

ORIGINAL RESEARCH

Imaging the breastfeeding swallow: Pilot study utilizing real-time MRI

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Abstract

Objective: Knowledge of the breastfeeding swallow is limited by practical challenges. Radiation exposure to both mother and infant and the radiolucent properties of breastmilk make videofluoroscopy an unsuitable imaging modality. Furthermore, ultrasound is not ideal for capturing the complex 3-dimensional functional anatomy of swallowing. In this study we explore the feasibility of using real-time MRI to capture the breastfeeding swallow.

Methods: Prospective observational study: Review of imaging from 12 normal infants (<5 months of age) and their mothers while breastfeeding using real-time MRI.

Results: Static images were successfully captured in 11 infants and dynamic images in nine infants. This imaging modality confirms the dorsal surface of the infant's tongue elevates the maternal nipple to the hard palate, closing the space around the nipple with no air visible in the oral cavity during sucking and swallowing. We obtained dynamic imaging of mandibular movement with sucking, palatal elevation and pharyngeal constriction with swallowing, diaphragm movement with breathing and milk entering the stomach. Breastmilk was easily visualized, being high intensity on T2 sequences. Technical challenges were encountered secondary to infant movement and difficulties acquiring and maintaining midsagittal orientation. The similarity in tissue densities of the lips, tongue, nipple and hard palate limited definition between these structures.

Conclusion: Real-time MRI imaging was successful in capturing dynamic images of the breastfeeding swallow. However, technical and practical challenges make real-time MRI unlikely at present to be suitable for swallow assessment in clinical practice. Advances in technology and expertise in dynamic image capture may improve the feasibility of using MRI to understand and assess the breastfeeding swallow in the near future.

Level of evidence: 4.

KEYWORDS

breastfeeding, cine, dynamic imaging, infant, MRI, swallow

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1 | INTRODUCTION

The breastfeeding swallow has proven challenging to capture radiologically, resulting in a significant knowledge gap with respect to normal and abnormal swallow function in the breastfeeding infant. Most research on infant swallowing has used video fluoroscopic swallow studies (VFSS) to view and assess swallowing during bottle-feeding.¹ However, the validity of applying this knowledge to breastfeeding infants should not be presumed, with increasing evidence for differences in biomechanics and physiology between bottle and breastfeeding sucking and swallowing.²⁻⁴ As an imaging modality, VFSS is unsuitable for assessment of the breastfeeding swallow, requiring the need for un-natural positioning of the mother and infant and undesirable radiation exposure. Also, breastmilk is radiolucent on x-ray, so the fluid bolus is not visible. Only two studies have used cine radiography to image breastfeeding. The first, in 1958, visualized tongue movement during breastfeeding by coating the mother's nipple with a barium paste mixed in lanolin, but did not attempt to image swallowing dynamics.⁵ The second study, published in 2019, used VFSS to assess the breastfeeding swallow in 25 infants by utilizing trans lactation supplementation to deliver barium as the infant fed at the breast.⁴ Although VFSS has high accuracy in identifying penetration and aspiration in these infants, the added flow of the barium and the infant positioning, 40° elevated lateral decubitus, are likely to have an impact on their swallow physiology, creating uncertainty regarding the study's outcome measures and their interpretation.

Ultrasound imaging has contributed significantly to the understanding of biomechanics of sucking during breastfeeding using a submental approach in the mid-sagittal plane.^{2,6-8} Ultrasound has also been used to evaluate the breastfeeding swallow,⁹ with potential to view the movement of specific anatomical structures such as the soft palate. However, it has limited ability to capture the rapid and dynamic 3-dimensional events occurring during the breastfeeding swallow and requires a high level of expertise in both image acquisition and interpretation.

Flexible endoscopic evaluation of swallowing (FEES) involves placement of a thin endoscope via the patient's nasal airway to provide a 3-dimensional view of the pharyngeal phase of the swallow,¹⁰ with findings shown to have good validity when compared with VFSS.¹¹⁻¹⁴ FEES is limited to viewing the pharyngeal phase of the swallow. Clear views are usually attained pre and post swallow, with a temporary but crucial loss of the image during the pharyngeal constriction phase of the swallow. FEES is dependent on the infant's tolerance of passing the endoscope and being willing to feed with the endoscope in situ. Nevertheless, it has been shown to be a safe and appropriate modality for viewing the breastfeeding swallow.^{12,15} Despite the increasing utilization of FEES, there is still no published normative data for the breastfeeding swallow, highlighting the significant gaps in knowledge which impacts on the interpretation of FEES in breastfeeding infants.

