion of advanced training doesn't exist because there osteopaths are medical practitioners. They are called doctor, they have the prestige of a medical practitioner, they wear a white coat and they decide on their treatment themselves. They are relatively content in themselves, do not visit advanced training events and if they visit them, then only to hear what they already know and have that confirmed. For those reasons osteopathy hibernates in America. There are hardly any innovations there in osteopathic medicine. And I think that therefore – through the physiotherapists who have assumed control – changes are very welcome in osteopathy. Tensegrity is just something new but it is not more interesting than other news. There are many other things that are gladly accepted as news."* (HARRER 3/54-61 und 4/1-17)

According to Klein they are only a temporary trend, mainly in the German speaking countries. (KLEIN 4/8-9)

7.13. Forecast – Will the Tensegrity Model find its Place in Osteopathy?

I always asked this question at the end of an interview and carried out the evaluation of this question also at the end. I found it astonishing that none of the experts answered with a strict „No“ or „Yes“.

Although Sommerfeld and Klein regard the model very critically, they do not close the doors on it. *„No, I do not think so, I think it is a trend.“* (SOMMERFELD 5/13). But he differentiates between osteopathy in general and the osteopath as an individual. *„Yes, if it helps an osteopath and he can achieve clinical success with it, perhaps. Then I would say, yes. But I rather observe from the point of view as of a lecturer. I do not think it is something that will bring osteopathic medicine further in any way. But I think it is important to occupy yourself with it, as it is something that influences osteopathy and you ask yourself what the reason is. I think the question "why it is so" is more exciting than the statement that it is so. If we were not talking about tensegrity, it would be something else – just look at quantum physics. But I do not think that these things will have an effect on osteopathy in future.“* (SOMMERFELD 5/20-27) According to Klein today's level of knowledge is relevant. He therefore does not think that the model will be implemented. If, however, there will be studies to confirm the model, it should be implemented everywhere. *„Based on today's knowledge, I do not hope that the model succeeds. If there will be studies to confirm tensegrity, or at least in parts, then of course* (it will find its place). *Then not only in osteopathy and biomechanics, but in the whole of nature. The world does not belong to osteopathy alone.“* (KLEIN 3/58-61)

Siemsen believes there is a firm place for the tensegrity model due to the clarity of Still's principles through the model. *„I think so. Because we can define Still's principles and many other unexplained types of effectiveness in our body with it.“* (SIEMSEN 3/51-52). According to Van Dun it can only keep it's place if one continues to work with the model sensibly. *„Only if osteopaths take the trouble to further their knowledge sensibly on tensegrity, not when it remains on the surface. Then it is of no use ... That applies to amazingly many things in osteopathy. Things are mentioned, they become a highlight for a short time and then they are not expanded. That is a shame. For example the concept of the elasto-collagen complex. It was worked out on the surface in two osteopathic books and then it was not mentioned again or worked on, even though it could have been a mechanical model of the functions of an indirect technique. That is a shame. If the same thing happens to the tensegrity model, then that does not make sense."* (VAN DUN 3/54-55 und 4/3-8)

According to Harrer the tensegrity model will receive it's place in biomechanics. *„I think it will keep it's place in biomechanics and make many things in biomechanics comprehensible. Because biomechanics do not really explain the function of anything. It is a very unsuitable model to describe the perfection of the human body."* (HARRER 5/29-32) Furthermore Harrer has another explanation as to why models like tensegrity will always have their place: *„I think tensegrity is a kind of secret sign, whether you are up to date or not. I have already noticed that. During a conversation, people mention the term (tensegrity) and that is how you check the other person. If he knows it, he is open for new things. If he doesn't – well, forget him. And I think one needs it for that alone, as a kind of secret slogan. Whether tensegrity will remain in this place is not clear, new things will come up. …there are always new things … and that is how you can recognise someone as somebody, who does not „work according to the book" and may have visited the last advanced education twenty years ago, but as someone who is open for new ideas."* (HARRER 5/18-29)

Girardin finally very much hopes that tensegrity will establish itself as a principle, at the same time he fears it as a model. *„On the one hand I hope for this establishment but on the other hand I fear it. I have hope, because it is a physical base principle. I have fears, as it will probably be used to construct phantasy hypothesises, and there are already too many in osteopathic medicine. People have difficulty accepting natural principles as they are, they ARE - no more, but also no less."* (GIRARDIN 4/17-21)

8. Summary

8.1. Summary of Content

Literature analysis in chapter 4 shows that the application of the tensegrity principles on the microscopic level, also in the area of the cytoskeleton and the extra cellular matrix have a scientific basis. Experimental studies give basis for the theory that tensegrity seems to be a useful model for the explanation of mechanical principles of these structures. It therefore appears to be justifiable to discuss these mechanical principles also within osteopathy. All applications however, which exceed these mechanical principles of tensegrity, have difficulties going beyond a model or analogy character. Although the application of such models is approved by the majority of experts, these applications are always subject to a critical discussion. In their opinion, this discussion happens too rarely in osteopathy. They also believe that the tensegrity model is used in osteopathic literature too often without reservation.

