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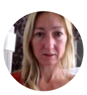

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Ultrasound Imaging of Breastfeeding—A Window to the Inside: Methodology, Normal Appearances, and Application

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Abstract

Ultrasound imaging has been employed as a noninvasive technique to explore the sucking dynamics of the breastfeeding infant over the past 40 years. Recent improvements in the resolution of ultrasound images have allowed a more detailed description of the tongue movements during sucking, identification of oral structures, and measurements of nipple position and tongue motion. Several different scanning planes can be used and each show sucking from a different perspective. Ultrasound techniques and image anatomy are described in detail in this review and provide the basis for implementation in the objective assessment of breastfeeding.

Keywords

breastfeeding, feeding, imaging, lactation, sucking, ultrasound

Background

For breastfeeding to be biologically successful, it is essential that the infant removes adequate amounts of milk from the breast to ensure both optimal infant growth and stimulation of continued milk synthesis.[1,2] Physiologically, breastfeeding requires a complex interaction and coordination of the jaw, hyoid bone, tongue, palate, pharynx, and larynx to coordinate sucking, swallowing, and breathing.[3,4] Infants exhibit 2 types of sucking patterns: nutritive sucking (NS), where milk is consumed typically in long bursts with short rest periods,[5] and nonnutritive sucking (NNS), which is characterized by a series of regulated burst and rest periods along with no removal of milk.[5]

The function of the tongue is of major importance during infant sucking as it is integral in both the removal of milk from the breast and the safe clearance of the milk bolus from the oral cavity,[6] yet exactly how the tongue functions during sucking is often the subject of considerable debate. Two theories have been put forward: stripping action theory[7,8] and vacuum theory.[9] The stripping action theory suggests that compression of the breast by the superior ridge of the infant's mandible followed by a peristaltic tongue movement squeezing milk from the nipple is critical to milk removal.[8] The intraoral vacuum theory, on the other hand, suggests that vacuum created by the descent of the tongue is the primary mechanism of milk removal. Evidence is rapidly accumulating emphasizing the importance of adequate vacuum for effective feeding in preterm infants, infants with bronchopulmonary disease, and infants with cleft lip and palate.[10,11] Furthermore, recent ultrasound studies in term infants have not shown marked peristaltic tongue actions during breastfeeding.[12,13]

Although safe and efficient feeding is known to require good coordination of sucking, swallowing, and breathing,[5,14,15] very few objective techniques exist to assess these processes. The purpose of this report is to describe in detail ultrasound and intraoral vacuum techniques that can be used to investigate infant sucking dynamics during breastfeeding.

A single author (DTG) performed a literature search of the PubMed and MEDLINE databases for original studies measuring sucking in term and preterm infants. The search combined variations of the following keywords: sucking, vacuum, ultrasound, feeding, and infant feeding, in association with breastfeeding and bottle feeding and term or preterm infants. Papers were limited to English and human infants. Letters, commentaries, case studies, and reviews were excluded. Of the original papers, all papers were

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assessed for methodology, results, and interpretation. Articles that measured both breastfeeding and bottle feeding were included.

Ultrasound Equipment

Transducer requirements for the examination of the breastfeeding infant include

- appropriate size—not so small as to disturb the infant as the transducer is manipulated and not too large to alter the positioning and attachment of the infant to the breast
- ability to be readily manipulated, allowing for movement of either the mother or the infant during feeding
- wide field of view to image the whole of the oral cavity and high frequency to provide the best resolution image possible.

Jacobs and colleagues[16] tried several different types of ultrasound transducers to image the infant intraoral structures during breastfeeding, including a linear array (7 MHz), a sector phased array (7 MHz), and a long-handled convex array (endocavity) transducer (7 MHz). The linear array transducer was T shaped with a thin rectangular head (50 mm). Despite yielding images of high resolution, the shape and size of this transducer made scanning difficult, as it was large and difficult to fit under the infant's chin. The sector array produces a wide vector from a smaller rectangular footprint than that of the linear. Although the image quality was acceptable, the handling of this transducer also interfered with breastfeeding. Jacobs and colleagues concluded that the endocavity transducer provided both optimal resolution and the least interference with feeding as assessed by a lactation consultant. It should be noted that a 5 MHz convex transducer was tried briefly and discarded due to very poor resolution.

The transducer frequency should be as high as possible to produce images of the best quality without compromising tissue penetration. Typically, the frequency used for modern equipment would be in the range of 8 to 10 MHz for infants younger than 12 weeks. Previously, lower frequencies such as 5 MHz were employed, as higher frequencies were not available, rendering poor quality images compared to those acquired now.[17,18] Often, the frequency selected is decreased for larger and older infants to achieve adequate penetration to image the palate.

