



Cupping: From a biomechanical perspective

L.M. Tham^a, H.P. Lee^{a,b,*}, C. Lu^a

^a*Institute of High Performance Computing, 1 Science Park Road, #01-01 The Capricorn, Singapore Science Park II, Singapore 117528, Singapore*

^b*Department of Mechanical Engineering, National University of Singapore, 9 Engineering Drive 1, Singapore 117576, Singapore*

Accepted 29 June 2005

Abstract

The effectiveness of the cupping technique, a treatment modality in Traditional Chinese Medicine, in stimulating acupuncture points for pain relief was examined in this paper from a biomechanical perspective. Parametric studies including the effects of vacuum pressure, loading rate, friction coefficient at the cup–skin interface, and size and shape of the cup were carried out using a model based on the finite-element method. The anatomical structures of skin, fat, and muscle were modelled. All the soft-tissue layers were assumed to be nonlinearly elastic and viscoelastic. The rim of the cup was also modelled to study the interaction between cup and skin; the cup rim was assumed to be rigid. The simulation results showed that the stresses in the soft tissue were increased for increasing applied vacuum pressures and that the effects of cupping were mostly limited to the region enclosed by the cup. The simulations also indicated that the magnitude of the applied vacuum may have had direct implications for the severity of bruising of the skin following cupping treatment. Most significantly, the simulation results contradicted the established practice of cup size selection according to the depth of the disorder. Experimental verification of the proposed multi-layered finite-element model is presented. The nature of the bruising inherent to the cupping treatment is also explained by the proposed model.

© 2005 Elsevier Ltd. All rights reserved.

Keywords: Cupping; Acupuncture; Finite-element model; Soft-tissue mechanics; Mechanical testing

1. Introduction

In Traditional Chinese Medicine (TCM), cupping is a method of treatment that involves the application of a vacuum to a localized area of the skin (see Fig. 1) (Xue and O'Brien, 2003; Yoo and Tausk, 2004). Practitioners of TCM believe that diseases are caused by stagnant or blocked *Qi*, the vital energy or life force, and that cupping is able to unblock and correct imbalances in the flow of *Qi*, thereby restoring health (Stux and Pomeranz, 1998). In East Asia, cupping is a popular alternative therapy for a variety of ailments (Cheng, 1990; Xue and

O'Brien, 2003; Yoo and Tausk, 2004). It is mainly prescribed as a treatment for chronic pain, but is also indicated for a whole array of respiratory, gastroenterological, and gynaecological disorders.

It is also not uncommon for TCM practitioners to apply cupping to acupuncture points or acupoints. In classical acupuncture, very thin, solid, metallic needles are inserted and manipulated at precisely defined locations on the body chosen according to TCM theory (Kaptchuk, 2002; Xue and O'Brien, 2003). However, by employing the cupping method, cups and suction are used to move and balance *Qi* instead of needles. By dispensing with needles, the skin no longer needs to be punctured, thereby avoiding many of the risks associated with acupuncture. These include infections such as viral hepatitis, bacterial infections at the site of needle insertion, and other blood-borne diseases (Tait et al., 2002).

*Corresponding author. Institute of High Performance Computing, 1 Science Park Road, #01-01 The Capricorn, Singapore Science Park II, Singapore 117528, Singapore. Tel.: +65 6419 1303; fax: +65 6419 1480.

E-mail address: hplee@ihpc.a-star.edu.sg (H.P. Lee).



Fig. 1. Cupping performed on the broad area of the back; courtesy of Ms. Anita Shannon, Massage Cupping for Healthcare and Spa Practitioners, www.massagecupping.com.

While very promising results have recently emerged, for example, in the acupuncture treatment of post-operative and chemotherapy induced nausea and vomiting and post-operative dental pain, chronic pain is so far the only scientifically acceptable use of acupuncture (Pomeranz, 2001; Stux and Pomeranz, 1998). Of all the hypotheses proposed to-date to explain the pain-abating effects of acupuncture or acupuncture analgesia (AA) in scientific terms, the neural mechanism theory is the most comprehensive (Pomeranz, 2001). According to this theory, AA is initiated by the stimulation of the small diameter nerves in muscles, which then send impulses to the spinal cord. The three neural centres, namely, the spinal cord, the mid-brain, and the pituitary are subsequently activated and release transmitter chemicals, such as endorphins and monoamines, which block the pain messages.

Cupping is traditionally performed using a small round cup made of thick glass with a rolled rim to ensure uniform and air-tight contact with the skin in order to preserve the vacuum (Kravetz, 2004). The negative pressure is created by heating the air within the cup and then allowing it to cool and contract while in contact with the skin. The air is heated either by swabbing the interior of the cup with alcohol and then setting it aflame, or by igniting an alcohol-soaked cotton ball or other flammable material held inside the cup (King and Davis, 1983; Kouskousis and Leider, 1983; Kravetz, 2004; Look and Look, 1997). Just before the flame is extinguished, the mouth of the cup is positioned firmly against the skin at the desired location. The suctioning effect produced by the vacuum anchors the cup on to the skin and draws it upwards into the cup. Nowadays, cupping is increasingly carried out with plastic cups and a manual hand-pump to create the vacuum. The most common sites on which the cups are applied are the back, chest, abdomen, and buttock;

areas of abundant muscle (Yoo and Tausk, 2004). The cups are typically left in place for 5, 10, or more minutes. The after-effects of cupping often include erythema, edema, and ecchymoses in a characteristic circular arrangement. These bruises may take several days to several weeks to subside (Manber and Kanzler, 1996; Xue and O'Brien, 2003; Yoo and Tausk, 2004).

The use of alternative or complementary therapies is becoming increasingly widespread (Eisenberg et al., 1993). Of these therapies, acupuncture is one of the best-known and accepted treatment modalities. This is undoubtedly a result of the wide indication of its therapeutic properties, simplicity of application, low cost, and rapid results from the treatment of certain disorders (Yong et al., 1999). In this connection, it is worth exploring the use of cups and suction instead of needles in acupuncture treatment because of the reduced risks. Our study is based on the hypothesis that the cupping technique is effective in stimulating acupuncture points for pain relief. This means that a cup of a certain diameter that possesses an appropriately rounded rim within which a sufficiently large vacuum is developed can be used in place of needles for stimulating acupoints to relieve pain, with or without the application of a lubricant. In this paper, the efficacy of cups and suction in stimulating acupoints for administering acupuncture analgesia was studied from a biomechanical perspective. As a result of its long history, a number of practices and beliefs have become entrenched in the application of cupping, and which may have little or no scientific basis. These practices and beliefs were also investigated with a view to confirming or dispelling them. This study was concluded with recommendations for improving the application of cupping. Experimental verification of the numerical technique used in this investigation is presented. The nature of the bruising inherent to the cupping treatment is also explained.

