

# Advancements in skin grafting: Development and application of a novel two-blade dermatome for concurrent split-thickness and dermal graft harvesting

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## ARTICLE INFO

**Keywords:**  
Skin graft  
Dermatome  
Dermal graft  
Donor site

## ABSTRACT

This investigation delineates the evolution and prospective utilisation of an innovative two-blade dermatome, designed for the concurrent harvesting of a conventional split-thickness skin graft (STSG) and an additional dermal graft within the same surgical harvest. Historically, the extraction of dermal grafts has encountered substantial technical impediments, contributing to its limited acceptance and utilisation in clinical practice. The prototype dermatome, introduced in this technical note, offers a solution that could facilitate the more extensive adoption of dermal grafting techniques.

The dermal segment of an STSG, obtained as a second graft, confers four notable advancements: First, employing solely the dermal component for grafting and repositioning the uppermost skin flap to the donor site, markedly diminishes donor site morbidity. Second, owing to its elasticity, the dermal graft reduces the need for meshing, thereby enhancing cosmetic outcomes. Third, utilising both the uppermost skin layer and a deeper dermal layer for the recipient site can reduce donor site areas. Fourth, the dermal segment of the graft can serve as a dermal matrix in reconstructive procedures, potentially reducing the need for an allogenic dermal matrix and obviating the subsequent STSG; the dermal graft may heal independently, eliminating the need for an additional conventional STSG.

The findings of this study, predicated on the application of a first-generation two-blade dermatome on four cadavers, demonstrate the feasibility of extracting at least two distinct grafts with pre-determined thicknesses in a single, technically less challenging, surgical harvest procedure.

In conclusion, this proof-of-concept research elucidates the feasibility of a two-blade dermatome, capable of simultaneously yielding at least one conventional STSG and one dermal graft, thereby simplifying skin graft harvesting. Although these preliminary investigations were conducted on human cadavers, the results hold promise for the development of two-blade dermatomes and represent a significant advancement in skin graft harvesting. Further research is imperative to refine the prototype and to broaden our comprehension of the potential applications of dermal grafting in various clinical scenarios.

## 1. Introduction

Skin grafting remains an essential and beneficial method to address

skin defects, regardless of their origin or location. Among the wide variety of graft types utilised in reconstructive surgery, the STSG (split-thickness skin graft) sees the most frequent use and exhibits the widest

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range of applications in routine surgical care, including burns and coverage of large skin defects.

The STSG, essentially a detached segment of cutaneous tissue, relies on capillary ingrowth to survive. Although the concept of skin grafting has been acknowledged for 2500 years, the technique emblematic of contemporary STSG methodology was initially documented by Ollier de Lyon in 1872 [1].

Notably, the core principles of this technique have endured for over 150 years. However, it is far from flawless, with four major shortcomings. First, there are issues pertaining to donor site morbidity, especially in the elderly [2], an area of growing concern. Second, there is recipient site scarring mostly due to the need for a meshing procedure to expand the skin graft. Third, there is very commonly, e.g., in burn care and in large skin defects, a lack of available tissue to use for the STSG. Furthermore, a common complication to conventional skin grafting is healing with a contracture, not least in the areas of the neck and over large joints [2–6].

In cases with high risk of contractures (e.g. over large joints, head and neck area), artificial dermal substitutes have been used [7,8]. However, recent data from a well done prospective randomized controlled trial (the control was the STSG) strongly suggested that the gains from artificial dermal matrices are very limited for contracture treatment. The data even supported the regular STSG to be superior. With this context, and with the knowledge that STSG not uncommonly heal by contracture, an autologous dermal matrix generated by means of the dermal graft procedure may prove valuable and should be evaluated. Another advantage is that the dermal graft fully heals in one procedure and does not need a second STSG for coverage, as does the artificial matrix material [9,10].