Recently, 3-dimensional imaging has been used to investigate whether this new modality adds to the understanding of breastfeeding sucking dynamics. It is unfortunate that the frequency of the sector probe used was 2 to 7 MHz, and therefore, the resolution was not sufficient to visualize milk flow, nipple ducts, or the soft palate. Hence, it was able to describe only the tongue surface motion.[19]

Recording of the entire feed is recommended along with the facility to store selected video clips for retrospective analysis. On-screen measurements are not possible due to the high suck rate of breastfeeding infants. Frame-by-frame viewing has been recommended for analysis in order to correctly identify artefacts that may lead to error in measurements.[20] More recently, Elad et al[13] employed advanced computational modeling of 2-dimensional sagittal images to automate analysis of feeding images, allowing registration of the hard palate and frame-by-frame analysis and ultimately graphing the phase shift of the tongue.

Figure 1. Positioning of the Endocavity Ultrasound Probe for Submental Imaging during Breastfeeding.

Orientation of the transducer can provide either a sagittal or transverse image of the infant oral cavity.

Ultrasound Technique

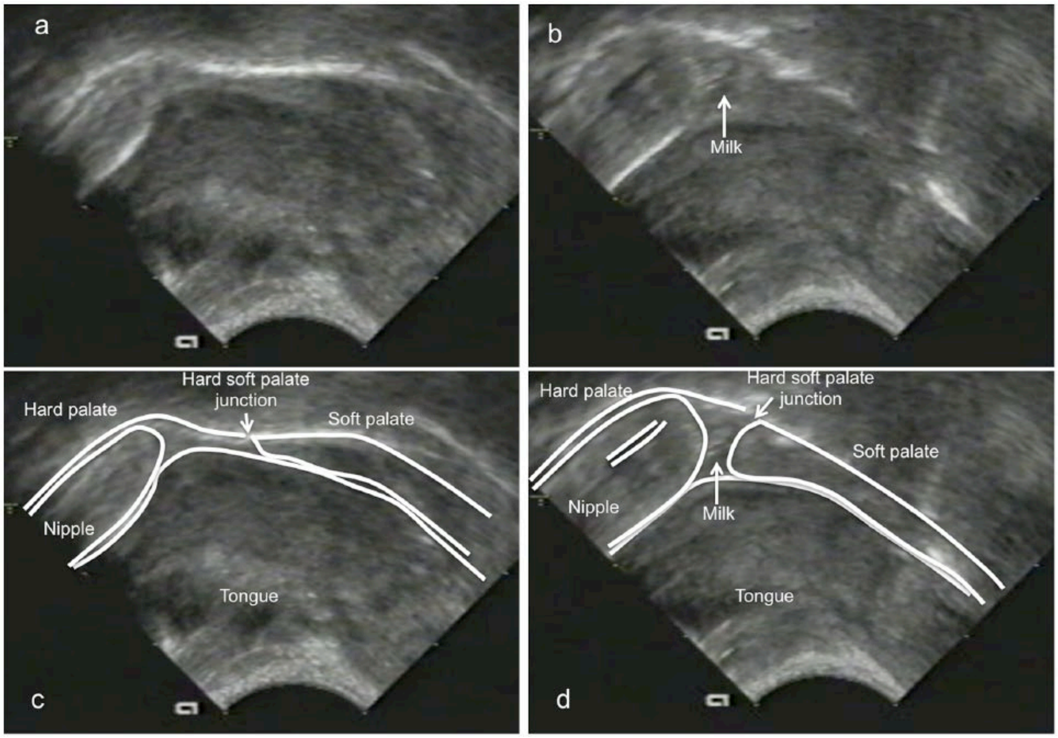
This section will provide details on scan technique including the ultrasound appearances and measurements of anatomical structures for each scanning plane.

The mother should be seated in a comfortable chair and be provided with appropriate support such as pillows (if necessary) to feed her infant. The cradle hold or variations on this hold are the most amenable to good imaging, whereas the football hold or prone position limits access to the mandible and restricts the views that can be obtained.

It is essential that the sonographer is seated comfortably and is prepared to scan as soon as the infant goes to the breast. Often, it is pertinent to lay the probe along the infant's body, prior to attachment to the breast, so that neither the infant nor mother is disturbed once breastfeeding begins (Figure 1).

