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COMMENTARY

Osteopathic decapitation: Why do we consider the head differently from the rest of the body? New perspectives for an evidence-informed osteopathic approach to the head

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Abstract The osteopathic management of the head was initially founded on a biomechanical model which has since proved to be highly controversial. The current call for the evidence-informed practice of osteopathy, and the level of critical reasoning we expect from our students, are no longer compatible with Sutherland's ideas on cranial osteopathy.

Meanwhile, an interesting field has developed called tissue mechanics. This may provide osteopaths with useful evidence to develop a treatment model of the head that fits better with current knowledge. Biomechanics is not limited to kinematics to the human body. It includes tissue mechanics that aims to describe the way living tissues distort under different types of loading. It has been extensively applied to understand the role and development of cranial sutures and the distribution of stresses and strains over the skull.

Even though it is among the hardest materials in the body, bone distorts during normal function and more obviously during trauma. Bone tissues undergo stresses and strains when loaded, like any other material, and cranial bones are no exception to this rule.

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In this article we review the mechanical properties of the cranial bones and sutures and highlight the fact that the muscles are the main cause of cranial bone deflections. Muscle contraction is now recognized to be one of the principal causes of bone loading and this is true for the head: apart from in the case of traumatic events, a large amount of research into the mechanical properties of cranial bones and sutures confirms that muscle contraction is the main cause of skull deflection.

Introduction

The osteopathic approach to the head has for a long time been founded on principles[1] that are now proving highly controversial.[2–4] The current call for the evidence-informed practice of osteopathy[5] and the level of critical reasoning we expect from our students are no longer compatible with Sutherland's cranial model.

Existing questions about the biological basis and the clinical efficacy of the techniques used in Osteopathy in the Cranial Field (OCF) merit deeper investigation[2] but this will not be examined in this paper. Researchers in OCF have mostly attempted to prove Sutherland's intuitions starting from the assumption that they are valid, and seeking evidence to support the way they already practise[6–9] and eventually trying to convince a wider clinical and scientific community of the validity of these concepts. Our purpose is to draw educators' and students' attention to the sound evidence that is already available in the field of biomechanics regarding the mechanical properties of the head. This evidence has the advantage of being largely accepted by the scientific community and provides the osteopathic profession with potentially important avenues of research to develop a treatment model of the head that is consistent with current knowledge (see Fig. 1).

In this article, we suggest and adopt a deductive line of reasoning, beginning by collecting and analysing the existing high-quality, up-to-date evidence on the mechanical properties of the head; that is to say the skull and the surrounding tissues. Our aim is to promote further research by providing information on where to find sound, up-to-date evidence, which is already widely shared and accepted by the scientific community. This is in the hope of informing future models for the osteopathic management of the head in terms of palpation pressures, diagnostic criteria and treatment techniques, which would then require clinical assessment.

A necessary paradigm shift: from biomechanics to tissue mechanics

OCF was born in the 1930s. It is unsurprising that its founders describe it in biomechanical terms;[1,10] biomechanics is suited to the study and description of the complex moments and loads that lead to the movement of bone segments and joints during normal function. Sutherland's reasoning was based on the rigorous study of dry skulls.[11] Even if the rationale leading to hypothesise cranial bone mobility from the suture's shape in the context of patent sutures is valid, as has been demonstrated on animals through the action of the masticatory muscles,[12–14] his assumptions about a hypothetical inherent motility of the central nervous system causing bone deflections are inconsistent with current findings.[3,15] The continuing controversy surrounding Sutherland's model therefore remains justified. Some osteopaths have reacted to the dissatisfaction with the biomechanical model of the skull by substituting a subtler, energetic-based model,[16] but absence of supporting evidence remains an obstacle to teaching and multidisciplinary research.

Meanwhile, the interesting and relevant field of *tissue mechanics* has developed.[17] This may provide osteopaths with useful evidence to develop a model for the management of the head that fits better with current knowledge.

