The Collagen Matrix of Human Dermis: Mechanical and Histological Characterization

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Purpose: Acellular Dermal Matrix (ADM) is a commonly used biological implant. Tutoplast® Processed ADM implants are collagen matrices with an intact basement membrane (BM) at the dermal-epidermal junction. Human dermis is comprised of papillary and reticular regions. The density and organization of the collagen in each region has been evaluated; however, the contribution and correlation between the microstructure of each region to the matrix material properties is not well understood. The thickness of each region is dependent on the initial full thickness, but the papillary region only represents approximately 10% of the entire thickness of the dermis. Production of ADM can require splitting full thickness dermis to obtain implants of a desired thickness. A biomechanical and histological investigation was designed to compare the mechanical and material properties of Tutoplast processed ADM: Full thickness, 1x and 2x split superior layers having an intact BM, and 1x and 2x split inferior layers without an intact BM.

Methods: Processed samples (n=180) were prepared from 90 donors (dry thickness of 0.8-1.8mm).

Group	Description
C-1	Superior layer, 2x split dermis (n=30)
C-2	Superior layer, 1x split dermis (n=30)
C-3	Full thickness dermis (n=30)
E-1	Adjacent inferior layer (middle) to C-1 (n=30)
E-2	Adjacent inferior layer (bottom) to E-1 (n=30)
E-3	Adjacent inferior layer (bottom) to C-2 (n=30)

Table 1: Sample ID (dog-bone geometry 3:1 aspect ratio)

A laser micrometer was used to acquire pre- and post-rehydration thicknesses. An Instron was used to tensile test samples to failure (cross-head speed of 60 mm/min) Actuator displacement and reactive forces were recorded at 0.1 sec intervals. Randomly selected samples (n=5) were histologically evaluated to compare fiber to void ratios and density variations between sample sets (Image Pro Plus). Sample geometry, linear stiffness, failure load and extension were used to calculate grip to grip strain, stress at failure and linear modulus of elasticity. Paired t-tests were performed using Minitab Statistical Software.

Results:

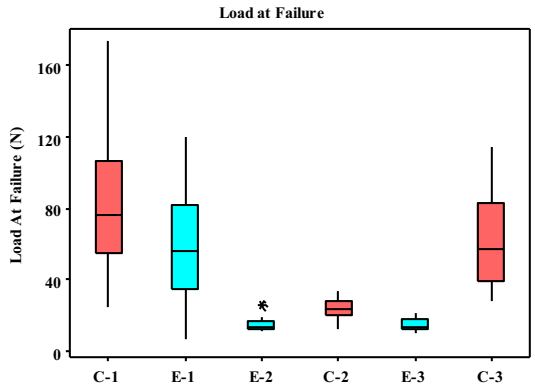


Figure 1: Box plot of load at failure.

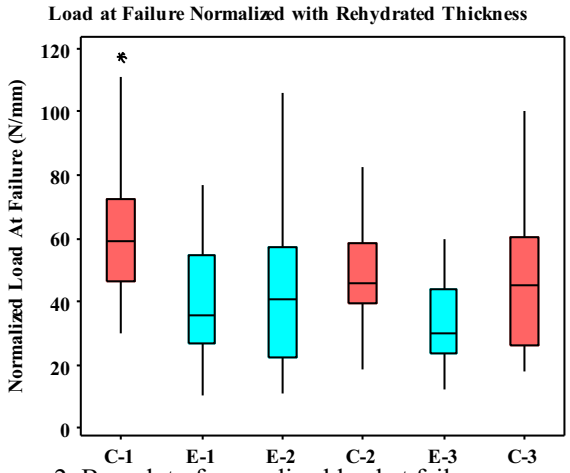
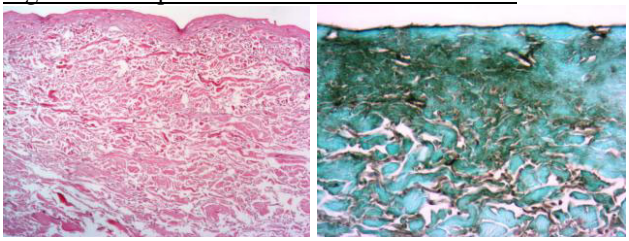


Figure 2: Box plot of normalized load at failure.



Figures 3 and 4: Processed Dermis
H&E, 50x and Collagen IV Immunohistochemistry, 400x

Multiple statistical differences between and within the control and experimental sample sets for measured load (N) at failure (Figure 1) were shown. No significant difference was shown between or within the control and experimental sample sets for normalized load (N/mm) at failure (Figure 2). E-2 and E-3 sample sets exhibited significantly less displacement prior to a reactive force being recorded.

Discussion: Human skin is a non-homogeneous, anisotropic, non-linear viscoelastic material, which makes it difficult to correlate material properties to microstructure. The collagen component of dermis is a primary contributor to the biomechanical behavior. The differences observed in measured load at failure among sample sets, indicates tensile strength is dependent on absolute thickness and the histoarchitecture of the dermis layer/subsection tested. Additionally, samples of E-2 and E-3 sample sets which lack a BM and are retrieved from the most inferior/reticular region of the dermal matrix, exhibited distinct differences in material behavior compared to the more superior layers. Additionally, control samples sets, which have an intact BM, predominately experienced one-dimensional swelling of thickness, where experimental sample sets showed three-dimensional changes, with non-uniform changes in length, width and thickness. These distinctly different material properties as a function of histoarchitecture, offer the possibility to tailor ADM implants to specific surgical applications.