Historically, a submental approach to acquire midsagittal images of the oral cavity has been used during both breastfeeding and bottle feeding due to the ease of recognition of the infant oral structures. It is unfortunate that bulkier scan heads, low frequency transducers,[21] and less sophisticated equipment used previously limited both manipulation of the transducer and image resolution.[21,22] Smith et al[21] used the transbuccal and transverse (submental approach) plane to investigate changes in the human nipple during breastfeeding, but this has been used to a much lesser extent.[18]

Figure 2. Submental Midsagittal Images of a Breastfeeding Infant.



Ultrasound appearances: hard palate—echogenic, soft palate—mid gray with an echogenic superior border due to reflection of air in the maxillary sinus, tongue—mid gray with echogenic areas representing muscle fibers, nipple—mid gray with echogenic borders, nipple duct—hypoechoic with echogenic walls, breast milk—hypoechoic with echogenic flecks. Tongue up (A and C). The tongue fills the majority of the oral cavity and is in apposition with the soft and hard palates. The nipple is reduced in diameter and is placed 7 to 9 mm from the nipple hard–soft palate junction. Tongue down (B and D). The tongue moves downward away from the palate as vacuum strengthens, expanding the nipple evenly and drawing the nipple closer to the hard–soft palate junction. Milk flows into the space between the nipple and soft palate bounded superiorly by the palate and inferiorly by the tongue.

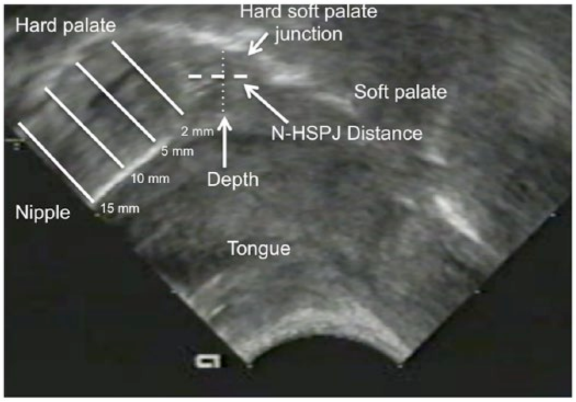
Midsagittal Plane

In general, the image is inverted so that the palate is oriented to the top of the screen and the nipple to the left of the image. The transducer is placed, with a small amount of gel, under the chin in the midsagittal plane. The probe is then rotated until the long axis of the hard and soft palate is achieved. Slight movement of the probe in the right and left lateral directions will determine the widest part of the nipple, ensuring a midline view. The angulation of the probe will depend largely on the position of the infant at the breast, that is, the relationship of the midsagittal axis of the infant's head to the breast. If simultaneous vacuum measurements are being performed, the intraoral component of the pressure transducer can be imaged if the plane is not true midsagittal.

Ultrasound appearances. The hard palate appears as an echogenic border superiorly with the distal portion obscured by the acoustic shadow created by the mandible. Adjacent and posterior to the hard palate, the soft palate is a homogeneous structure of medium echogenicity. The upper border of the soft palate is highly echogenic due to the attenuation and reflection of the sound beam by the air in the nasopharynx. The junction of the hard and soft palates is easily identifiable as movement occurs during sucking. The nipple is of medium echogenicity, whereas nipple ducts appear as hypoechoic tubular structures within the nipple. The tongue fills the majority of the oral cavity and is heterogeneous due to the numerous muscle fibers that run at varying degrees of obliquity (Figure 2). The hyoid bone, seen adjacent to the posterior tongue, is highly reflective and casts a strong acoustic shadow.

During NS, the infant draws his or her tongue downward and the soft palate also moves downward in apposition with the posterior tongue. During the downward motion, vacuum increases, peaking at the lowest point of the tongue excursion.[23] At this point, the nipple has maximally expanded in diameter, nipple ducts may become visible, and it moves slightly toward the hard–soft palate junction. Milk accumulates in the space bounded by the palate, tongue, nipple, and soft palate. Milk has a variable appearance from anechoic (black) to quite echogenic. Often, it appears anechoic with

Figure 3. Ultrasonic Measurements of Nipple, Nipple–Hard-Soft Palate Junction (N-HSPJ) Distance, and Depth (of Tongue Lowering), Adapted from McClellan et al.[20]



small white flecks in the bolus. This can be attributed to high reflectivity of the milk fat globules in the milk.[24] As the tongue is raised, vacuum decreases to baseline level (Figure 2, Supplementary Video [available online]). Subsequently, ultrasound measurements of the nipple diameter (as a proxy for tongue movement), nipple hard–soft palate junction distance, and depth of midtongue movement have been made according to the tongue up and tongue down position and validated.