Biomechanics is too often considered as a mere application of kinematics to the human body. It actually also includes the study of how living tissues continually distort and change in response to tissue environment, including the mechanical environment. This sub-field of biomechanics is called tissue mechanics. It is a field that can describe the way the tibia bends during running or jumping,[18] the mechanism behind fatigue fracture,[19–21] intervertebral disc degeneration,[22,23] and the process of bone damage and remodelling.[24,25] Tissue mechanics aims to describe the way living tissues distort under different types of loading.[17,26] In particular, it has been used successfully to understand the role and

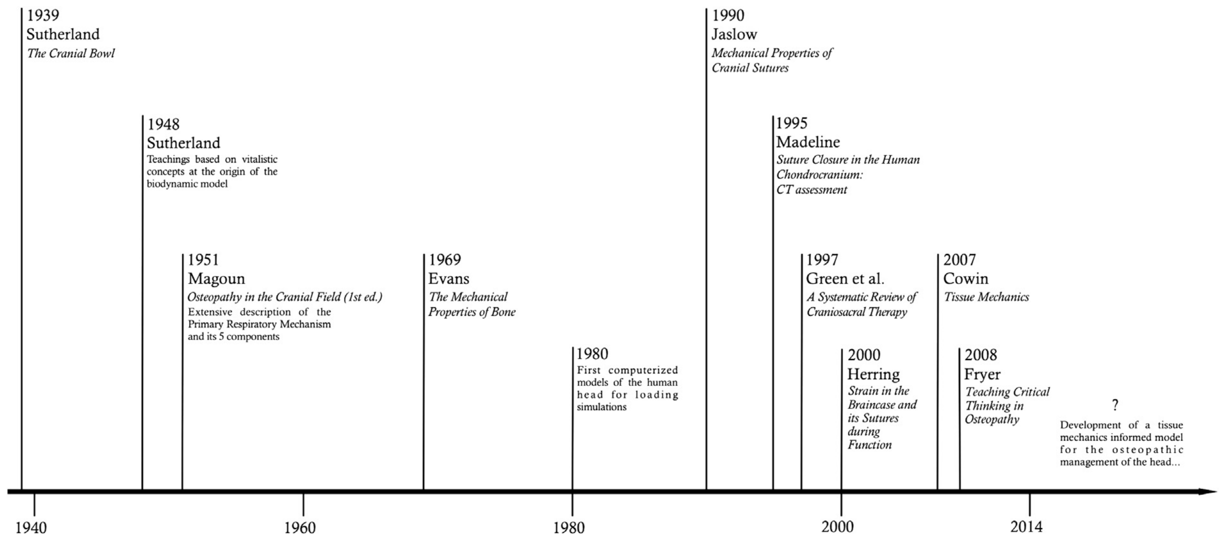

Fig. 1 Chronology of references used in this article that contribute to the understanding of the concepts underlying the management of the head in osteopathy.

development of cranial sutures and the distribution of stresses and strains over the primates' skull.[27–31]

The scope of this article is to outline these findings about the head and to bring them to the attention of students and educators in osteopathy.

Some tissue mechanics basics

When a force is applied to an object prevented from translating or rotating indefinitely, the object distorts (see Fig. 2). Loading an object generates a type of force within it, known as a stress. There are two types of stress: normal stresses (σ), that tend to distract or compress particles in the material; and tangential (τ) or shear stresses that tend to make particles slide over each other. Both are expressed in N/m^2 (or Pa), and represent the way external forces are distributed within the material. When an object distorts, the amount of change in shape and size is termed strain (epsilon, noted ε). The strain reflects how much the object is stretched or compressed and it is expressed as a percentage of the object's initial dimensions. In tissue mechanics where strains are relatively small, strain is usually expressed in millionths of the initial length. Strains are measured as microstrains ($\mu\varepsilon$). 1 microstrain corresponds to a deformation of 0.0001%.

