Skin anisotropy: finding the optimal incision line for volar forearm in males and females.

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Biomechanical properties · viscoelastic properties · scars · Langer’s line· BEST lines

PURPOSE: Proper understanding of skin biomechanics, viscoelasticity and investigation of skin tension vectors is necessary to find optimal incision lines. Great tension across a healing wound after any surgical procedure might lead to forming hypertrophic scars. The aim of the study was to investigate tension lines in volar forearm skin in young males and females, in order to ensure best incision line. METHODS: Five biomechanical and viscoelastic parameters were measured using a hand-held myotonometer: Oscillation Frequency [Hz], Dynamic Stiffness [N/m], Logarithmic Decrement of tissue’s natural oscillation, Mechanical Stress Relaxation...
Time [ms], and Creep. Measurements were taken in four different directions; Along Forearm, Across Forearm, Along Langer’s Line and Across Langer’s Line. RESULTS: Significant main effects for direction were found for Oscillation Frequency (p<0.001, $\eta^2=0.371$) [Hz], Dynamic Stiffness (p<0.001, $\eta^2=0.522$) [N/m], Logarithmic Decrement (p<0.001, $\eta^2=0.083$), Mechanical Stress Relaxation Time (p<0.001, $\eta^2=0.494$) [ms] and Creep (p<0.001, $\eta^2=0.480$). For each parameter except for logarithmic decrement results obtained Along Langers Line and Across Forearm were significantly different to Across Langers Line and Along Forearm (p <0.001, d= -2.76 – 2.66). Significant main effects for sex were found for logarithmic decrement Along Forearm (p<0.001, d=1.698) and Across Langer’s Line (p=.021, d=1.697). CONCLUSIONS: Our results suggested that optimal incision line for this age group in males and females could potentially be performed diagonally i.e. Across Langer’s Line or parallel i.e. Along Forearm to forearm axis. These directions would provide the lowest tension across a healing wound and possibly minimize the risk of hypertrophic scarring post incision.

1. Introduction

Volar forearm is one of the most investigated areas in skin research (Mazzarello et al., 2018). It was previously confirmed that photo-aging and aging process leads to changes in skin biomechanical properties, such as decrease of skin elasticity (Krueger et al., 2011; Mazzarello et al., 2018; Nomura et al., 2017; Ohshima et al., 2013). The Volar forearm is less exposed to sunlight, therefore the impact of photo-aging process is lower (Nomura et al., 2017) and the skin is not as thick as other areas of the body e.g. forehead or cheeks (Woo et al., 2014). Despite the complex, heterogeneous structure of the skin and the fact that each layer (stratum corneum, epidermis and dermis) is characterized by different intrinsic properties, they work in harmony to maintain homeostasis (Agache and Vatchon, 2017a). Consequently, it is justified to investigate mechanical properties of skin globally, as if it was a homogenous material (Agache and Vatchon, 2017a).