All these above listed issues when working with STSG are particularly problematic in the field of burns. Troubles here manifest not only as a scar contraction after STSG, but also as the frequent mesh pattern observed post-transplantation, which exacerbates non-optimal healing, or more specifically, creates dissatisfying scars. Harvesting STSG commonly leaves a conspicuous texture difference or colour mismatch (except in the scalp area) on the donor site and may result in troublesome scarring or discolouration, especially after donor site infection or the harvest of thick grafts. Complications are well known and described, particularly in the elderly [2].

The potential benefits of the dermal graft (DG) technique include faster healing and reduced healing trajectory at the donor site; improved cosmetic outcome due to fewer meshing procedures (at the recipient site); greater flexibility in donor site selection with increased tissue grafting material (for large skin defects) and finally; it allows for the availability of dermal matrices for reconstructive surgery – all of which present a compelling case for further exploration [11].

The meshing procedure, which is commonly applied to cover larger areas than the donor site, is necessitated by the inherent inelasticity of the STSG, specifically its inability to expand and where large areas need to be covered. This procedure is bypassed, as an exception, in facial grafts. Here for aesthetic reasons, an unmeshed, non-expandable mesh graft, or sheet graft, is preferred to minimise the unpleasant mesh pattern associated with increased risk of severe scarring [12,13]. As a consequence, some surgeons now chose to not utilise the meshing procedure at the cost of increased donor sites [12]. Additionally, sheet grafts may also be used for functional purposes in order to reduce contraction [14] over areas such as larger joints, neck, hands, fingers, axilla, elbows, feet and toes. With this said, the thicker dermis graft may play a major benefit in reconstruction over these areas.

Indeed, the use of a dermis graft for the recipient site has been explored in the literature [15,16]. Here, the skin is harvested in two layers from the same site: a conventional split-thickness skin graft from the superficial layer, including a thin STSG with minimal dermal component, and a dermal graft from the deeper layer.

The superficial portion is returned to the donor site, while the dermal part is transplanted on to the recipient site. This method has garnered

considerable interest of late due to its favourable features addressing both donor and recipient site issues inherent in the traditional STSG procedure. The elasticity of the dermal graft, in particular, is promising, and potentially facilitates an expandable graft, thereby mitigating, if not completely eliminating, the necessity of a mesh procedure [11].

In the most recent studies, it has been underscored that despite the methodological advantages of the multi grafting technique, its technical complexity has hindered widespread adoption [17,18]. The complexities associated with this technique can be summarized as follows:

Modern dermatomes typically feature a solitary blade with an adjustable width ranging between 5 to 15 cm, often fixed at 7.5 cm (3 in.). Thus, several grafting procedures on the same site are needed to yield two or more grafts (STSG and dermis graft). Harvesting the second graft includes technical challenges for the surgeon [11,17]. First among these is the angle of the dermatome blades towards the skin surface along the initial passage, requiring near millimetric precision and a firm hand grip. Any misalignment most often results in overlap, and produces fragmented skin pieces. Secondly, the less firm and less pliable skin texture for the second graft increases the risk of overlap and fragmentation of the dermal skin graft.

Such difficulties led to substantial hurdles in patient recruitment in a previous study due to a dearth of proficient surgeons and extended operation times arising from technical impediments. Albeit the technique has been favourably described repeatedly in publications from 1954 it has not been properly implemented in clinical practice discouraged due to its inherent technical intricacies.

Similar techniques has been presented before. The bilaminar “trap-door” method by removing a thin dermal graft after epidermal-dermal elevation in the palmar or the plantar regions have demonstrated advantages such as less surgical time, minimal donor site morbidity, graft integration as well as maintenance both in donor and recipient areas. Especially the favourable healing of the grafted area has been commented upon [19].

The objective of this study was to elucidate the process involved in developing a two-blade dermatome and to present the preliminary results yielded by this prototype when employed on human cadavers. The intent of this prototype is to facilitate the simultaneous production of a conventional STSG and a dermal graft during a single and simple surgical harvest procedure. Additionally, we seek to document the thickness of the grafts and examine the physical appearance, elasticity, and histomorphology with dimensions ranging from 7.5 × 15 cm to 7.5 × 30 cm. An exploratory endpoint was to obtain a thicker dermal graft with the ambition to investigate the possibility to obtain dermal tissue for reconstructive purposes.

