EXPERIMENTAL METHODS FOR CLINICAL PRACTICE

Optimal Choice of Vacuum-Membrane Skeletal Muscle Extension

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Peculiarities of skin extension under vacuum applicators (nozzles) of various design was studied in 20 volunteers aged 18-25 years. The data obtained made it possible to chose optimal parameters of elastic membranes of the vacuum cups that produce stretch sufficient for vacuum-membrane skeletal muscle extension with minimal traumatic damage to the skin. Local negative pressure varied from 10 to 70 kPa. It was found that for 4.5-cm applicator with one 1.4-2.0-cm central orifice the optimal thickness of the membrane is 0.3 cm.

Key Words: *vacuum applicator; muscle; skeleton; extension*

Local negative pressure (LNP) and mechanotherapy such as extension therapy are now widely used for correction of intervertebral disk pathology and for improving physical endurance. Extension therapy is a very old therapeutic method. It can be applied both by manual maneuvers and with the help of special apparatuses. According to the mode of application of the traction forces, this therapy can be subdivided into joint-muscular, skeletal, and muscular-skeletal extension [8].

A specific feature of joint-muscular extension is the fact that the traction facilities are attached to various parts of the body with a belt or loops. Extension is carried out in a single plane in water or air [7]. During skeletal extension, the strainers are fixed to a bone, so extension can be made in all planes. The joint-muscular extension is performed in the transversal and/or longitudinal-transverse directions by gripping the joints of extremity muscles that are connected with vertebra or bones. Gripping and extension is performed with a vacuum sucker (applicator). The applicator is equipped with perforated elastic membrane and placed onto skin area adjacent to the muscle. Displacement of membrane is zero at the rim, and it increases to the maximum value at the center. Displacement of the membrane is accompanied with shifts of skin, subcutaneous fat, and the muscle, which transfers the traction force to joints and bones [1-3,8].

LNP is widely used for the treatment various diseases: neuralgia, plexites, arthrites, spine osteochondrosis, *etc*. It is applied as baromassage with the help of pressure chamber, vacuum massage (VM), and vacuum-membrane massage (VMM). The latter is performed with an applicator equipped with elastic membrane having a pinhole necessary to suck skin to the membrane during rarefaction [4,5].

By contrast to VM applicators, the applicators for vacuum-membrane muscular-skeletal extension (VMMSE) have a membrane. They differ from VMM applicators in the diameter of the hole. At present, it is unclear what properties and design of the applicator membrane are optimal.

Applicators for VMMSE were constructed on the basis of applicators with planar seal, which do not disturb blood flow in major vessels even during high LNP, preserve the positive effects of LNP, and widely expanse the use of this method.

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Our aim was to study changes in the length of skin area under vacuum applicators of various designs to find the optimal parameters of elastic membrane, which make it possible to develop composite membrane—tissue system during VMMSE that produces minimal damage to the skin, and also to obtain the formulas for calculating of the degree of skin extension under applicators of various designs.

MATERIALS AND METHODS

The study was carried out on 20 healthy male volunteers aging 18-25 years. The original applicators had the membranes made of rubber 9024 of various thickness (0.1-0.6 cm) with a round orifice of different diameters (0.2-2.5 cm). Tissue elevation produced by LNP (10-70 kPa) was measured with the help of specially designed "elevation meter" [1]. Negative pressure was produced in applicator by vacuum massager "Elektronika VM-01". The degree of skin extension (an increase in the length of skin patch under applicator) was calculated after the measurement of tissue elevation.

To obtain the formulas for calculation of the degree of skin extension under membrane-free applicator (Fig. 1, *a*) or applicator equipped with elastic membrane (Fig. 1, *b*, *c*), we proceeded from the following assumptions. When a pressure difference is applied across a shell (skin), it would assume the spherical shape of minimal surface. Therefore, the radial cross-sections of this sphere will be the circular arcs. Three points on the circular arc under applicator are known: the ends of applicator diameter and elevation of tissues (in an applicator without membrane) or membrane with tissues (in the membrane-type applicator). Three points of a circular arc determine the entire arc, so one can calculate the necessary geometrical parameters.