Measurements. McClellan et al[20] performed intrarater and interrater reliability tests regarding the recognition of ultrasonic landmarks and ultrasonic measurements made for 30 submental sagittal ultrasound scans of successfully breastfeeding infants. Measures included midtongue depth (depth), nipple–hard-soft palate junction (N-HSPJ) distance, and nipple diameter at the specified intervals along the nipple.

Depth was measured as the minimum internal distance from the HSPJ to the midtongue. Measurements of the N-HSPJ distance were taken as the perpendicular distance from this line to the nipple tip. Nipple diameters were made at 2, 5, 10, and 15 mm from the tip of the nipple (Figure 3). Good intraobserver reliability (ICC > 0.7 mm) and interobserver reliability (ICC > 0.7 mm) was confirmed. The most extreme difference in measurement between raters was 0.5 mm. Major sources of error between observers were misidentification of the end of the nipple, particularly when the milk bolus was highly echogenic, and the edge of the hard palate when it artefactually appeared lengthened. Careful frame-by-frame analysis has been found to reduce this error substantially.[20] Measurements of the changes in intraoral structures are given in Table 1.

The motion of the anterior and midtongue, which corresponds to milk removal from the breast, has been reported to move as a rigid body rather than a peristaltic action (Figure 2, Supplementary Video).[12,25] Differences in the movement of oral structures are, however, apparent between NS and NNS. Nipple expansion and midtongue excursion were greater during NS compared to NNS; however, nipple position (N-HSPJ distance) was not different between NS and NNS or across lactation.[26]

Table 1. Ultrasonic Measurements of Infant Oral Structures during Breastfeeding (mean ± SD) for Nutritive Sucking, Based on McClellan et al.[25]

Measurement	Tongue Up	Tongue Down
Nipple–hard-soft palate junction distance, mm	8.2 ± 2.2	4.7 ± 2.2
Depth of intraoral space, mm	0.2 ± 1.8	6.9 ± 0.6
Nipple diameter, mm		
2 mm	5.1 ± 1.3	7.9 ± 1.0
5 mm	7.5 ± 1.7	10.2 ± 1.4
10 mm	9.0 ± 2.2	11.1 ± 1.8
15 mm	9.2 ± 2.3	10.4 ± 1.9
Depth of intraoral space, mm	0.2 ± 1.8	6.9 ± 0.6

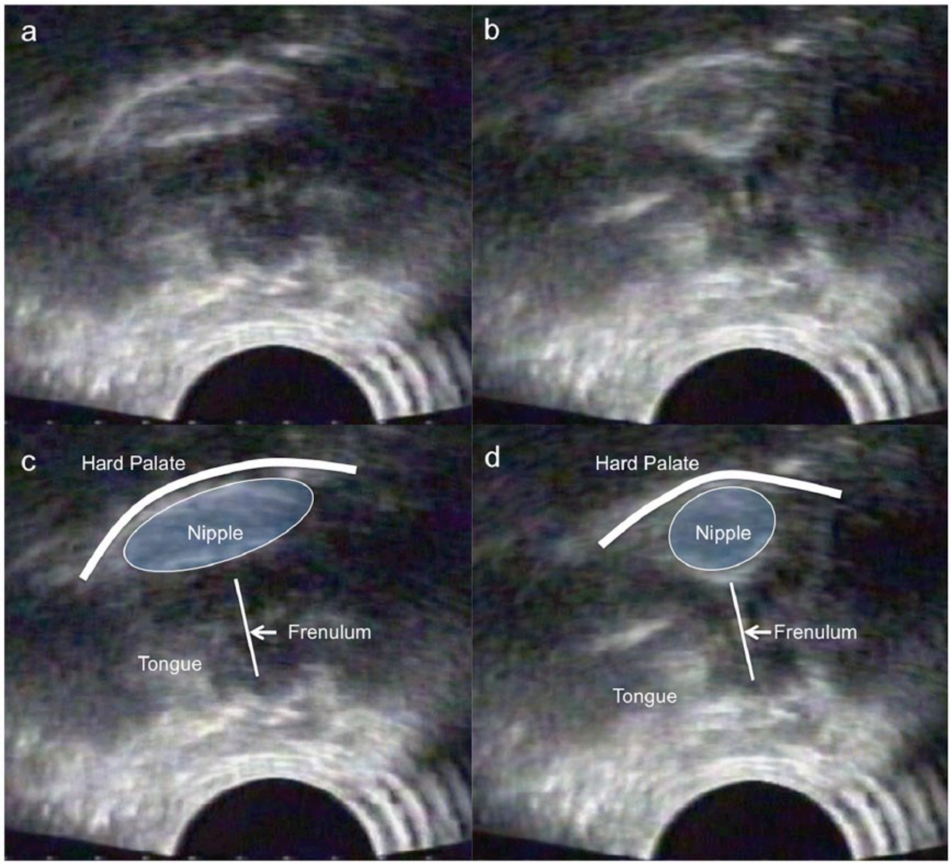
Whereas infants become more efficient at feeding over time, only minor changes have been detected in tongue movement between day 3 and 21-43 in that the depth of the intraoral space (downward movement of the midtongue) increased, and this is attributed to be a response to a large increase in milk production after the initiation of lactation.[12] Nipple position, on the other hand, did not change (N-HSPJ distance) over time.[16,26]

