

Original Article

A universal skin stretcher inspired by a wheel and a hypothesis for large wound closure

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Abstract: Existing skin stretchers merely allow the skin expansion in the opposite directions. This study was designed to present and evaluate a modified skin stretcher (the universal skin stretcher) that enabled the skin expansion in any direction in a controlled way. Four types of the universal skin stretcher were assembled and employed on the wound of a bama pig at the suction pressure of -20 KPa. The stability of the device was assessed on a piece of wounded pig skin at different suction pressures (-20 KPa, -25 KPa, -30 KPa, -35 KPa, and -40 KPa respectively). The primary outcome measures: the weight it withstands in the horizontal direction (W_h) and the vertical direction (W_v). It was observed that any part of the universal skin stretcher can be cut and assembled into different sizes easily. At the suction pressure of -20 KPa, all four types of the universal skin stretcher can be installed on anywhere of the wounds by negative pressure. Both the W_h and W_v increased with either the suction pressures or sizes of the universal skin stretcher. The results show that the universal skin stretcher can be used easily and withstand satisfactory weight that is deemed to be relatively safe for skin expansion.

Keywords: External expansion, skin stretcher, negative pressure wound therapy, wound closure

Introduction

Large wounds pose many challenges to the reconstructive and orthopedic surgeon. These injuries are often contaminated and, are associated with bones and tendons exposure. Conventional methods such as wide undermining, split thickness skin grafting, artificial dermal template, local, distant or free flaps are now frequently used [1]. Numerous undesirable aspects of these tissue coverage techniques exist, including the technically more demanding, requirement for repeated application, graft failure, etc [2, 3]. Negative Pressure Wound Therapy (NPWT) has been widely used in many surgical fields [4-9]. The standard NPWT consists of a piece of foam, a large transparent plastic adhesive film, and an evacuation tube with side ports. When used, it appears that the device is fixed on the skin by negative pressure rather than the adhesive film itself.

First described in the 1970s by Barrer S [10], skin stretchers have also been used in more and more surgical fields because of ease of use, and the safety. Remarkable and unexpected

outcomes of skin stretchers have been reported by surgeons of general surgery [11], plastic surgery [12], orthopedic surgery [13], burn surgery [14], etc. Compared with the internal skin expansion, it has been regarded as a kind of "sure closure". Skin stretchers are designed according to the principle of viscoelastic properties of skin, known as mechanical creep and stress relaxation, which have been well described. The mechanical creep is originally defined as "skin that is stretched by a constant force will elongate beyond normal state within a short time", similarly, the stress relaxation was originally defined as "skin that is stretched to a constant distance will elongate with time and lead to a decrease in the tension across it" [15, 16]. It is also reported that the stretching force of no more than 30 N on the skin margins is relatively safe [17, 18]. However, using existing skin stretchers, the wound margins are unable to be stretched to any direction in a controlled way. It appears that this limitation might be well overcome through installing a fix point that withstands no more than 30 N on anywhere of the wounds itself.

