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REVIEW ON SOUNDBOARD IN REBAB-MAKING. PART II: RELATIONSHIP BETWEEN THE MECHANICAL BEHAVIOR OF BOVINE PERICARDIUM AND SOUND

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Collagen fibrils, which may already possess a compact configuration in the absence of stress, realign and adopt a more rigid structure when subjected to tension. Microfeatures, including the D-period in collagen's molecular structure, variations among collagen types, the presence of glycosaminoglycans, intercellular substances, and collagen linkages, along with macrofeatures, provide strength through their mechanical properties and influence sound mechanics. The nonlinear, heterogeneous, and anisotropic nature of most collagens complicates the assessment of the mechanical properties of skin. As sound traverses' porous structures, it is attenuated, resulting in energy loss. Bovine pericardium has regional variation; yet, its features, including fiber density and orientation, remain consistent throughout the tissue. The instrument conveys the sound produced by the vibrating bow and wood into the air. The front and rear plates alternately expel air via the openings in the front plate, facilitated by vibration. Simultaneously, the membrane typically decreases the modal frequency under air loading conditions. The scaffold is characterized by the textural angles of the bovine pericardium, orthotropic anisotropy, thinness, strength, viscoelasticity, and the acoustic properties it produces, along with sound mechanics. This review made assumptions by concentrating on bovine pericardium, which has not yet been examined through an academic lens in the context of rebab-making.

Keywords: Collagen structure, mechanical characteristics of bovine pericardium, sound mechanics, instrumental acoustics.

INTRODUCTION

Collagen is a polypeptide chain characterized by a segmental structure. It lacks flexibility; however, it can extend by 5% due to the fibrils interlocking in a helical configuration. In the absence of the force inducing elongation, they can revert to their original state due to the elastic fibers (Harmancioglu & Dikmelik, 1993) and are encased in type I collagen, an extracellular matrix protein prevalent in various tissues including skin, tendons, bones, and blood vessels (Francis-Sedlak *et al.*, 2009; Avery & Bailey, 2006). Dry skin comprises almost 70% of its mass (Naffa *et al.*, 2019). Cellular behavior influenced by collagen and the extracellular matrix is determined by the substrate's chemical, mechanical, and physical characteristics (Kuzuya *et al.*, 1998). The consistency of the solid extracellular matrix, migration (Hartog *et al.*, 2005), and proliferation (Francis *et al.*, 2008) affect cellular activity, including its features (Francis-Sedlak *et al.*, 2009). The integrity of the skin is conferred by the embedded tropocollagen molecules and collagen glycosylation within the fibers and fibrils, as well as the cross-covalent bond architecture facilitated by glycosaminoglycan (Fratzl, 2008). Elastin cross-links: deH-LNL and Des; Collagen cross-covalent linkages include deH-HLNL, deH-DHLNL, HHL, and HHMD (Fratzl, 2008; Naffa *et al.*, 2016). Drawing inferences based solely on the association between collagen fibril diameter and skin strength would be inappropriate. The intricate and varied structure of

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collagen can alter its characteristics. Nonetheless, cross-covalent connections, many hydrogen bonds, or hydrophobic interactions in collagen might enhance its strength (Wells *et al*., 2013).

Acoustic mechanics and tissue scaffolding are two interrelated ideas. The quantity of collagen, its molecular configuration (D-period of collagen, collagen type), its capacity for self-crosslinking, fiber dimensions, and orientation are the determinants of skin strength (Sizeland *et al*., 2013). D-period pertains to the fibril length and the mean angular orientation inside collagen bundles. Collagen fibrils exhibit a D-period amplitude distribution of up to 10 nm in the dermis, bone, and tendon. The D-period value of collagen in the tendon is around 67 nm. The D-period along the fibril axis represents the projection of the actual D-period, α=17-18° (Fang *et al*., 2012; Ottani *et al*., 2001).

$$64 \approx 67 \cdot cos(\alpha) \tag{1}$$

The molecules constituting the linear fibrils of collagen stretch at an angle of less than 5° relative to the fibril axis, whereas the same molecules in the helical configuration maintain a stable angle of 17° (Ottani *et al*., 2001). This property is congruent with the partially crystalline hexagonal configuration (Yamauchi *et al*., 1996). Measurements of collagen orientation and D-period indicate that fibrils under tension reorient and adopt a more compact form (Basil-Jones *et al*., 2012). Research suggests that collagen fibrils can be categorized into two distinct forms: The first kind is T-type collagen, characterized by its heterogeneous composition, tightly packed in parallel arrangements, exhibiting exceptional tensile strength; the second type is C-type collagen, distinguished by its helical structure, comprising small homogeneous fibrils, and demonstrating resistance to multidirectional strain (Ottani *et al*., 2001). Collagen orientation can be quantified through reflection anisotropy (Kronick & Buechler, 1986; Schofield *et al*., 2011), small-angle scattering (Friedrichs *et al*., 2007), confocal laser scanning microscopy (Billiar *et al*., 1997), Raman scattering (Jor *et al*., 2011), anisotropic Raman scattering (Falgayrac *et al*., 2010), multiphoton microscopy (Janko *et al*., 2010), and small-angle X-ray scattering (Lilledahl *et al*., 2011; Basil-Jones *et al*., 2011).