Skin is an anisotropic tissue which behaves differently depending on the direction of an applied force (Agache and Vatchon D, 2017a; Graham et al., 2019). Tensile testing to rupture of porcine skin tissue had been conducted to evaluate the sensitivity of the skin elasticity and fracture-related properties to varying tissue direction (Wong et al., 2016). It was found that the elastic modulus and fracture strength vary significantly with the tissue direction. It has been previously reported that age affects the skin biomechanical and viscoelastic properties, as well
as its directionality (Rosado et al., 2017; Pawlaczyk et al., 2013; Thieulin et al., 2020). The sensitivity of skin biomechanical properties to age may be underpinned by variation in collagen composition and structure. Age-related changes in collagen fibril cross-sectional area fraction could affect the elastic modulus and fracture strength of tendons (Goh et al., 2008); age-related changes in the resilience and fracture toughness could be directed by changes in the frequency distribution of collagen fibril sizes (Goh et al., 2012). In older groups skin mechanical behaviour differs significantly depending on force direction, while in younger populations the differences are less visible (Thieulin et al., 2020). With regard to viscoelastic-related properties, tensile testing to rupture of porcine skin tissue for varying strain rate had been conducted (Wong et al., 2016). It was found that some but not all the mechanical properties were sensitive to strain rate. For example, while elastic modulus increases and strain to rupture decreases with increases in strain rate, the fracture strength was not sensitive to variation in strain rate. Therefore, investigating skin anisotropy is an appropriate approach to characterize skin aging (Gahagnon et al., 2012). Moreover, proper understanding of skin biomechanics, viscoelasticity and investigation of skin tension vectors is necessary to find optimal incision lines (Son and Harijan, 2014). Great tension across a healing wound after any surgical procedure might lead to forming hypertrophic scars (Son and Harijan, 2014). Skin tension lines were originally described by Karl Langer in 1861 (Langer, 1978; Langer 1861). Langer used 2.5 cm spike to puncture holes into skin of cadavers. He noticed that holes were ellipsoid shaped, which helped him to determine direction of the lines. Langer’s Cleavage Lines indicate direction of increased tension in skin and are still widely used by clinicians to plan incision direction (Carmichael SW, 2014). While Langer’s observations describe static behaviour of skin, Kraissl based his investigation on wrinkles, which are perpendicular to underlying muscles, appearing on skin with movement (Kraissl and Conway, 1949). Borges’ relaxed skin tension lines (RSTL) can be identified by pinching the skin, the largest wrinkle designate RSTL (Borges, 1989). Striae distensae reflects natural anti-tension lines of the skin, and occurs perpendicular to the optimal skin incision lines (Lemperle et al., 2014). However, all these observations are not based on quantitative measurements. Recently in order to establish the most effective way for surgical excisions a new computerised tensiometer was used to map biodynamic excisional skin tension (BEST) lines (Paul, 2017; Paul et al., 2016; Paul, 2018a, 2018b, 2017) but BEST lines are indicated for excisional surgeries not to incisional procedures (Paul et al., 2016). Therefore, there is still lack of scientific evidence concerning best incision lines.
It is important to develop methods dedicated for clinical use that will enable the quick and accurate assessment of many different skin parameters in a non-invasive manner (Agache P., 2017; Agache and Vatchon, 2017a; Rodrigues , EEMCO Group, 2001; Piérard, EEMCO Group, 1999; Rodrigues and Fluhr , EEMCO Group., 2020). Such an approach would contribute to evaluation of skin condition and diagnosis, as well as, provide information regarding optimal incision lines (Agache P., 2017). MyotoPRO has been used in recent research to accurately and quickly measure skin stiffness in healthy subjects (Dellalana et al., 2018), in patients with cutaneous chronic graft-versus-host-disease (cGVHD) to evaluate cutaneous sclerosis (Chen et al., 2018) and to assess post caesarean section scars (Gilbert et al., 2020.). Recent research has revealed greater reliability of this device for assessment of skin stiffness using L-shape probes (Rosicka et al., 2020). Moreover, it was previously reported that inter-observer and intra-observer ICC (Inter-Class Correlation) values showed great or excellent reliability of the MyotonPRO for stiffness measurement (Dellalana LE, Chen F, Vain A, et al., 2018) as well as all other parameters (Gilbert et al., 2020.). However it was noted that differences between skin stiffness among different body areas might be associated with tension lines.(Rosicka et al., 2020.) At present there is limited understanding as how the skin behaves depending on the direction of an applied force. Investigating the mechanical and viscoelastic properties of the volar forearm skin according to the direction of applied force would inform clinicians of appropriate surgical procedures.

Therefore, the main purpose of this study was to investigate tension lines in volar forearm skin in young males and females, in order to ensure best incision direction. This study will provide novel information about skin anisotropy and how force direction influences skin mechanical and viscoelastic properties. We hypothesised that Langer’s lines are the lowest tension lines in volar forearm skin. Furthermore, we hypothesise that lower tension may be a result of lower stiffness and greater elasticity of the tissue, with increased recovery time of the tissue and a higher creep value.

2. Methods

2.1. Participants

Twenty five volunteers (males; n = 15 , age; 24.6 ± 5.0 years, height; 177.5 ± 5.2 cm, mass; 77.1 ± 13.3 kg, females; n = 10, age; 21.0 ± 1.6 years, height; 167 ± 5.3 cm, mass; 61.3 ± 8.9 kg) participated in this study. All participants initially completed a health screen questionnaire
to assess eligibility for the study. Only volunteers without skin diseases, scars, tattoos and wounds on the examined skin areas participated in our study. The measurement location was taken in the upper third of forearm (Rosicka et al., 2020.). Participants were fully aware of the procedures and potential risks involved in the experiment, and provided written, informed consent prior to data collection. The experimental procedures were carried out in accordance with the standards outlined in the WMA declaration of Helsinki and the study received approval by the institutional ethics committee (ID: P109131).