## 2. Method

### 2.1. Dermatome construction

A skin dermatome is a technically intricate device demanding high precision. This is illustrated by the standard thickness of a split-thickness graft, which typically ranges between 0.203 mm (8/1000 in.) for a thin graft to 0.305 mm (12/1000 in.) for a thick graft. The present experiments were geared towards producing thicker grafts. It was recognised early that our initial endeavour should aim to modify an existing commercially available device. For this purpose, the following commercially available dermatomes were evaluated: Zimmer®, Padget®, Humby Knife®, Brown®, Watson®, Humecca®, Aygun®, De Soutter Medical®, and Nouvag®. The Nouvag dermatome was selected due to the following attributes: it is electrically powered, has a high blade oscillation frequency (4000 Hz), possesses a drive arm for the blades that can be readily modified to handle two or more cutting blades, and lastly, the producer asserted that the device is easy to operate, even with limited training.

The subsequent step was to modify the dermatome to function with two blades prior to clinical trials (Fig. 1). This task was undertaken by

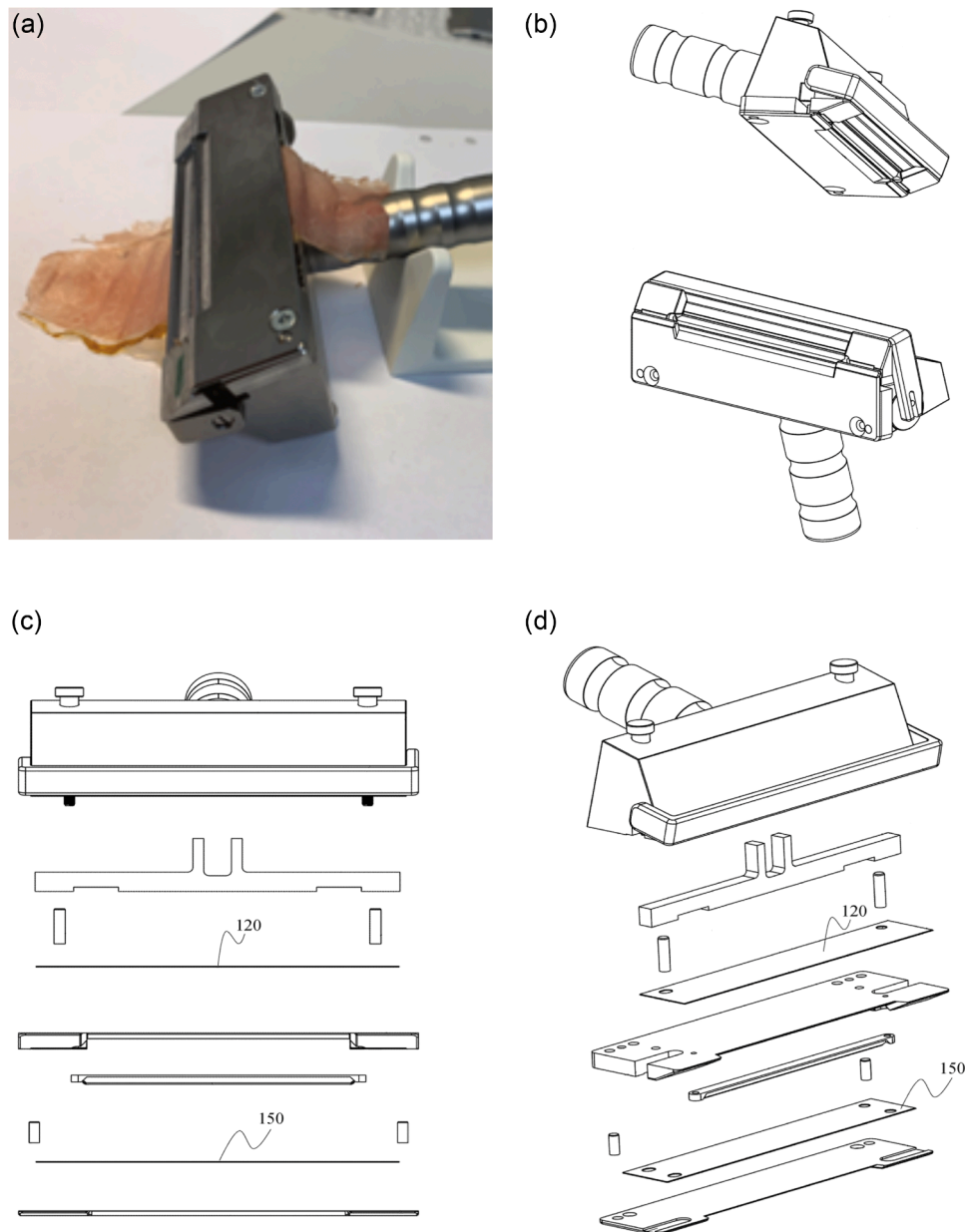


**Fig. 1.** A) The dermatome overview picture exposing the cutting perspective, i.e., two oscillating blades and the skin passing through the dermatome. B) The original patent figures show the dermatome from two angles. C) and D) show the two cutting blades in detail from two angles, marked with number 120 and 150 in the original patent figures.

Scanfil Åtvidaberg AB, Åtvidaberg, Sweden, a micro-mechanical company. The work centred on three crucial points: 1. The construction of a drive arm capable of supplying power and oscillations to two blades; 2. The addition of a new holder and orifice for skin cutting in the same dermatome cutting house; and 3. The creation of a mechanism capable of determining and setting the thickness of the dermal graft. This was completed ahead of the planned experiments first on tissue *ex vivo* and thereafter on cadavers. Initial experiments were conducted on *ex vivo* human tissue discarded post-surgery, primarily from abdominoplasty operations (data not shown).

## 2.2. The dermatome prototype

The dermatome (Nouvag©) underwent several mechanical modifications. The primary changes were as follows:

1. The initial singular drive arm was complemented (the drive arm was made stronger) geared at driving the two distinct blades.