Transverse Plane

From the submental midsagittal plane, the transducer is rotated 90 degrees to obtain a transverse view. Often, the probe needs to be angled toward the apex of the mandible; however, since movement of the transducer is often limited during breastfeeding, this view may be difficult to obtain. Furthermore, there are no landmarks visible in this plane to ensure correct orientation; therefore, there is a strong possibility that an oblique plane of the nipple will be produced rather than a true transverse section. It is also not possible to determine at which point along the nipple the image corresponds to.[21]

Ultrasound appearances. The echogenicity of the tongue and nipple are identical to that in the midsagittal plane. The frenulum is depicted as a solid echogenic line within the central tongue, and the tongue is seen to completely surround the nipple, with the lateral edges of the tongue contacting the palate (Figure 4). However, this is variable between infants, depending on the size of the infant's oral cavity and the dimensions of the mother's nipple. The nipple is compressed to half its height when the tongue is in the up position.[21]

Figure 4. Submental Transverse Images of a Breastfeeding Infant.



Ultrasound appearances: hard palate—echogenic, tongue—mid gray with echogenic areas representing muscle fibers, frenulum—markedly echogenic vertical line in the midline of the tongue, nipple—mid gray with echogenic borders. Tongue up (A and C). The tongue fills the majority of the oral cavity and is in apposition laterally with the hard palate. The nipple is reduced in the vertical diameter and is elliptical in shape. Tongue down (B and D). The tongue moves downward away from the palate as vacuum strengthens, expanding the nipple and creating a more circular shape.

Axial Plane (Transbuccal)

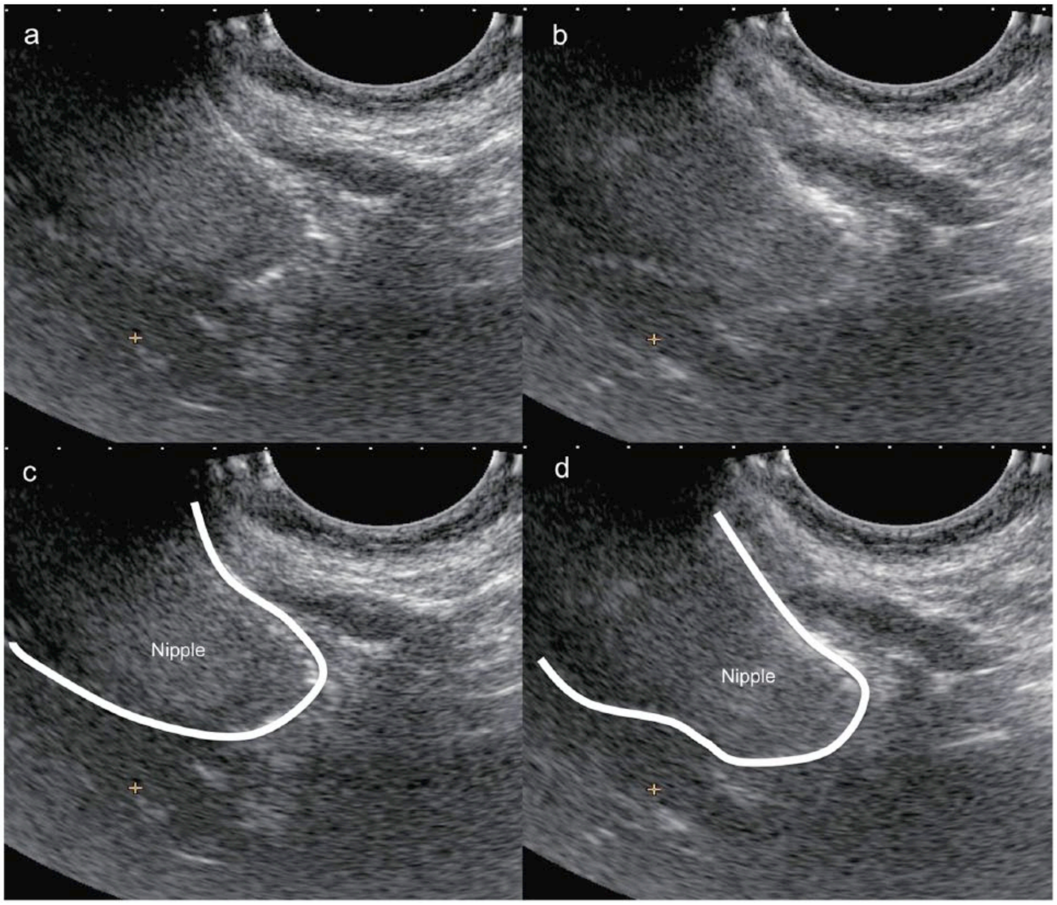
The transducer is placed along the cheek (transbuccal) of the infant as he or she is feeding and is oriented so that a long axis of the nipple and breast is achieved. Again, there are no landmarks visible in this plane to guide the sonographer, but with correct positioning of the probe, the palate may be visualized when there is milk in the oral cavity or the tongue is in contact with the palate.[6]