2.2 Procedures

The study required one visit to the laboratory, where all measurements were carried out in the same laboratory where the room temperature was maintained around 23°C. Participants wore loose fitting short-sleeved t-shirts. The participants lay supine in a relaxed and comfortable position on the examination bed for a period of 5 minutes prior the measurement. During measurements, each subject maintained a supine position on the examination bed.

2.3 Skin Mechanical and Viscoelastic Properties

A handheld myotonometer was used to measure the volar forearm area (MyotonPRO, Myoton AS, Estonia). The biomechanical properties of the skin were examined using an L-shaped probe (arm length 20 mm) with a disc attachment (diameter 10 mm), which has been found to be reliable for measuring the surface of human skin (Rosicka et al., 2020.). The device’s probe applies automatically and user independently controlled constant pre-load force (0.18 N) to lightly compress subcutaneous tissues or in case of horizontal skin measurements it applies slight pre-tension. In standard configuration the device delivers under constant pre-load a brief (15 ms) mechanical impulse (0.4)N, eliciting tissue response in a form of damped oscillation. The interval’s time between each impulse is 0,8 s. This standard configuration is recommended by Myton SA as default values for skin measurements while using L-shape probe. The L-shape probe delivers measurement impulses horizontally along with skin surface without involvement of deeper subcutaneous layers and causing damped oscillation of the skin surface alone, as the device is held parallel to the skin surface while being measured. Since the device is held parallel to the skin surface the L-shape probe delivers measurement impulses horizontally along with skin. To obtain firm contact of the probe and skin a thin (0.1 mm) double-sided stickers (10 mm diameter) were used (Rosicka et al., 2020.). The experimental process is presented on Figure 1. Measurements were taken in four different directions: (1) Along Forearm, (2) Across Forearm, (3) Along Langer’s Line and (4) Across Langer’s Line as presented on Figure 2.
Langer’s Lines are still often used by many surgeons, dermatologists (Carmichael, 2014). Although comparing to Langer’s original work, many textbooks and authors depict Langer’s lines differently, which can cause confusion (Carmichael, 2014; Paul, 2018c). Our force direction described as *Along Langer’s Line* is based on original figures drawn by Langer’s from 1861 (Lemperle, 2020; Lemperle et al., 2014). Furthermore despite the fact that striae do not occur frequently on upper limbs (Lemperle et al., 2014) case report by Rotsztjen et al. presented a 14-year-old boy with striae distensae in this area (Rotsztejn et al., 2010), his stretch marks coincide with our *Along Langer’s Line* direction. Striae distensae can be considered as natural antitension lines of the skin (Lemperle et al., 2014). On the other hand the force direction described as *Across Forearm* can be identified with Kraissl lines, since they run perpendicularly to underlying muscles, as well as main folding lines described by Pinkus (Lemperle, 2020; Lemperle et al., 2014).

The following parameters were recorded: (1) oscillation frequency [Hz], which represents intrinsic tension of the tissue, (2) dynamic stiffness [N/m], which indicates the resistance to an external force that deforms tissue from its initial shape, and (3) logarithmic decrement of tissue’s natural oscillation, which defines its elasticity and dissipation of mechanical energy when tissue recovers from being deformed. A further two viscoelastic properties were measured: (4) mechanical stress relaxation time [ms], which indicate the time needed for tissue to recover to its initial shape after removal of an external force and (5) creep, which indicates a gradual elongation of tissue over time, while it is under constant tensile stress (Ko et al., 2018; Schneider et al., 2015). Multi scan measurement contains five single measurements (device delivers five short mechanical impulses) and it is automatically presented as the average of this consecutive measurements. Moreover multi scan measurements were repeated three times with an average of those measures used in the subsequent analysis. Measurement for one reference point took about five seconds, while the total examination time was less than five minutes.