2. Methods

2.1. The finite-element model

The mechanical response of the soft tissue when cupped was analysed using a multi-layered axi-symmetric finite-element (FE) model as shown in Fig. 2. The soft tissue was assumed to be composed of a layer of skin (representing the epidermis, stratum corneum, and dermis), subcutaneous tissue (fat), and muscle. The skin, fat, and muscle were assigned thicknesses of 2, 10, and 10 mm, respectively, which were assumed to approximate the thicknesses of the soft-tissue layers found on the broad area of the back of a human subject. These thicknesses were obtained from a study on soft-tissue modeling from 3D scanned data (Nebel, 2000) and

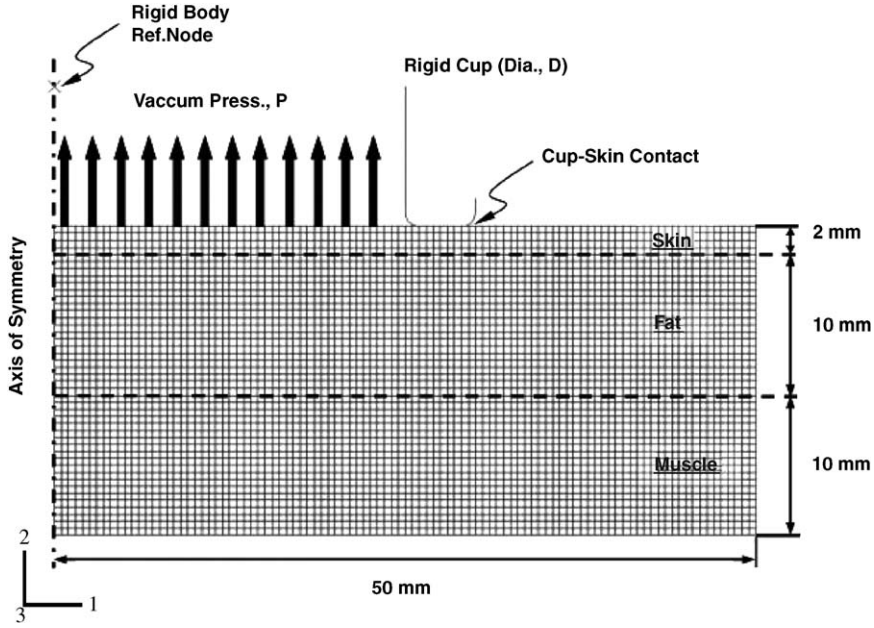


Fig. 2. Axisymmetric finite element model of the cupping of soft tissue. The soft tissue is composed of skin, fat, and muscle. All three soft tissue layers were assumed to be nonlinearly elastic and linearly viscoelastic. The suction force was applied to the surface of the skin on the area enclosed by the cup. Only a portion of the cup was modelled (rim and part of the side-wall) and it was assumed to be rigid.

correspond to those in the shoulder region of an adult male. The bonds between the various layers of the soft tissue were considered to be perfect, i.e., separation and tangential sliding were not permitted. The FE analyses were carried out using a commercial finite-element software package (ABAQUS, version 6.4). Only a portion of the cup in contact with the skin was modelled (rim and part of the side-wall). It was created using analytical surfaces and was regarded as rigid. It demarcates the area over which the vacuum pressure was applied. The cup–skin contact was modelled using a “contact pair”, which is an option in ABAQUS. This FE model of the soft tissue contained 4400 axisymmetric 4-noded elements (Element type: CAX4R).

The model is composed of nonlinearly elastic and linearly viscoelastic soft-tissue layers; the total tissue stress (Cauchy stress) was assumed to comprise an elastic stress component, representing the instantaneous tissue response, and a viscous stress component, representing the time-delayed tissue response. The material models and parameters for the different layers of the soft tissue used in the present investigation were obtained from published experimental data. The nonlinear elasticity of the skin, fat, and muscle were modelled using the Polynomial, Mooney-Rivlin, and Ogden strain-energy functions, respectively. The material parameters for the skin were obtained from a recent study on the effects of hydration and experimental length scale on the mechanical response of human skin subjected to suction (Hendriks et al., 2004); $C_{10} = 29.6$ kPa and $C_{11} = 493$ kPa. The form of the poly-

nomial strain-energy potential used to describe the skin is given below (ABAQUS Analysis User’s Manual, version 6.4):

$$U = \sum_{i+j=1}^N C_{ij} (\bar{I}_1 - 3)^i (\bar{I}_2 - 3)^j + \sum_{i=1}^N \frac{1}{D_i} (J^{\text{el}} - 1)^{2i}, \quad (1)$$

where U is the strain energy per unit of reference volume; N , C_{ij} , and D_i are material parameters; \bar{I}_1 and \bar{I}_2 are the first- and second-deviatoric strain invariants, respectively; J^{el} is the elastic volume ratio. The materials properties of the subcutaneous tissue were obtained through a numerical-experimental technique employing indentation and the finite-element method (Hendriks et al., 2000); $C_{10} = 1.7$ kPa. The form of the Mooney-Rivlin strain energy potential used to describe the subcutaneous tissue is given below (ABAQUS Analysis User’s Manual, version 6.4):

$$U = C_{10} (\bar{I}_1 - 3) + C_{01} (\bar{I}_2 - 3) + \frac{1}{D_1} (J^{\text{el}} - 1)^2, \quad (2)$$

where U is the strain energy per unit of reference volume; C_{10} , C_{01} , and D_1 are the material parameters, \bar{I}_1 and \bar{I}_2 are the first- and second-deviatoric strain invariants, respectively; J^{el} is the elastic volume ratio. In the absence of material data for human skeletal muscle, we used data from the in-vivo experiments on the transverse properties of rat skeletal muscle (Bosboom et al., 2001); $\mu_1 = 15.6$ kPa and $\alpha_1 = 21.4$. The form of the Ogden strain energy potential used to describe the muscle is as follows (ABAQUS Analysis

User's Manual, version 6.4):

$$U = \sum_{i=1}^N \frac{2\mu_i}{\alpha_i^2} (\bar{\lambda}_1^{\alpha_i} + \bar{\lambda}_2^{\alpha_i} + \bar{\lambda}_3^{\alpha_i} - 3) + \sum_{i=1}^N \frac{1}{D_i} (J^{\text{el}} - 1)^{2i}, \quad (3)$$

where $\bar{\lambda}_i$ are the deviatoric principal stretches $\bar{\lambda}_i = J^{-1/3} \lambda_i$; λ_i are the principal stretches; N , μ_i , α_i , and D_i are the material parameters. The material parameters obtained from animal studies were used on the assumption that the parameters for these tissues are at least within an order of magnitude of the corresponding human tissues (Oomens et al., 2003).

