OPEN

PRS GLOBAL OPEN

ORIGINAL ARTICLE

Reconstructive

Skin Stretching Techniques: A Review of Clinical Application in Wound Repair

Tian Yang, BS
Zhixiang Tan, MS
Xuejie Chen, PhD
Fang Wang, BS
Rui Tao, BS
Yilan Tong, MS
Xiaoli Wang, PhD
Huajun Fan, MS
Mosheng Yu, MS
Zhanyong Zhu, PhD

Background: The repair of skin defect wounds is a long-term goal of clinical pursuit. Currently, free or pedicled skin flap transplantation is commonly used to repair skin defects. However, these methods may lead to complications such as flap necrosis, thrombosis, scarring, diminished sensation, and pigmentation in both the donor and recipient areas. Since its introduction in 1976, skin stretching techniques were widely used for minor skin and soft-tissue defects in the surgical field.
Methods: A narrative review was conducted to identify relevant articles about the skin stretching techniques for promoting wound healing. We searched the Web of Science and PubMed databases for all articles containing different combinations of "skin stretch techniques" and "wound repair," "skin defects," and "tissue expansion."
Results: Through the screening of 500 articles, 84 representative and persuasive articles were selected in this review. These studies collectively demonstrate the technique's effectiveness in reducing wound size, facilitating primary closure, and improving cosmetic outcomes. Reported complications were generally minor, including transient erythema and mild discomfort, with rare instances of skin necrosis.
Conclusions: Skin stretch techniques emerge as a promising approach for managing large-area wounds, offering the advantage of achieving primary healing without compromising surrounding healthy tissue. However, to optimize its clinical application, further research is warranted, particularly in addressing challenges related to precise stretching and infection management. *(Plast Reconstr Surg Glob Open 2024; 12:e6405; doi: 10.1097/GOX.0000000000006405; Published online 20 December 2024.)*

INTRODUCTION

With the rapid development of modern society, including advancements in industrial traffic and construction industry, open injuries from accidents are increasing annually.[1] Clinically, human skin and soft-tissue defects, caused by factors such as tumors, surgery resection, skin lesions due to inflammation, compromised postoperative incision healing, and osteofascial compartment syndrome, often exposing deep tissues and diminishing patients' quality of life.[2] Traditional repair methods, including skin grafts and flap transfer technique, involve intricate surgical procedures, extended operation times, considerable donor morbidity, long hospital stays, and high costs. As medical humanities evolve, there is growing resistance to the concept of "robbing Peter to pay Paul" through such treatments, prompting the quest for better wound repair methods.[3]

Over the years, skin stretching has emerged as a key approach for repairing skin defects. Skin stretching, a novel surgical technique, harnesses the intrinsic elasticity, mechanical ductility, biological ductility, and stress relaxation properties of the skin to close wounds by stretching the normal skin surrounding the affected area.[4] The biological characteristics and stress relaxation of the skin are the foundation for skin stretching and remodeling. Mechanical forces at the cellular and subcellular levels significantly influence the shape and reconstruction of skin tissue.[5,6] Consequently, through mechanical traction, skin tissue is stretched to facilitate the closure of the skin defect wounds.

METHODS

Literature Retrieval

The following PubMed search was mapped: (Skin stretch techniques [MeSH Terms]) AND (Wound Repair [MeSH Terms]) "Skin stretch techniques" [MeSH Terms] AND ("Skin Defects" [MeSH Terms] OR "Tissue Expansion" [MeSH Terms]). This strategy identified 61 studies published between 1976 and 2023.

Disclosure statements are at the end of this article, following the correspondence information.

From the Department of Plastic Surgery, Renmin Hospital of Wuhan University, Wuhan, China.

Received for publication February 25, 2024; accepted October 22, 2024.

Tian Yang and Zhixiang Tan contributed equally to this work.

DOI: 10.1097/GOX.0000000000006405

Inclusion Criteria

Significant case reports, cellular mechanism studies, animal studies investigating the mechanism of skin stretch techniques in the treatment of skin defects, and articles detailing the clinical course and outcomes in hospital settings were included.

Exclusion Criteria

Articles focusing on skin expansion techniques rather than skin stretch techniques were excluded.

Search Methodology

The selected studies were manually evaluated for relevance. Key endpoints considered included successful wound closure, healing time, incidence of complications, and overall patient outcomes. The focus was on extracting comprehensive data on the efficacy, complications, and clinical applications of skin stretching techniques.

Review

The origins of skin stretch techniques can be traced back to the 1960s when researchers commenced investigating the biological characteristics and other facets of the skin, leading to notable achievements in basic research. With achievements in medical science, it became possible to use the skin's specific biological properties to effectively close certain skin defect wounds. Consequently, skin stretching techniques have entered the clinical practice. Two types of traction devices use skin stretch techniques by applying mechanical force to the normal skin surrounding the wound: invasive skin stretch devices, which apply mechanical force and traction technology to the damaged skin around the wound, and minimally invasive or noninvasive pull devices, which utilize mechanical force and pull technology with minimal or no damage to the surrounding skin. Globally, various skin stretch devices have been utilized to repair skin defect wounds (Table 1).

Takeaways

Question: Despite significant recent advancements in medical technology for clinical skin transplantation, challenges remain, notably concerning the high costs and limited shelf life.

Findings: This review meticulously examines the concept of skin stretching techniques, their evolution, various variants, basic biological principles, and the advantages and disadvantages of skin stretching procedures for reference.

Meaning: This review meticulously examines skin stretching techniques.

Common Types of Skin Stretchers

Bidirectional Adjuster-hook Skin Closure System

The Bidirectional Adjuster-Hook Skin Closure System (BHS) was approved for closing large skin soft-tissue defects after soft-tissue sarcoma resection in 2017 and, finally, obtained successful functional and cosmetic results. The BHS is operable and cost-effective due to the advantages of simple design, reusability, and ease of adjustment.

The possibility of stimulating tumorigenesis greatly limits BHS use in soft-tissue tumors.[1] Additionally, a wider range of applications, such as in traumatic and chronic wounds, is required to further clarify the indications and contraindications of this technique (Fig. 1).

Table 1. History of Skin Stretch Techniques

Year	Study	Event
1976	Barrer et al.[7]	A new retaining bridge device was invented for the first time
1987	Bashir[8]	The skin edge was gradually closed by continuously drawing 2 Kirschner needles
1990	Maekay et al.[9]	Both skin dilation and appropriate subcutaneous ionization were found to reduce wound closure time
1988	Liang et al.[10]	Predilation of the planned surgical area was performed before the first operation, and the wound was sutured postoperatively
1992	Choen and Shafit[11]	The Miami Star tension regulator was invented to rapid close large wounds
1995	Zhang et al.[12]	A new device to produce extra skin tissue for the repair of defects by continuous traction over the skin
1993	Hirshowitz et al.[13]	The first nominal skin stretcher was introduced, further advancing the clinical application of skin stretch technology
1996	Zhou et al.[14]	A new type of pinch-claw skin stretcher was designed to avoid the damage to skin blood flow caused by subcutaneous ionization
2002	Risnes et al.[15]	The zip closure system was invented to lead skin closure to the future without piercings
2003	Li et al.[16]	A miniature skin stretcher was invented, which is smaller and lighter than previous stretchers
2006	Barnea et al.[17]	A stretching device was developed, which is composed of metal needle, safety hook, and rotary knob to maximize the protection of the skin tissue
2012	Topaz et al.[18]	The TopClosure system was developed, which effectively avoided the occurrence of complications such as ischemia and necrosis caused by the pulling process of the skin edge
2013	Guo et al.[19]	The children's syndactal stretcher was designed to solve the problem of insufficient skin during pediatric syndactal surgery
2017	Song et al.[20]	A new type of pull rod skin retractor was developed, which is more suitable for the treatment of large wounds than the old type of retractor
2018	Chen[21]	A skin traction band was applied, making the scar heal linearly, softer, and less pigmented
2021	Dong et al.[22]	The skin stretching and secure wound closure system can reduce the skin and soft tissue defects or close the wound directly, and even replace the skin graft and skin flap repair