### 2.4 Statistical Analysis

Statistical analysis was performed using Jeffreys’s Amazing Statistics Program 0.14 (JASP TEAM 2020., Amsterdam, Netherlands). The normality of the distributions were assessed with the Shapiro–Wilk test. All variables showed normal distributions except for oscillation frequency across forearm in females and logarithmic decrement along forearm in males. Mauchly test was performed to assess homogeneity of variances. Within-session reliability was examined between the second and third trials. We found high intraclass correlation coefficients
and low coefficients of variation for Oscillation Frequency (ICC: 0.8 - 0.99; CV: 1.73 - 2.88), Dynamic Stiffness (ICC: 0.95 - 0.99; CV: 2.15 - 2.46), Logarithmic Decrement (ICC: 0.6 - 0.99; CV: 4.01 - 7.18), Mechanical Stress Relaxation Time (ICC: 0.97 - 0.99; CV: 1.86 - 2.77) and Creep (ICC: 0.97-0.99; CV: 1.89 - 2.86). A Mixed Analysis of Variance (ANOVA) with Bonferroni’s post-hoc was used to examine differences of all parameters measured in both sex groups and in all directions. For ANOVA results, effect sizes are reported as partial eta-squared value ($\eta^2$) where appropriate. Cohen’s d effect sizes (d) are reported for post hoc comparisons with an effect size of 0.2, 0.6, 1.2 and 2.0 indicating small, medium, large and very large effects, respectively. The alpha value was a priori set at $p < 0.05$ for all analyses.

3. Results

Mean values for all variables with standard deviation, ranges and, significant differences are presented in Figure 3 for males and females.

**Oscillation Frequency [Hz]**: A significant main effect within subjects for direction was found ($p<0.001$, $\eta^2=0.371$). Follow up post-hoc revealed a statistically significantly higher Oscillation Frequency Along Forearm when compared to Across Forearm ($p<0.001$; $d=1.69$) and Along Langers Line ($p<0.001$; $d=1.84$). The values obtained Across Langer’s Line were also significantly higher that Across Forearm ($p<0.001$; $d=-1.74$) and Along Langers Line ($p<0.001$; $d=-1.89$). There was no difference observed between Along Forearm and Across Langers Line ($p=0.999$, $d=-0.05$) and between Across Forearm and Along Langer’s Line ($p=1$, $d=0.15$). There was no interaction between direction and sex was found ($p=0.252$, $\eta^2=0.01$) and no significant main effect of sex between subjects ($p=0.452$, $\eta^2=0.01$).

**Dynamic Stiffness [N/m]**. A main effect within subjects for direction was found ($p<0.001$, $\eta^2=0.522$). Follow up post-hoc revealed statistically significant differences between the mean values obtained Along Forearm versus Across Forearm ($p<0.001$; $d=2.56$) and Along Langers Line ($p<0.001$; $d=2.66$). The Dynamic Stiffness values Across Langer’s Line differ significantly to Across Forearm ($p<0.001$; $d=-2.67$) and to Along Langer’s Line ($p<0.001$; $d=-2.76$). There was no difference observed between Along Forearm and Across Langers Line ($p=1$, $d=-0.1$) and between Across Forearm and Along Langer’s Line ($p=1$, $d=0.1$). There was no main effect of sex between subjects ($p=0.303$, $\eta^2=0.017$) and no interaction between direction and sex was found ($p=0.629$, $\eta^2=0.003$).

**Logarithmic Decrement**. A significant main effect within subjects for direction was found ($p<0.001$, $\eta^2=0.083$). Follow up post-hoc reviled significant differences between the
Logarithmic Decrement values obtained Along Forearm and Across Forearm (p<0.001; d= 2.56) and to Along Langers Line (p < 0.001; d= 2.66). The Logarithmic Decrement values recorded Along Langer’s Line were found to be significantly different to Across Langer’s Line (p<0.001; d= -2.76). There was main effect of sex between subjects (p<.001, \(\eta^2= 0.36\)). There was significant difference between results recorded Along Forearm (p<0.001, d=1.7) and Across Langer’s Line \((p=.021, \text{d}=1.7)\) between males and females. There was found an interaction between direction and sex \((p= 0.039, \eta^2= 0.013)\). In males significant difference was found only between mean values obtained Along Forearm and Along Langer’s Line \((p=0.009; \text{d}= 1.18)\). While in females there were significant differences between mean values recorded Along Forearm and Across Forearm \((p<0.001; \text{d}= 0.8)\), as well as Along Forearm and Along Langer’s Line \((p<0.001; \text{d}= 1)\).