Mechanical Characteristics of the Bovine Pericardium

The quality and quantity of collagen dictate the mechanical strength of the contained pericardium (Sacks *et al*., 1994; Paez *et al*., 2003). The bovine pericardium exhibits an anisotropic structure, with its strength and mechanical properties demonstrating predictable variation based on orientation angles. This guarantees superior membrane functionality, longevity, and efficacy (Zioupos & Barbenel, 1994a; Zioupos & Barbenel, 1994b).

Bovine pericardium can be characterized as mechanically (Gabbay *et al*., 1984) and structurally (Clark, 1973) anisotropic (Zioupos & Barbenel, 1994a). Despite the inability to establish a correlation between mechanics and tissue, this structure is characterized as uniaxial (Clark, 1973; Lee *et al*., 1989) and biaxial (Choi & Vito, 1990) according to test methodologies (Zioupos & Barbenel, 1994a). Despite the difficulty in detecting, it within collagenous tissues like the pericardium, the expansion capability of the asymmetric axis surface further corroborates this characteristic (Zioupos *et al*., 1992). Alterations in the orientation of collagen fibrils induce anisotropic behavior (Paez *et al*., 2000; Paez *et al*., 2001; Sacks *et al*., 1994), but reorientation loadings do not influence anisotropy (Zioupos *et al*., 1994).

Three possible fibril distributions were analyzed to comprehend the material symmetry. The elongation results indicated by the modulus of elasticity demonstrate that the pericardium is orthotropic. Despite being a nonlinear anisotropic material, it is important to note that soft tissue fibrils are realigned in the direction of maximal tensile force (Zioupos & Barbenel, 1994a).

Biaxial mechanical tests were conducted on 12-18-month-old cow pericardium samples to ascertain the link between collagen structure and mechanical anisotropy (Sacks *et al.*, 1994).

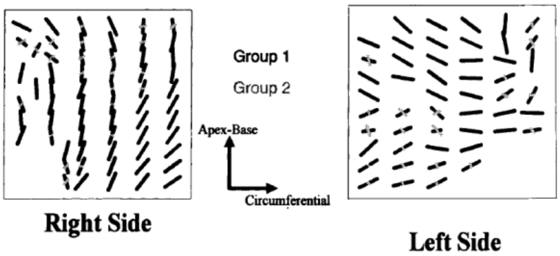

Figure 1. Vectorial condition of collagen fibrils in the anterior right and left regions of the bovine pericardium (Sacks *et al.*, 1994)

The orientation of collagen fibrils and their volumetric ratio exhibit partial consistency across several samples. The alteration of collagen fibril orientations in connective membrane tissues influences mechanical anisotropy. Additional histological characteristics, like fiber density and orientation degree, also maintain stability within the tissue. The material has considerable stability in its mechanical behavior owing to its collagen fiber architecture. Once more, the stability of outstanding strength, maximum strength, and complete stretchability qualities is contingent upon the collagen structure. The right section of the example exhibits greater instability and displays a broad spectrum of fiber orientations. The section on the left exhibits greater homogeneity (Sacks *et al*., 1994).

The thickness measurements revealed that bovine pericardium measures 0.42±0.01 mm, sheep pericardium measures 0.32±0.02 mm, porcine pericardium measures 0.20±0.01 mm, and canine pericardium measures 0.19±0.01 mm. Less elastic pericardiums are found in thinner canines and porcines. A robust association was observed between thickness and mechanical behavior. Stress values are defined by viscoelasticity (Sacks *et al*., 1994). The pericardium of canines and porcines is both viscoelastic and more rigid compared to the thicker pericardium of cattle and sheep. Biochemical investigations indicate that thin tissues possess elevated levels of strongly cross-linked type III collagen (Naimark *et al*., 1992).

By analyzing the mechanical properties of bovine pericardium, conclusions can be drawn concerning the appropriateness of these structures for the fabrication of rebabs.

Acoustic Physics; Instrumental Acoustics and Architecture

Sound is a perceptual phenomenon that arises in the brain when the periodic effects generated by a vibrational source in the environment are detected by the auditory system (Degirmenli, 2023). Sound constitutes a form of energy. Vibrations produced by a material system provide stimulus. The sound source arrives at the receiver via the transmitting medium. Movement in any section of the material environment also stimulates other sections of the material due to its inherent flexibility. Sound is conveyed through the cyclical conversion of kinetic and potential energy in the transmitting medium (Zeren, 1997). The formation and propagation of sound within the skin arise when the molecules in its structure become unstable due to mechanical forces, contingent upon the skin's structural features (Alaskan, 2013).