There is a substantial body of research on the coordination of sucking, swallowing, and breathing, with a particular focus on

premature infants during breastfeeding.¹⁶⁻²⁰ The majority of these studies have relied on indirect measures for the timing of breathing (such as plethysmography and thermistors) and swallowing (inferred by pauses in breathing and sucking) because of the challenges in measuring these events directly.

With the benefits of being a non-invasive, non-irradiating imaging modality, MRI has had an emerging role in the understanding of complex aerodigestive disorders. It has been used to develop a more detailed understanding of the complex anatomy of the pharynx and larynx enabling finite element modelling²¹ and has improved the understanding of dynamic airflow in infants.^{22,23} Dynamic or real-time MRI has been shown to have sufficient spatial and temporal resolution for assessing the normal and abnormal adult swallow.²⁴⁻²⁷ Functional MRI imaging has been used to assess cortical function during the pediatric swallow²⁸ but as yet no papers have reported on swallow assessment using MRI in the pediatric population. This pilot study was performed to assess the feasibility of using real-time MRI to view the breastfeeding swallow in normal infants.

2 | METHODS

This prospective study utilized real-time (dynamic) MRI imaging to view the breastfeeding infant swallow. The mothers gave informed consent and the study had ethics approval from the University of Auckland Human Participants Ethics Committee (#016224).

3 | SUBJECTS

Twelve infants and mothers (dyads) were recruited through local lactation and speech-language therapy networks between 1 January 2016 and 31 August 2019. Inclusion criteria was infant age <5 months and no significant comorbidities, airway or significant difficulties breastfeeding. Mothers were recruited who were comfortable feeding their infant in a side-lying position and had no claustrophobia. The infants included 2 females and 10 males and were on average 11 weeks old (range 2-20 weeks).

4 | REAL-TIME MRI

The imaging was conducted using Siemens 3T MAGNETOM Skyra (7 dyads) and 1.5T MAGNETOM Avanto (5 dyads) MRI scanners (Siemens Healthcare, Erlangen, Germany). Standard sound protection was provided for the mother (ear plugs and head-phones) and the infant (earplugs, mini-muffs, and strapping) with a crepe bandage used to prevent displacement with infant movement (Figure 1). The mother and infant were positioned side lying, facing each other, with breastfeeding imaged in this lateral decubitus position. A small flexible radiofrequency receiver (4 or 18 channel flex matrix coil) was draped over the mother's shoulder aligned with the infant's head, used in combination with the spine coil elements.

On the 3T (Syngo VE11 software) initial scout three plane localizers were followed by a stack of transverse Haste single shot slices (10 slices, 2.5 mm slice thickness, TR 1800 ms, TE 96 ms) to localize the midline. Once baby latched and started to feed, a pd/T2 weighted single 2.5 to 3 mm slice was aligned in the midline sagittal position. Parameters varied as follows TR 1250-3200 ms, TE 94-108 ms, parallel imaging factor 2, 320FOV (varied). The number of repeated measurements varied due to infant movement or alignment issues, with coronal Haste localizers interspersed to gain best angulation. Realtime cines on the 3T were compromised by susceptibility artifacts, SAR and heating issues so limited acquisitions only were possible. The 1.5T was considered as an alternative to attain real-time cines without the aforementioned issues.

On the 1.5T (Syngo VB17 software), a prototype sequence, LiveView, utilizing the 12channel body matrix coil in combination with posterior spine coil elements was utilized to acquire a single 8 mm slice in the mid sagittal plane. This sequence utilized fast radial k-space sampling to produce T1 weighted gradient echo images which can be adjusted during acquisition to achieve the optimal mid sagittal alignment. Parameters used were: slice thickness 8 mm, 500 mm FOV, matrix 192×192 , TR 50 ms, TE 1.4 ms, acquisition time 00.18 second ($2 \times$ frames per second). Low SAR and whisper mode were utilized for patient comfort. Attempts at sequence optimization were limited due to patient movement and tolerance.