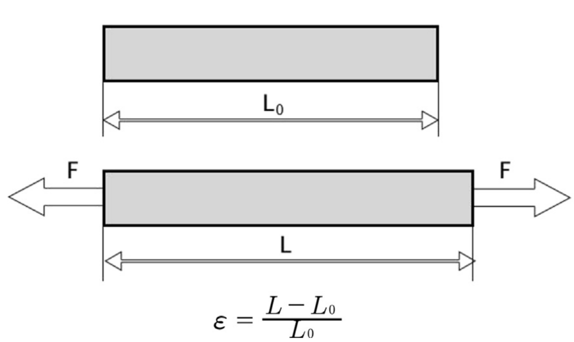

Fig. 2 Tensile testing and strain calculation.

Stresses and strain are not independent. It is easy to assume that the more you load a beam, the greater the stresses will be and the more the beam will distort. When load and distortion are proportional, the relationship between stress and strain is linear and can be written as:

$$\sigma = E \times \varepsilon$$

E is the elastic modulus, expressed in N/m^2 (Pa).

The elastic modulus gives an idea of how stiff a material is; it reflects the material's ability to resist deformation. For example a reasonable value for the elastic modulus of a stiff living tissue like cortical bone in humans is 15,000 MPa.[32,33] This can be more like 50 MPa[34] for more flexible collagenous tissues, like those found in patent cranial sutures.

Cranial bones

Mechanical properties of bony tissue

Understanding the mechanical behaviour of bones and bony tissues has always been a challenging issue, for both biologists and materials scientists.[35] Early research in the field of osseous biomechanics is well illustrated by the work of Evans (1969),[36] who considered bone analogous to pillars and beams. Since then, further research has shown that the mechanical properties of bones, and indeed any living tissue are more complex than initially appreciated.[17,37]

The following list highlights the key mechanical properties of bony tissue:[42]

1. The mechanical behaviour of bone is not linear and may be more accurately described as viscoelastic.[38,39] This means that bone distortion is not proportional to loading intensity, and that its mechanical properties may vary with loading rate.[38,40,41] Some have even refined the model for the mechanical behaviour of bone by taking into account the role of the liquids contained within it (the poroelastic behaviour of bones).[17]
2. Bone is a heterogeneous material, composed of different types of bony tissues, each with different mechanical properties.[39,42]
3. Bone is anisotropic; its mechanical properties are not identical in every direction.[32,38,43]
4. Bone is subject to constant remodelling, is capable of self-healing and possesses different properties at different periods of life.[24,44,45]

Even though it is among the hardest materials in the body, bone distorts during normal function and more obviously during trauma. Bone tissues undergo stresses and strains when loaded, like any other material[18,42–44,46–48] and cranial bones are no exception to this rule.[12,31,33,41,49]

Mechanical properties of cranial bones

Research into the mechanical properties of cranial bones began in the late 1960s. Its initial aim was to understand and prevent head injuries better but also to develop a model of the head that would permit impact and loading simulations.[36,50,51]

Research into the mechanical properties of cranial bones is carried out in two different ways. One consists in drilling out samples from cadaveric cranial bones and then testing their mechanical properties under different types of loading.[50,52] The other consists of measuring in-vivo strains directly to the head. This method is more likely to be of interest to manual practitioners because it provides information on how the whole head reacts to loading, in situations such as during mastication, traumatic events and perhaps even during manual diagnosis and treatment.

In-vivo measurements, mostly on miniature pigs (*sus scrofa*) and primates, show that the skull distorts during mastication whether or not it presents patent sutures.[12,28] The distortion measured in the frontal and parietal bones in miniature pigs during mastication is about 50 $\mu\varepsilon$ (0.005%), which represents a lengthening of about 2.5 μm. Researchers agree that the arrangement and relative size of masticatory muscles and the order of magnitude of bite forces are comparable in pigs and higher primates[12,34,49] and that the geometry and structure of monkey skull, mandible and cervical muscles are closer to those of human beings than other mammals.[37] This means that, though data taken from experiments on miniature pigs may differ from that which would be obtained with humans, the order of magnitude is highly likely to be the same. Currey cites an experiment Hillam conducted on himself during his thesis upon the response of bone to mechanical load.[42] Hillam installed gauges on his skull and recorded bone strains ranging from 100 to 200 $\mu\varepsilon$ during various activities like mastication, smiling and heading a ball. This supports the drawing of comparisons between miniature pigs, primates and humans.