The viscous behaviour of the soft-tissue layers was simulated using the stress-relaxation function based on the Prony series. In a study to simulate the mechanical responses of a fingertip to dynamic loading by Wu et al. (2002), the skin and fat layers were considered to make up a single soft-tissue layer. They employed a two-term Prony series with the following material parameters: \bar{g}_i^P ($i = 1, 2$) = 0.1480 and 0.2520; and τ_i^G ($i = 1, 2$) = 2.123 and 9.371 s. The Prony series expansion of the stress relaxation function $g_R(t)$ is given below (ABAQUS Analysis User's Manual, version 6.4):

$$g_R(t) = 1 - \sum_{i=1}^N \bar{g}_i^P (1 - e^{-t/\tau_i^G}), \quad (4)$$

where N , \bar{g}_i^P , τ_i^G , and $i = 1, 2, \dots, N$, are material constants. In the published works from which the viscoelastic material parameters were obtained, it was assumed that the stress-relaxation behaviour in volumetric deformation is identical to that in the shear deformation. As in the case of the muscle-elastic properties, the muscle viscoelastic material parameters used were those determined from the rat-skeletal muscle (Bosboom et al., 2001); $\bar{g}_1^P = 0.549$ and $\tau_1^G = 6.01$ s.

2.2. Numerical simulations

To demonstrate the effectiveness of the proposed multi-layered FE model, the experimentally measured skin deflection profile was compared to that predicted by our model. Subsequently, a series of cupping tests was carried out to study the dynamic response of the soft-tissue layers to variations in: (1) the vacuum pressure level, (2) the loading speed, (3) the friction coefficient at the interface between cup and skin, and (4) the cup size and shape. In all of the tests, the vacuum pressure was applied in a ramp-like manner as shown in Fig. 3. The skin and underlying soft tissue is drawn into and against the rigid cup, which is fixed in both the horizontal and vertical directions. The vertical edges of the soft-tissue model were constrained horizontally. The nodes on the bottom edge of the model were tied to the node on the lower left corner of the model; this was accomplished using TIE MPC in ABAQUS. No other

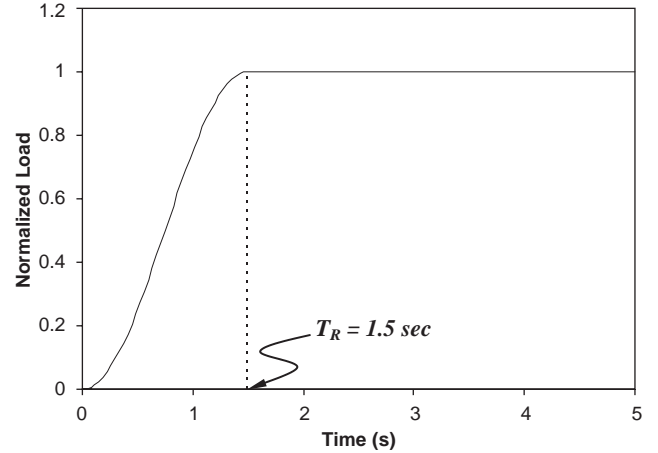


Fig. 3. The prescribed normalized load vs. time (s) curve for the application of the vacuum pressure (Note ramping period, $T_R = 1.5$ s).

boundary conditions were assumed in the simulations. The vacuum load was maintained for the duration of the simulation run of 5 s. The FE analyses were carried out to compute the stress levels developed within the soft-tissue layers. Owing to the large deformations of the soft-tissue layers under the highly localized loading, a finite-deformation analysis was employed in the present study. It should be noted that the suction pressure was applied to the surface of the skin enclosed initially by the cup for the entire duration of the simulation.

2.3. Experimental verification

In order to demonstrate the validity of the finite-element model proposed in the present study, the deflection profile of the skin (obtained experimentally) when cupped was compared to that predicted by our model. In the experiments, skin on the inside of the forearm of a male Chinese subject in the 35–40 year age range was subjected to two vacuum pressure loadings applied using a manual hand-pump. The experiments were conducted by gently pressing a cup of diameter 44.8 mm against the skin to ensure a good initial contact and then activating the hand-pump to create the vacuum inside the cup so that the skin is drawn into the cup. The bulging of the skin as a result of cupping is shown in Fig. 4; the images were captured using an HP Photosmart r607 digital camera and correspond to one and two pumps of the manual hand-pump. Assuming that the soft tissue is isotropic and homogeneous, the deformed tissue can be completely described by the profile when viewed directly from the side. The profiles of the deformed skin within the cup were extracted from the captured digital images and plotted in Fig. 5.

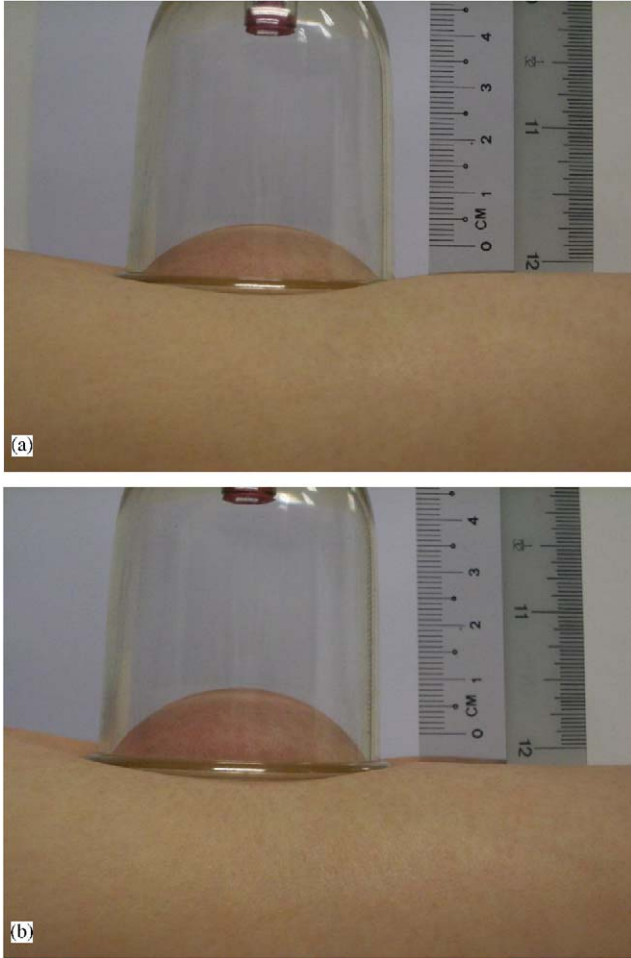


Fig. 4. Images showing the bulging of the skin during cupping; the images correspond to (a) one pump (vacuum pressure, $p = 141$ mbar) and (b) two pumps (vacuum pressure, $p = 254$ mbar) of the manual hand-pump.