Other sequences that were trialed at 1.5 T:

- 2D real-time GRE Cines were acquired as follows: 3 mm slice thickness, TR 13.64 ms, TE 3.48 ms, flip angle 15° , 192×128 matrix. Repeated measurements acquired until movement out of plane necessitated repositioning.
- 2D TRUEFISP Cines (1/second) TR 3.47 ms, TE 1.41 ms in sagittal plane

- 3D GRE Cine using 4×2.5 mm slices, TR 2.24 ms, TE 0.92 ms, 160×136 matrix, 320FOV.

Features of imaging that were evaluated are outlined in Table 1.

5 | RESULTS

MRI images of the latched infant were captured in 11 of the 12 dyads, with one infant too unsettled during scanning sequences to feed. Images were captured in midsagittal, coronal, and axial planes (Figure 2). With 9 days we were able to acquire midsagittal alignment and capture dynamic imaging of multiple sequential swallows (Video S1). Most captured sequences were less than a minute duration, with the longest being 3 minutes. With most infants moving during feeding,

TABLE 1 Evaluation of imaging

| Imaging was evaluated regarding ability to visualize: |
|---|
| <ul style="list-style-type: none"> • Differentiation between the soft tissues of the lips, nipple, tongue and palate |
| <ul style="list-style-type: none"> • Breast milk (in oral cavity, pharynx, esophagus and entering stomach) |
| <ul style="list-style-type: none"> • Presence of air in the oral cavity |
| <ul style="list-style-type: none"> • Mandibular movements |
| <ul style="list-style-type: none"> • Palatal elevation (velopharyngeal closure) |
| <ul style="list-style-type: none"> • Pharyngeal contraction |
| <ul style="list-style-type: none"> • Penetration/aspiration |
| Esophageal transit of fluid bolus |
| Diaphragm movement (elevation and depression) |



FIGURE 1 Securing infant hearing protection

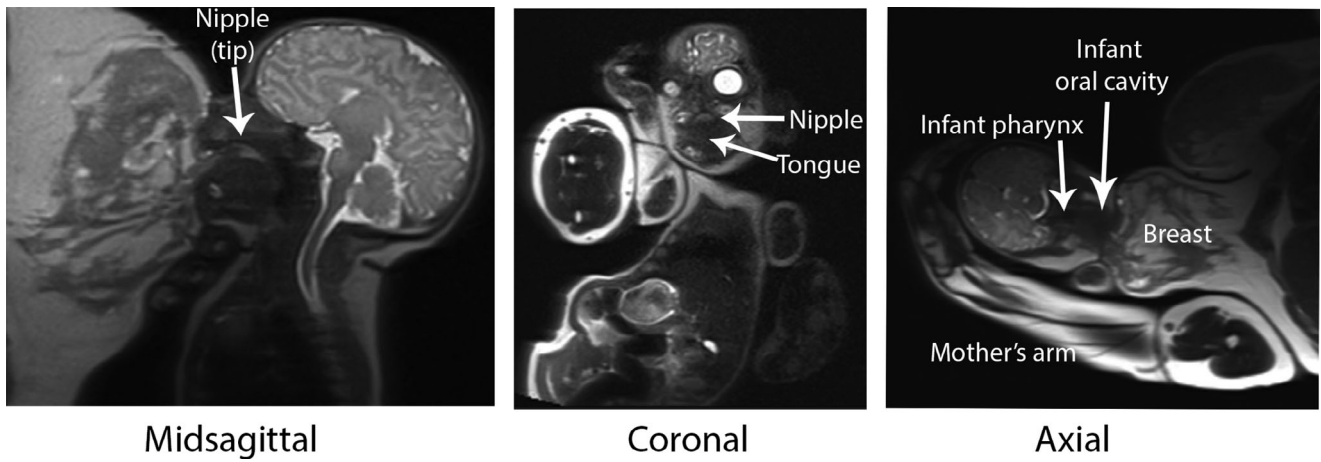


FIGURE 2 Planes of imaging (images of same infant in three planes, all T2)