The arc length L_1 of skin area sucked into an applicator (either without membrane or with stretched elastic membrane) was calculated by the formula:

$$L_1=\sqrt{D_0^2+4h_1^2},$$

where D_0 is diameter of applicator base and h_1 is elevation of skin or membrane.

The arc length L_3 of entire skin area under applicator supplied with membrane having a central orifice was calculated by the formula:

$$L_3=\frac{(D_0-d_0)\sqrt{(D_0+d_0)^2+4h_1^2}+d_0\sqrt{(D_0+d_0)^2+8h_1^2}}{(D_0-d_0)},$$

where d_0 is diameter of the orifice in the membrane; h is elevation of skin area that is sucked above the membrane orifice (it is measured from the base of applicator).

During VM, VMM, and VMMSE the procedure was as follows. Membrane-free vacuum applicator or applicator supplied with perforated elastic membrane was attached to the skin, and negative pressure was applied by pumping out the air (Fig. 1).

The data were processed statistically using Student's t test and correlation analysis.

RESULTS

Equal negative pressures produce a greater stretch of the skin in VM membrane-free applicator (Fig. 2, curve *1*) than in VMM applicators equipped with elastic membranes of various thickness (0.1, 0.3, and 0.5 cm, Fig. 2). When negative pressure was smaller than 30 kPa, the stretch of the skin was similar in applicators with thin (0.1-0.2 cm) and thick (0.3-0.6 cm) elastic membranes. However, at higher values of negative pressure (up to 70 kPa) the skin stretch in thick-membrane applicators was smaller than in thin-membrane devices. This feature results from the fact that thicker membrane has greater resistance to extension, and this resistance is summed with skin resistance to stretch.

Specifically, at negative pressures of 40 and 70 kPa, skin stretch in the applicators with 0.1-0.2-cm membranes is larger than that in the applicators with 0.3-cm membrane by 15.7% and 21%, correspondingly. However, skin stretch was similar for the membranes with thickness ranging from 0.3 to 0.6 cm. Correlation between skin stretch and negative pressure in membrane-free applicator was 0.943, while in applicators with the membranes of various thickness perforated with an orifice (d=0.2 cm) it was 0.940-0.997.

Therefore, one should purposefully select the thickness of the membrane in applicators designed for VMM and VMMSE.

Since equal negative pressures stretch the skin to practically the same value in applicators equipped with membrane of 0.3-0.6 cm in thickness, further study of dependence of skin extension on membrane orifice diameter was carried out with elastic membranes with the thickness of 0.3 cm.

The stretch of the skin placed under the membrane applicator with a small membrane pinhole (d=0.2 cm) is smaller than that under membrane-free applicator at any equal LNP ranging from 10 to 70 kPa (Table 1). Using applicators with a single central orifice 1.0-2.5 cm in diameter, we revealed an important property: in applicator with mem-