Cranial sutures

The sutures are known to have two major roles: allowing skull growth and improving the head's ability to absorb the energy of impacts.[34,53,54]

Age of suture closure

Sutures play a central role in skull growth and different types of ossification. The way sutures fuse with age depends on whether or not they are in the chondrocranium.

Sutures in the chondrocranium

Sutures in the human chondrocranium fuse progressively during infancy and adolescence, reaching complete fusion once the head is fully-grown. Madeline's study[55] is an exhaustive reference in this field giving the degree of fusion of any given suture of the chondrocranium. Other studies have more recently confirmed Madeline's results.[56,57] Osteopaths cannot legitimately continue to ignore these findings and should at least assume that explanatory models based on suture patency in the skull base can only be applicable to children and at best to young adults.

Sutures of the facial skeleton and the cranial vault

The evolution of sutures in the vault and facial skeleton is quite different from the chondrocranium. Literature in the field of forensic science shows that suture patency in the cranial vault over the age of 50 is usual.[58] Abundant research has been carried out to find out whether the degree of suture closure in the cranial vault could reliably be used to estimate the age of adult cadavers.[58,59]

Mechanical properties of cranial sutures

The mechanical properties of the cranial sutures have been extensively explored in many species over the last 30 years[12,53,60,61] revealing the following properties:

- Sutures play an important role during skull growth.[12,62]
- Mastication alternately tenses and compresses the cranial sutures, through the action of masticatory muscles. This phenomenon, better known as mechanotransduction, activates the cells contained in the sutures and contributes to the normal development of the cranial bones.[62,63]
- Sutures are known to increase the head's ability to absorb the energy from an impact.[34,54] This is in part because cranial sutures are less stiff than adjacent bones[12]; cranial sutures undergo strains 10 times greater (c. 500 $\mu\varepsilon$) than adjacent bone (c. 50 $\mu\varepsilon$).[12]
- Controversy remains about how much the sutures affect the distribution of stresses and strains over the skull under normal loading. The latest research appears to show that sutures have a negligible effect on the overall distribution of stresses and strains over the skull but that this may become more significant over a smaller area of the skull.[27,34]

The bone movements hypothesized in OCF suppose some degree of suture patency, but as discussed this condition is not always true over a full lifetime. Suture closure is a complex and gradual process as bony spicules appear well before complete suture fusion.[55] Any model based on suture patency would be limited to the period preceding the first stages of suture closure. Future models need to take into account sutures' specific mechanical properties and should also include the intermediate period of suture closure and the period following complete suture fusion.

Cranial muscles

Muscle contraction is now recognized to be one of the principal causes of bone loading[42,44,64,65] and this is true for the head. A large amount of research into the mechanical properties of cranial bones and sutures confirms that muscle contraction is a cause of skull deflection.[14,30,49,60,65,66]

Sutherland's cranial model makes little reference to the action of muscles. This is possibly because he analysed dry bones, as was the practice in other early osteopathic models. Sutherland hypothesised amongst other things that the skull deflects under the action of an inherent motility of the central nervous system and cerebrospinal fluid fluctuation. High-quality research on skull deflections and the distribution of stresses and strains over the head has, however, been successfully carried out for more than forty years without needing to take such hypotheses into account.

Any evidence-informed model for the management of the head in osteopathy should take into account all structures having the ability to transmit loads and motion to the head.

Conclusion

Existing research in the field of tissue mechanics is a potentially interesting source of evidence to inform the next model for the osteopathic management of the head. This may also lead osteopaths to reconsider whether a specific model for the head for diagnosis and treatment is necessary, or whether a model applicable to the whole body would be better.

The key points of this commentary are:

- cranial bones distort during normal function and more obviously during trauma
- the cranial muscles are the principal cause of skull deflection other than in traumatic events
- Sutures may affect the way the head distorts but the head will still distort if they are fused.

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