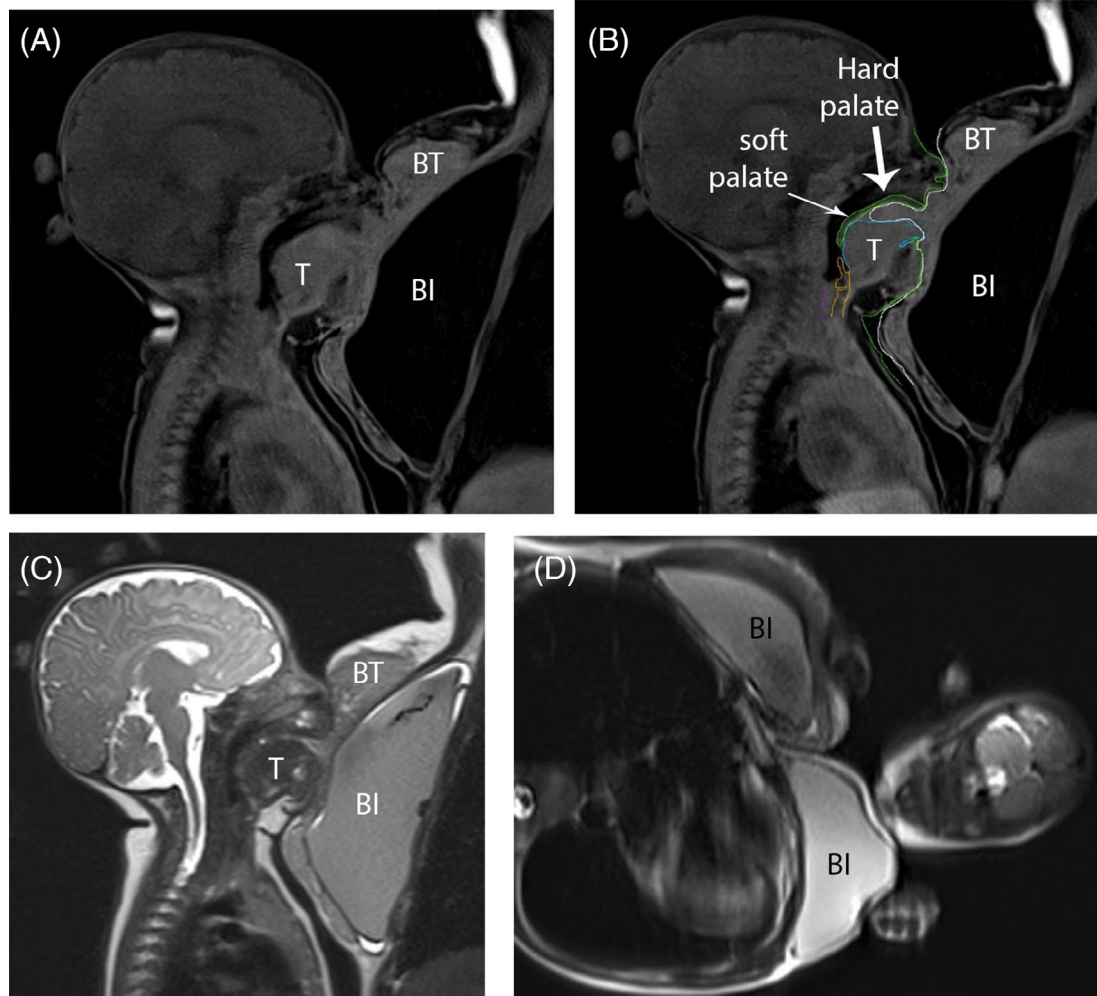


FIGURE 3 Infant latched at breast (maternal breast implants). A, (T1) Midsagittal: Air in nasal cavity and pharynx (black). B, (T1) Midsagittal: with lines drawn to define anatomy, nipple shown elevated up to hard palate. C, (T2) Parasagittal plane (just off midline): small amount of breastmilk shown (white) at tip of nipple, soft palate draped over tongue base. D, (T2) Axial plane. BI, breast implant; BT, breast tissue; T, tongue

attaining, and maintaining midsagittal alignment was challenging and therefore the quality of images captured was variable.

5.1 | Variability in maternal breast tissue and infant upper lip positioning for latching

Maternal breast size and ratio of glandular tissue varied significantly, with one mother having breast implants (Figure 3). Mothers with a generous volume of breast tissue were more likely to use their hand to ensure their breast tissue did not impact their infant's nasal patency during feeding (Figure 4) but this may have been caused by limited visual access to latch their infant in the confines of the scanner. In the 11 infants with imaging, we found the upper lip position during the latch was neutral (not everted) in eight infants, everted in two and in one we were unable to accurately determine lip position.