2. The metal housing, originally designed to accommodate a single blade, was adjusted to host two separate blades. These were tailored to be powered effectively by the newly fashioned drive arm.
3. An additional opening for tissue exposure was created for the second blade. Importantly, this opening slit was designed to be adjustable to permit alterations in the thickness of the second graft, termed the 'dermagraft'.

It needs to be pointed out that the total increase in weight for this add-on is very limited as the two metal parts of the metal housing are the metal blade around the second dermatome opening and the second blade. In future versions an adjustable opening mechanism might be preferable in order to be able to easily change the thickness of the dermal graft.

### 2.3. Human material

Cadavers were obtained from the Department of Pathology, Linköping University Hospital, Linköping, Sweden, following the acquisition of informed consent from next of kin. Split-thickness skin grafts including dermal grafts were harvested from the thorax, back, and extremities. The grafts were evaluated for physical appearance, including elasticity, at the morgue. The grafts were also subjected to histopathological examination.

Briefly, the grafts were fixed in 4 % paraformaldehyde, dehydrated and embedded in paraffin. The sections were stained with hematoxylin and eosin and photographed with Imageview software version X64 (Olympus Corp., Japan). Photos from 13 STSG and 7 dermal biopsies were analysed for epidermal thickness with the analysis function of Adobe Photoshop 2023. In average, twelve readings were obtained per section.

### 3. Results

The results outlined below are derived from skin grafting procedures conducted on four cadavers with the two-blade dermatome. As depicted in Fig. 2, three parallel incisions were made on one extremity, producing corresponding grafts. The superficial layer corresponds to the conventional STSG, while the deeper layer represents the dermal graft. The deeper dermal graft has its characteristic less rigid texture and can due to their more elastic properties be expanded.

Histological characterization showed clear distinction of the upper layer with epidermal architecture and the lower layer with its dermal components (Fig. 3). The median thickness of the upper graft was 309  $\mu\text{m}$  while that for the lower graft was 424  $\mu\text{m}$  (Fig. 4).