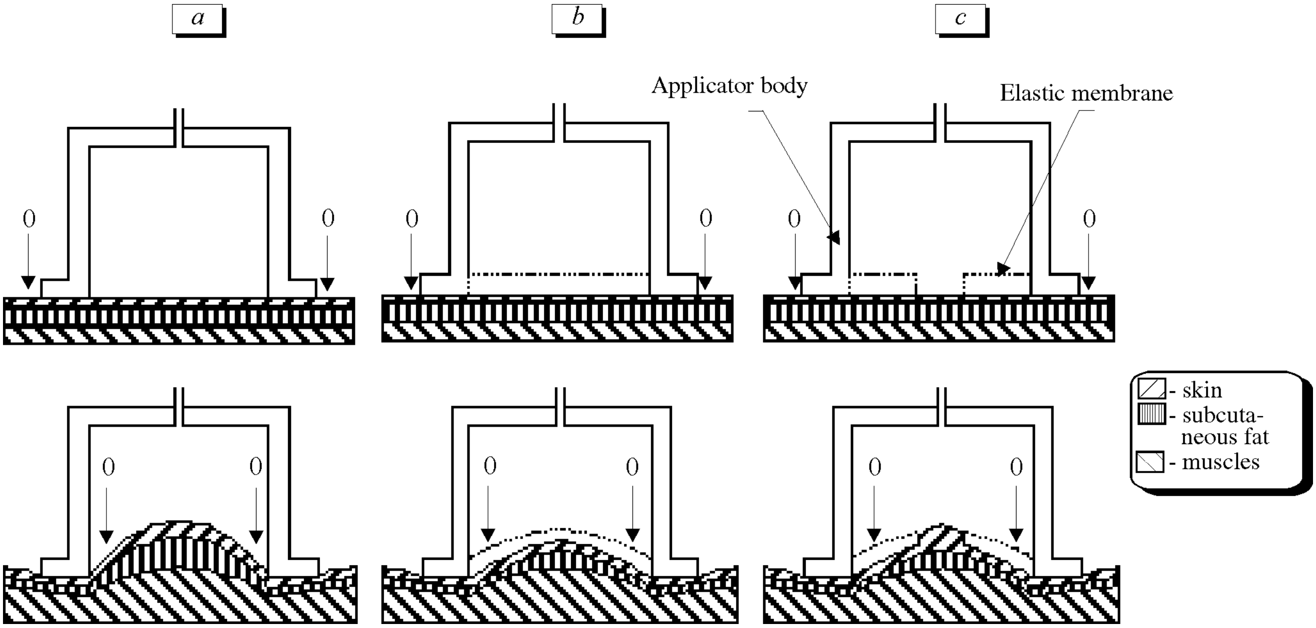

Fig. 1. Interaction of biological tissues with applicators of various design. *a*) membrane-free applicator, *b*) applicator with a membrane perforated by a pinhole, *c*) applicator with a membrane perforated by a large orifice. Initial state without negative pressure in applicator is shown at the top, and the effect of negative pressure (5-10 kPa) is demonstrated at the bottom.

brane orifice 1.0 cm in diameter, the skin stretch produced by LNP in the range of 20-70 kPa is progressively smaller in comparison with that in a membrane-free applicator. The same regularity was observed in the applicators with d=1.4 cm and d=2.0 cm starting from LNP of 30 and 40 kPa, respectively. When the orifice diameter was 2.5 cm, skin stretch was higher for all examined values of LNP.

Thus, this experimental series revealed a strict dependence between skin stretch in applicator with

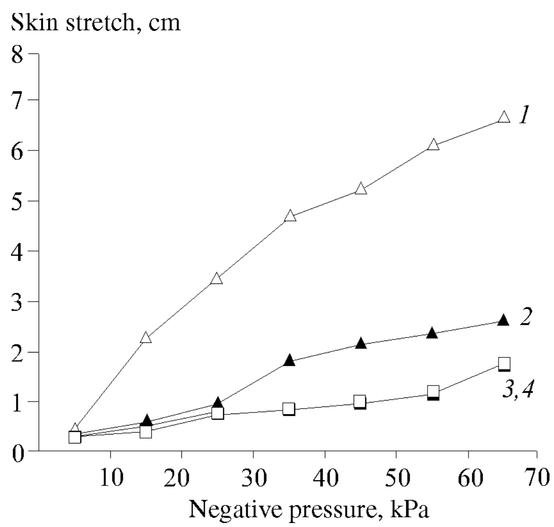

Fig. 2. Skin stretch at various levels of negative pressure in membrane-free vacuum massage applicator (*1*) and in applicator for vacuum-membrane massage with the membranes perforated by a pinhole (d=0.2 cm). The thickness of membrane was 0.1 (*2*), 0.3 (*3*), and 0.5 cm (*4*).

elastic membrane and the diameter of membrane orifice.