The vacuum pressures developed inside the cup were calculated using Boyle's Law:

$$P_i V_i = P_f V_f, \quad (5)$$

where the subscripts i and f refer to the initial (before pumping) and final (after pumping) states, and the measured volumes of the cup (80.0 ml) and pumping chamber (41.5 ml) in the hand-pump, and by assuming that the hand-pump has a pumping efficiency of about 60–65 percent. The vacuum pressures corresponding to one and two pumps of the manual hand-pump were estimated to be about 141 and 254 mbar, respectively. These pressure values were used as input data to generate the simulated skin deflection profiles, which are also plotted in Fig. 5 for comparison purposes. Fig. 5 shows that the calculated deflection profiles are a very good fit to the experimental data points at both the vacuum pressure levels applied. This demonstrates that the proposed multi-layered finite-element model is

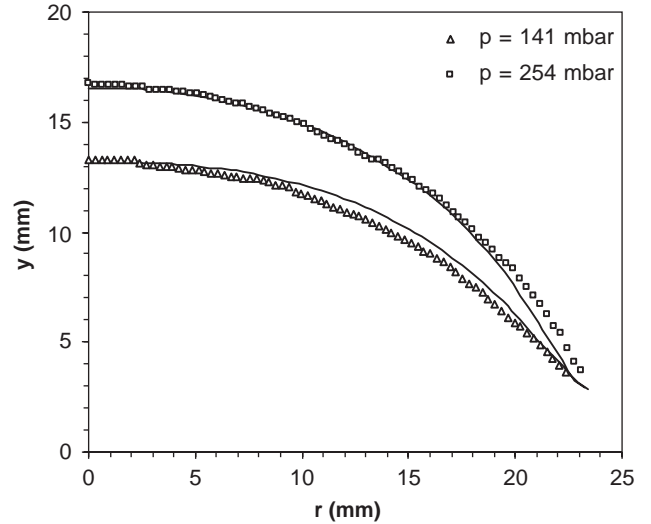


Fig. 5. Experimentally measured and simulated deflection profiles at two vacuum pressure levels. The solid lines represent the FEM simulations and the symbols represent the experimental data (Δ and \square denote the skin deflection profiles at 141 and 254 mbar, respectively).

adequate for describing the deformation behavior of human soft tissue when subjected to the cupping treatment.

3. Results

3.1. Effect of vacuum pressure

The predicted distribution of the normal stress in the vertical direction, σ_{22} (MPa), for a moderate vacuum pressure of 300 mbar is depicted in Fig. 6. It reveals that the soft tissue enclosed by the cup and that at the periphery of the model are in tension, while the soft tissue directly under the rim of the cup is in compression. The tensile stresses appear to be larger in a bulb-shaped region under the centre of the cup. This region extends to the muscle layer and at its widest point is about 0.4 times the diameter of the area over which the vacuum is applied. Fig. 6 also shows that the entire thickness of the skin under the cup is similarly stressed. However, the tensile stresses are a maximum in a very small region of the skin layer adjacent to and just inside of the rim of the cup. This is probably a result of the stretching of the skin as it and the underlying soft-tissue layers are drawn into the cup by the applied vacuum. The region directly under the rim of the cup, on the other hand, is in compression owing to the indentation of the soft tissue by the cup. The stresses here appear to be concentrated under the curved portions of the cup rim. We should note that the stresses in the soft tissue around and under the rim of the cup are about an order

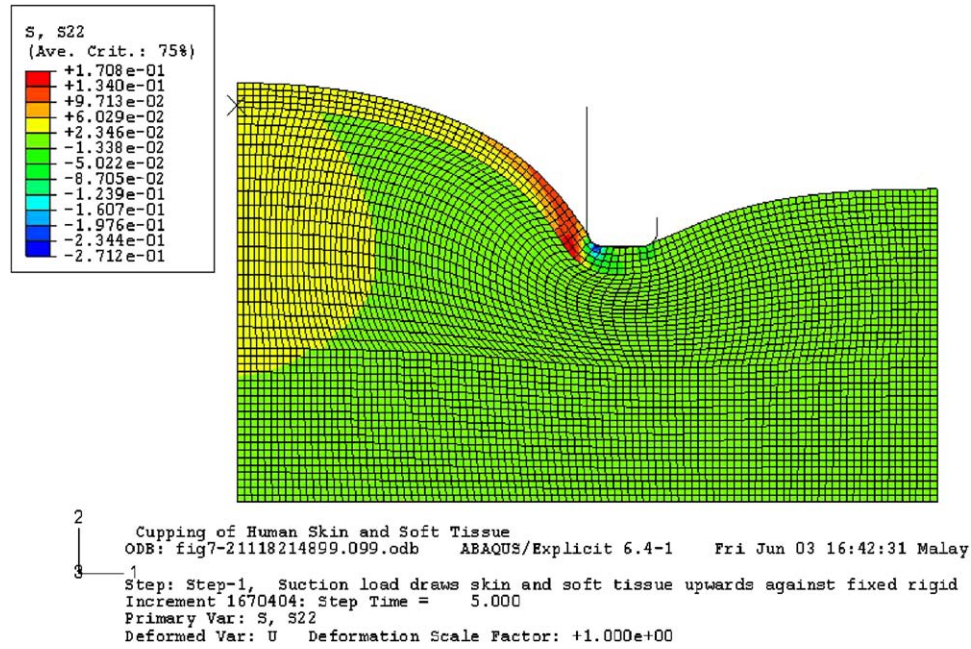


Fig. 6. Predicted distribution of the normal stress in the vertical direction, σ_{22} (MPa), in the soft-tissue layers at time, $t = 5$ s (simulation parameters: cup diameter = 50 mm, cup rim fillet radii = 1 mm, vacuum pressure = 300 mbar, ramping period = 1.5 s, friction coefficient = 0.5).

of magnitude larger than the applied vacuum pressure. These stresses and their consequences on cupping will be further discussed in Sections 3.4 and 4.

We should bear in mind that while unequivocal scientific data to prove the existence of acupoints is still lacking, a growing body of experimental work has over the years pointed to specific locations along certain nerve fibres as prime candidates for acupoints. In a report described by Pomeranz (2001), 80 percent of acupoints in a human cadaver were found to coincide with perforations in the superficial fascia, through which nerve vessel bundles penetrate (the superficial fascia refers to the surface of a flat band of tissue below the skin that encloses the muscle tissue and separates it from the other layers of tissue). In yet another experimental study described by Pomeranz (2001), intramuscular injections of procaine (a local anesthetic) in humans were found to abolish acupuncture analgesia (AA), whereas subcutaneous injections of the same anesthetic did not. Therefore, in order to evaluate the effectiveness of the different cupping parameters in stimulating the acupoints to produce pain relief, we chose to focus on the stresses at the interface between the fat and muscle layers.

