Ex vivo experimental investigations and modelling of visco-hyperelastic behaviour of the human facial tissues

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Abstract

Facial muscles are central to mastication, speech and facial expression, yet their nonlinear and time-dependent mechanical response remains insufficiently characterised. This extended abstract presents ex vivo uniaxial tensile investigations of human facial muscles under fresh and formalin-fixed conditions, with emphasis on visco-hyperelastic behaviour, strain-rate sensitivity and rupture. Samples from the masseter, zygomaticus major, zygomaticus minor, orbicularis oris and buccinator were tested at strain rates of 0.001 s-1 and 0.01 s-1. The results show pronounced rate dependence, marked inter-muscle variability and substantial stiffening after formalin fixation. Fresh tissues generally reached nominal stresses below 500 kPa, whereas fixed specimens exceeded 1000 kPa in selected muscles and exhibited reduced extensibility. These findings provide experimentally grounded data for constitutive model calibration and support more reliable computational simulations for surgical planning and soft-tissue reconstruction.

Introduction

Facial muscles play a crucial role in mastication, speech, and emotional expression, making them essential for both physiological function and social interaction. From a biomechanical perspective, these tissues exhibit complex behaviour governed by nonlinear elasticity and time-dependent effects. Accurate characterisation of their mechanical response is therefore fundamental to developing predictive computational models used in surgical planning, soft tissue reconstruction, and the simulation of facial dynamics.

While the mechanical behaviour of skeletal muscle has been extensively studied, limited experimental data are available for facial muscles, particularly regarding their strain-rate sensitivity and failure mechanisms. In addition, the influence of preservation methods, such as formalin fixation, remains insufficiently understood, despite their widespread use in experimental studies. These factors introduce uncertainty when calibrating constitutive models intended to represent in vivo conditions.

Furthermore, facial muscles differ structurally from skeletal muscles in terms of fibre arrangement, geometry, and functional role. Consequently, constitutive models developed for other muscle types cannot be directly applied. This study aims to provide

new experimental insights into the visco-hyperelastic and rupture behaviour of human facial muscles, with a particular emphasis on strain-rate effects and preservation conditions.

Materials and Methods

Human facial muscle tissues were obtained from cadaveric donors under both fresh and formalin-fixed conditions, allowing direct comparison of preservation effects. Several muscle groups, including the masseter, zygomaticus major, zygomaticus minor, orbicularis oris, and buccinator, were investigated to capture anatomical variability.

Following dissection, samples were cleaned and prepared into standardised geometries suitable for uniaxial tensile testing. Preliminary experiments were conducted to estimate rupture limits, which informed the design of a cyclic loading protocol consisting of five loading–unloading cycles with progressively increasing stretch levels.

Mechanical tests were performed at two strain rates, 0.001 s^{-1} and 0.01 s^{-1}. Force and displacement were continuously recorded and subsequently converted into nominal stress–stretch curves. These data were analysed to assess stiffness, hysteresis, and failure characteristics across muscle types and preservation conditions.

Results and Discussion

All tested samples exhibited pronounced strain-rate dependence, with higher strain rates leading to increased stiffness. This behaviour reflects the viscoelastic nature of facial muscle tissues.

The stress–stretch responses of fresh tissues are presented in Fig. 1, while those of formalin-fixed tissues are shown in Fig. 2. Both figures illustrate the full mechanical response up to rupture, including nonlinear stiffening, peak stress, and post-peak softening associated with damage.

A clear difference is observed between preservation conditions. Formalin-fixed tissues exhibit significantly higher stiffness and load-bearing capacity compared to fresh tissues. Peak stresses in formalin-fixed samples exceed 1000 kPa, whereas fresh tissues generally remain below 500 kPa. In addition, formalin-fixed tissues show reduced extensibility and altered post-peak behaviour, indicating changes in failure mechanisms. These effects are attributed to chemical cross-linking induced by formalin fixation, which restricts fibre mobility and increases resistance to deformation.

Variability between muscle types is also evident. The zygomaticus major consistently exhibits the highest stiffness and strength, while the masseter shows lower peak stress and earlier failure. Other muscles display intermediate responses. The post-peak stress reduction observed in all samples suggests progressive damage mechanisms, likely related to fibre rupture and microstructural degradation.

These findings highlight the importance of accounting for both strain-rate dependence and preservation effects in constitutive modelling. The significant differences between fresh and fixed tissues indicate that data from preserved samples should be used with caution when representing in vivo behaviour.

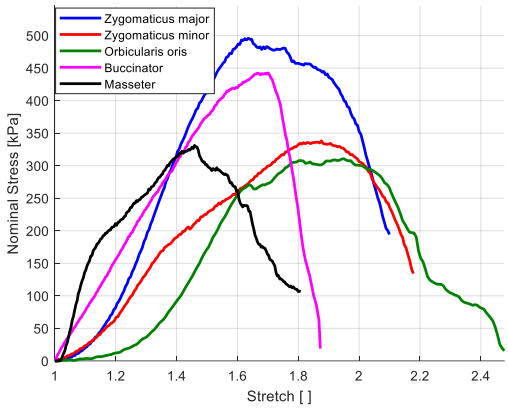

Figure 1*Stress–stretch response of fresh human facial muscles under uniaxial tensile loading up to rupture. The curves show nonlinear stiffening followed by failure, with variability between muscle types.*

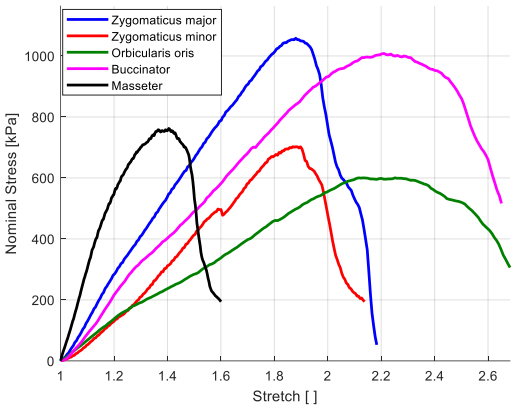

Figure 2*. Stress–stretch response of formalin-fixed human facial muscles under uniaxial tensile loading up to rupture. Increased stiffness and reduced extensibility compared to fresh tissues are clearly observed.*

Conclusion

This study provides new experimental evidence on the visco-hyperelastic and rupture behaviour of human facial muscles. The results demonstrate strain-rate sensitivity, muscle-dependent mechanical variability and pronounced stiffening due to formalin fixation. By documenting full stress-stretch responses up to failure, the study supplies data needed to improve constitutive model calibration and to enhance the predictive reliability of clinical biomechanical simulations.

References

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