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The role of lingual frenulum on tongue mobility: a biomechanical modeling study

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1. Introduction

Ankyloglossia, or tongue-tie, is a condition that limits tongue mobility and affects around 3% of infants, often making breastfeeding difficult. The lingual frenulum is seen as a key factor in this disorder. Since the early 2000s, the number of frenotomies—surgical cuts of the frenulum—has increased significantly, despite ongoing debates about their effectiveness and the lack of long-term data (Sawai et al., 2024).

To better understand the impact of the lingual frenulum on tongue mobility during breastfeeding and evaluate treatment options, the TongueTieNum project aims to develop a biomechanical finite element (FE) model of a newborn's tongue. This model simulates the tongue's mechanical interactions with the mother's nipple to estimate the tongue's pressure on the nipple depending on the frenulum's morphology and mechanical properties. The objective of this preliminary study is to quantify the influence of the frenulum on the pressure that the tongue can exert on the nipple.

2. Methods

2.1 Generation of the FE newborn tongue model

The FE newborn tongue model was generated starting from a model that represents the tongue of a French male called "Reference Subject" (bmi of 20 kg/m^2, aged 60), using a 3D non-rigid landmark-based volume image registration method (Bijar et al., 2016) between MRI 3D views of the heads of the Reference Subject (RS) and of a newborn. The optimal transformation between the 2 MR image sets was applied to the RS FE tongue model (Calka et al., 2025) in order to transform its morphology into the one of the newborn tongue.

2.2 Nipple modelling

As a first step, a rough model of the nipple was generated (Figure 1 – panel d), which consists of a deformable cylinder of 24 mm in diameter and 35 mm long (Alatalo et al., 2019). In a first approximation the nipple was assumed to have the same material properties as the tongue. Standard mechanical contacts were defined between the tongue, from the tip to the blade, and the lowest part of the cylinder that represents the nipple.

2.3 Studying tongue mobility: a sensitivity study

Simulations were carried out to determine the impact of the frenulum's morphological and mechanical characteristics on tongue mobility for a gesture that simulates tongue movement during breastfeeding. In these simulations, the front part of tongue was raised by the activation of the superior longitudinalis (SL) muscle. This elevation induced an increase of tongue pressure on the nipple. A sensitivity study was carried out on 3 characteristics of the frenulum (F): morphology, thickness and stiffness. Three morphologies were considered according to the proximity of the frenulum's insertion relative to the tongue tip (Figure 1 – panel c): posterior (P), median (M), anterior (A). Two thicknesses (T) were

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tested: 1 mm and 3 mm. Stiffness (S) was defined based the value proposed by Souiki et al., 2025 (this conference), considering ratio of 1 or 3 with regard to the rigidity of the tongue (Yeoh 2 parameters, C1=192Pa, C2=90Pa). Thus, 12 simulations were carried out that were referenced as F-(P, M, A) T-(1, 3) S-(1, 3).

3. Results and discussion

3.1 FE newborn model

The FE newborn model is shown in Figure 1. The registration process enabled us to obtain an accurate morphology that fits well to the MRI ground truth.

3.2 Sensitivity study of the tongue frenulum

The simulations show that the most important property is the position of the frenulum used. For each position, Table 1 lists the mean and the standard deviation of the tongue pressure exerted on the cylinder representing the nipple, together with the maximum pressure (4 simulations for each position with various T and S).

Table 1. Mean and standard deviation of the pressures exerted by the tongue against the cylinder that represents the nipple for each frenulum position tested.

	Mean (Pa)	SD (Pa)	Max (Pa)
F-P	123.7	1.7	224
F-M	87.5	4.9	186
F-A	75.5	11.7	178

These preliminary results show that an anterior frenulum is more restrictive than a posterior one, supporting the idea that ankyloglossia results from an overly forward frenulum that limits tongue mobility, especially its elevation toward the palate in newborns. In addition, low standard deviation shows that thickness and stiffness parameters have little influence for posterior tongue frenulum, but much more for the anterior ones, with a maximum pressure of 178 Pa for the F-A T-3 S-3 simulation.

4. Conclusions

To conclude, this work presents the design of a FE newborn tongue model including an account of the tongue frenulum with the aim of carrying out a sensitivity study to characterize which parameters play major roles in the emergence of an ankyloglossia.

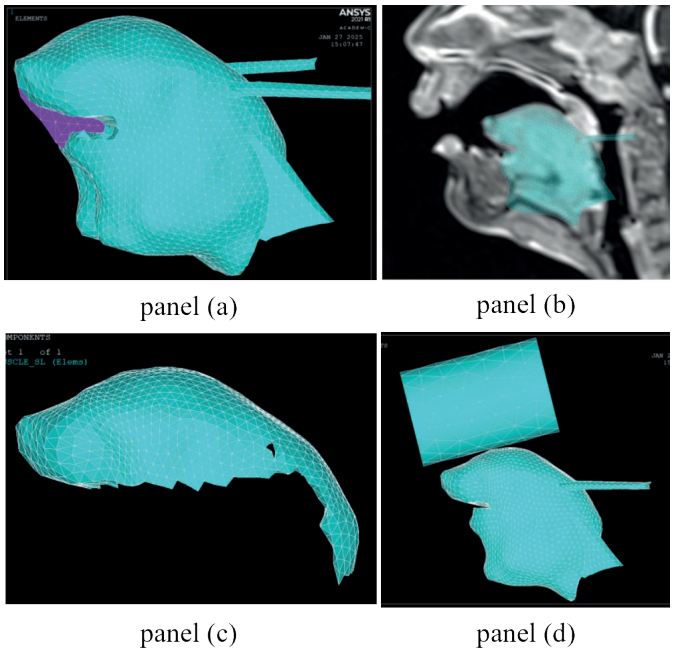

Figure 1. FE newborn model. Panel (a): FE newborn with anterior tongue frenulum (in violet). Panel (b): FE model superimposed on newborn MRI in the sagittal plane of the head. Panel (c): SL muscle. Panel (d): FE model with nipple model.

This work is preliminary and does not yet allow us to draw definitive conclusions about the role of the frenulum and its morphology in breastfeeding. However, it does offer a new approach based on biomechanical modeling that can further be used in research on breastfeeding and its impairments.

As a short-term perspective, the realism of the model will be improved by adding the mandible while sucking movements will be simulated using tongue muscle coactivation.

In the long term, this model could be coupled with the breast model developed within the TIMC laboratory (Mîra et al., 2018).

Conflict of Interest Statement

None.

Contributor Roles

Maëlle Courtin: Modeling, Methodology, Writing; Yohan Payan: Methodology, Writing, Supervision, Funding; Pascal Perrier: Methodology, Writing, Supervision; Morgane Evin: Methodology, Writing, Supervision, Project initiator; Emily Clady: Consulting, Writing; Pierre Frémondiere: Consulting, Writing;

Mohammad Ali Nazari: Modeling, Writing; Maxime Calka: Methodology, Writing, Supervision;

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