

# INTRINSIC AND EXTRINSIC PORTIONS OF SOFT PALATE MUSCLES IN VELOPHARYNGEAL AND OROPHARYNGEAL CONSTRICTION: A 3D MODELING STUDY

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## 1. INTRODUCTION

The soft palate is essential in speech, yet understanding of soft palate muscle function remains quite coarse. Traditional descriptions of the soft palate highlight the 2D midsagittal actions of the palate with a focus on two muscles in particular: levator veli palatini (LVP), described as constricting the velopharyngeal port (VPP) by raising the soft palate, and palatoglossus (PG), described as constricting the oropharyngeal isthmus (OPI) by lowering the soft palate (Fritzell, 1969). The present paper argues that these descriptions are founded on the line-of-action of the extrinsic portions of those muscles, neglecting the role of the intrinsic portions. We present a 3D biomechanical model of the soft palate with the goal of clarifying the distinct roles that the intrinsic and extrinsic portions of these muscles play in VPP and OPI control.

Both LVP and PG comprise intrinsic and extrinsic portions relative to the soft palate (Cho et al., 2013; Kuehn & Azzam, 1978). While the extrinsic portions of LVP and PG are relatively thick and accessible, making them easy to monitor with EMG, the intrinsic portions are thin, fanned-out, and interdigitated with other muscles, making accurate EMG measurements of the intrinsic portions of these muscles prohibitively challenging (Kuehn et al., 1982). While previous studies have thus focused almost exclusively on the extrinsic portions of these muscles, the limited observations available in the literature suggest that the intrinsic portions are essential in soft palate function. E.g., Gick et al. (2014) show that the intrinsic portion of PG is important in modeling OPI closure, while Serrurier & Badin (2008) provide 3D image data revealing intrinsic reshaping of the soft palate, forming a large hump in the central posterior region of the superior palate surface as part of the closure mechanism. Further, the suggestion that the extrinsic and intrinsic portions of speech muscles may serve distinct functions finds analogy in previous studies of tongue muscles (e.g. Honda et al., 2013).

## 2. METHODS

Our upper airway (UA) model, defined and simulated using the Artistry biomechanical simulation toolkit (Lloyd, Stavness, & Fels, 2012) and composed of finite element (FE) components, rigid bodies, and skin meshes, generally follows the descriptions given in Anderson et al. (2015); however, changes were made to the soft palate

warranting further description here (illustrated in Figure 1). Based on stiffness values from Birch & Srodon (2009), the soft palate was modeled using a linear elastic material with  $E = 500$  Pa and point-to-point muscles (modeled after Peck et al. 2000) were given a passive force to approximate the muscle contribution to the overall soft palate stiffness. Muscle paths were informed by anatomical descriptions of the soft palate (Drake et al., 2010; Cho et al., 2013; Kuehn & Kahane, 1990). Reported cross-sectional areas of the LVP (Perry et al. 2013) and PG (Cho et al., 2013) were used to define the maximum muscle force following Peck et al. (2000), giving values of 10.8N for LVP, 2.1N for PGa, and 1.1N for PGp; other muscles, which do not play an active role in these simulations, were assigned a value of 3 N. Simulating Kuehn & Moon's (1998) protocol as a means of validation, a skin mesh representing the inner surface of the nasal airway was added to monitor cross-sectional area (CSA) and VPP closure; the location in the model of minimal CSA and maximal closure force was identified, and is the location reported in the remainder of this study.