Ultrasound appearances. The echogenicity of the tongue and nipple are similar to that in all other planes used to image the infant's oral cavity (Figure 5), although Smith et al[6] reversed the image (black to white and white to black) in their article to accentuate the border of the nipple.

Ultrasound measurements. Measurements are scant for this plane and often stated in terms of change in dimensions with tongue movement, that is, tongue up or down. Nowak et al[18] reported that the nipple at rest measures 12.22 mm and lengthens by 209% (doubles) during sucking. Whether the change in length can be attributed entirely to nipple extension is questionable given that it is not possible to distinguish the nipple–breast interface with ultrasound. Intraobserver and interobserver measurements were stipulated to be within 0.5 mm agreement; however, no details of measurement or analysis were given.

Differences between breastfeeding and bottle feeding. The main differences between breastfeeding and bottle feeding occur in the tongue down position. In this position, the artificial teat is compressed rather than expanded as observed during breastfeeding.[27] This difference is likely due to the increased compressibility of the artificial teat compared to the human nipple. Similarly, peristaltic movements of the tongue during bottle feeding have been observed with ultrasound in preterm

Figure 5. Horizontal Transbuccal Images of a Breastfeeding Infant.



Ultrasound appearances: nipple—mid gray with echogenic borders. The lateral portions of the tongue are heterogeneous and difficult to visualize anterior and posterior to the nipple. Tongue up (A and C). The tongue fills the majority of the oral cavity. Tongue down (B and D). The tongue moves forward (right side of the image) with increasing vacuum.

infants.[28] These observations are preliminary and should be treated with caution, as the tongue movement may be affected not only by the type of artificial teat but also by the maturity of the suck reflex and/or the ability of the infant to create an intraoral vacuum. Indeed, we have made ultrasound measurements of term breastfeeding infants feeding with an experimental teat designed to release milk only when the infant applied a vacuum. The design ensured that compression of the teat by the infant's tongue and jaw would not result in milk removal. Sixteen of 18 infants who fed only once under laboratory conditions successfully removed milk from the experimental teat using vacuum rather than compression.[25]

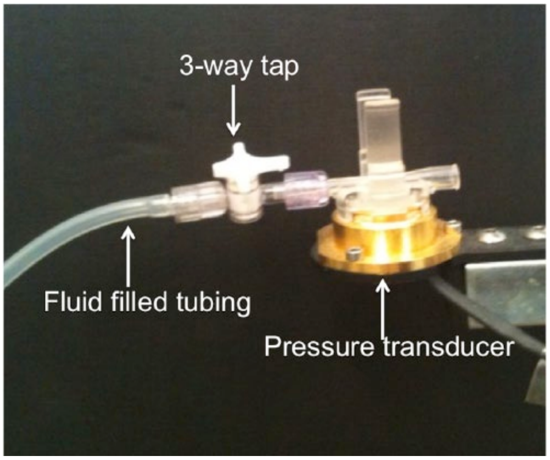
Intraoral Vacuum Measurement

To fully investigate the mechanism of milk removal of the feeding infant, it is imperative that simultaneous intraoral vacuum measurements are made with the ultrasound imaging. This enables the sonographer to accurately determine where the tongue is positioned in relation to the vacuum curve and the accumulation of milk in the infant oral cavity.[12]

