A 3D Muscle Element Based on Equilibrium Point Hypothesis (EPH) and its Application in a Biomechanical Face Model

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1. Introduction

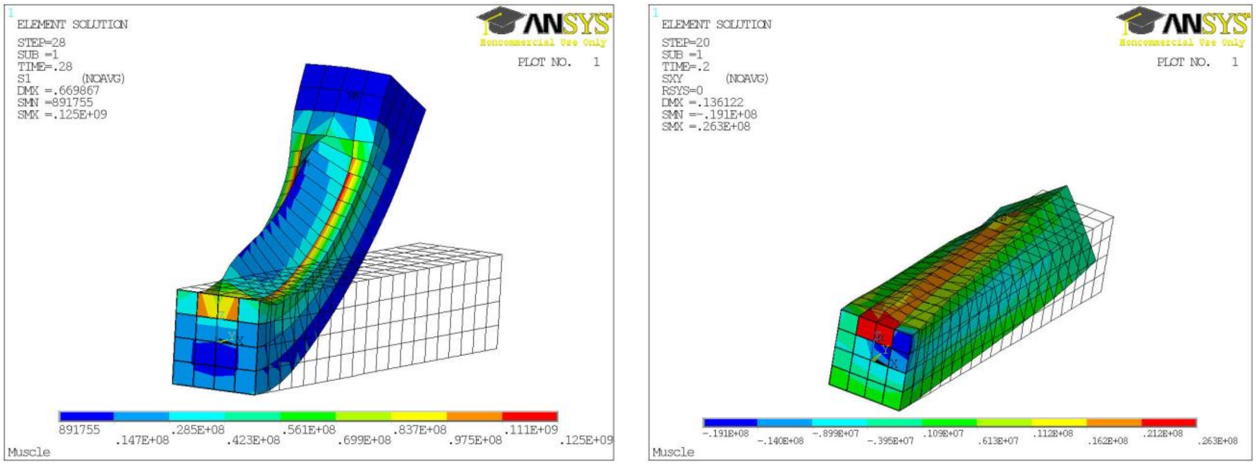
Numerous works on limb and speech motor control have shown evidence for the fact that articulatory stiffness has a strong influence on the achievement of gestural timing as well as on gestural stability and accuracy. In a recent work, using a 3D biomechanical model of the face, we have shown another important property of stiffness: it can be a determining factor in the achievement of specific shaping of the soft articulators (in our case, of lip rounding) [1]. This result has reinforced our opinion that speech motor control cannot be fully understood without accounting as realistically as possible for the physical properties of soft tissues articulators, and in particular of muscle soft tissues. Indeed, muscle mechanical characteristics vary in a complex way during a movement due to the impact of activation. The present work is a new step toward the design of increasingly realistic muscle models and their integration in biomechanical models of speech articulators. Contrary to our preceding approach in which models have been represented as isotropic passive tissues which elastic properties were functionally modified as a function of activation, and in which muscle forces were externally applied to macro-fibers ([2, 3]), the proposed model integrates all these features in the mechanical description of the muscle tissues themselves.

2. Muscle Element

Numerical modelling of muscle's behavior in a 3D continuum should consider a ground base *matrix* in which the muscle fibers are embedded ([4]). These fibers generate force and accordingly cause movement of the surrounding attached organs. Since the mechanical properties of fibers are different from the surrounding tissues (the *matrix*), the assumption of isotropic characteristics is not accurate for modelling a muscle. The properties along muscle fibers should be different from the ones in the directions perpendicular to fibers (transversal directions). Hence, a muscle has a special type of anisotropy which is called transversal isotropy. Therefore a continuum muscle model should consider this anisotropy due to its fibrous structure and at the same time it should provide a capability for fibers to generate force. The mechanism governing the force generation is often accounted for with a Hill based muscle model (see [5] for a review).

The usual tool for modelling a continuum is finite element method (FEM). Modelling a muscle in a 3D mesh needs the introduction of force generating entities. It can be done with existing standardized elements [3] or with external forces distributed on nodes [2]. Toward a more realistic model of a muscle first of all it should include the anisotropy of its structure [6] and at the same time it should take into account the capability of force generation along the fibers [7].

A 3D muscle element has been designed to be used under ANSYS© software. This element models transversal isotropy behavior with nearly incompressible hyperelastic strain energy through the Usermat programming tool of the software. Since the force generation mechanism in a muscle is a function of its current length and its velocity, an 8-node brick element is designed to take account for this relation. This feature is integrated through the Userelem programming tool, which allows defining a user specific element. Some test examples have been run to verify the behavior of the new element. Fig. 1 shows the example of a rectangular cuboid bar made of isotropic hyperelastic material (surrounding tissues) on top of which two rows of muscle elements are modelled. The fibers in muscle elements are modelled in the first case along the bar axis (Y direction in Fig. 1(a)) and in the second case along a 45° direction with respect to the bar axis (XY plane in Fig. 1(b)). Activation causes bending (1(a)) or twisting (1(b)).



(a) (b)

Figure 1. Example of a Hill-based type activation (see text).

Muscle passive properties are tuned to be in the same order of magnitude in our previous work [3]. For the active part, the Equilibrium point hypothesis is chosen [2]. This element is used to model the orofacial muscles. Some facial gestures are modelled and the role of the orbicularis oris in lip shaping is studied.

3. Conclusion

This new element is very flexible and it can be used in all type of muscle modelling problems. Due to the intrinsic tensile force generation, the tissue stiffness increases in the transversal direction with increasing activation. Thus, activated muscles can withstand greater force in transversal directions than non activated muscles (stress stiffening effect). In contrast to our previous work [2,3] the stress stiffening effect is taken into account automatically. Another important feature of the muscle model is the fiber direction definition. These fibers can be defined independently of the element orientation and muscles can be thus implemented independently of the mesh geometry.

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