The predicted normal stress levels, σ_{22} , are plotted in Fig. 7 for typical low, moderate, and high-vacuum pressures of 100, 300, and 500 mbar, respectively (1000 mbar = 0.1 MPa). For this set of numerical simulations, a cup of diameter, $D = 50$ mm was used. The results reported were for time, $t = 5$ s, where time was measured from the instant the vacuum load was first

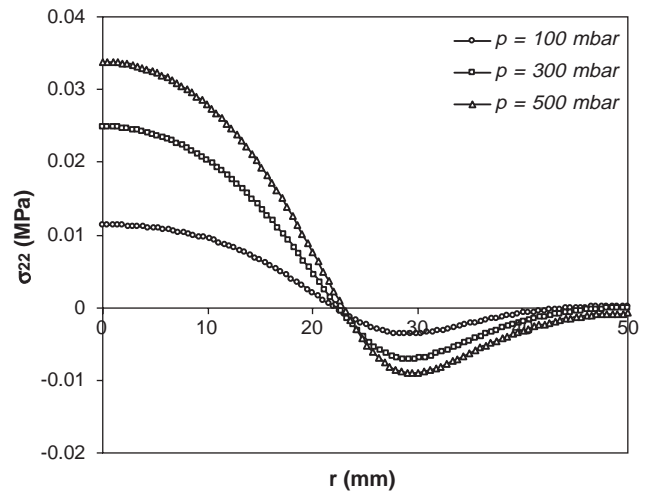


Fig. 7. Predicted normal stress, σ_{22} , for the different applied vacuum pressures, p , at the interface between the fat and muscle layers at time $t = 5$ s (simulation parameters: cup diameter = 50 mm, cup rim fillet radii = 1 mm, ramping period = 1.5 s; friction coefficient = 0.5).

applied (refer to the figure caption for all the parameters used in the numerical simulation). The results of Fig. 7 clearly show that the tensile stresses at the centre of the cup ($r = 0$ mm) and the compressive stresses just beyond the rim of the cup ($r \geq 25$ mm) are increased for increasing vacuum pressure loads. For the vacuum pressures applied, the results also show that the effect of cupping does not extend beyond the area enclosed by the cup; at twice the cup diameter ($r = 50$ mm), the stresses at the fat–muscle interface are negligible.

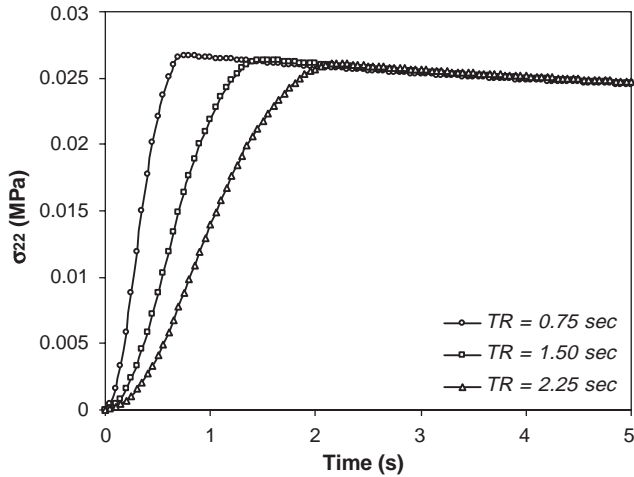


Fig. 8. Predicted normal stress, σ_{22} , vs. time response for the different ramping periods, T_R , at a point within the muscle layer which is adjacent to the fat–muscle interface and located along the axis of symmetry (simulation parameters: cup diameter = 50 mm, cup rim fillet radii = 1 mm, vacuum pressure = 300 mbar, friction coefficient = 0.5).

3.2. Effect of loading rate

The previous simulations were carried out using a loading rate described by a ramping period, T_R , of 1.5 s (Fig. 3). In order to investigate the effect of the loading rate, a vacuum pressure of 300 mbar was applied for two other ramping periods ($T_R = 0.75$ and 2.25 s). Fig. 8 illustrates the normal stress versus time response of a point within the muscle layer, adjacent to the fat–muscle interface, and located along the axis of symmetry of the model. As expected, the maximum stress is reached more quickly for the shorter ramping periods. The results also show that the stress levels decrease with time irrespective of the ramping periods. In fact, after time $t = 2.25$ s, all three predicted stress levels coincide with identical rates of decrease.

3.3. Effect of friction coefficient at cup–skin interface

Fig. 9 illustrates the simulation results for the different coefficients of friction, μ , between the rim of the cup and the surface of the skin. Three friction coefficients were considered to simulate conditions ranging from free sliding to the absence of sliding; this condition was simulated by specifying the “rough” parameter in the “friction” option in ABAQUS. This range of friction coefficients is believed to be typical of conditions arising during the cupping treatment. The results show that the stresses developed at the interface between the fat and muscle layers are not very sensitive to changes in the coefficient of friction. However, the tensile stress for the case where the skin and the rim of

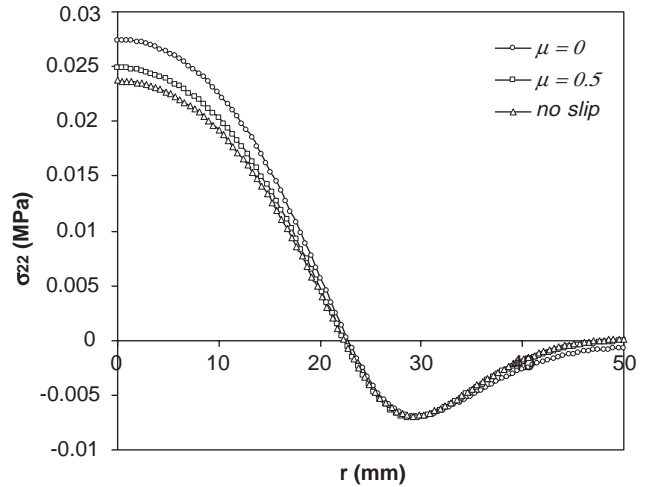


Fig. 9. Predicted normal stress, σ_{22} , for the different friction coefficients, μ , at the interface between the fat and muscle layers at time, $t = 5$ s (simulation parameters: cup diameter = 50 mm, cup rim fillet radii = 1 mm, ramping period = 1.5 s, vacuum pressure = 300 mbar).

the cup slide freely past one another is the highest by a very small margin over the area enclosed by the cup.

3.4. Effects of cup size and shape

The normal stresses developed at increasing depths within the soft-tissue layers for cups of different diameters are depicted in Fig. 10. The stresses were computed for cups of diameters 35, 50, and 65 mm at the mid-thickness of the fat layer, the interface between the fat and muscle layers, and mid-thickness and base of the muscle layer. In all of the simulations, a constant vacuum pressure of 300 mbar was maintained. From Fig. 10, we see that at any of the four depths considered, the normal stress is a maximum for the largest cup and a minimum for the smallest along the axis passing through the centre of the cup ($r = 0$ mm). In addition, for increasing depths, measured from the surface of the skin, the normal stress induced by cupping is progressively reduced for all the three cup sizes.

As described earlier in Section 3.1, the indenting of the skin by the rim of the cup affects the soft tissue in a much more localized manner. The largest tensile and compressive stresses appear to be restricted to the skin layer only and in the regions directly below and immediately inside of the cup rim. This is very clearly illustrated in Fig. 11, which is a magnification of the region of the soft tissue under the cup rim and shown previously in Fig. 6. Accordingly, in analysing the effect of the shape of the cup, we focused on the stress levels at mid-thickness of the skin layer only.

