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Methodological procedures for ultrasonographic assessment of the tongue during sucking in full-term infants: A scoping review

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Abstract

Background This scoping review aimed to identify methodological procedures for acquiring and analyzing ultrasound images of the tongue during sucking in full-term infants. The Participants, Concept, and Context strategy was used to define the inclusion criteria: population (full-term infants); concept (ultrasound assessment); and context (assessment of tongue movements during sucking).

Methods It included observational, experimental, descriptive, and analytical studies, and excluded those unavailable in full, with premature infants, babies with craniofacial changes and syndromes, studies on animals, in vitro, letters to the editor, errata, and using ultrasound for other purposes. There were no language or time restrictions. Two blinded professionals independently selected 20 articles that met the inclusion criteria from different databases.

Results The most evaluated parameters were related to the morphometric and kinematic aspects of the tongue, considering the physical behavior of the nipple and bottle nipple; sucking, swallowing, and breathing; distance from the tip of the nipple to the hard-soft palate junction; and milk flow. An endocavity transducer was positioned in the submental region at 5 MHz to 8 MHz.

Conclusions The studies present the acquisition and static analysis of ultrasound images of the tongue, hard and soft palate, nipple, and bottle nipple, and of kinematic measurements of the tongue, nipple, bottle nipple, and hyoid bone. They evaluated quantitative and qualitative parameters. Frequency adjustment depended on the child's age (the B mode was the most used), with babies reclined on the mother's lap to feed from the mother's breast and/or bottle.

Keywords Tongue, Suction, Ultrasonography, Breast Feeding, Infant, Newborn, Clinical Protocols, Diagnosis

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Introduction

Nutritive sucking is a complex oral sensorimotor activity, essential for adequate growth and development in infants. It includes the coordination of sucking, swallowing, and breathing, which require movements of the tongue and jaw [1]. The complexity of tongue development and its functional role during breastfeeding generates controversy regarding criteria for monitoring, evaluation, diagnosis, treatment indications, and clinical interventions [2, 3]. During the first half of the sucking cycle, the baby moves the tongue downwards, creating a stronger vacuum (average: − 122 to − 163 mmHg) that coincides with the removal of milk from the breast. During the second half of the sucking cycle, the tongue rises, and the milk is transported from the oral cavity to the pharynx to be swallowed. The vacuum returns to its baseline, thus completing a suction cycle [4].

Sucking stimulates nerve impulses through the efferent arc of the milk ejection reflex to the hypothalamus, which prompts the posterior pituitary gland to release oxytocin into the maternal circulation. Oxytocin binds to receptors on the myoepithelial cells surrounding the alveoli, causing them to contract, ejecting milk toward the nipple (milk ejection). Thus, negative pressure (intraoral vacuum) combined with positive pressure, caused by milk ejection, are the driving forces for the flow of milk from the breast to the baby during breastfeeding. As the breast empties, the rate of milk flow changes with subsequent milk ejections, suggesting that babies may modify their sucking patterns as breastfeeding progresses[4].

Some clinical tools allow observing and diagnosing sucking patterns in babies, such as the Neonatal Oral Motor Assessment Scale (NOMAS), which distinguishes between a normal, disorganized, and dysfunctional sucking pattern, and the Digital Swallowing Workstation (DSW, KayPentax, USA), which quantitatively measures a disorganized sucking pattern, characterized by difficulties in coordinating sucking, swallowing, and breathing during feeding [1, 3]. Ultrasonography (US), among clinical tools, has been described as an image evaluation method that allows the acquisition and analysis of biomechanical parameters of the tongue during sucking [5–7]. US provides different modes of static and dynamic images through a transducer, from the reflection or scattering of a pulsed low to high-frequency sound beam (1 to 16 MHz) [5]. In the assessment of tongue movements during sucking, ultrasound B-mode provides a real-time, two-dimensional image, allowing qualitative and quantitative analyses of its movements in a sagittal plane.

Studies used US to analyze the tongue kinematics of healthy and post-frenotomy babies during sucking. They observed the number of sucking cycles, the amplitude of tongue movements, its distance in relation to the hard and soft palate junction (HSPJ), the amplitude and elasticity of the nipple, and the speed of milk transfer from the oral cavity to the pharynx [8, 9]. The advantage of US over other imaging exams for evaluating tongue movements during sucking is that it does not use contrast media, does not expose to ionizing radiation, is non-invasive, with low cost, and captures dynamic, real-time images, focusing on the visualization of soft tissues, the number of cycles during the baby's feeding. Although studies indicate the US is an easy resource, it is challenging to maintain the transducer in the submandibular plane, to standardize images for comparison, to establish measurements with reliable parameters, and to maintain the mother/infant's positioning during the US evaluation (ELAD 2014) [5, 8, 10].

Thus, US has numerous advantages and clinical applicability for evaluating tongue movements during sucking in normal individuals and those with anatomical and functional changes. However, studies describe the methodological procedures for using US individually, which makes it difficult to compare and analyze results. They differed regarding the transducer type, frequency, and positioning; US image acquisition mode and analysis; instructions to the mother/baby; and evaluator's experience. Hence, this study carried out a scoping review to identify the procedures performed during US assessment of sucking during breastfeeding in full-term infants. This study design seeks to explore the main findings of the topic in question, investigate the dimension, scope, and nature of the studies, condense the data, and make it possible, based on their findings, to identify gaps that direct questions to be answered by systematic reviews and assist in the development of a protocol for US evaluation of sucking during breastfeeding for infants.