5.2 | Mandibular movement, oral cavity, and sucking movement

Mandibular movements with sucking were easily visualized. Clear definition between lips, nipple, tongue, and palate was not achieved in real time imaging but were distinguishable in static images (Figure 5). The infant's tongue tip generally rested on the lower gums and was not protruded beyond the lips in any infant. Using a combination of sagittal and coronal plane imaging confirmed that when the latch is maintained there is no air present within the oral cavity. In all imaging, the infant's tongue elevates the mother's nipple to the roof of the hard palate, with the lateral sides of the tongue cupping to close the space around the nipple. If the infant briefly released the intraoral vacuum, an air-tissue interface was visible in the oral cavity and the nipple, palate and tongue would be clearly visualized (Figure 6).

5.3 | Pharyngeal phase of the swallow, breathing, and aspiration

Soft palate elevation and velopharyngeal closure was well defined because of the air-tissue interface in the pharynx. Soft palate elevation was followed by a wave of peristaltic pharyngeal constriction. Laryngeal elevation occurred early in the swallow but epiglottic movement and position was not well defined as no air was present in the pharynx during pharyngeal constriction to define soft tissue contours. The trachea was easily visualized, dependent on imaging alignment. Aspiration was not visualized in any of the studies, but being normal subjects was not expected to be present. However, with the current study using observation in a single axis view of the swallow (in the midsagittal plane), this modality would be expected to have poor sensitivity for detecting aspiration. Infant diaphragm movement was easily visualized when in the scanning field, enabling accurate identification of the inspiratory and expiratory phases of the breathing cycle.

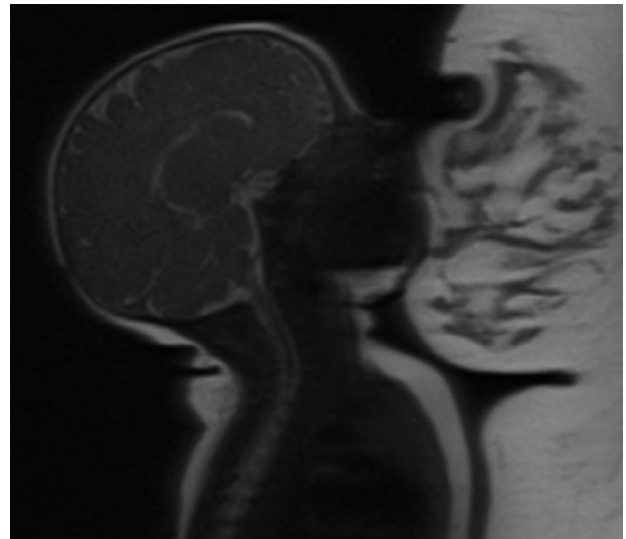


FIGURE 4 Generous breast: mother optimizing infant's airway with finger compression of breast (T2)

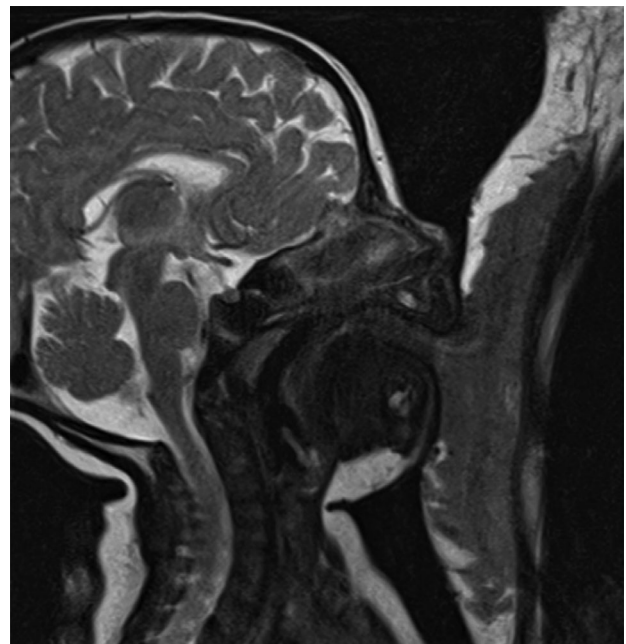


FIGURE 5 Well defined palate/nipple/tongue (T2)

5.4 | Breast milk

Breast milk was high intensity and most easily visualized on T2 sequences. Milk could often be seen entering the oral cavity in the space just distal to the tip of the nipple, however during transit through the pharynx would usually pass out of view in the midsagittal plane. Where alignment allowed, the milk bolus could be glimpsed transiting through the esophagus and milk was easily seen jetting into the stomach.