The results presented for the effect of the cup shape (Fig. 12) show that the peak tensile stress and the two

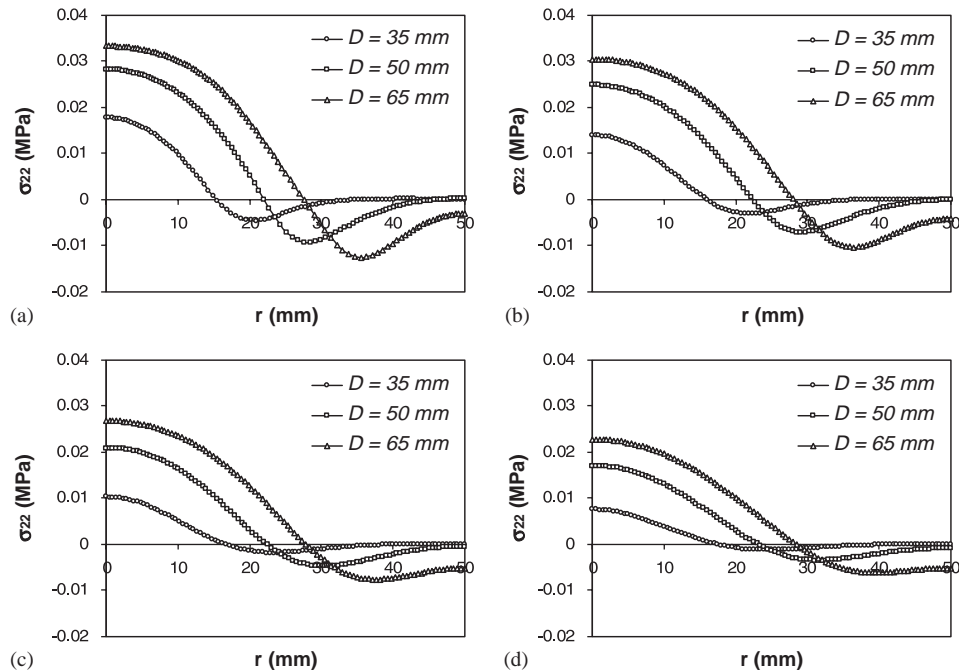


Fig. 10. Predicted normal stress, σ_{22} , for the different cup diameters, D , at (a) the mid-thickness of the fat layer, (b) the fat–muscle interface, (c) the mid-thickness of the muscle layer, and (d) the base of the muscle layer at time, $t = 5$ s (simulation parameters: cup rim fillet radii = 1 mm, ramping period = 1.5 s, vacuum pressure = 300 mbar, friction coefficient = 0.5).

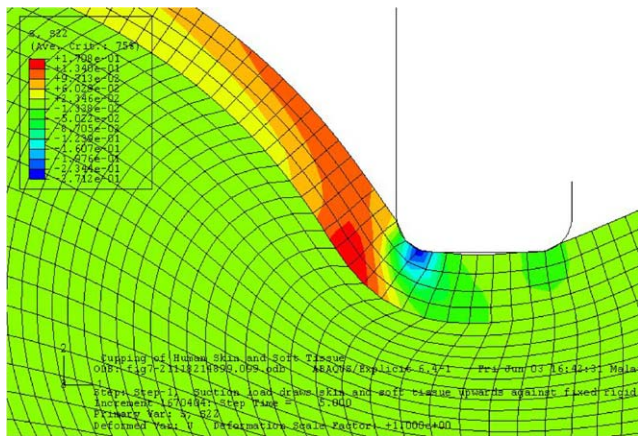


Fig. 11. Predicted distribution of the normal stress in the vertical direction, σ_{22} (MPa), in the skin layer at time, $t = 5$ s (simulation parameters: cup diameter = 50 mm, cup rim fillet radii = 1 mm, vacuum pressure = 300 mbar, ramping period = 1.5 s, friction coefficient = 0.5).

peak-compressive stresses correspond to the regions immediately inside of and directly below the curved portions of the cup rim, respectively, as seen previously in Fig. 11. As expected, the cup with the sharpest rim (fillet radii, $r_f = 0.5$ and 1.0 mm), gives rise to the highest compressive stress. However, the roundness of the cup rim does not seem to affect the peak tensile stress.

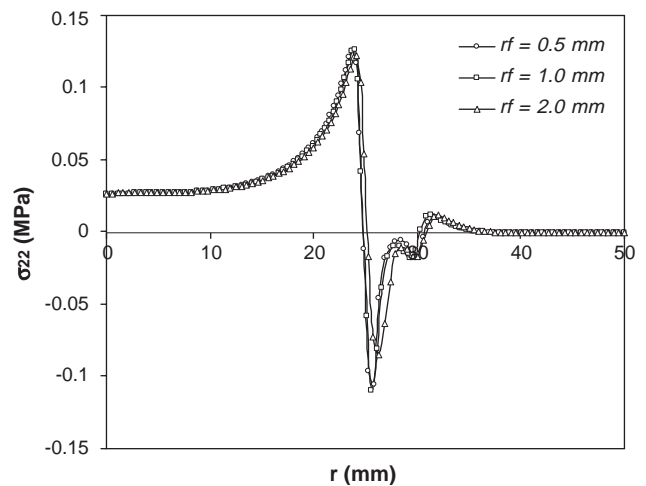


Fig. 12. Predicted normal stress, σ_{22} , for the different fillet radii, r_f , at the rim of the cup at mid-thickness of the skin layer at time, $t = 5$ s (simulation parameters: cup diameter = 50 mm, ramping period = 1.5 s, vacuum pressure = 300 mbar, friction coefficient = 0.5).

4. Discussion

The therapeutic applications of cupping have been very well documented as a result of several thousand years of clinical experience. It is purported to be beneficial in the treatment of a whole array of disorders, a few of which have been alluded to earlier. Various theories have been put forward to explain its workings.

In one of these theories, it was reasoned that cupping increases the circulation around the area being treated and enables toxins trapped deep in the soft-tissue layers to be brought to the body surface (Look and Look, 1997; Kouskoukis and Leider, 1983; Yoo and Tausk, 2004). When combined with a technique called “blood-letting”, which involves piercing the skin, cupping has the effect of drawing out the toxins together with blood (Xue and O’Brien, 2003). It is, however, important to note that according to the American Cancer Society no clinical studies have been carried out on cupping to-date and that there is no scientific evidence to show that cupping can cure cancer or any other disease or even lead to any health benefits. And reports of successful treatment by cupping are purely anecdotal.

Cupping, on the other hand, is known to be an effective alternative to needles in stimulating acupoints in acupuncture treatment. One of the major advantages must be that the transmission of blood-borne diseases can be avoided since skin is not penetrated. Acupuncture is, nowadays, used more often to control certain types of pain than in the treatment of illnesses. The American Cancer Society notes that acupuncture can help control chemotherapy-related nausea and vomiting and ease cancer pain. In fact, in the country of its origin (China), acupuncture is used instead of drug or gas anesthesia during surgical operations and major dental work. Accordingly, the goal of this study was to investigate the efficacy of cups and suction in stimulating acupoints for administering acupuncture analgesia.