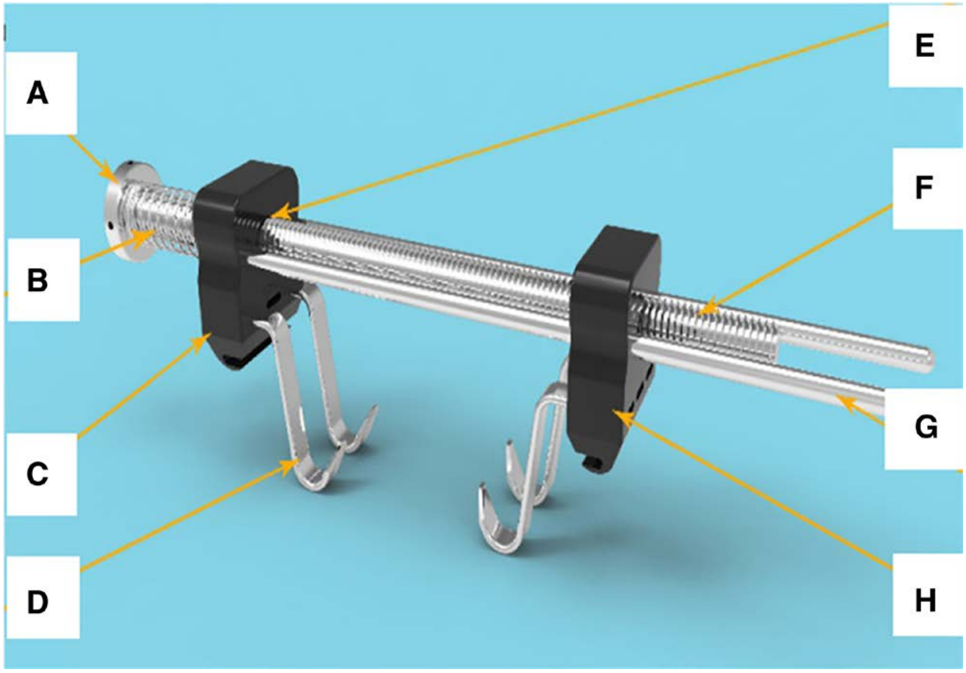

Fig. 1. BHS comprises 2 hook clamping modules (c) and a compression module. Each holder module consists of a threaded rod cap (a), a threaded plunger hole (e), 2 guide holes, and 3 hooks with sharp tips (d), positioned to face each other. The compression module includes a threaded rod (f), a spring (b), and 2 guide rods (g). The threaded rod passes through the threaded plunger hole (e) on the hook holder module using the 2 guide rods. Reprinted with permission from *World J Surg Oncol.* 2020;18:247.

DermaClose

Another noteworthy skin tensioner is the DermaClose system. Originally utilized in military settings, the DermaClose external tissue expander has demonstrated successful outcomes in treating scalp and forehead injuries, aiding wound healing following limb blast injuries, diabetic foot wounds, and osteofascial compartments. Its earliest documented application was in October 2015 by the Henry Ford Health System for managing sternal wound dehiscence.[23] The tension wire facilitates wound closure and offers a certain degree of tension controllability. Compared with negative-pressure suction systems, DermaClose external tissue dilators are more cost-effective and require a shorter application time. Its operational simplicity and ease of use are notable features, but it still has limitations. DermaClose should not be utilized on ischemic or infected tissue or delicate tissue surrounding the wound edges. Careful consideration of DermaClose applicability is essential in such cases (Fig. 2).

TopClosure

TopClosure represents an innovative technology for the effective management of both simple and complex wounds. It offers a means of skin stretching and secure wound closure, serving as a valuable aid in the healing process of posttraumatic, surgical, acute, and chronic skin wounds.[18] This versatile device can be affixed to the skin using either invasive methods, such as adhesives, staples, or surgical sutures, or noninvasive means and is useful both before and after surgery. The key feature of this device lies in its ability to provide tension parts situated away from the skin edge. This unique design allows for robust local adhesion to the underlying skin, enabling significant pulling on the skin with minimal tangential shear stress. This design minimizes pain and excessive skin damage during the healing process.[18] Moreover, the TopClosure device boasts several desirable characteristics, including reduced wound injury, diminished pain, accelerated healing time, fewer complications, and aesthetically pleasing wound closure. However, a flat cut is a prerequisite before applying the device (Fig. 3).

Mechanism of Action of Skin Stretchers

Mechanism of Action of Skin Stretchers in Skin Tissues

Mammalian skin is a complex anatomical structure composed of the epidermis, dermis, and subcutaneous tissue layer. The dermis contains elastic fibers, collagen fibers, and reticular fibers, with elastic fibers and collagen fibers being crucial for the skin's viscoelastic properties.[24] These heterogeneous tissue components possess distinct mechanical properties and respond differently to applied forces.[25] Under normal conditions, collagen fibers within the dermis are randomly arranged. However, when external forces pull on the skin, collagen and elastic fibers in the dermis align in a parallel arrangement. Collagen fibers, characterized by high tensile strength and rigidity, provide primary structural support, whereas elastic fibers contribute to the skin's ability to return to its original shape after stretching. Excessive tension can damage elastic fibers, reducing their ability to retract and leading to dermolysis. The viscoelastic

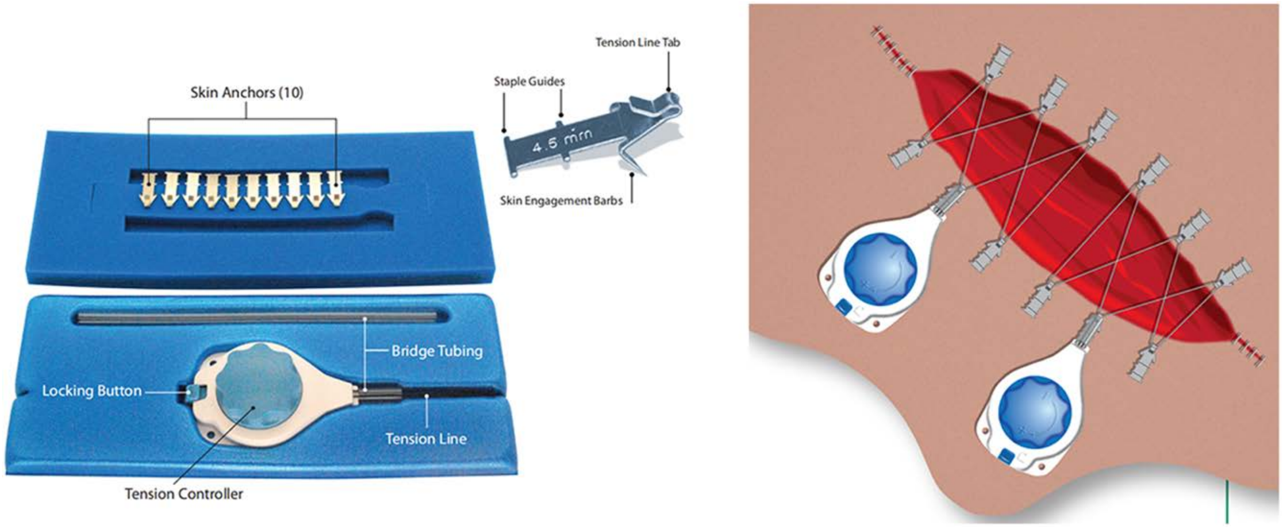

Fig. 2. DermaClose consists of several skin anchors and a tension controller. It is intended to be used with 3 skin anchors per side of the wound and 1 tension controller for each 10 cm of wound length. Affix each skin anchor with a minimum of 2 skin staples. Press the stapler firmly against each anchor and staple between each of the staple guide tabs found on the skin anchors. Reprinted with permission from DermaClose (https://dermaclose.com).