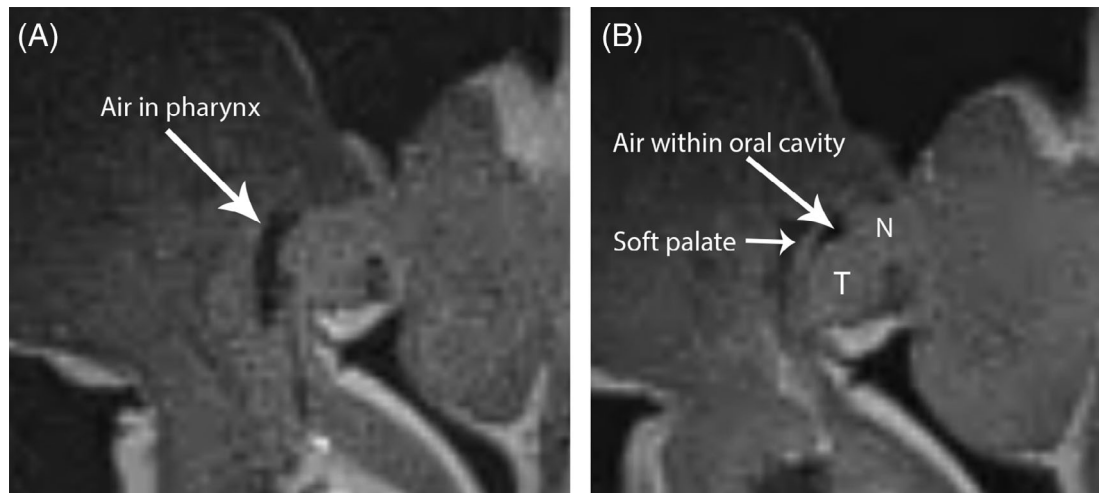


FIGURE 6 Intraoral vacuum (T2). A, Intraoral vacuum maintained with no air within oral cavity. B, Intraoral vacuum released with air visible in oral cavity. N, nipple; T, tongue

TABLE 2 Outline of technical challenges

Potential limitations or challenges for using real-time MRI to image breastfeeding

- Fitting both mother and baby into the scanner
- Side lying feeding due to the scanner dimensions
- Potential maternal claustrophobia
- Noise disturbance for the infant
- Practical challenges of latching and feeding in a confined space
- Active feeding has limited time window
- Finding alignment of infant midsagittal plane
- Infant movement creating a mobile target
- Limitations in image quality (being unable to use a dedicated head coil on infant)
- Limited visual definition between key structures (lips, nipple, tongue, palate)

6 | DISCUSSION

This study has confirmed that it is possible to visualize the breastfeeding swallow using real-time MRI and has provided dynamic images of breastfeeding previously not captured. Despite the technical limitations encountered (outlined in Table 2) preventing reliable image capture of an acceptable quality for quantitative analyses, this imaging modality shows promise for future research on the breastfeeding swallow when these issues can be addressed.

This study has improved our understanding of some dynamic anatomical aspects of breastfeeding. Our results support the current understanding of breastfeeding sucking biomechanics from ultrasound studies, that an intraoral vacuum is maintained during sucking.^{2,6} We have shown that no air is present in the oral cavity when the latch is maintained, with the dorsal surface of the tongue raising the nipple to the hard palate. In a 3-dimensional manner, the tongue dorsum closes all of the air space around the nipple. Visualization of air between the

dorsal tongue surface and nipple was identified only when a loss of intraoral vacuum occurs, which was a rare event during any sucking bursts captured in this study. The clinical implications of this relates to our understanding of how ankyloglossia impacts on breastfeeding in limiting tongue elevation and the ability to create and sustain an intraoral vacuum. With the MRI images giving an overview of the whole oral cavity, the degree of tongue elevation required appears to be impacted by the height and contour of the infant's hard palate as well as the volume of maternal nipple and areolar tissue. This introduces other anatomical variables that need to be considered (in addition to the infant's frenulum morphology) when assessing for causes of infant sucking dysfunction.

The role of the upper lip frenulum in limiting upper lip mobility and optimal positioning for latching is controversial.²⁹ We observed that in this cohort of infants with no reported breastfeeding difficulties, the majority did not have upper lip eversion while latched and actively sucking. This information challenges the common belief that it is essential for the upper lip to evert to attain an effective and comfortable latch,³⁰ suggesting that upper lip eversion is not always necessary.