**Mechanical Stress Relaxation Time [ms].** The main effect within subjects for direction was found \((p<0.001, \eta^2 =0.494)\). Follow up post-hoc reviled significant differences between the Mechanical Stress Relaxation Time mean values obtained Along Forearm and Across Forearm \((p<0.001; \text{d}= -2.13)\) and to Along Langers Line \((p < 0.001; \text{d}= -2.19)\). The values obtained Across Langer’s Line were significantly lower to Across Forearm \((p<0.001; \text{d}=2.21)\) and to Along Langer’s Line \((p<0.001; \text{d}= 2.26)\). There was no difference observed between Along Forearm and Across Langers Line \((p=1, \text{d}= 0.08)\) and between Across Forearm and Along Langer’s Line \((p=1, \text{d}= -0.05)\). There was no main effect of sex between subjects \((p=0.45, \eta^2 =0.009)\) and no interaction between direction and sex \((p= 0.308, \eta^2=0.008)\).

**Creep.** The main effect within subjects for direction was found \((p<0.001, \eta^2 =0.480)\). Follow up post-hoc reviled significant lower Creep values obtained Along Forearm when compared to Across Forearm \((p<0.001; \text{d}= -2.11)\) and to Along Langers Line \((p < 0.001; \text{d}= -2.13)\). The Creep values Across Langer’s Line differ significantly to Across Forearm \((p<0.001; \text{d}=2.24)\) and to Along Langer’s Line \((p<0.001; \text{d}= 2.27)\). There was no difference observed between Along Forearm and Across Langers Line \((p=1, \text{d}= 0.14)\) and between Across Forearm and Along Langer’s Line \((p=1, \text{d}= -0.13)\). There was no main effect of sex between subjects \((p=0.425, \eta^2 =0.01)\) and no interaction between direction and sex was found \((p= 0.262, \eta^2=0.008)\).

4. Discussion
There is currently limited quantitative evidence for the choice of incision lines based on anisotropic nature of skin. The research presented here is the first to quantify how force direction influences skin mechanical and viscoelastic properties of volar forearm skin in young males and females. In accordance with our hypothesis, Langer’s lines provide the lowest tension in volar forearm skin.

In line with our hypothesis, Oscillation Frequency values obtained *Across Forearm* and *Along Langer’s Line* were significantly lower when compared to mean values recorded *Along Forearm* and *Across Langer’s Line*. Oscillation Frequency represents the internal structural tension of the tissue, the higher value of this parameter the higher intrinsic tension within the tissue(Schneider et al., 2015.). Therefore, lower tension was observed *Along Langer’s Line*, as well as *Across Forearm*. It was previously reported by Thieulin et al. that higher tension was observed in the direction 225° and 45° particularly in older groups (Thieulin et al., 2020), which was similar to the *Across Langer’s Line* direction in the current study. The greater tension across the healing wound, the more force it will need to hold itself together, which can cause increased collagen deposition(Son and Harijan, 2014). To avoid hypertrophic scarring or forming keloid it is essential to close the wound under the least tension (Paul, 2018; Paul, 2017; Son and Harijan, 2014). Low tension was noted *Along Langer’s Line*, that also coincides with direction of striae distensae, which were previously reported to develop perpendicular to the optimal skin incision lines (Lemperle, 2020; Lemperle et al., 2014). This suggests that the optimal incision line should potentially be performed across this direction i.e. *Across Langer’s Line* (Figure 4.B). Incisions in this area should potentially be planned obliquely on the outer side in pronation and on the inner side in supination(Lemperle, 2020). Our study displayed similar low-tension results *Across Forearm*, which means the incision line could be planned perpendicular to this direction as well, i.e. parallel to forearm axis which coincides with *Along Forearm* (Figure 4.A). Therefore, incision lines could be directed similar to excisional Biodynamic Excisional Skin Tension (BEST) lines (Paul, 2017; Paul, 2018c) for the volar forearm. However, it was previously reported that longitudinal scars on the radial quadrant of the distal forearm are potentially wider with an increased incidence of hypertrophy when compared to those on the ulnar quadrant (Lemperle, 2020). Our findings refer exclusively to proximal part of volar forearm and therefore further research into the skin mechanical and viscoelastic properties of different areas of the volar forearm are warranted.