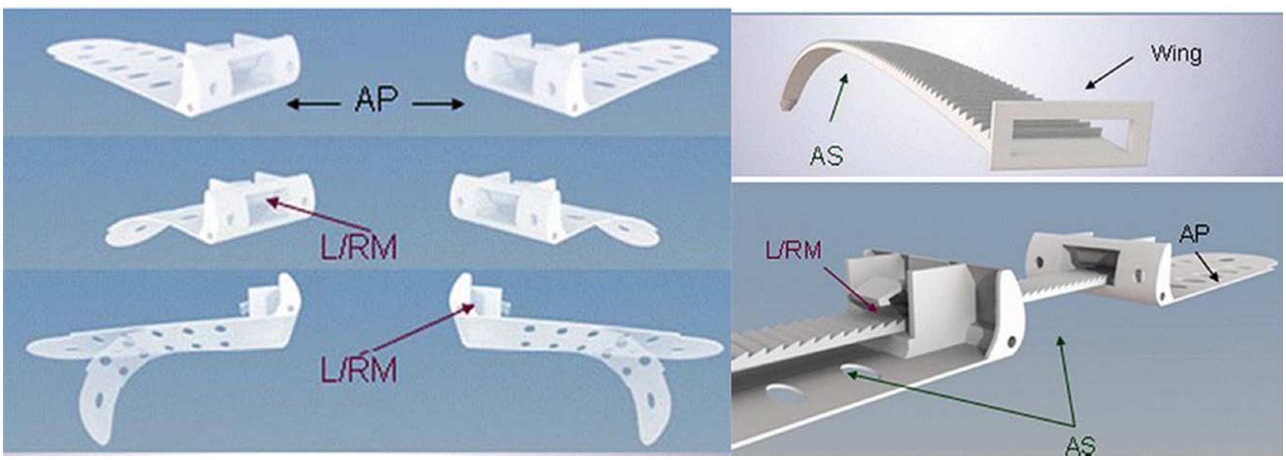

Fig. 3. TopClosure consists of 2 flexible attachment plates placed near the wound edges, secured with adhesive and skin staples. Interconnecting straps gradually bring the wound edges together. After initial debridement, TopClosure Tension Relief System allows for a slow approximation of damaged tissues by gently pulling the skin edges closer. Tension is applied for 30 seconds, followed by 1–2 minutes of relaxation on alternating sutures. Once the wound margins are approximated, tension sutures will be tightened and locked. Reprinted with permission from *Eur J Plast Surg*. 2012;35:533–543. AP; AS; L/RM.

nature of the skin underpins the clinical application of skin stretchers, involving stress relaxation and mechanical creep. Mechanical creep is a gradual elongation of the skin over time under constant force, increasing skin volume as observed during pregnancy or extreme weight gain. When the skin is stretched to a constant distance, tension initially rises and gradually decreases over time, resulting in stress relaxation. Repeated stress relaxation causes permanent elongation of the skin. These biomechanical mechanisms enable skin stretchers to transcend the limitations of traditional sutures. Topaz et al[3] mentioned stress relaxation and mechanical creep as major skin stretching mechanisms aiding wound healing. Under external tension, the interconnected network of collagen, elastin, and matrix materials in the extracellular matrix of the tissue undergoes deformation, causing the tissue to stretch within a limited range.[3] However, excessive stimulation can cause tissue damage, loss of mechanical properties, decreased cellular responsiveness, and apoptosis.[5] Stress relaxation characteristics, stress–strain relationships, and tensile strength of soft tissues undergo significant changes under external forces, with extended tissue tending to regain its original biorheological properties.[26] Morphological changes in extended skin include increased epidermal cell layers; slight thickening of the epidermal layer; blunting of the epithelial spike process and dermal papillary ridge; denser collagen fiber bundles; increased fibroblasts, and a slight increase in dermal blood vessel count, predominantly in the dermal papillae[14] (Fig. 4).