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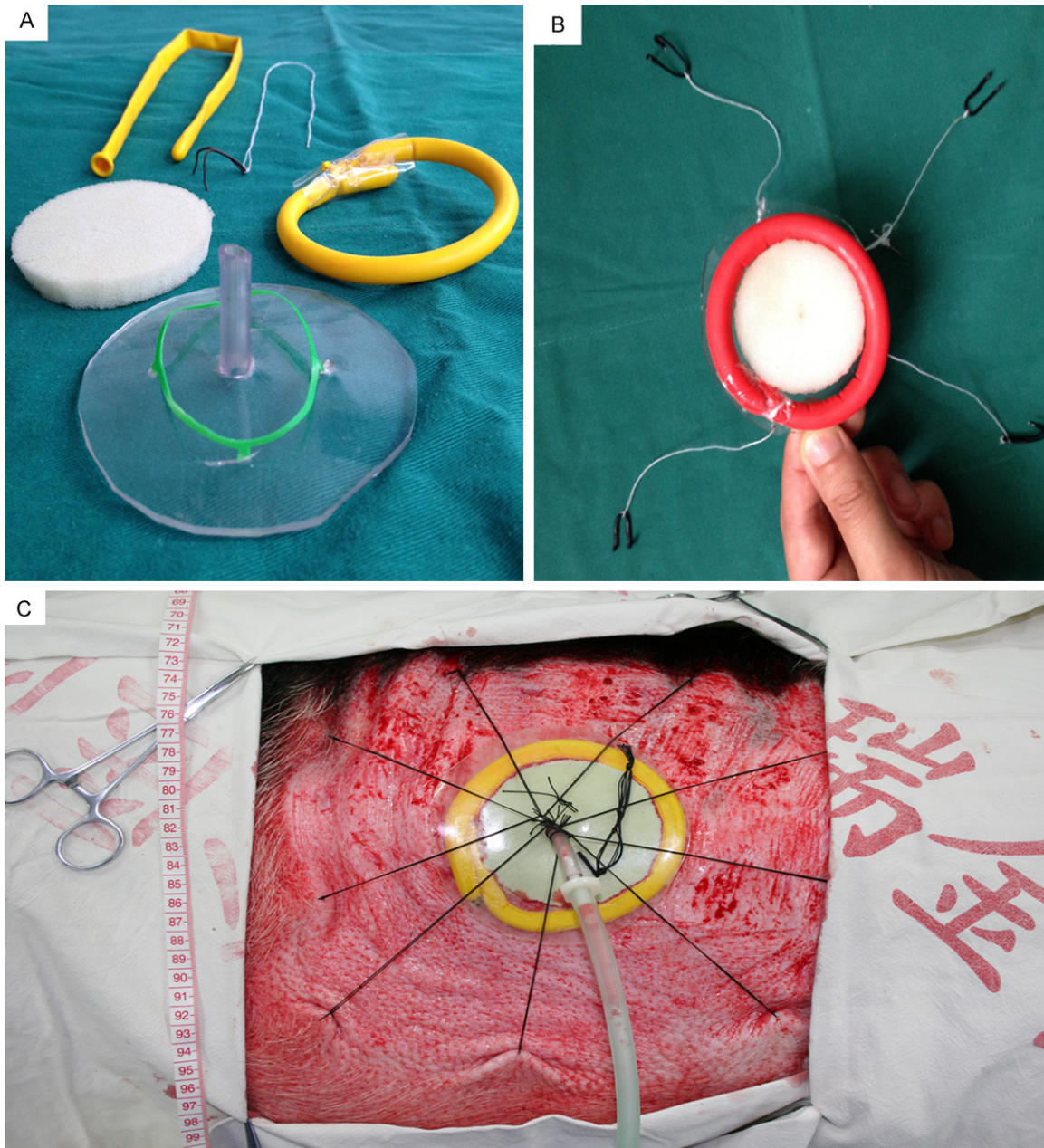


Figure 1. The structure and application of the universal skin stretcher. The universal skin stretcher consists of a piece of sponge, a long balloon, several nylon sewing threads and hooks, a cover plate with one set of built-in evacuation tube and a ring (A). When used, the sponge is placed on anywhere of the wound bed. The long balloon filled with water is sealed and linked end-to-end by adhesive film according to the size of the sponge, and then placed around the sponge. The cover plate is cut according to the shape of the sponge and then placed over both the sponge and the balloon. The evacuation tube is connected to an electric suction apparatus. Application of negative pressure causes the universal skin stretcher to be fixed on the wound bed. The wound margins are hooked and stretched towards the center of the wound bed by nylon sewing threads and hooks (B, C).