Results of the present study suggest significantly lower values of Dynamic Stiffness occurs *Along Langer’s Line* and *Across Forearm* in comparison to *Across Langer’s Line* and
Along Forearm. Dynamic Stiffness reflects the resistance to an external force that deforms the tissue from its initial shape, whereby higher values correspond to greater tissue stiffness (Schneider et al., 2015.). Values of skin stiffness in our study obtained Along Forearm (males: 505.6±77.2 ; females: 489.3±59.7 ) and Across Langer’s Line (males: 519.7±101.6; females: 487.1±48.6) are similar to studies by Dellalana et al., (Dellalana et al., 2018) in healthy groups (interobserver measurements left forearm:456.5 and right forearm: 435.1; intraobserver measurements left forearm: 415.7 and right forearm : 414.1), and Rosicka et al. on volar forearm performed across Langer’s tension line in healthy females (461.8±63.6) (Rosicka et al., 2020.). Surgical technique and the operator experience are modifiable factors in preventing hypertrophic scarring (Son and Harijan, 2014). Although less traction and less crushing force while performing incision provide atraumatic handling of wound edges. By minimalizing traction and crushing force while performing incision, wound edges are treated in atraumatic way, which provide better healing (Son and Harijan, 2014). In clinical practice it is more desirable to perform a straight incision on more firm tissue to avoid pulling or tearing the tissue apart (Zdanowicz, 2001.). Consequently, determining incision line in direction of higher stiffness, such as Across Langer’s Line and Along Forearm, could contribute to better, more aesthetic outcomes (Figure 4).

Our result suggest that values of Logarithmic Decrement (means and ranges) recorded by L-shape probe differs depending on directions, as well as depending on sex. The statistically significant differences were found between Along Forearm and Along Langer’s Line in males and between Along Forearm and Across Forearm as well as Along Forearm and Along Langer’s Line in females. This is the first study to present the Logarithmic Decrement of volar forearm skin depending on the direction of force applied. Elasticity characterises the tissues ability to return to its initial shape when the external force is removed and Logarithmic Decrement is inversely proportional to elasticity (Schneider et al., 2015.). The similarity of results (means and ranges) obtained may be explained by the homogeneity of the age of the participants. Although not measuring Logarithmic Decrement, previous research has already reported that elasticity of skin is age related parameter (Jemec et al., 2001; Krueger et al., 2011; Mazzarello et al., 2018; Nomura et al., 2017; Ohshima et al., 2013), which can be more diverse while comparing skin of younger and older groups participants. It was previously reported that in younger groups mechanical behaviour of the skin can be assumed as quasi- isotropic i.e. almost not depending on force direction (Thieulin et al., 2020). Therefore, the Logarithmic Decrement or elasticity of the volar forearm skin may be less diverse and less depending on the
direction of force in young adults. We observed a significant main effect of sex between males and females in values of Logarithmic Decrement. It was previously suggested that female skin shows greater elasticity compared to males, especially in younger age groups (i.e. 20–29 and 30–39 years) (Luebberding et al., 2014). However, our study observed lower values of logarithmic decrement (higher elasticity) in males when compared to females. These differences to previous literature could be attributed to the age and health status of the participants. Our participants were classified as physically active and were significantly younger (males: 24.6 ± 5.0 years; females: 21.0 ± 1.6 years) than the age group in Luebberding study (female group I: 24.73± 2.59, group II: 33.30 ± 2.92; male group I 25.70± 2.48, group II: 33.23± 2.90). The observed difference between males and females in logarithmic Decrement support current understanding that a significant contrast between male and female skin elasticity is significant after puberty as a consequence of matured female hormones (Luebberding et al., 2014). Our findings suggest that there may be differences between male and female skin concerning elasticity in the volar forearm. However in our study in both sex groups values of Logarithmic Decrement were significantly higher (lower elasticity) Along Forearm. It should be stressed that increased skin elasticity is one of major factor of hypertrophic scars in children (Parell and Becker, 2003; Son and Harijan, 2014) , hence incision should be performed along direction of lower elasticity of the skin i.e. Along Forearm. Nevertheless, further investigation on age-diverse groups are required.