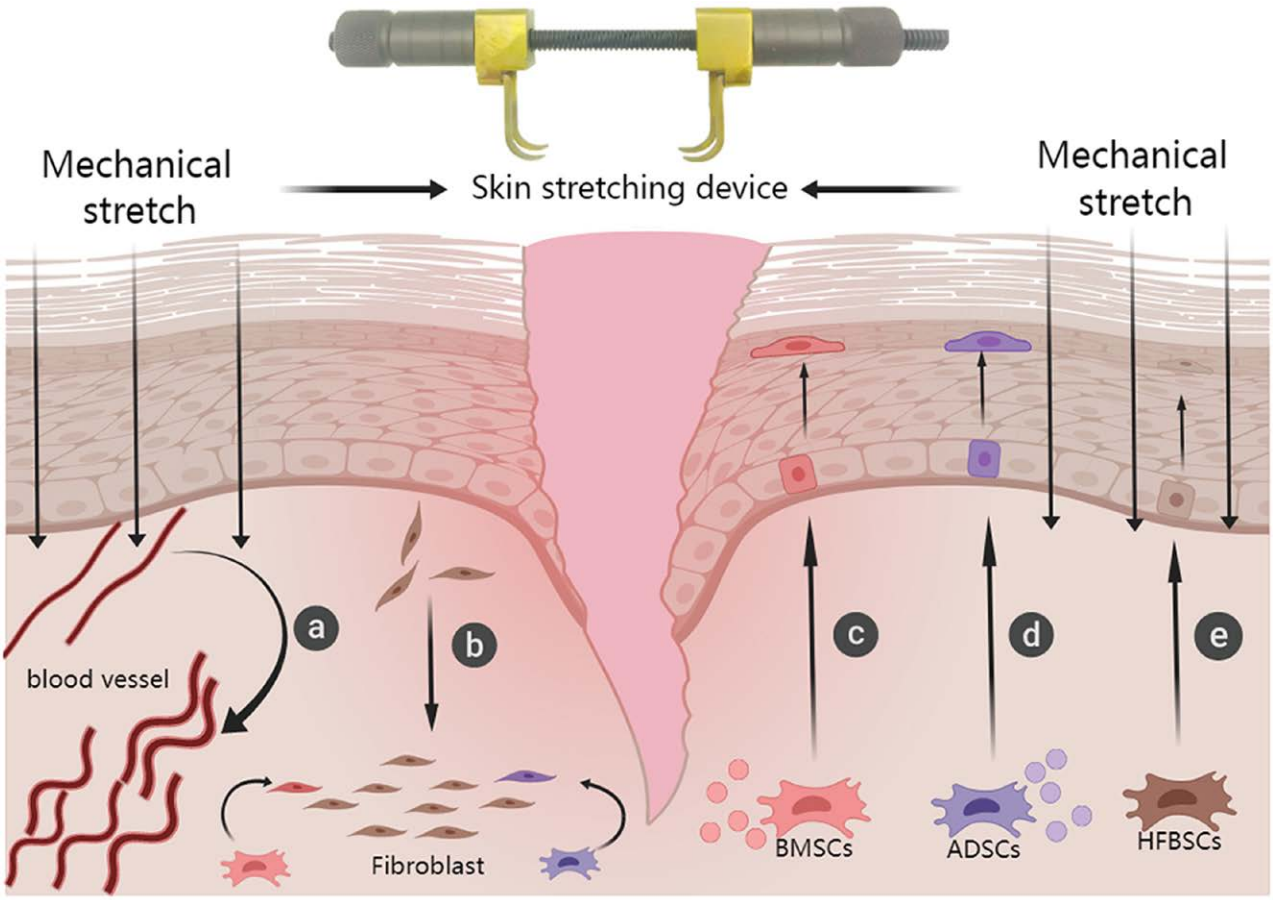

Fig. 4. Schematic diagram of the mechanism of action of skin stretchers in tissues and cells. (a) The dermal vessels increased in curvature, density, and diameter after continuous periodic stretching, resulting in a significant increase in epidermal proliferation; (b) after mechanical stretching, the number of fibroblasts increased, the volume increased, the cytoplasm was abundant, and the overall arrangement became parallel; (c–e) Bone marrow mesenchymal stem cells and adipose tissue-derived stem cells differentiate into keratinocytes, fibroblasts, and endothelial cells under mechanical stretching and secrete a variety of growth factors. In addition, HFBSCs also differentiate into keratinocytes, endothelial cells, and outer root sheath cells under mechanical stretching, and secrete growth factors (created with MedPeer.com).

Mechanism of Action of Skin Retractor in Cells

Mechanical stretching initiates mechanotransduction processes through cell–cell adhesion and cell–extracellular matrix interactions.[27] These physical connections impart mechanical integrity and enable the transfer of physical forces within the cytoskeletal network of each cell, acting as mechanical sensors that detect forces and coordinate reactions over various time scales.[28] Initially identified in ion channels, mechanotransduction has been extended to mechanochemical processes that connect ion channels across cells.[29] Cell adhesion is the only physical structure in the cell that can be stimulated by mechanical input. At the cellular level, the contractile forces generated by the actin filament network balance the external forces from stretching at cell–cell adhesion sites. Mechanosensory processes respond to external stress by strengthening connections between cells.[30] Under external load, cadherin bonds can become long-lived force-induced bonds, known as capture bonds.[31–33] When mechanical sensors detect increased stress, signaling pathways increase bond numbers. Most wound healing processes result from the activation of these mechanical pathways. In the embryonic repair of epithelial tissue, cells collectively migrate around the wound bed, coordinating movements through mechanical force. Mechanical stretching can further induce the migration of stem cells, promoting skin tissue enlargement and regeneration.[34] Bone marrow mesenchymal stem cells and adipose tissue-derived stem cells differentiate into keratinocytes, fibroblasts, and endothelial cells under mechanical stretching and secrete growth factors.[35] Hair follicle bulging stem cells similarly differentiate and secrete growth factors.[36] Appropriate mechanical stretching increases keratinocyte division and reduces apoptosis, forming the basis of epidermal expansion. Kippenberger et al[37] mentioned that appropriate mechanical stretching enhanced keratinocyte division and reduced apoptosis. Huo et al[38] found that dermal fibroblasts undergo similar stimulation during the expansion of skin soft tissue, proliferating and increasing dermal cell density after dilator implantation (Fig. 4).

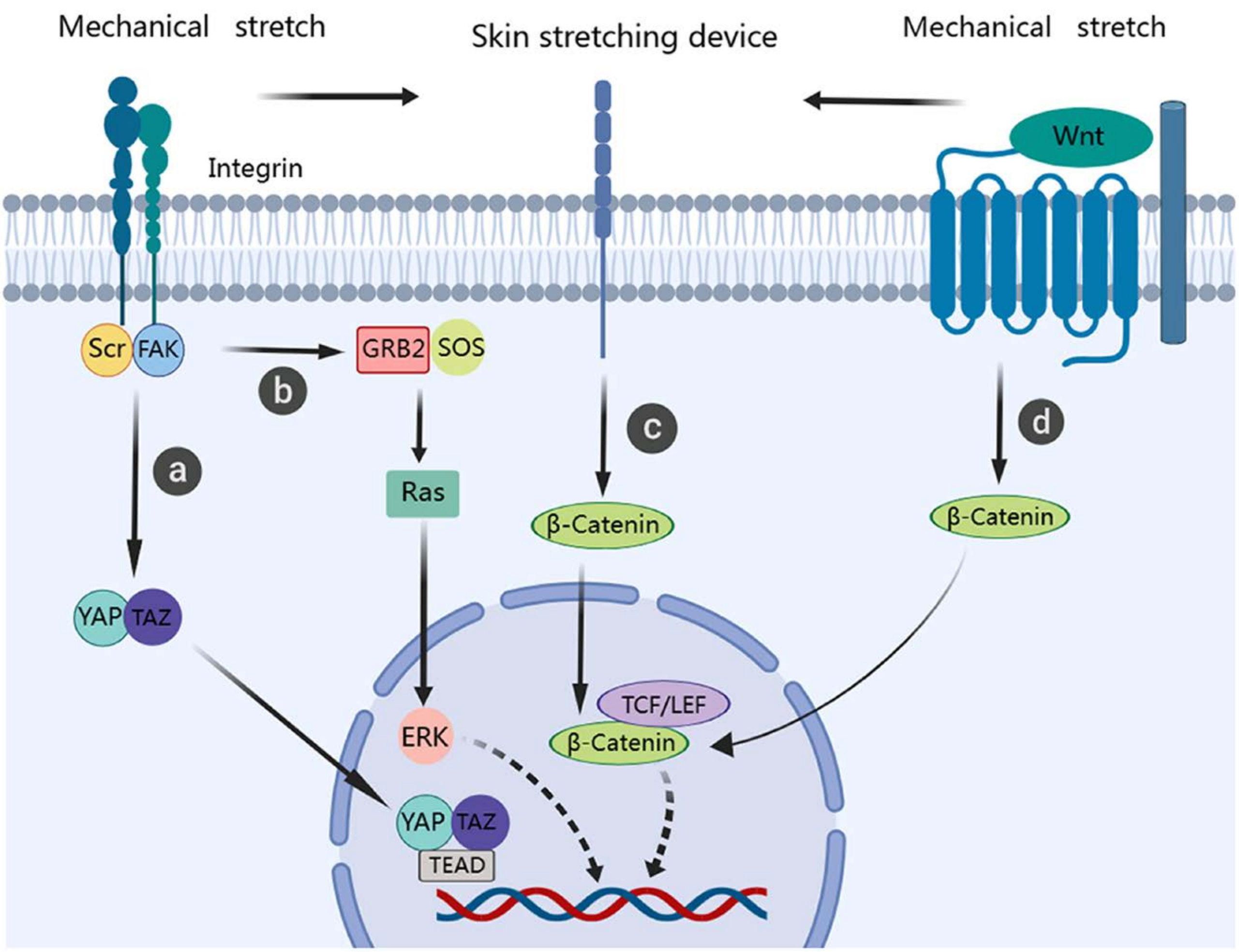

Fig. 5. Schematic depiction of the molecular mechanisms underlying skin stretching. (a) YAP activation: mechanical stimulation triggers the recruitment and activation of FAK and Src, subsequently direct activating YAP/TAZ through integrin activation with their translocation into the nucleus. The activated YAP/TAZ complexes then bind to transcription enhanced association domain, thereby orchestrating the regulation of gene expression; (b) Ras-Raf-MEK-ERK cascade: the engagement of integrins by mechanical stimulation induces their activation, leading to the recruitment and activation of FAK. FAK, in turn, activates Ras through GRB2 and SOS, thereby instigating the Ras-Raf-MEK-ERK signaling cascade. Ultimately, ERK, upon activation, is translocated into the nucleus to modulate gene expression. (c) Wnt protein-independent pathway: mechanical stimulation can also lead to the degradation of E-cadherin, releasing β-catenin in the E-cadherin binding pool. Consequently, β-catenin accumulates within the nucleus, where it governs the transcription of specific target genes. (d) Wnt protein-dependent pathway: The application of mechanical stretching enhances the expression of Wnt proteins, initiating Wnt signaling. Upon disabling the β-catenin-degrading complex, β-catenin accumulates in the nucleus. This accumulated β-catenin binds with the transcription factor TCF/LEF, orchestrating the regulation of target gene transcription (created with MedPeer.com). ERK, extracellular signal-regulated kinase; FAK, focal adhesion kinase; SOS, son of sevenless protein.