Based on these observations and inspired by a wheel, we hypothesized that we might design a modified skin stretcher that could be installed on anywhere of the wounds by negative pressure, and hence realize the skin expansion to

any direction in a controlled way. This study was designed: 1) to introduce this modified skin stretcher. 2) to determine whether it can be used easily. If it was, whether it can with stand certain weight. 3) to establish a hypothesis for

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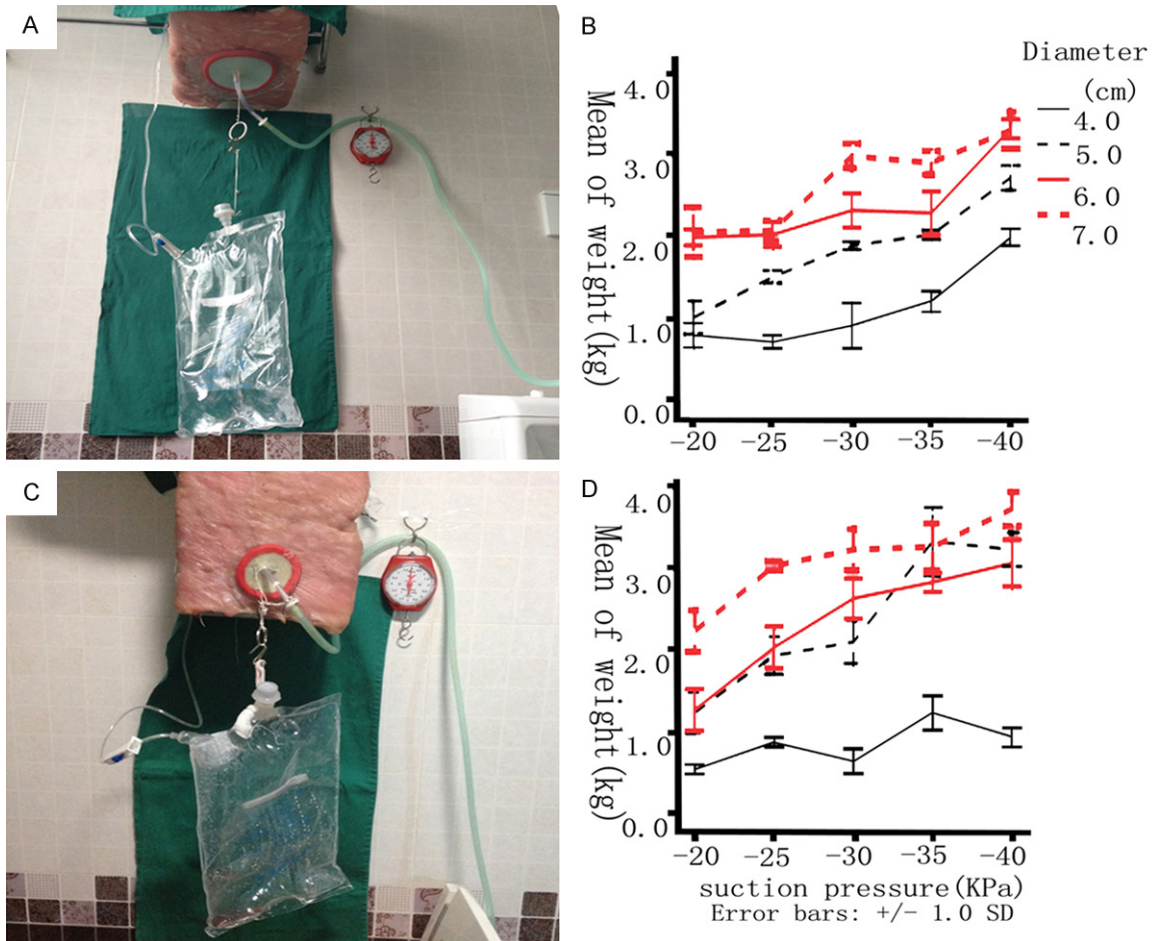


Figure 2. The measurement and values of the weight the device withstand in the horizontal/vertical direction (W_v / W_h). Firstly, the device is fixed on the wounded skin by the negative pressure. Secondly, a rope tied to a plastic bag is located in the base bottom of the evacuation tube. Thirdly, the plastic bag is filled with water consistently and controllably until the device is removed from the wounded skin. Lastly, the weight of the plastic bag is weighed by a hanging spring scale (A, C). Either the W_v or the W_h increase with the suction pressures or the size of sponge (B, D).

large wound closure based on this modified skin stretcher.