Throughout active sucking, the infant's soft palate remains approximated to the tongue base, with no air gap present between the tongue base and lingual surface of the soft palate, in spite of significant antero-posterior excursion of the tongue base during sucking. It is well established that active contraction of *levator* and *tensor veli palatini* muscles elevate the palate to create closure of the nasopharynx during swallowing. However, rather than the muscles of the soft palate being relaxed and draping passively over the posterior tongue during sucking, we propose that the palate is actively contracted to maintain this approximation to the tongue base during sucking. It seems possible that palatoglossus contraction is important in maintaining closure of the posterior aspect of the intraoral space, assisting in maintaining the intraoral vacuum required for milk transfer during breastfeeding.³¹ It has been shown that palatoglossus in the infant is relatively larger in the infant tongue when compared to adult

morphology,³² with its proposed role in maintenance of intraoral vacuum during breastfeeding a potential explanation for this. This also helps our understanding of breastfeeding difficulties in infants with structural palatal anomalies or palatal muscle weakness.

In this study, real-time MRI has been able to capture simultaneously mandibular movements during sucking, soft palate and pharyngeal constriction during swallowing as well as diaphragmatic movements during breathing. Coupling of tongue movement to mandibular movement is variable in adults,^{33,34} but tongue and mandible were seen to move synchronously as the infants were actively sucking. Given that it is assumed that lowering of the mandible is coupled with depression of the anterior to mid tongue this likely is an over simplification given the complexity and variability of the tongue and its movements. Real time MRI therefore may not only offer the opportunity to directly measure and describe the relative timing of breathing, swallowing and sucking but also can define tongue movement with respect to mandibular movement. Unfortunately, due to the inconsistency of the imaging quality and length of real time runs we were unable to make comprehensive measurements and inferences.

Although breastmilk has sufficient fat content to be well visualized on MRI, there was inadequate milk coating the mucosal surfaces within the oral cavity to provide a natural delineation of these structures. We utilized a supplementary coil draped over the mother's shoulder at the level of the infant's head, but we could not achieve the improved image definition shown in a recent adult study using dedicated head and neck coils.³⁵ The poor differentiation between palate, nipple, and tongue tissues limits visualization of dorsal tongue movement and therefore ultrasound remains the superior imaging modality for assessing sucking biomechanics.

Most adult real-time MRI studies have assessed the swallow with the subject placed supine. The adult subjects participating in these studies had no underlying swallowing difficulties and did not report any difficulties drinking in this position. However, supine positioning would not be considered a usual or ideal position for an adult to eat or drink, particularly when dysphagia is present. In our study, side-lying positioning for feeding was required because of space limitations within the scanner. All of the volunteer mothers had been utilizing side-lying feeding as an option for positioning for breastfeeding prior to participating in the study, so this does not appear to be a non-physiologic position to use for assessment. Infant positioning during breastfeeding has a clinically significant impact on their swallow and airway and accordingly we suggest that the infant's position during imaging would ideally emulate their normal feeding position. When using flexible endoscopy to observe the breastfeeding swallow in an infant in a lateral decubitus position, a swallowed fluid bolus transits through the pharynx to the gravity dependent piriform fossa. In any form of imaging, the fluid bolus would therefore be expected to momentarily pass out of view in the midsagittal plane, to be centralized and visible again when passing through cricopharyngeus. We attempted 3-dimensional cine image to improve capture of the fluid bolus through the pharynx but unfortunately this was not successful. However, given the software advances allowing 3-dimensional image capture of dynamic airway collapse^{22,23} this certainly may be possible in the future.

7 | CONCLUSION

Imaging of breastfeeding using real-time MRI proved feasible and has provided unique images and improved our understanding of events occurring during sucking and swallowing. However, there have been significant challenges that limit the utility of this modality for research and clinical practice. The infant's variable tolerance of the noise and environment as well as the challenges of needing real-time alignment adjustments to respond to infant movement during feeding provided significant barriers for use of real-time MRI as a diagnostic tool for breastfeeding swallow. Further technological advances may facilitate research that can address some of the challenges to provide further insights into the functional anatomy of the breastfeeding swallow.

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CONFLICTS OF INTEREST

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SUPPORTING INFORMATION

Additional supporting information may be found online in the Supporting Information section at the end of this article.

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