Mechanism of Action of Skin Stretchers in Molecules

Yes-associated Protein/Transcription Coactivator Tafazzin Signaling

Yes-associated protein (YAP) and transcription coactivator tafazzin (TAZ) are 2 core cotranscription factors in the hippo pathway.[39] After activation, YAP/TAZ migrates to the nucleus, binds to the transcription-enhanced association domain transcription factor family, regulates gene expression, promotes tissue growth, and inhibits apoptosis.[40–43] Mechanical stimulation activates YAP/TAZ via integrin-recruited focal adhesion kinase (FAK) and Src.[44] FAK and Src also inhibit YAP/TAZ signaling via large tumor suppressor kinase 1/2. The activated YAP/TAZ then translocates to the nucleus, binds to transcription-enhanced association domain, and regulates gene expression. Mechanical stretching also activates extracellular signal-related kinases (ERK) signaling, promoting fibroblast and keratinocyte proliferation, vascularization, and skin regeneration. This process involves integrin activation, FAK phosphorylation, and subsequent activation of the Ras-Raf-MEK-ERK cascade. The activated ERK then upregulates and activates c-Fos, binding to c-Jun to regulate gene expression (Fig. 5).

Wnt/β-catenin Signaling

Wnt pathway, a highly conserved signaling pathway, is crucial for early embryonic development, organogenesis, tissue regeneration, and other physiological processes. In the skin, Wnt signaling is involved in embryonic

Table 2. Skin Stretch Has Been Reported to Close Different Wound Sizes

Device	Position	Year	Object	Factor	Defect Size (cm × cm)	Follow-up (mo)	Study
TopClosure	Head	2015	More than 10 d of birth of female infants	Head giant hemangioma surgery	6.5 × 5.2	6	Zhu et al[68]
TopClosure	Chest wall	2017	A 36-y-old man	Chest contracture scar with ulceration underwent cicatricectomy	24 × 16	18	Zhu et al[69]
SureClosure	Abdominal wall	2014	A 20-y-old female patient	Burn scar excision wound	8. 5 × 19	12	Verhaegen et al[70]
TopClosure	Right chest wall	2016	An 81-y-old woman	Right breast cancer surgery	16 × 11	6	Zhu et al[71]
TopClosure	The right low back	2014	A 60-y-old man with schizophrenia	Large ulcerative squamous cell carcinoma surgery	15 × 25	6	Topaz et al[3]
Elastic rubber bands	Right hip joint	2017	A 76-y-old man	Stage IV pressure ulcer	25 × 15	2	Cheng et al[72]
EASApprox closure	Right lower extremity	2018	A 41-year-old man	Open infected wound	40 × 35	3	Lei et al[64]
EASApprox closure	Left knee joint	2017	A 25-y-old man	Postoperative peripheral trauma	15 × 11	5	Dong et al[22]
KWs + wires	Calf	2018	Patients around the age of 37.5 y	Open infected wound	14 × 5 ~ 20 × 7	2	Chen et al[73]
KWs + BHS	Right leg	2020	A 76-y-old woman	After resection of fibrosarcoma	13 × 8	3	Wu et al[1]
KWs + wires	The back of the right foot	2018	A 36-year-old man	Nonhealing burn wound	18 × 9	2	Zhang et al[74]
EASApprox-Closure	The ulnar side of the left foot	2020	A 66-y-old woman	Peripheral neuropathy due to diabetes	9 × 3	6	Ji et al[75]

KWs, Kirschner wires.

development, hair follicle development, maintenance of normal epidermal spines, and epidermal differentiation and stratification during skin homeostasis.[45–47] Mechanical stretching induces β-catenin activity both dependently and independently of Wnt protein, leading to Wnt signaling activation and β-catenin accumulation in the nucleus. β-catenin binds to T cell factor/lymphoid enhancer factor family transcription factors to regulate target gene transcription. Mechanical stimulation can also cause cadherin degradation, releasing β-catenin, which accumulates in the nucleus to regulate gene transcription (Fig. 5).

Transcriptome Changes Induced by Mechanical Stretch

Transcriptome sequencing technology has been increasingly applied to skin and soft-tissue expansion to explore gene expression changes at the RNA level and reveal their molecular mechanisms.[48] Key differentially expressed genes in expanded skin mainly affect inflammatory response, tissue remodeling, cytoskeleton, and cell contraction.[49] Intact epidermal organ system regeneration and scarless wound healing mechanisms indicate that mechanical stress signaling and immune responses play an important role in determining wound healing patterns.[50] Mechanical stress and immune response regulate skin regeneration through a complex interaction. CXCL1, CXCL2, and CXCL8 are mechanoreactive proteins. CXCR2, a co-receptor of CXCL1, CXCL2, and CXCL8, was mechanically stimulated to upregulate keratinocyte proliferation and angiogenesis in keratinocytes and fibroblasts. CXCR2 activates the MAPK-ERK signaling pathway and the β1 integrin-FAK signaling pathways and participates in the hypoxia-inducible factor-1 (HIF-1) pathway, enhancing cell tolerance to hypoxia.[51–53] T transcriptome changes induced by mechanical tension, such as CXCR2 conversion to HIF-1 and CCL20 conversion to CCR6. Inflammatory-related genes such as CXCL1, CXCL2, CXCL8, and CXCR2 are upregulated in the early stage of dilatation.[54–56]

Application of Skin Stretch Techniques

Free tissue and regional flaps for reconstructing skin and soft-tissue defects have significant limitations, including donor site damage, abnormal sensations, poor wear resistance, bulky flaps, and necrosis risks. Free flap procedures, involving vessel anastomosis and skin grafts, increase the economic and medical burden on patients due to the need for postoperative functional dressings and anticoagulant drugs. Skin-grafting and free flap techniques also involve long learning curves and higher complication rates.[57–61] Xu et al[62] found that although both free flap transplantation and skin stretch techniques promote wound repair, skin stretchers cause less damage, reduce patient pain, and significantly shorten operation time. Originally, skin stretch techniques were limited to small- and medium-sized wounds. However, Futran et al[63] demonstrated that Sure Closure can effectively close large wound defects in a single operation, avoiding delays in mobility, scarring, and additional procedures. Lei et al[64] also mentioned that for large buttock defects where surrounding conditions are poor, skin retractors are more suitable than local flaps or skin grafts. In pediatric syndactyly surgery, skin retractors address skin deficiency, avoid complications, and shorten hospital stays.[65] For patients with pressure ulcers, traditional flap techniques are prone to postoperative infection, poor local blood flow, and flap ischemia, leading to surgical failure. Skin stretch closure after thorough debridement can avoid the above risks and achieve satisfactory healing.[66] In heel defects, skin stretch techniques enable single-stage healing, avoiding the need for secondary procedures.[67]