Synchronization of Ultrasound Imaging and Intraoral Vacuum

Recording of synchronized ultrasound imaging and intraoral vacuum can be achieved by use of LabChart's Video Capture Module (AD Instruments, Castle Hill, New South Wales, Australia). The video capture module enables both synchronized recording and playback of a QuickTime movie and the LabChart data file, thus allowing the comparison of real-time ultrasound imaging with recorded intraoral pressures. Irrespective of the chosen setup, it is important that the capture settings such as selection of video recordings, movie size options, and hard disk space allocation are set appropriately. Ultrasound settings including the compression type, frame rate, contrast, and brightness can be entered into the set-up module. It is also useful to have the ultrasound image displayed in a live preview window, allowing confirmation of optimal image quality before commencing the recording. Alternate systems may be commercially available to perform these measurements; however, it is critical to test the synchronization prior to

Figure 6. MEMSCAP Pressure Transducer Connected to the Wider Part of the Fluid-Filled Tube Attached to the Maternal Breast.



beginning a study. Currently, we are using a custom-made system that allows synchronization of 4 video channels (LactaSearch I; Medela AG, Baar, Switzerland).

Placement of the Intraoral Tube

A very small silicone tube filled with sterile water (0.75 mm internal diameter, 33 cm in length) is attached to a larger tubing (4 mm internal diameter, 53 cm in length), which is then attached to the pressure transducer according to the manufacturer's instructions. Our laboratory currently uses a MEMSCAP SP854 (Bernin, France; Figure 6). We have also used transducers from Cobe Laboratories (Frenchs Forest, New South Wales, Australia). Care is taken to minimize the number of air bubbles introduced so as not to adversely affect pressure measurements. The tube is long enough or positioned so that it can be placed alongside the mother's nipple 1 to 2 mm past the tip (Figure 7). This ensures that the tube is located at the tip of the nipple as it is extended during feeding. In general, the mother holds the tube as she guides the nipple into the infant's mouth with occasional help from a researcher. Different readings will be obtained when the fluid-filled line is optimally placed (Figure 8) and when the line is not placed far enough past the tip of the nipple (Figure 9). Once the tubing is in the ideal location, it is taped to the breast using micropore tape (3M, North Ryde, New South Wales, Australia; Figure 7) away from the infant's face, and another anchoring position is normally the mother's shoulder.

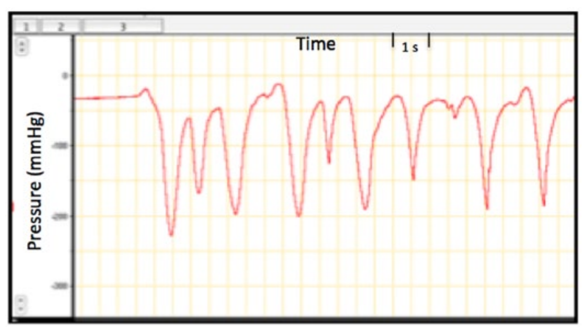
Measurements of Intraoral Vacuum

Few measurements have been made of the intraoral vacuum applied by infants during breastfeeding, particularly in those with oral anomalies or breastfeeding difficulties such as maternal nipple pain. Those studies that have made measurements are summarized as mean values in Table 2. It is clear that there will be overlap of infants with anomalies and those without due to variation in nipple size, shape, and pliability. More literature exists for bottle feeding intraoral vacuum values in both term and preterm infants (with and without feeding difficulties). It is impossible to make meaningful comparisons between these studies due to the marked

Figure 7. Distal End of the Fluid-Filled Tube Placed alongside the Nipple and Positioned inside the Infant's Mouth.

Proximally, it is connected to the MEMSCAP pressure transducer.

Figure 8. Intraoral Vacuum Trace of a Breastfeeding Infant.



Note the variability of the strength of vacuum applied.

Figure 9. Poor Intraoral Vacuum Trace of a Breastfeeding Infant Due to the Fluid-Filled Pressure Line Being Placed Too Proximal in Relation to the Tip of the Nipple.