Wavelengths are the recurring equal intervals when a wave propagates. Sound waves can propagate both transversely and longitudinally in solid materials. Amplitude refers to the extent to which a structure in equilibrium deviates from its existing position in response to a stimulus. The wave speed is the distance covered by the wave per unit of time. The frequency of vibrations per unit time is referred to as the period. The frequency is defined as the rate of expansion and compression (vibration) occurring per unit of time (Degirmenli, 2023; Oflaz, 2008; Mazlum, 2011; Alaskan, 2012; Alaskan, 2013).

$$v = \lambda f \tag{2}$$

$$x = v\, t \tag{3}$$

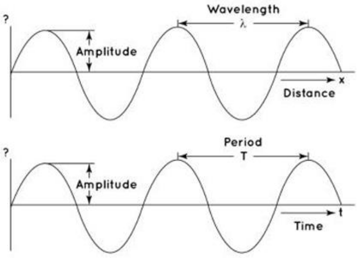

Figure 2. Sine wave equations (Degirmenli, 2023)

Waves exhibit distinct phenomena including reflection, refraction, diffraction, and interference. The reflected wave returns from the surface at an equivalent angle. A wave entering a different medium alters its direction and refracts due to a change in velocity, unless it approaches at a perpendicular angle. When the crest of the wave in the same medium encounters an impediment, it decelerates, alters its trajectory, and undergoes refraction. The velocity of sound in a given environment fluctuates due to variables including temperature, humidity, and pollution (Zeren, 1997).

The operational basis of membranes is that air loading, bending resistance, and shear resistance influence their modal frequencies. Primarily, air loading generally reduces modal frequencies, whereas the other two components typically augment them. In thin membranes, air loading typically exerts a predominant influence (Fletcher & Rossing, 1998).

The scientific understanding of vibrating strings was initiated by Galileo Galilei (1564-1642) and Marin Mersenne (1588-1648) (Fletcher & Rossing, 1998).

In the rebab, vibrations generated by the bow are conveyed to the resonance box and the rear of the instrument via a bridge. The broad plates of the body are often constructed from wood to generate frequency-induced oscillations in the vibrating bow. The instrument conveys the sound produced by the vibrating bow and wood into the air. The front and back plates sequentially expel air through the apertures in the front plate, facilitated by vibration (Berg & Strok, 1982). The materials chosen for each component of the rebab must be modified based on the material's flexibility and strength (Rai *et al*., 2019).

RESULTS AND CONCLUSIONS

Sound is a basic mechanical phenomenon resulting from the vibrating of molecules within a medium (Alaskan, 2012; Alaskan, 2013). The instrument's strings vibrate due to the bow, and as the waves propagate along the string at a consistent speed, they experience a reduction in velocity upon reaching the threshold, subsequently transitioning to the membrane with a change in direction. Energy conversions within the membrane will likely occur concurrently.

Each leather kind possesses distinct strength and acoustic characteristics attributable to its unique collagen composition. Molecular characteristics, including collagen type and D-period structure, significantly influence sound transmission within the membrane or leather. If the impediments posed by the partially crystallized hexagonal structure and the variable angular configurations along the fibril axis exceed the wavelength, it will result in wave refraction, altering the trajectory and direction of the sound wave. Density variations or humidity zones inside the structure induce wave breaking, resulting in the absorption and conversion of some sound energy into thermal energy. Additional losses will transpire in viscous areas.

The parameters of strength, tightness, thickness, and viscoelastic properties of the structure collectively influence the sound behavior and determine its acoustic characteristics. The diverse alignment of collagen bundles is a crucial aspect. The skin exhibits anisotropy due to the volumetric expansion of the animal, leading to inconsistent mechanical performance (Sizeland *et al*., 2013). In Part I, we noted that the fibrous structure of aged animal skin strengthens and exhibits favorable properties. This condition may vary due to variances in internal structure and mechanical behavior tendencies. Regional heterogeneous anisotropy can result in both scenarios (Hiester & Sacks, 1997b). The angular ratio and orthotropic anisotropy of the pericardial tissues confer remarkable strength. Its stable structure is in harmonious alignment with the sound mechanics.

The vibrational characteristics within the instrument's resonance box may vary based on the dimensions and wavelengths of the apertures in the box. Concurrently, the membrane often decreases the modal frequency under air loading conditions.

The mechanical properties and density of the extracellular matrix, along with the presence of glycosaminoglycans, will influence minimal wave orientations. Hooke's Law was employed to elucidate the structure of the collagen pair (Atanackovic & Guran, 2000); analogous straightforward mathematical modeling techniques were devised (Berg & Stork, 1982). The hypothesis is as follows: The greatest number of oligomers in a glycosaminoglycan chain of maximum length can be identified, and the activity of this chain can be transmitted to the force between collagen fibrils, thereby preserving the stabilization of the collagen pair (Chan *et al*., 2009).

Due to the significant variation in rawhide structure, the characteristics of different sections of the skin also differ markedly. This applies not only to physical properties but also to chemical properties. The investigation considered hide samples and adhered to the standards outlined in (EN ISO 3376:2008). Tensile strength, bulk density, scanning electron microscope examination, and acoustic signal analyses were conducted (Alaskan, 2012; Alaskan, 2013). The steps undertaken in this study may serve as a guide for informed academic action. To acquire empirical data, the propagation of sound waves under mechanical influences must be associated with the results of physical-chemical tests on leather, analyses of interior microscopic structure, and sound assessments, followed by statistical evaluation.

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