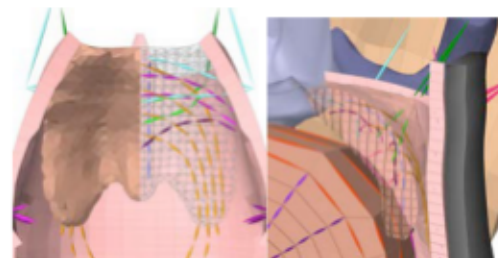
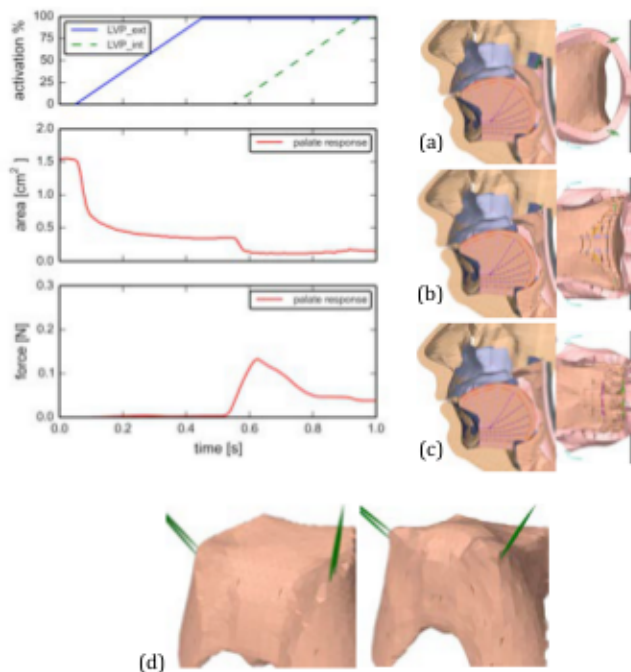


Figure 1. Front (left image) and oblique (right image) views of the soft palate model, showing: LVP (green), anterior PG (magenta), posterior PG (dark magenta), tensor veli palatini (cyan), palatopharyngeus (orange), musculus uvulae (purple).

## 3. RESULTS

Figure 2 shows results of sequentially activating the extrinsic and intrinsic portions of LVP. The CSA response (left, middle plot) shows that extrinsic LVP alone achieves 2/3 of VPP closure, yet only after the intrinsic portion of LVP is activated does the VPP completely close and the palate produce a substantial closure force (left, bottom plot) on the rear pharyngeal wall. Activating extrinsic LVP alone appears to create near-closure midsagittally, but droops along the line of the LVP (Fig. 2b). Only after the intrinsic portion of LVP activates does the soft palate strongly push back into the rear pharyngeal wall. As Figure 2d shows, activating LVP produces the characteristic "hump".



**Figure 2.** Left: sequential activation of extrinsic and intrinsic LVP. Right: soft palate model responses at (a)  $t = 0.0$ s; (b)  $t = 0.5$  s (extrinsic LVP only); (c)  $t = 1.0$  s (extrinsic + intrinsic). Bottom (d): oblique posterior view of soft palate showing hump (right image) formed by LVP (50% activation).

After LVP was activated as above and allowed to reach steady state for VPP closure, PG activation was added. We considered activation of PG as a whole, activation of only posterior PG (PGP), and activation of only the intrinsic portion or extrinsic portion of PGP. Results show that activating PG as a whole increases CSA of VPP closure and diminishes VPP closure force; however, activating only intrinsic PGP leads to no appreciable loss of VPP closure area or force. Examining the OPI, we observe that intrinsic PGP causes the largest forward motion of the uvula, producing the greatest OPI closure without compromising VPP closure. In contrast, activating any combination involving extrinsic PGP results in less forward motion of the uvula and greater compromises to VPP closure.

#### 4. DISCUSSION AND CONCLUSIONS

The intrinsic portions of LVP and PG play important roles in speech. The action of intrinsic LVP, through mediolateral compression of its fan-like shape, produces the expected hump observed in the posterior palate during VPP closure and is responsible for most of the closure force; intrinsic PG constricts the OPI without compromising VPP closure. The significant roles of the intrinsic portions of these muscles indicate serious shortcomings in the “trapdoor” representation of the soft palate, and suggest that intrinsic LVP should be carefully considered in VPP biomechanics and cleft palate repair surgery. The present simulations show that the intrinsic muscles of the soft palate

are needed for the soft palate to achieve the versatility that it is observed – and required – to have for speech production.

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