Researchers in the field of acupuncture have since the early 1970s noted the essential correlation between analgesia and the sensation referred to as *De Qi* (Pomeranz, 2001). This sensation of numbness, fullness, and sometimes soreness is felt when the acupoints are properly stimulated. In classical acupuncture, when *De Qi* is achieved, the acupuncturist would sometimes also feel a “grabbing” motion of the needle by the muscle. This has perhaps the greatest implication for cupping performed using plastic cups that employ a manual hand-pump to create the vacuum. The pressure can be increased incrementally until the *De Qi* sensation is achieved. When glass cups are used, under-pressurising the cup will not produce the required analgesic effect. Over-pressurising the cup, on the other hand, would cause unnecessary discomfort to the patient. In either case, repeated applications will probably be necessary to achieve the *De Qi* sensation. Changes in the ramping period would also seem to be more applicable when a manual hand-pump is used to create the vacuum in the plastic cups. The differential increase in the stresses in the soft-tissue layers is small for the shorter-ramping periods and this effect is also transient owing to the relaxation of the stresses in the soft-tissue layers. And as the affected region within the soft-tissue layers produced by cupping is quite localized (see the bulb-shaped region

in Fig. 6), it should be possible with an appropriate vacuum pressure level to stimulate individual acupuncture points. This is critical in acupuncture because different acupoints are stimulated to relieve pain and discomfort in different parts of the body. In this investigation, a maximum vacuum pressure of 500 mbar was simulated. While actual vacuum pressure measurements are not available from published experimental data, it has been speculated that much less than one atmosphere of vacuum pressure is achievable when glass cups are used (Kouskoukis and Leider, 1983).

The cups typically used in cupping treatment have diameters in the range of about 38 mm (1.5 in.) to 50.8 mm (2 in.) (Kravetz, 2004). As our simulation results reveal (Fig. 10), a small cup may be unable to exert the force required to stimulate an acupoint. For a fixed vacuum pressure, a larger cup is able to exert a higher stress at the interface between the fat and muscle layers. These results are consistent with the experimental data reported by Hendriks et al. (2004) from a study of the mechanical behaviour of skin using a suction device with different aperture diameters. Their data clearly show that increasing the aperture diameter on the suction device leads to larger skin–surface displacements. This results in correspondingly larger uplifts at the different tissue layers and larger stresses at those layers. Our results therefore suggest that the cup used should be as large as the anatomical area for which treatment is sought can accommodate.

Our results also demonstrate that for increasing depths within the soft-tissue layers, the normal stresses induced by cupping are progressively reduced for all three cup sizes considered (Fig. 10). This result contradicts the guidelines proposed by an ancient Greek physician named Hippocrates for administering cupping (Turk and Allen, 1983). To the ancient Greeks, cupping was also indicated for a wide array of disorders. They used it to diminish headaches, restore appetite, improve digestion, draw “matter” to the surface, etc. While the theory behind the Greek version of cupping is different from that of TCM, both versions appear to be identical from a biomechanical perspective. Hippocrates recommended that for disorders that are deep-seated, the cup used should have a small diameter. And for a disorder that is close to the surface, the cup used should be wide. As pointed out previously, for effective suctioning of the soft tissue at different depths, our results indicate that as large a cup that the anatomical area can accommodate should be used.

The consequences of the cupping treatment, mentioned briefly in Sections 3.1 and 3.4, are a direct result of the stresses developed within the skin layer. The skin has a very rich blood supply (Gawkroder, 2002). Arteries in the subcutaneous tissue layer branch upwards across the thickness of the dermal layer to form a superficial plexus (or network) very close to the skin surface (at the papillary-reticular dermal

boundary). The existence of high tensile stresses in the skin layer just inside the cup rim (see Fig. 11) and in the central region enclosed by the cup (see Fig. 6) is believed to be the primary cause of ecchymosis, a discolouration of the skin caused by the escape of blood into the tissue from ruptured blood vessels. This is a characteristic feature of the cupping treatment and takes the form of a circular lesion (see Fig. 13). This lesion may take several days to several weeks to subside. The tensile stresses are believed to cause severe dilation of the capillaries and lead to their rupture. Because the tensile stresses are comparatively higher in the region just inside the cup rim, the rupture of the capillaries are expected to be more widespread there. And as more blood accumulates in the spaces within the tissues at this location, the skin should take on a deeper red colour, which exactly corresponds to what is observed in Fig. 13; reddish central regions of the lesions circumscribed by even redder borders. Although the stress levels in the skin are even higher directly under the rim of the cup, these stresses are compressive and are not expected to cause the capillaries to rupture. Because there is no leakage of blood, skin colour under the rim should not be altered. As expected, an examination of Fig. 13 reveals that the colour of the skin in the area indented by the rim of the cup is no different from that of the surrounding skin outside of the cup; the indented area is clearly demarcated by the residual impression of the cup rim on the skin. Although the details of the cupping



Fig. 13. Consequences of cupping (Manber and Kanzler, 1996); courtesy of Helen Manber, M.D., and Matthew Kanzler, M.D., Stanford University Hospital, Palo Alto, California.

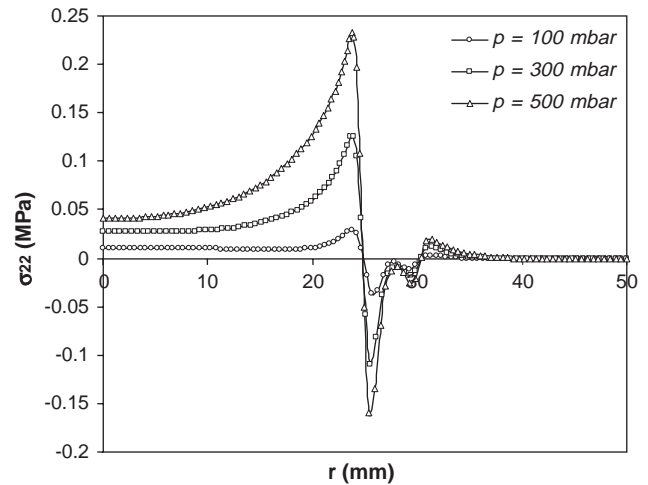


Fig. 14. Predicted normal stress, σ_{22} , for the different applied vacuum pressures, p , at mid-thickness of the skin layer at time, $t = 5$ s (simulation parameters: cup diameter = 50 mm; cup rim fillet radii = 1 mm; ramping period = 1.5 s; friction coefficient = 0.5).

treatment were probably unavailable to Manber and Kanzler (1996), we can quite safely assume that a range of vacuum pressures was applied. The normal stress levels at mid-thickness of the skin layer for the different applied vacuum pressure loads (Fig. 14) show that the peak tensile stresses just inside the rim of the cup are substantially higher for higher suction loads. This can perhaps explain, in part, the varying degrees of redness of the bruising observed in Fig. 13; the different tensile stress magnitudes cause varying incidences of blood vessel rupture and varying amounts of leakage of blood into the surrounding tissues.