The application of the tensegrity principles on a macroscopic level, that means the perception, that the myofascial system as a whole is a tensegrity structure, was not confirmed. No data based on an experimental basis results from literature. This is also reflected in the opinion of the experts, who, by the majority, are opposed to a model for the myofascial or skeletal structures. Therefore, the application of tensegrity in this dimension does not go beyond a didactic model.

The basis for the application of the tensegrity principles in the microanatomic area is formed by the principles established by Buckminster Fuller. It was shown that his geodesic domes were used by Ingber for his models. These domes form a three-dimensional framework structure, the stability of this structure is based on pre-stress of the individual parts. However, each individual element can absorb discontinuous compression, independent of the degree of strain. Snelson's "airy" pre-stressed structures are another type of tensegrity structure. Even though these structures are beautiful, none of the authors mentioned in chapter 4 regard them as a basis for the application in biological systems. It is all the more astounding, that some of the experts interviewed .see the tensegrity model of the cytoskeleton in correspondence with Snelson's sculptures. It is however not surprising, that these are the experts which are critical of this model. Literature analysis, however, showed that that such a perception of this model is not justified. The perception, that a biological tensegrity structure like the cytoskeleton is a mere compression and tension element in an empty space, is certainly wrong. Buckminster Fuller defined clearly that the elements of a tensegrity structure follow geodesic principles and may consist of various kinds of materials, even liquid. And Buckminster Fuller's principles are the only principles which Ingber consults for the model of the cytoskeleton.

8.1.1. Personal Summary

In my opinion, tensegrity is a mechanical natural principle, that is applied in the area of microscopic structures and the examination of hierarchic systems. This approach has helped me personally to deepen my knowledge and my understanding of mechanical principles and functions of biological systems. These systems are the systems I work with as osteopath. I therefore regard the application of these principles on this level as justified also in osteopathy. However, one should always try to increase the understanding of these principles. I personally regard the application of these principles as model for many phenomena in osteopathic medicine critically, as often an attempt is made to simply replace one model with a new one. Therefore, the following two sentences were of personal importance to me during the research:

"After reaching the goal, we integrate the knowledge, we forget it and concentrate again on our real experience. Otherwise we run the risk of adding new dogmas to osteopathy." (Noelmans 2001)

People have difficulty accepting natural principles as they are, they ARE - no more, but also no less." (GIRARDIN 4/17-21)

8.2. Discussion and Criticism of the Expert Interviews

One problem of evaluating the interviews was, that in some points I did not have a statement from all experts, as some points arose during the interview (core statement), or some questions appeared inappropriate during the course of the interview (weaknesses of the model). In retrospect I can conclude that it would have been better to carry out a kind of trial interview to test the existing guidelines and set up rules which are important for the qualitative content analysis. Even though the balancing act between „asking too many questions" and „drifting off too far from the guidelines" succeeded to a very large degree, however it was not always successful.

9. Appendices

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9.3. Abbreviations

CNS	Central nervous system
CRI	Cranial rhythmic impulse
CSF	Cerebrospinal fluid
CSK	Cytoskeleton
CV4	Compression of the 4^{th} ventricle
DNS	Deoxyribonucleic acid
ECM	Extra cellular matrix
EMG	Electromyography
JAOA	Journal of the American Osteopathic Association
MMG	Mechanomyography
PRM	Primary respiratory mechanism

9.4. Tensegrity websites

Buckminster Fuller's Synergetics

Das Originalwerk von Buckminster Fuller - Synergetics - ist auf dieser Website komplett einzusehen: www.rwgrayprojects.com/synergetics/synergetics.html

The Buckminster Fuller Institute

Website über den Vater von Tensegrity und seine Visionen. Mit großem Forum, wo ein reger Austausch stattfindet: www.bfi.org

Kenneth Snelson

Die wohl schönste Website über Tensegrity und die Skulpturen von Kenneth Snelson. Außerdem erfährt man hier alles über seine Arbeit: www.kennethsnelson.net

The Ingber Lab

Donald E. Ingber stellt seine Arbeit über Tensegrity vor. Alle Forschungsarbeiten und Artikel von Ingber und seinem Team werden kostenlos zum Download als PDF bereitgestellt: www.childrenshospital.org/research/ingber

Biotensegrity

Stephen Levin's Website über Biotensegrity und seine Arbeiten über Tensegrity im menschlichen Körper. Alle seine geschriebenen Artikel kann man hier einsehen: www.biotensegrity.com

Intension Designs

Website von Tom Flemons. Er entwickelt Strukturen nach dem Tensegrity Prinzip. Er hat unter anderem das Kinderspielzeug „Skwish" entwickelt: www.intensiondesigns.com

A Fuller Explanation

Amy C. Edmondson hat ein umfassendes Buch über die Visionen und Ideen von Buckminster Fuller geschrieben. Dieses Buch hat den Vorteil, dass es sehr verständlich geschrieben ist. Dieses Buch ist hier komplett im Internet veröffentlicht: www.angelfire.com/mt/marksomers/41.html