Table 3. Summary of Skin Stretching Devices and Clinical Outcomes

Type of Skin Stretching Device	Devices	Indications	Contraindications	Complication
Bidirectional skin stretchers	BHS KWs + BHS[1]	Acute and chronic wounds, moderate to large wound closure	Infected wounds, necrotic tissue, poor skin elasticity	Transient erythema, mild discomfort, rare skin necrosis
Mechanical skin stretchers	DermaClose[23] TopClosure[18] SureClosure[70]	Larger acute wounds, extensive surgical defects	Severe infections, compromised vascular supply	Pain, transient swelling, occasional wound dehiscence
Elastic skin stretchers	Elastic rubber bands[72] EASApprox closure[75]	Small to medium-sized wounds, trauma wounds	Severe scar tissue, infection	Mild skin irritation, occasional slippage
Hook and wire systems	KWs + wires[73,74]	Extensive burns, posttumor excision reconstruction	Insufficient surrounding tissue, poor general health	Device migration, infection, skin necrosis

KWs, Kirschner wires.

Given these limitations, wound healing strategies need to be redesigned to optimize outcomes in patients with severe skin abnormalities. Many skin stretchers listed in Table 2 are used as alternatives for wound healing. The skin stretch method applies to nearly every part of the body, except the maxillofacial region. The maximal breadth and direction of traction vary depending on the anatomical portion of the skin due to its variable viscoelastic characteristics. Table 2 presents a compilation of clinical findings on wound closure in different anatomical locations and with different causative variables since the introduction of skin stretching techniques in wound healing. Table 3 summarizes the 4 types of stretchers, including the indications, contraindications, and complications of various skin stretching devices.

DISCUSSION

With a range of significant advantages over traditional methods, skin stretching techniques have gained attention as a promising approach to solving the problem of skin defects:

Simplicity and speed: the procedure is straightforward, quick, and cost-effective.

Minimally invasive: avoids the risks associated with internal dilator placement and secondary operations.

Reduced scarring: prevents multiple scars and avoids donor site wound care.

Aesthetic benefits: after healing, results in linear scar with good local skin quality and minimal aesthetic impact.

However, the skin stretch techniques also have their limitations:

Anatomical constraints: effective on the trunk and extremities but limited on the face and other areas due to aesthetic concerns and tissue toughness (eg, scalp, heel).

Size of wound defects: ineffective for very large defects requiring immediate coverage; alternative methods like skin grafts may be needed.

Special areas: excessive traction in narrow sites can compress blood vessels and nerves, requiring careful application.

Complications: includes pain, swelling, wound dehiscence, skin irritation, and rare cases of necrosis.

In addition, there are some absolute contraindications to skin stretch techniques:

Exposed critical structures: these include bones, cartilage, blood vessels, nerves, and joints.

Compromised systemic health conditions: skin stretching is contraindicated in patients with systemic infection, compromised cardiopulmonary function, shock, multiple organ dysfunction syndrome, mental illnesses, uncooperative children, and older patients with poor skin elasticity.

Adverse local tissue condition: this includes severe soft-tissue contusions, acute inflammation, poor skin condition (such as atrophy), active bleeding, unresolved pathogenic factors (such as pressure sores), and ongoing radiation therapy to the affected area.[76]

According to the traditional reconstruction ladder, closure options for complex wounds include dressings, primary closure, delayed closure, skin grafts, and internal tissue dilation, which involves a phased process using skin grafts.[77] Skin stretch techniques can be an alternative to tension sutures, skin grafts, and even resurgery. They promote delayed primary closure or primary closure with an ideal color and skin texture match by enlarging the healthy skin at the edge of the wound without creating a donor area, thus eliminating the need for a second operation under general anesthesia. External tissue expansion has been reported to reduce wound healing time, hospital stay, and total wound care costs.[78] Additionally, the skin stretch technique can shorten the time it takes to start rehabilitation after surgery and has advantages in battlefield applications compared with skin grafts and artificial dermis.[79,80] However, the effects are not definitively demonstrated in high-level randomized controlled trials.[1] Free flaps remain the ultimate surgical technique for complex soft tissue defects, especially when skin stretching techniques are either inapplicable or unsuccessful.[81] Complications of skin stretch techniques include infection, skin necrosis, skin cracking, skin lesions, hernia formation (abdominal defect), enterodermal fistula (abdominal defect), hematoma, pain, and scar enlargement.[82] Factors such as defect area, defect type, defect location, and underlying disease affect the technique's effectiveness, and the lower incidence of infection compared with internal dilators is notable because external devices make infection easier to identify and control.[83]

Skin stretch techniques play a revolutionary role in the repair of skin wounds, alleviating the pain and shortening the recovery time of clinical skin wounds to a certain extent. However, due to the short research period and limited clinical application, many issues still require further discussion, analysis, and research. In the promotion of precision medicine, it is crucial to consider that skin elasticity varies across different body parts, properties, ages, and genders.

Developing skin pulling devices with scales corresponding to exact tension values and combining them with devices that can monitor local skin temperature changes in real time to indirectly monitor changes in local skin blood flow under mechanical force will help better regulate skin tension and further reduce complications. Continued advancements in clinical research and refinement of skin stretch devices will expand their application. In specific body surface areas, these technologies may eventually eliminate the need for skin grafting or flap repair, offering a more patient-friendly alternative. The continuous improvement of skin stretch techniques promises to significantly contribute to the management of human skin defects. However, considering the current limitations and the need for further exploration, future studies should aim to address the remaining challenges and optimize the clinical utility.

CONCLUSIONS

The skin stretch techniques present a promising avenue for skin defect treatment, demonstrating several advantages over traditional methods. Although certain limitations exist, addressing these concerns and continuing research efforts will unlock the full potential of skin stretching, revolutionizing the approach to skin wound repair and benefiting patients worldwide.

Zhanyong Zhu, PhD
Department of Plastic Surgery
Renmin Hospital of Wuhan University
Wuhan 430060, China
E-mail: zyzhu@whu.edu.cn

DISCLOSURES

The authors have no financial interest to declare in relation to the content of this article. This study was supported by departmental resources. This work was supported by Hubei Provincial Natural Science Foundation of China (2022CFB298) and China University Industry Research Collaboration Innovation Fund (2020ITA03006 2021ITA03006).