### 4. Discussion

This manuscript delineates the inception of preliminary data and the developmental trajectory of a novel two-blade dermatome designed to concurrently harvest a conventional STSG and a dermal graft during a skin graft procedure. It asserts the viability of designing a dermatome capable of facilitating the acquisition of dual skin grafts, thus overcoming the technical challenges associated with the use of conventional dermatomes for dermal graft harvesting, challenges which have

previously limited its extensive clinical application [11,17].

The immediate beneficiaries of this technological innovation include patients within plastic surgery realms requiring grafts for small areas, such as those resulting from tumour excisions or minor burns. This demographic often encompasses elderly individuals, who present a heightened risk of complications in donor site healing. The extent of donor site healing complications has recently been highlighted [20].

The rapid healing of the donor site, attributable to the reapplication of the thin STSG to the donor site, diminishes the risk of infection and protracted healing durations. Moreover, the dermal graft's enhanced elasticity potentially obviates the need for meshing, thus promising superior cosmetic outcomes akin to sheet grafts [12].

Not surprisingly, the dermis graft technique is not new and great potential for improvement exists. By developing a device that might ease the handling and harvesting procedure, it can be of great benefit to certain patients. Donor sites should be addressed with accuracy taking into account the thickness of skin in different part of the body. Marques et al. presented four cases with a bilaminar trapdoor technique being a good option for the reconstruction of palmar-plantar wounds. With this context, dermal grafts might provide good outcomes related to the features of healing of the grafted wound bed and moreover, less morbidity on the donor site [19].

Additionally, individuals with large skin defects, such as those sustained from burns or major surgical interventions, stand to benefit from the increased tissue availability during grafting procedures, thereby reducing the requisite donor areas. This effect could be further enhanced with a two-blade construction providing more than two grafts in the same grafting procedure.

A notable application of the two-blade dermatome includes its utility in reconstructive surgery, traditionally reliant on allogenic materials [21].

The inherent qualities of the dermal component harvested through this technique, particularly its inclusion of appendages, confer it the potential for spontaneous healing without necessitating a conventional STSG overlay on allogenic dermal material.

Despite these promising advancements, certain challenges persist with the dermal grafting technique. The complexity of this technique has, to date, when based on conventional dermatomes, limited its documentation across patient cohorts [11,17]. Initial explorations should target patients with minor skin defects to ascertain the dermal



Fig. 2. Three conventional STSGs to the left and the corresponding three dermal grafts to the right harvested with the two-blade dermatome.

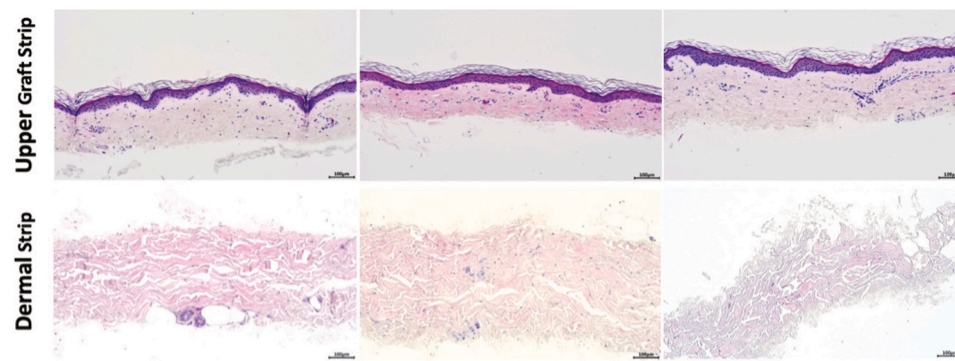


**Fig. 3.** Hematoxylin and eosin (H&E) staining of the conventional STSGs (upper section of the figure) and dermal grafts (lower section of the figure) showed the characteristic histological pattern of epidermis and upper dermis area as well as the pure dermal morphology, respectively. The uniformity in the graft width was also evident.

