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Graft orientation influences meshing ratio

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ABSTRACT

Objectives: The technique of meshed skin grafting is known since 1960s. It was shown that there is a difference between the declared and real expansion ratio of the skin meshed graft. We hypothesize that the orientation of the Langer's lines in a split thickness skin graft is a key parameter in the resulting expansion ratio.
Methods: The skin graft meshing process was analyzed in two steps. In the first step, *ex vivo* uniaxial tests of human skin were performed. This served as an input for the constitutive model used for numerical simulations. In the second step, finite element analyses were performed so that stress distributions and expansion ratios could be determined.
Results: It was shown that peaks of true stress tended to be concentrated around the vertex of the mesh pattern region for all cases. The declared expansion was impossible to obtain for all expansion ratios having the meshing incision perpendicular to the Langer's lines. The highest difference between declared and real expansion ratio reaches 37%.
Conclusions: With regard to literature dealing with expansion of skin grafts by meshing, a high scatter amongst data results is observed. This finding was also explained by our research, demonstrating the significance of Langer's lines and their relative orientation to the direction of meshing.

1. Introduction

Split thickness skin grafting is a mainstay surgical technique for soft tissue reconstruction worldwide. In cases of large defects or limited donor site availability, the classic example being major burn injuries, skin grafts may be expanded beyond their original geometry. This permits a smaller graft to reconstruct a larger defect. Principally, there are two techniques used for skin expansion: tissue expansion, and skin graft meshing [1,2]. The first technique consists of overstretching the skin by gradual mechanical distention, usually in the form of a surgically inserted underlying silicone implant that is progressively expanded. This procedure is slow and usually takes several weeks, but allows skin to be expanded without significant attenuation of thickness [3]. The biomechanics of tissue expansion have also been studied through the use of computational models [4,5]. In contrast, meshing consists of the patterned placement of innumerable uniform short parallel incisions into a sheet of graft, usually through a specialized roller device. The incisions open upon application

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of perpendicular stretch, producing a regular pattern of rhomboid interstices. These two approaches therefore utilize fundamentally different biomechanical principles. The first creates new tissue through a slow, guided biological process, while the second one simply maximises the use of existing tissue through immediate mechanical means. While tissue expansion is well documented in the medical literature, there is a relative dearth of research on skin expansion through meshing.

The technique of meshed skin grafting was first introduced by Tanner et al. in 1964 [6,7]. While the original principles remain to this day, time and innovation have allowed modifications and refinements to the technique; variable expansion ratios can be achieved by utilizing longer incisions, while convenience has advanced through innovations such as electrical devices. Henderson et al. performed a detailed comparison of declared and real expansion ratios [8]. While a large difference (up to 46%) was found, they did not propose a specific reason for this difference. The clarification of this phenomena was not solved elsewhere [9,10].

Human skin is a stratified tissue with a highly nonlinear and anisotropic behavior, Langer's lines correspond to the natural orientation of collagen fibers in the dermis and are generally parallel to the orientation of the underlying muscle fibers [11]. So that it is favorable to use this natural orientation in the following hypothesis. It is clear that skin graft orientation may play a role in the expansion achievable by meshing.

The following study introduces the dependency of skin mesh expansion ratio as a function of Langer's lines orientation. We hypothesize that the orientation of the Langer's lines in a split thickness skin graft is a parameter playing a key role in the resulting expansion ratio.

2. Materials and methods

The skin graft meshing process was analyzed in two steps. In the first step, *ex vivo* uniaxial tests of human skin were performed. This served as an input for the constitutive model used for numerical simulations. In the second step, finite element analyses were performed so that stress distributions and expansion ratios could be determined. The finite element method (FEM) is a standardized tool in biomechanics used for solving different tasks [12], and has been successfully used in the field of plastic and reconstructive surgery [13–16].

2.1. *Ex vivo experiments*

All the *ex vivo* experiments were carried out under ethical approval in accordance with Czech Republic laws and medical regulations. Skin was harvested from the discarded abdominoplasty specimen of a 44-year-old female. The skin graft was visually without any colour changes. The orientation of Langer's lines was recorded prior to graft harvest. The skin was then manually tensioned to its original size, and eight rectangular grafts were harvested using a powered dermatome (*Zimmer Czech, Czech Republic*) set. The grafts were planned to be 0.75 mm thick. Consistency of graft thickness was inspected using an optical microscope (*Nikon, Czech Republic*). The effective dimensions of the test specimens were 8 × 20 mm. Specimens were obtained in two orientations: parallel and perpendicular to the direction of the Langer's lines, Fig. 1. Tensile tests were performed using a universal tensile test machine Testometric M350-5CT with 10N force gauge. The samples were pre-tensioned by a force 0.1N, and then tested to failure with a stretch rate of 20 mm/min.

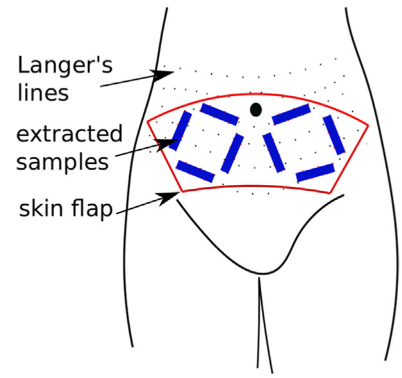

Fig. 1 – Orientation of skin samples according to Langer's lines on abdomen.

2.1.1. *Finite element models*

The proposed computational model was based on the geometry of a standard skin graft mesher (*Zimmer Czech, Czech Republic*) with expansion ratios of 1.5:1, 2:1 and 3:1, and graft dimensions of 24 × 47 mm. The finite element model was created in the software MSC.Marc 2016.0 (*MSC.Software, Czech Republic*). The FEM mesh was created semi-automatically and was defined by four node planar elements (38 750 elements). The thickness of elements was 0.75 mm. The slits were modelled by coincident nodes that were not connected, so that the free edges could open in the loading direction. The convergence error was minimized by using the adaptive mesh refinement Zienkiewitz–Zhu stress criterion in the location with the highest field gradient. The behavior of the skin graft was assumed to be isotropic elastic and nonlinear [17]. The nonlinear elastic Yeoh phenomenological model was used [18]. The material constants for the constitutive law were estimated by using Matlab (*Humusoft Ltd., Czech Republic*), Table 1. The curve fit is shown on Fig. 2. The following boundary conditions were taken into consideration for numerical purposes, Fig. 3:

- The left edge of the domain was constrained kinematically in all degrees of freedom.
- Nodes corresponding to the right edge of the graft were connected *via* rigid body (RB) linked to a control node that was positioned further right.

Table 1 – Material constants used for Yeoh nonlinear elastic model.

Yeoh model	C_{10} [MPa]	C_{20} [MPa]	C_{30} [MPa]
Parallel to LL	0.3701	1.5023	0.3714
Perpendicular to LL	0.0024	0.2843	0.0012