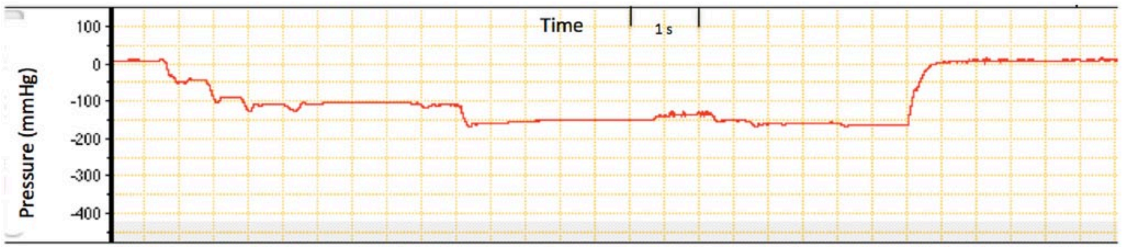


Table 2. Summary of Intraoral Vacuums Measured in Infants during Both Breastfeeding and Bottle Feeding.[a]

	Term < 1 Mo		Term > 1 Mo		Nipple Pain > 1 Mo	Ankyloglossia[b] > 1 Mo	Cleft Infants	Preterm Infants
Vacuum	Breast	Bottle	Breast	Bottle	Breast	Breast	Bottle	Bottle
Mean	−98		−50[28]		−152[29]			
Peak	−77 to −155[30,31]	1 wk-130[32]; > 2 wk −88 to −107[31,32,33]	−122 to −197[28,30,34]	−77 to −155[30,31]	−214 to −238[29]	−113 to −250[35]	Lip: −144; palate: −1.4; lip and palate: 0[36]	−28 to −84[32,33,37]
Baseline					−90 to −95[29]	−3 to −170[35]		

[a]All vacuum values are mmHg.
[b]There were no feeding issues.

differences in teat design and the populations investigated as well as the methods used to make the measurements. It is interesting that the infant will adapt to differences in teat flow rates by reducing vacuum with high flow rates and increasing it with slower rates.[29,30] In general, however, stronger intraoral vacuums are associated with more effective and efficient feeding; for example, infants with cleft lip and/or palate or those that cannot generate a vacuum have a poor feeding performance.[31] Furthermore, as premature infants increase their strength of vacuum over time, they become more effective and efficient feeders.[32] Similarly, conditions resulting in hypertonia (eg, Down syndrome)[33] or respiratory compromise (eg, bronchopulmonary dysplasia)[10] result in weaker intraoral vacuums that translate to reduced feeding effectiveness and efficiency.

Application

Ultrasound imaging during breastfeeding has been used to elucidate the mechanism by which the infant removes milk from the breast. Some conflicting reports exist and this is most likely due to ultrasound scanning technique, the imaging plane, equipment, and experience.[6,19,20,23,34] Much more information is gained when ultrasound imaging can be performed simultaneously with intraoral vacuum measurement and should be done so where practically possible. In addition, one should be acutely aware that oblique planes may distort the nipple shape and oral structures, giving an inaccurate representation of tongue movement.

To date, ultrasound imaging during breastfeeding has also been employed to show a difference in tongue movement in infants with ankyloglossia (tongue tie) after frenulotomy in that distortion of the nipple was reduced and tongue movement more closely approximated that of infants without ankyloglossia.[35] A small case series of infants with ankyloglossia who were breastfeeding successfully has demonstrated differences in tongue movement and strength of intraoral vacuums.[36] Further work is required to understand why some infants with ankyloglossia are able to breastfeed successfully and others cannot.

Ultrasound imaging has been more extensively applied to bottle-feeding infants mainly to compare different types of teats[11] and occasionally breastfeeding.[18]

Ultrasound has also been used to investigate bottle feeding in infants with oral anomalies. Infants with cleft palate are unable to produce a vacuum as a means of removing milk effectively from a bottle. Mizuno et al[11] showed that feeding improved with a bottle that allowed more expression pressure. Similarly, Mizuno and Ueda[33] showed that infants with Down syndrome applied weaker vacuums and had a different tongue movement from normal infants, resulting in less efficient milk transfer. These differences were attributed to weak muscle tone rather than the lesser urge to suck.

Conclusion

It is clear that both ultrasound and intraoral vacuum measurement have the potential to provide useful information to both the researcher and lactation clinician. Correct scanning technique and placement of the pressure line in the infant's mouth are critical to obtaining accurate diagnostic data. Validated ultrasound and intraoral vacuum measurements have significant potential in aiding the diagnosis and treatment of sucking anomalies.

Authors' Note

This work was performed while Dr Sakalidis was a student at The University of Western Australia.

Declaration of Conflicting Interests

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Supplementary Material

Supplementary material for this article is available online at http://jhl.sagepub.com/supplemental.

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