REFERENCES

1. Wu Q, Shao Z, Li Y, et al. A novel skin-stretching device for closing large skin-soft tissue defects after soft tissue sarcoma resection. *World J Surg Oncol.* 2020;18:247.
2. Verhaegen PDHM, van Trier AJM, Jongen SJM, et al. Efficacy of skin stretching for burn scar excision: a multicenter randomized controlled trial. *Plast Reconstr Surg.* 2011;127:1958–1966.
3. Topaz M, Carmel NN, Topaz G, et al. Stress-relaxation and tension relief system for immediate primary closure of large and huge soft tissue defects: an old-new concept: new concept for direct closure of large defects. *Medicine (Baltim).* 2014;93:e234.
4. Tong X, Lu J, Zhang W, et al. Efficacy and safety of external tissue expansion technique in the treatment of soft tissue defects: a systematic review and meta-analysis of outcomes and complication rates. *Burns Trauma.* 2022;10:tkac045.
5. Pietramaggiori G, Liu P, Scherer SS, et al. Tensile forces stimulate vascular remodeling and epidermal cell proliferation in living skin. *Ann Surg.* 2007;246:896–902.
6. Ismavel R, Samuel S, Boopalan PRJVC, et al. A simple solution for wound coverage by skin stretching. *J Orthop Trauma.* 2011;25:127–132.
7. Barrer S, Pavlides CA, Matsumoto T. Ideal laparotomy closure: comparison of retention sutures with new retention bridging devices. *Am Surg.* 1976;42:582–584.
8. Bashir AH. Wound closure by skin traction: an application of tissue expansion. *Br J Plast Surg.* 1987;40:582–587.
9. Hussmann J, Kucan JO, Zamboni WA. Elevated compartmental pressures after closure of a forearm burn wound with a skin-stretching device. *Burns J Int Soc Burn Inj.* 1997;23:154–156.
10. Liang MD, Briggs P, Heckler FR, et al. Presuturing—a new technique for closing large skin defects: clinical and experimental studies. *Plast Reconstr Surg.* 1988;81:694–702.
11. Cohen M, Shafir R. Alopecia: an unfavorable result of using a skin-stretching device. *Plast Reconstr Surg.* 1995;96:747–748.
12. Zhang M, Wang D, Hao L, et al. The development of skin external expander and clinical applications. *Chin J Plast Surg.* 1995;11:161–164.
13. Hirshowitz B, Lindenbaum E, Har-Shai Y. A skin-stretching device for the harnessing of the viscoelastic properties of skin. *Plast Reconstr Surg.* 1993;92:260–270.
14. Zhou L, Li Z, Guo S, et al. Biomechanical and histomorphologlcal changes in stretched pig skin. *Chin J Aesthetic Med.* 2000;4:244–246+250.
15. Risnes I, Abdelnoor M, Lundblad R, et al. Leg wound closure after saphenous vein harvesting in patients undergoing coronary artery bypass grafting: a prospective randomized study comparing intracutaneous, transcutaneous and zipper techniques. *Scand Cardiovasc J.* 2002;36:378–382.
16. Li J, Wang B, Chen M, et al. Development and clinical application of micro skin stretcher. *Chin J Plast Surg.* 2003;2:70.
17. Barnea Y, Gur E, Amir A, et al. Delayed primary closure of fasciotomy wounds with wisebands, a skin- and soft tissue-stretch device. *Injury.* 2006;37:561–566.
18. Topaz M, Carmel NN, Silberman A, et al. The TopClosure® 3S system, for skin stretching and a secure wound closure. *Eur J Plast Surg.* 2012;35:533–543.
19. Guo Y, Lu Y, He P, et al. Clinical application of children distraction apparatus. *Henan J Surg.* 2013;19:17–19.
20. Song M, Zhang Z, Liu T, et al. EASApprox® skin-stretching system: a secure and effective method to achieve wound closure. *Exp Ther Med.* 2017;14:531–538.
21. Chen Q. Treatment of 16 cases of skin defect by stretch regeneration according to law of tension stress. *Chin J Orthop Trauma.* 2018;20:537–540.
22. Dong Q, Gu G, Wang L, et al. Application of modified adjustable skin stretching and secure wound-closure system in repairing of skin and soft tissue defect. *Chin J Reparative Reconstr Surg.* 2017;31:1481–1484.
23. DermaClose. Wound Closure & Nerve Repair Devices | Nerve Regeneration Device. Available at https://dermaclose.com/. Accessed July 2, 2023.
24. Qin W, Liu K, Su H, et al. Tibial cortex transverse transport promotes ischemic diabetic foot ulcer healing via enhanced angiogenesis and inflammation modulation in a novel rat model. *Eur J Med Res.* 2024;29:155.
25. Wilhelmi BJ, Blackwell SJ, Mancoll JS, et al. Creep vs. stretch: a review of the viscoelastic properties of skin. *Ann Plast Surg.* 1998;41:215–219.
26. Huang K, Zeng Y, Xia H, et al. Alterations in the biorheological features of some soft tissues after limb lengthening. *Biorheology.* 1998;35:355–363.
27. Monemian Esfahani A, Rosenbohm J, Reddy K, et al. Tissue regeneration from mechanical stretching of cell-cell adhesion. *Tissue Eng Part C Methods.* 2019;25:631–640.
28. Tian H, Li S, Jia W, et al. Risk factors for poor hemostasis of prophylactic uterine artery embolization before curettage in cesarean scar pregnancy. *J Int Med Res.* 2020;48:300060520964379.