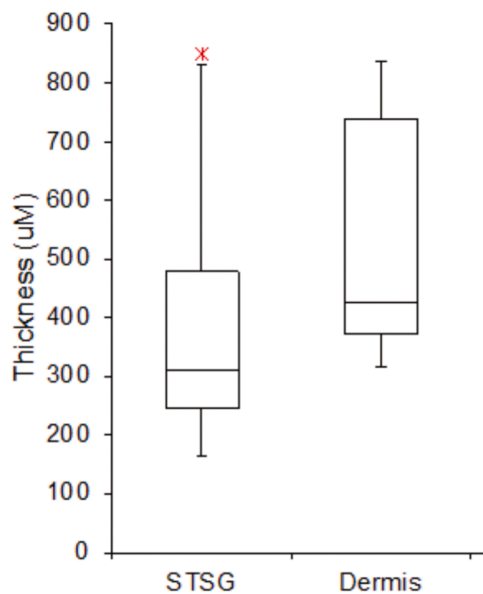


**Fig. 4.** The thickness of the different graft types is displayed (median and quartiles). \* represents the maximum outlier.

graft's expansibility, currently expected to be 1:1.5. Further investigations are warranted to elucidate the impact of a thicker dermal graft on expansibility and to assess its application in larger defects to quantify the additional surface area coverable with material from two layers.

Regarding the technical specifications of the dermatome, additional exploration is required. Contemporary dermatomes achieve a specified precision in the thickness of conventional grafts. In the prototype introduced, the blades were calibrated to extract a dermal graft of intermediate thickness. However, Fig. 3 demonstrates some variation in this regard. The mechanism for adjusting graft thickness, which involves the integration of metal blades between the cutting blade and the dermatome head, needs refinement for simpler thickness modification. Additionally, a more potent dermatome might be necessary to accommodate the incorporation of more than two blades. The challenge lies in procuring thin dermal grafts that maintain adequate quality and expandability, particularly when not meshed, to effectively serve as coverage of skin defects.

Considering the historical perspective, the STSG technique has witnessed few improvements over the past 150 years. The concept of a dermal graft, proposed as early as 1954 [13], and which have not yet reached common use due to the technical difficulties in obtaining

dermal grafts, may now find broader application with the advent of the dermatome described herein. The utilisation of the dermal graft could be significantly advanced, given its anatomical benefits, such as the presence of more potent skin cells and stem cells, in conjunction with appendages.

The aesthetic concerns of patients regarding scar appearance, particularly in the head, neck, upper extremities (including the axillary region), and lower extremities near joints, are well-documented. [22]. A complete revision includes the release of the scar contracture and resurfacing of the resulting defect. With this said, the DG, with its thicker and more pliable tissue and minimal donor site morbidity may be a promising option for reconstruction of for example burn scar contractures. Ideal reconstruction yielding a good functional and aesthetic result depends on the extent of the defect.

Hypertrophic scars, the most common type, persist despite various treatment modalities like local steroids, laser therapy, radiotherapy, and surgery, with high recurrence rates [14]. The introduction of a dermal graft at the recipient site post-scar revision could circumvent the exposure of donor sites and eliminate the need for flap surgery, representing an intriguing area for further exploration. To our knowledge, donor site morbidity, a significant issue particularly for burn patients, could potentially be mitigated with the dermal graft technique [6].

The market offers a plethora of dermal substitutes, increasingly integral to burn treatment strategies, improving both functional and aesthetic outcomes during the acute phase [15]. Contrasting with these substitutes, the dermal graft represents an autologous option that may offer superior cost-effectiveness and cosmetic outcomes as a reconstructive alternative in burn scar treatment. Its elasticity, allowing for the expansion of the dermal graft and possibly averting a mesh-pattern, is an additional benefit previously highlighted [6]. Referring to Almeida and Correas study the use of dermal matrices did not reduce burn scar contractions and their utility should be considered [9,10]. With this said, bypassing dermal substitutes and a second step procedure by using a dermal graft for burn scar reconstruction might be beneficial and time-saving.