In our study the significantly lower values of Creep for Across Langer’s Line and Along Forearm when compared to Along Langer’s Line and Across Forearm corresponded to similar results for the Mechanical Stress Relaxation Time. To the author’s knowledge, no previous research has examined the effect of direction of force on Creep or Mechanical Stress Relaxation Time of volar forearm skin. When skin is submitted to sudden and sustained strain, the following phases are found: immediate deformation, purely elastic nature (phase I), viscoelastic deformation (phase II) and late deformation or viscous (phase III) (Agache and Vatchon 2017a, 2017b). Both Creep and Mechanical Stress Relaxation Time parameters relate to each other. For example, the faster tissue recovers to its initial shape (smaller values of Mechanical Stress Relaxation Time) the smaller the Creep value. It was reported on muscles that the smaller values of Creep parameter characterises healthier and younger tissues(Schneider et al., 2015.), therefore it makes the expectation tenable that creep is also an important characteristic for the skin. Closing wounds under the lowest tension is a primary rule for better outcomes (Son and Harijan, 2014), however it is especially challenging while performing large procedures
(Ashkenazi et al., 2020). The TopClosure 3S System has been tested for pre-operative stretching by utilizing creep properties of tissue, replacing traditional tissue expanders (Topaz et al., 2012). As a result of skin stretching, wound closing tension decreases over time, allowing primary closure of relatively large defects (Topaz et al., 2012). A smaller Creep value and shorter Mechanical Stress Relaxation Time of the skin might result in better wound healing. Therefore, our results may suggest that incision lines are planned along direction of smaller Creep or Mechanical Stress Relaxation Time, further supporting our argument that incision lines be made Along Forearm and Across Langer’s Line (Figure 4). Further research is required to determine the importance of Creep or Mechanical Stress Relaxation Time on optimal incisions in human skin.
4.1. Limitations and Future Directions

We hope that our research is the first step to evaluating skin anisotropy and detecting optimal incision lines using quantitative methods that are quick, reliable and valid. We examined the viscoelastic properties of the volar forearm skin in young healthy males and females. It should be stressed that skin anisotropy is an age-related feature (Rosado et al., 2017; Thieulin et al., 2020) and our results may have limited generalisability to older or clinical populations. Furthermore, our research examined the proximal part of the volar forearm and it has been suggested that there is an increased risk of scarring on aspects that are more distal. Finally, this is a novel explorative study into the volar forearm and future research should focus on different regions of the human body to provide a more holistic understanding of optimal incision lines for the skin.

5. Conclusion

This study demonstrated that the volar forearm skin has different mechanical and viscoelastic properties depending on the direction of force applied. The optimal skin incision line for this age group in males and females could potentially be performed Across Langer’s Line (i.e. diagonally) or Along Forearm (i.e. parallel to forearm axis). These directions would provide the lowest tension across a healing wound and potentially minimalize the risk of hypertrophic scarring post incision. Taking into consideration Logarithmic Decrement incision direction Along Forearm should contribute to better outcomes. Furthermore, our study evidenced a quick and reliable quantitative measurement method in order to plan the optimal incision line. Finally, some differences were observed between males and females that warrants further investigation along with a more age diverse group on different areas of human body skin.
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https://doi.org/10.1097/GOX.0000000000001614


Figure 1 shows experimental process, measurement Along Forearm. The device is held parallel to the skin surface the L- shape probe delivers measurement impulses horizontally along with skin. To obtain firm contact of the probe and skin a thin (0.1 mm) double-sided stickers (10 mm diameter) were used.
Figure 2 shows four investigated directions: (1) Along Forearm, (2) Across Forearm, (3) Along Langer’s Line and (4) Across Langer’s Line.
Figure 3 presents mean±SD and ranges of all five parameters (i.e. Oscillation Frequency, Dynamic Stiffness, Logarithmic Decrement, Mechanical Stress Relaxation Time and Creep) in females and males in all investigated directions i.e. Along Forearm (AF.), Across Forearm (ACF.), Along Langer’s Line (AL.) and Across Langer’s Line (ACL.). Box represents mean ±SD, and whiskers shows ranges of parameters.

* shows significant differences between values of obtained parameters.

Figure 4 shows optimal incision lines: (A) parallel to forearm axis i.e. Along Forearm and (B) diagonally to forearm axis i.e. Across Langer’s Line.