29. Humphrey JD, Dufresne ER, Schwartz MA. Mechanotransduction and extracellular matrix homeostasis. *Nat Rev Mol Cell Biol*. 2014;15:802–812.
30. Charras G, Yap AS. Tensile forces and mechanotransduction at cell-cell junctions. *Curr Biol*. 2018;28:R445–R457.
31. Buckley CD, Tan J, Anderson KL, et al. Cell adhesion. The minimal cadherin-catenin complex binds to actin filaments under force. *Science*. 2014;346:1254211.
32. Jurado J, de Navascués J, Gorfinkiel N. α-Catenin stabilises cadherin-catenin complexes and modulates actomyosin dynamics to allow pulsatile apical contraction. *J Cell Sci*. 2016;129:4496–4508.
33. Huang DL, Bax NA, Buckley CD, et al. Vinculin forms a directionally asymmetric catch bond with F-actin. *Science*. 2017;357:703–706.
34. Song G, Ju Y, Soyama H, et al. Regulation of cyclic longitudinal mechanical stretch on proliferation of human bone marrow mesenchymal stem cells. *Mol Cell Biomech*. 2007;4:201–210.
35. Chen Z, Jin M, He H, et al. Mesenchymal stem cells and macrophages and their interactions in tendon-bone healing. *J Orthop Translat*. 2023;39:63–73.
36. Guo Y, Song Y, Xiong S, et al. Mechanical stretch induced skin regeneration: molecular and cellular mechanism in skin soft tissue expansion. *Int J Mol Sci* . 2022;23:9622.
37. Kippenberger S, Loitsch S, Guschel M, et al. Mechanical stretch stimulates protein kinase B/Akt phosphorylation in epidermal cells via angiotensin II type 1 receptor and epidermal growth factor receptor. *J Biol Chem*. 2005;280:3060–3067.
38. Huo R, Yang W, Shangbin L, et al. A microscopic and biomechanical study of skin and soft tissue after repeated expansion. *Dermatol Surg*. 2009;35:72–79.
39. Shen Z, Chen S, Duan Y, et al. Application of adjustable skin stretchers in repairing wound-related defects. *Clin Cosmet Investig Dermatol*. 2023;16:2409–2417.
40. Misra JR, Irvine KD. The hippo signaling network and its biological functions. *Annu Rev Genet*. 2018;52:65–87.
41. Wang J, Zhang Y, Gao Y, et al. EZH2 regulates the correlation between skin regeneration and the duration of mechanical stretch. *J Invest Dermatol*. 2021;141:894–902.e9.
42. Koontz LM, Liu-Chittenden Y, Yin F, et al. The hippo effector Yorkie controls normal tissue growth by antagonizing scalloped-mediated default repression. *Dev Cell*. 2013;25:388–401.
43. Meng Z, Moroishi T, Guan KL. Mechanisms of Hippo pathway regulation. *Genes Dev*. 2016;30:1–17.
44. Dasgupta I, McCollum D. Control of cellular responses to mechanical cues through YAP/TAZ regulation. *J Biol Chem*. 2019;294:17693–17706.
45. Stern CD. Neural induction: old problem, new findings, yet more questions . *Development (Cambridge, England)*. 2005;132:2007–2021.
46. Houschyar KS, Borrelli MR, Tapking C, et al. Molecular mechanisms of hair growth and regeneration: current understanding and novel paradigms. *Dermatology*. 2020;236:271–280.
47. Zhu XJ, Liu Y, Dai ZM, et al. BMP-FGF signaling axis mediates Wnt-induced epidermal stratification in developing mammalian skin. *PLoS Genet*. 2014;10:e1004687.
48. Long T, Li C, Xu F, et al. Therapeutic efficacy of platelet-rich fibrin on surgical site wound healing in patients undergoing oral carcinoma resection: a meta-analysis. *Int Wound J*. 2024;21:e14386.
49. Ledwon JK, Kelsey LJ, Vaca EE, et al. Transcriptomic analysis reveals dynamic molecular changes in skin induced by mechanical forces secondary to tissue expansion. *Sci Rep*. 2020;10:15991.
50. Kimura S, Tsuji T. Mechanical and immunological regulation in wound healing and skin reconstruction. *Int J Mol Sci* . 2021;22:5474.
51. Nakamura Y, Matsuzaka T, Tahara-Hanaoka S, et al. Elovl6 regulates mechanical damage-induced keratinocyte death and skin inflammation. *Cell Death Dis*. 2018;9:1181.
52. Devalaraja RM, Nanney LB, Du J, et al. Delayed wound healing in CXCR2 knockout mice. *J Invest Dermatol*. 2000;115:234–244.
53. Korbecki J, Kupnicka P, Chlubek M, et al. CXCR2 receptor: regulation of expression, signal transduction, and involvement in cancer. *Int J Mol Sci* . 2022;23:2168.
54. Furue M, Furue K, Tsuji G, et al. Interleukin-17A and keratinocytes in psoriasis. *Int J Mol Sci* . 2020;21:1275.
55. Rath-Deschner B, Memmert S, Damanaki A, et al. CXCL5, CXCL8, and CXCL10 regulation by bacteria and mechanical forces in periodontium. *Ann Anat*. 2021;234:151648.
56. Nazet U, Feulner L, Muschter D, et al. Mechanical stress induce PG-E2 in murine synovial fibroblasts originating from the temporomandibular joint. *Cells*. 2021;10:298.
57. Rother U, Müller-Mohnssen H, Lang W, et al. Wound closure by means of free flap and arteriovenous loop: Development of flap autonomy in the long-term follow-up. *Int Wound J*. 2020;17:107–116.
58. Agostini T, Lazzeri D, Spinelli G. Anterolateral thigh flap: systematic literature review of specific donor-site complications and their management. *J Craniomaxillofac Surg*. 2013;41:15–21.
59. Trevatt AEJ, Filobbos G, Ul Haq A, et al. Long-term sensation in the medial plantar flap: a two-centre study. *Foot Ankle Surg*. 2014;20:166–169.
60. Demir A, Kucuker I, Keles MK, et al. The effect of learning curve on flap selection, re-exploration, and salvage rates in free flaps; a retrospective analysis of 155 cases. *Microsurgery*. 2013;33:519–526.
61. Hansen N, Espino S, Blough JT, et al. Evaluating mastectomy skin flap necrosis in the extended breast reconstruction risk assessment score for 1-year prediction of prosthetic reconstruction outcomes. *J Am Coll Surg*. 2018;227:96–104.
62. Xu J, Chang R, Zhang W, et al. Skin stretch suturing with Nice knots in the treatment of small- or medium-sized wounds. *J Orthop Surg Res*. 2020;15:488.
63. Futran ND. Closure of the fibula free flap donor site with the sure-closure skin-stretching device. *Laryngoscope*. 1996;106:1487–1490.
64. Lei Y, Liu L, Du S, et al. The use of a skin-stretching device combined with vacuum sealing drainage for closure of a large skin defect: a case report. *J Med Case Rep*. 2018;12:264.
65. Ogawa Y, Kasai K, Doi H, et al. The preoperative use of extra-tissue expander for syndactyly. *Ann Plast Surg*. 1989;23:552–559.
66. Zhang Q, Xu L, Liu Y, et al. Application of skin-stretching device for closing scalp defect. *J Craniofac Surg*. 2023;34:374–380.
67. Wang L, Wang C, Chen H, et al. The combined use of a non-invasive skin-stretching device and the negative-pressure wound therapy technique in the treatment of postoperative diabetic foot. *Diabetes Metab Syndr Obes*. 2021;14:3523–3532.
68. Zhu Z, Yang X, Zhao Y, et al. Early surgical management of large scalp infantile hemangioma using the TopClosure® tension-relief system. *Medicine (Baltim)*. 2015;94:e2128.
69. Zhu Z, Zhao Y, Li A, et al. The clinical application of the TopClosure ® skin stretch closure device in the repair of large area skin defect of chest wall. *J Clin Surg*. 2017;25:630–633.
70. Verhaegen PDHM, Bloemen MCT, van der Wal MBA, et al. Skin stretching for primary closure of acute burn wounds. *Burns*. 2014;40:1727–1737.
71. Zhu Z, Zhao Y, Li A, et al. The clinical research of the skin stretching system in the reconstruction of the chest wall after resection of locally advanced breast cancer. *J Clin Surg*. 2016;24:179–182.
72. Cheng L, Lee J, Hsu H, et al. Simple skin-stretching device in assisted tension-free wound closure. *Ann Plast Surg*. 2017;78:S52–S57.
73. Chen J, Yan Z, Zhong G, et al. Application of skin stretcher for repair of postoperative skin and soft tissue defects in tibial fractures. *Chin J Reparative Reconstr Surg*. 2018;32:596–600.
74. Zhang D, Song W, Chen X, et al. Application value of adjustable skin stretcher used for repairing the wound area of the femoral anterior lateral flap. *Chin J Bone Jt Surg*. 2018;11:124–126+132.

75. Ji P, Zhang Y, Hu DH, et al. Clinical effects of combined application of skin-stretching device and vacuum sealing drainage in repairing the diabetic foot wounds. *Chin J Burns*. 2020;36:1035–1039.
76. MacKay BJ, Dardano AN, Klapper AM, et al. Multidisciplinary application of an external tissue expander device to improve patient outcomes: a critical review. *Adv Wound Care*. 2020;9:525–538.
77. Janis JE, Kwon RK, Attinger CE. The new reconstructive ladder: modifications to the traditional model. *Plast Reconstr Surg*. 2011;127:205S–212S.
78. Bonaparte JP, Corsten M, Allen M. Cost-effectiveness of a topically applied pre-operative tissue expansion device for radial forearm free flaps: a cohort study. *Clin Otolaryngol*. 2011;36:345–351.
79. Medina C, Spears J, Mitra A. The use of an innovative device for wound closure after upper extremity fasciotomy. *Hand (New York, N.Y.)*. 2008;3:146–151.
80. Topaz M, Ashkenazi I, Barzel O, et al. Minimizing treatment complexity of combat-related soft tissue injuries using a dedicated tension relief system and negative pressure therapy augmented by high-dose in situ antibiotic therapy and oxygen delivery: a retrospective study. *Burns Trauma*. 2021;9:tkab007.
81. Barnea Y, Gur E, Amir A, et al. Our experience with Wisebands: a new skin and soft-tissue stretch device. *Plast Reconstr Surg*. 2004;113:862–869; discussion 870.
82. Safa B, Belson A, Meschter C, et al. In vivo efficacy study showing comparative advantage of bacterial infection prevention with zip-type skin closure device vs. Subcuticular sutures. *Cureus*. 2018;10:e3102.
83. Armstrong DG, Sorensen JC, Bushman TR. Exploiting the viscoelastic properties of pedal skin with the sure closure skin stretching device. *J Foot Ankle Surg*. 1995;34:247–253.