Materials and methods

Structure of the universal skin stretcher

The universal skin stretcher consists of a piece of circular sponge (Weida Sponge Products Co., Ltd. Guangdong, China), a long balloon (Dongguan Brother Balloon Co., Ltd. Guangdong, China), several nylon sewing threads and hooks, and a cover plate (Shenzhen Quanda Plastic Co., Ltd. Guangdong, China). The cover plate has a built-in evacuation tube (Suzhou Xida Medical Equipment Co., Ltd. Jiangsu, China) and a ring fixed in its wall, which allows several nylon sewing threads to be fixed on it to stretch

the wound margin by hooks, and a connection to a negative pressure device (**Figure 1A**).

Application of the device on the skin wound of a pig

Firstly, one young, healthy bama pig (appropriately 50 kg), before administering euthanasia in another experiment, was used in this study. The experimental procedures were performed in accordance with the National Institutes of Health Guide for the Care and Use of Laboratory Animals with the approval of the Scientific Investigation Board of Shanghai Jiao Tong University School of Medicine, Shanghai, China. All animal procedures were performed by veterinary services personnel as previously described by Yuan [19] with some modifications. In

brief, general anesthesia was initiated through intramuscular injection of pentobarbital sodium (20 mg/ml, 0.833 mL/kg, Westang Biotechnology Inc., Shanghai, China) and followed by intravenous propofol (4 mg/kg/h, Fresenius Kabi Deutschland GmbH, Germany). After clipping the hair on the right dorsum, we created a square wound about 75 cm on a side with a standard roller dermatome (Medical Instruments Corp. Ltd., Shanghai, China).

Secondly, as shown in **Figure 1B, 1C**, the sponge was cut into a circle and placed on anywhere of the wound bed. The long balloon filled with water was sealed and linked end-to-end by adhesive film (Smith & Nephew Medical, Hull, UK) according to the size of the sponge, and then placed around the sponge. The cover plate was cut according to the shape of the sponge and then placed over both the sponge and the balloon. The evacuation tube was connected to an electric suction apparatus 7A-23D (Yuyue Medical Equipment & Supply Co., LTD, Jiangsu, China). Application of negative pressure of -20 KPa caused the universal skin stretcher to be fixed on the wound bed.

Thirdly, the wound margin was hooked and stretched towards the center of the wound bed by nylon sewing threads and hooks. The stretching force was timely adjusted according to the color and tension of the skin. During the continuous stretching time, the exposed wound bed was covered with clean dry gauze.

The measurement of the weight the device withstand in the horizontal/vertical direction (W_h/W_v)

Four types of the universal skin stretcher with different sizes of sponge(with a diameter of 4.0 cm, 5.0 cm, 6.0 cm, and 7.0 cm respectively) were fixed on the wounded pig skin that was fixed on a flat board at different suction pressures (-20 KPa, -25 KPa, -30 KPa, -35 KPa, and -40 KPa respectively). The primary outcome measures: the weight it withstands in the horizontal direction (W_h) and the vertical direction (W_v). The measurement methods were as follows (**Figure 2A, 2C**): Firstly, the device was fixed on the wounded skin by the negative pressure. Secondly, a rope tied to a plastic bag was located in the base bottom of the evacuation tube. Thirdly, the plastic bag was filled with water consistently and controllably until the

device was removed from the wounded skin. Lastly, the weight of the plastic bag was weighed by a hanging spring scale (Yongkang Huihuang Hardware Factory, Zhejiang, China). The change of the W_h and W_v were recorded at different suction pressures. This part of the experiment was repeated three times.

Results

Any part of the universal skin stretcher can be cut and assembled into different sizes easily. During the study period, no obvious bleeding of the wound caused by pain were observed. Morykwas et al [20]. showed that the greatest increase in wound edge blood flow occurred at -125 mmHg (approximately -16.6 KPa), which was the pressure selected for further studies and is now the pressure of choice in clinical practice. For a better simulation of the clinic, all four types of the device were fixed on anywhere of the wounded pig skin at the suction pressures of -20 KPa. It was observed that all the universal skin stretchers can be fixed without any difficulty. The mean time from assembling the device to finishing skin expansion was no more than 15 min.