It is noteworthy that freely moving skin can penetrate into membrane orifice, fix in it, and even protrude through the membrane like a bud (Fig. 3, *b*, *c*). When LNP grows, the soft tissues protruding through the orifice and closely adjacent skin under the membrane are subjected to independent extension. The tissues contacting the membrane are stretched to the same degree as the membrane, while the tissues fixed in the orifice and above it are subjected to the same stretch as those in membrane-free applicator of the corresponding size. Therefore, the total stretch of the skin in the applicator is the sum of these two stretches. The revealed regularities in the effect of LNP made it possible to develop a new variant of VMM (the vacuum membrane-composite massage) and VMMSE based on it [1-3,8].

It is important that skin, subcutaneous fat, and muscles are sucked into membrane orifice even when initial LNP of 5-10 kPa is applied to seal the internal chamber of applicator. During fixation, an integrate multilayer composite is formed, which is made of membrane, skin, subcutaneous fat, and the muscles. Further increase in LNP stretches this composite set as a single object, and it is possible to change the range of the stretching forces both in the value and direction by varying LNP. Changes in the properties of elastic membrane can be produced by varying its geometrical parameters: thick-

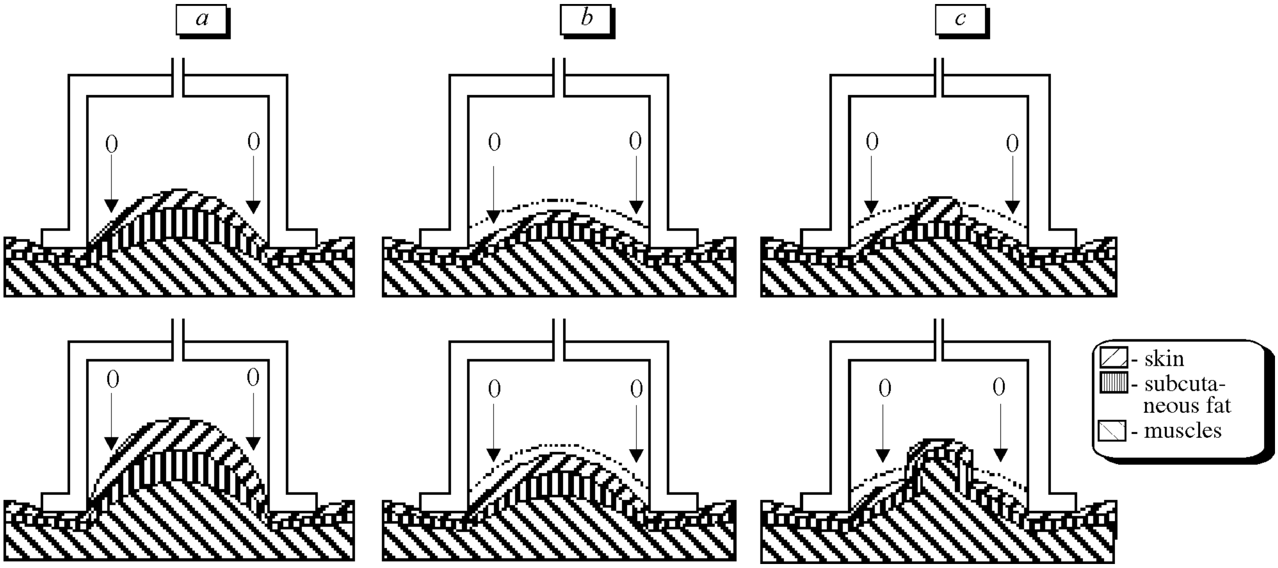

Fig. 3. Interaction of biological tissues with applicators and peculiarities of skin extension during vacuum massage (*a*), vacuum-membrane massage (*b*), and vacuum-membrane muscular-skeletal extension (*c*) performed by negative pressure of 5-10 kPa (the upper panels) and 50 kPa (the lower panels).

ness, the diameter of orifices, and the pitch of orifice array.

Thus, VMMSE should be carried out with elastic 0.3-0.6-cm thick membranes with a 1.4-2.0-cm central orifice. Smaller orifices does not ensure tight membrane-skin-subcutaneous fat-muscle composite, while membranes with larger holes (>2.5 cm) stretch the skin pronouncedly and may produce great damage to it during VMMSE.

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