Histopathological evaluation in this study elucidates the structural composition of both the DG and STSG. The DG displays a loose meshwork of collagen fibres, devoid of an epithelial layer. The success of dermal grafts, as established in prior research, hinges on both the loose texture facilitating expansion and the remnants of appendages like hair follicles, sweat glands, and sebaceous glands, along with their epithelial lining, which facilitates surface migration and subsequent healing [10, 12]. The uniform thickness and continuity of grafts from both layers affirm the efficacy of the novel double-bladed dermatome.

Dermal substitutes are widely used in reconstructive surgery, both Integra and BTM (Biodegradable Temporising Matrix) is fully synthetic materials that can be used in combination with skin grafts to cover wounds associated with tendon, bone or joint exposure. These

mentioned grafts are thicker than the thickness to the dermal graft [23]. The dermal graft can on the other hand be used without supplementary templates which may be an advantage [24].

Lastly, the advantage with the dermatome prototype presented in this proof of principle is that it should hold an extra opening and adjustment possibilities so that you could use it either as a regular (one-blade) and when needed as a two-blade alternative. The stronger drive-arm might facilitate the harvest precision with less tension on the tissue. In the developmental process we will also investigate the possibility of a third opening for the third and multiblade setup.

#### 4.1. Limitations

The two-blade dermatome device has, to date, been exclusively tested on cadavers, a fact that may constrain its applicability, given the dissimilarities between cadaveric and living tissues. However, the findings from these initial trials suggest that the device's operation is straightforward, and quality grafts can be harvested with less technical complexity than with a conventional dermatome. The discrepancy in tissue texture between cadavers and living humans, particularly the lack of identical skin tonus, may influence the interpretation of the results. However, the histopathological results presented in this study show a high similarity to those seen with STSG in living humans [11]. Another drawback is that the method has not been evaluated on toddlers. This group should be evaluated as a separate group because of their anatomical skin characteristics that distinguish them from adults.

In summary, this proof-of-concept research highlights the viability of a two-blade dermatome, capable of concurrently procuring at least one conventional STSG and one dermal graft. This innovation simplifies the skin graft harvesting procedure and offers multiple advantages over the conventional STSG technique. Notably, it has the potential to diminish donor site morbidity and enhance cosmetic outcomes at the recipient site, particularly as the dermal graft does not require meshing due to its inherent elasticity, also being able to produce thicker grafts with less recoil and contraction. Moreover, the dermal graft technique can yield larger volumes of tissue for transplantation in scenarios necessitating extensive coverage, such as in cases of trauma and burns. The dermal graft component also possesses unique properties conducive to reconstructive surgery, presenting a novel application within the realm of STSG. While these initial investigations were conducted on human cadavers, the findings are promising and indicate a significant advancement in STSG methodologies. Further research is crucial to refine the prototype and to expand our understanding of the potential applications of dermal grafting across diverse clinical scenarios, where dermal grafts may offer significant benefits.

#### Ethical Approval

All methods were carried out in accordance with relevant guidelines and regulations. The study was approved by the Swedish Ethical Review Authority (Dnr 2020–01745). Informed consent was obtained from the from next of kin of all subjects.

#### Author credit

On behalf of the authors, I confirm that the manuscript has been seen and approved by all authors. All authors contributed substantially to this work. Study conception and design: S.D., F.S., M.E., J.V., A.L., acquisition, analysis, or interpretation of data: S.D., F.S., Z.S., A.T.E., J.V., I.A., A.L., drafting of the manuscript: S.D., F.S., A.T.E., M.E., J.V., I.S., M.K., A.L., revising it critically for important intellectual content: S.D., F.S., A.

T.E., Z.S., I.A., I.S., M.K., P.O., A.L., J.V., M.E.

#### Funding

Linköping University and Linköping University Hospital, Linköping, Sweden. Lead (<https://lead.se/>); Medtech4Health (<https://medtech4health.se/>); VINNOVA, Swedish Governmental Agency for Innovation Systems, 2017.

The paper has not been presented at any conferences yet.

#### Conflict of Interest

The authors declare that there is no conflict of interest.

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