Caruso [17] and Hirshowitz [18] reported that the stretching force of no more than 30 Newton on the skin margins was relatively safe. To determine the exact weight the universal skin stretcher can withstand and determine the appropriate size of the device, we measured the W_h of four universal skin stretchers with different sizes of sponge(with a diameter of 4.0 cm, 5.0 cm, 6.0 cm, and 7.0 cm respectively). It was observed that the W_h increased with either the suction pressures or the size of sponge. The biggest device in this study can even withstand more than 3.0 kg. To further test the stability of the universal skin stretcher, we also measured the W_v , which showed the similar tendency with W_h . At the suction pressures of -20 KPa, the biggest device withstood more than 2.0 kg and exhibited more stability than the others (**Figure 2B, 2D**).

Discussion

A number of studies have confirmed that external expansion is a simple and reliable method for wound closure. Many types of skin stretchers have been well described in the literature for the closure of various wounds [13-16]. The

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advantages of wound closure by skin stretchers are manifold. Firstly, its use avoids the need for flap coverage. Secondly, the stretched skin is similar to the adjoining skin in color and hair-bearing properties. Last but not least, its use results in a functional outcome possibly better than skin grafts or local flaps [21]. Based on our clinical experience, we here introduce this modified skin stretcher inspired by a wheel that designed for large wound closure. Generally, our hypothesis is congruent with our findings. Firstly, this device can be assembled and applied on anywhere of the wound within a short time. Either in the vertical or horizontal direction, the device can withstand satisfactory weight that is deemed to be relatively safe for skin expansion. The sealing principle of the device is summarized to this: The balloon filled with water is so easy to be shaped that it is easy to achieve a firm but non-adhesive attachment of the long balloon to both the cover plate and the pig skin as soon as the suction pressure is applied. Mainly because of the difficulty to fix the pig in an ethical way and the ethical restriction of clinical trial, we have not yet explored the durability of the device, the time for wound closure, the possibility of contamination, and the pain degree of patients.

Large wounds, in which direct closure by skin apposition is not possible, are frequently encountered in clinical practice. There have been many reports on the remarkable and unexpected outcomes of NPWT as a skin grafts bolster [4-9]. In brief, wounds are immediately covered with various skin grafts and/or artificial skin. Then the sponge of the NPWT is directly placed onto the implants and continuous subatmospheric pressure is applied. It has been reported that topical negative pressure increases quantity and quality of split skin graft take compared to traditional bolster dressings [9]. Based on these observations and the universal skin stretcher, we propose a hypothesis for large wound closure, which can be summarized to this: Firstly, the wound beneath the sponge is treated with skin grafts. Secondly, the skin grafts are covered by the universal skin stretcher, by which the wound margins are stretched. During the continuous stretching time, the stretching force is timely adjusted according to the color and tension of the skin. In the end, the wound is covered by the expanded skin and the skin grafts. Although we now

are unable to determine whether it really works or not, it might offer a new perspective for large wound closure.

Conclusions

In conclusion, we identify a technical challenge of the existing skin stretchers and propose a possible solution. Our data show that the modified skin stretcher can be installed on anywhere of the wounds by negative pressure, and hence realize the skin expansion to any direction in a controlled way. It is also observed that the modified skin stretcher can be used easily and withstand satisfactory weight that is deemed to be relatively safe for skin expansion. Based on this modified skin stretcher and existing reports on NPWT, we propose a hypothesis for large wound closure. Although we now are unable to determine whether it really works or not, it might shed light on large wound closure.

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Disclosure of conflict of interest

Yanhai Zuo MMed. is the patentee of a patent for a universal skin stretcher applied in China in 2014 (Application Number: 201420471917.5). Shuliang Lu ph.D. has nothing to declare.

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