While the degree of roundness of the cup rim (Fig. 12) is not expected to cause bruising as discussed earlier, the larger compressive stresses associated with a sharper rim (i.e., smaller fillet radii) are expected to cause more pain or discomfort to the patient. A cup with a more rounded rim should therefore be used. Such a rounded rim is commonly referred to as a rolled rim or rolled edge (Kravetz, 2004).

In a type of cupping treatment, known as gliding cupping, a lubricant is spread on the surface of the skin before the cup is applied (Xue and O'Brien, 2003). While the reduced friction between the rim of the cup and the skin surface increases the stress levels only very slightly as shown by the simulated results (Fig. 9), the primary purpose is to allow the cup to be moved or dragged smoothly over the skin surface while the skin is being suctioned. Here, cupping is used as a form of massage.

5. Conclusions

The computed trends in the stresses developed in the soft-tissue layers as functions of the different cupping

parameters considered have allowed us to better understand, at the qualitative level at least, the mechanics of the cupping treatment and some of its entrenched practices. The following conclusions were drawn from the present study.

1. The proposed multi-layered finite element model is effective in describing the behaviour of the skin and underlying soft-tissue layers when subjected to cupping.
2. Achieving the *De Qi* sensation and, hence acupuncture analgesia, would seem to be easier using the plastic cup with a manual hand-pump.
3. Cupping should be capable of stimulating individual acupuncture points.
4. The cups employed should preferably be as large as the anatomical surface to be treated can accommodate.
5. Cupping for acupuncture analgesia can be performed without the application of a lubricant.
6. The nature of the bruising inherent to the cupping treatment can be explained by the proposed multi-layered finite-element model.

Acknowledgements

TLM would like to thank Dr. S.S.J. Quek, Mr. C.Y. Tham, and Mr. A. Malik for their help with the experimental portion of the investigation.

References

- ABAQUS Analysis User's Manual, volume III: materials, version 6.4., Hibbitt, Karlsson, and Sorensen, Inc., Pawtucket, USA
- Bosboom, E.M.H., Hesselink, M.K.C., Oomens, C.W.J., Bouten, C.V.C., Drost, M.R., Baaijens, F.P.T., 2001. Passive transverse mechanical properties of skeletal muscle under in vivo compression. *Journal of Biomechanics* 34, 1365–1368.
- Cheng, X., 1990. *Chinese Acupuncture and Moxibustion*. Foreign Languages Press, Beijing, China, pp. 339–347.
- Eisenberg, D.M., Kessler, R.C., Foster, C., Norlock, F.E., Calkins, D.R., Delbanco, T.L., 1993. Unconventional medicine in the United States—prevalence, costs, and patterns of use. *New England Journal of Medicine* 328, 246–252.
- Gawkrodger, D.J., 2002. *Dermatology: An Illustrated Colour Text*, third ed. Churchill Livingstone, Edinburgh, UK.
- Hendriks, F.M., Brokken, D., Oomens, C.W.J., Baaijens, F.T.P., Horsten, J.B.A.M., 2000. Mechanical Properties of Different Layers of Human Skin. Internal Poster (<http://yp.bmt.tue.nl/pdfs/249.pdf>), Department of Biomedical Engineering, Eindhoven University of Technology.
- Hendriks, F.M., Brokken, D., Oomens, C.W.J., Baaijens, F.T.P., 2004. Influence of hydration and experimental length scale on the mechanical response of human skin in vivo, using optical coherence tomography. *Skin Research and Technology* 10, 231–241.
- Kapchuk, T.J., 2002. Acupuncture: theory, efficacy, and practice. *Annals of Internal Medicine* 136, 374–383.
- King, D.F., Davis, M.W., 1983. Cupping: an erstwhile common modality of therapy. *Journal of the American Academy of Dermatology* 8, 563.
- Kouskoukis, C.E., Leider, M., 1983. Cupping: the art and the value. *The American Journal of Dermatopathology* 5, 235–239.
- Kravetz, R.E., 2004. Cupping glass. *The American Journal of Gastroenterology* 99, 1418.
- Look, K.M., Look, R.M., 1997. Skin scraping, cupping, and moxibustion that may mimic physical abuse. *Journal of Forensic Sciences* 42, 103–105.
- Manber, H., Kanzler, M., 1996. Consequences of cupping. *The New England Journal of Medicine* 335, 1281.
- Nebel, J.-C., 2000. Soft Tissue Modelling From 3D Scanned Data. In: *Proceedings of Deform 2000*. Nebel, J.-C., 2001. Soft tissue modelling from 3D scanned data. In: Magnenat-Thalmann, N., Thalmann, D. (Eds.), *Deformable Avatars*. Kluwer, Dordrecht, pp. 85–97.
- Oomens, C.W.J., Bressers, O.F.J.T., Bosboom, E.M.H., Bouten, C.V.C., Bader, D.L., 2003. Can loaded interface characteristics influence strain distributions in muscle adjacent to bony prominences? *Computer Methods in Biomechanics and Biomedical Engineering* 6, 171–180.
- Pomeranz, B., 2001. Acupuncture analgesia—basic research. In: Stux, G., Hammerschlag, R. (Eds.), *Clinical Acupuncture: Scientific Basis*. Springer, Heidelberg, Germany, pp. 1–28.
- Stux, G., Pomeranz, B., 1998. *Basics of acupuncture*, fourth revised ed. Springer, Heidelberg, Germany.
- Tait, P.L., Brooks, L., Harstall, C., 2002. *Acupuncture: Evidence from Systematic Reviews and Meta-analyses*. HTA 27: Series A—Health Technology Assessment. Alberta Heritage Foundation for Medical Research, AB, Canada.
- Turk, J.L., Allen, E., 1983. Bleeding and cupping. *Annals of the Royal College of Surgeons of England* 65, 128–131.
- Wu, J.Z., Dong, R.G., Rakheja, S., Schopper, A.W., 2002. Simulation of mechanical responses of fingertip to dynamic loading. *Medical Engineering & Physics* 24, 253–264.
- Xue, C.C., O'Brien, K.A., 2003. Modalities of Chinese medicine. In: Leung, P.-C., Xue, C.C., Cheng, Y.-C. (Eds.), *A Comprehensive Guide to Chinese Medicine*. World Scientific, Singapore, pp. 19–46.
- Yong, D., Lim, S.H., Zhao, C.X., Cui, S.L., Zhang, L., Lee, T.L., 1999. Acupuncture treatment at Ang Mo Kio Community Hospital. A Report on Our Initial Experience 40, 260–264.
- Yoo, S.S., Tausk, F., 2004. Cupping: east meets west. *International Journal of Dermatology* 42, 664–665.