The research question was guided by the PCC mnemonic elements (population, concept, and context) suggested by the Joanna Briggs Institute (JBI) scoping review guide [11]. The population comprised full-term infants, up to 180 days old, without risk factors such as syndromes, craniofacial malformations, and oropharyngeal dysphagia; the concept consisted of the methodological procedures for acquiring and analyzing US images related to tongue movements during sucking; and the context encompassed aspects of tongue assessment during sucking. Therefore, the research question of this scoping review was, "What are the methodological procedures for acquiring and analyzing US images of the tongue during sucking in full-term infants?".

Methods

This research is a scoping review, with a structured protocol registered in the Open Science Framework (OSF). The protocol is available from: https://www.osf.io/d7cyr/

and was published in the CEFAC journal https://doi.org/10.1590/1982-0216/20232551223s'Human Ethics and Consent to Participate declarations: not applicable'.

Eligibility criteria

Participants

This scoping review included primary studies that used US to assess measures related to tongue mobility during sucking in full-term babies up to 180 days old, of both sexes. The scope of this review did not include studies with premature babies, with craniofacial malformations, syndromes, or swallowing disorders, studies that used US for therapy, to assess facial muscles, or to assess only swallowing.

Concept

The concept of this review consisted of describing the methodological procedures for US acquisition and analysis of tongue movements during sucking. A standardized protocol for quantifying tongue movements in US videos could lead to more efficient and reproducible measurements by different researchers and clinicians. US has been described as an image evaluation clinical tool that acquires and analyzes biomechanical parameters of the tongue during sucking [5–7]. US obtains different modes of static and dynamic images through a transducer, from the reflection or scattering of a pulsed low to high-frequency sound beam (1 to 16 MHz) [5]. In the assessment of tongue movements during sucking, US B-mode provides a real-time, two-dimensional image, allowing qualitative and quantitative analyses of its movements in a sagittal plane.

Context

This scoping review included literature evidence published in scientific journals or other means of scientific dissemination (e.g., dissertations, theses) that assessed tongue movements during sucking in full-term infants with US. This made it possible to identify the procedures used to assess tongue movements with US and the available evidence on the topic. Furthermore, studies that used US as a tool for acquiring and analyzing images related to sucking in full-term infants were included.

Source types

Observational, experimental, descriptive, and analytical studies were included, and published in English, Portuguese, and Spanish, without restrictions on the date of publication. Expert opinion studies, letters to the editor, errata, annals, study protocols, and studies that could not be acquired in full, animal studies, and in vitro studies were excluded, as they did not approach the population in question.

Search strategy

The search strategy (Fig. 1) was applied individually to each database, namely: MEDLINE (via PubMed), EMBASE, Web of Science, and Scopus. This strategy was developed based on a guiding search (ultrasonic AND sucking behavior). To validate the guiding research terms, Medical Subject Headings (MeSH) were used for the MEDLINE, Scopus, and Web of Science databases, while the "EMTREE terms" were used in Embase. Two professionals blindly and independently screened the studies based on the eligibility criteria.

Selection of studies/sources of evidence

All identified citations were collated using Rayyan software (Qatar Computing Research Institute, Doha, Qatar). Relevant studies with full texts available in English, Portuguese, and Spanish were imported into the software; disagreements that arose between reviewers were resolved through discussion or with a third reviewer for eligibility.

Data extraction

Two independent reviewers extracted data from the articles included in the scoping review, using a structured Microsoft Excel spreadsheet developed by the reviewers. This mapping allowed the data to be synthesized and interpreted, generating a detailed description for the review (Fig. 2). Thus, the results were separated, summarized, and reported to present an overview of all the material through specific categories.

Data analysis/presentation

The article analysis protocol considered the year of study, study design, number of babies assessed, age, sucking assessment method, US sucking image acquisition method, and US sucking analysis method.

Results

The review mapped 770 studies, of which 280 were excluded due to duplication, leaving 490 for reading titles and abstracts. Of these, 467 articles were excluded for not meeting the inclusion criteria established for this review, leaving 23 articles for reading in full. After reading the studies in full text, only 20 articles were eligible for analysis in this review (Fig. 3). Two blind evaluators carried out the selection process, with a Kappa coefficient of 0.96. Fig. 4.

The studies [4, 6–24] were published between 1986 and 2023, with a greater concentration in the last 10 years. Between 1986 and 1988, studies focused on evaluating the behavior of the nipple and tongue during

Databases	Search strategies
MEDLINE via PubMed	('echography'/exp OR 'diagnostic ultrasonic examination' OR 'diagnostic ultrasonic imaging' OR 'diagnostic ultrasonic method' OR 'diagnostic ultrasound' OR 'duplex echography' OR 'scanning, ultrasonic' OR 'sonographic examination' OR 'sonographic screening' OR 'ultrasonic detection' OR 'ultrasonic diagnosis' OR 'ultrasonic examination' OR 'ultrasonic scanning' OR 'ultrasonogram' OR 'ultrasonographic examination' OR 'ultrasonographic screening' OR 'ultrasonography' OR 'ultrasound diagnosis' OR 'ultrasound scanning') AND ('sucking'/exp OR 'sucking' OR 'sucking behavior' OR 'sucking behaviour' OR 'sucking movement' OR 'finger sucking'/exp OR 'breastfeeding'/exp).
EMBASE	('echography'/exp OR 'diagnostic ultrasonic examination' OR 'diagnostic ultrasonic imaging' OR 'diagnostic ultrasonic method' OR 'diagnostic ultrasound' OR 'duplex echography' OR 'scanning, ultrasonic' OR 'sonographic examination' OR 'sonographic screening' OR 'ultrasonic detection' OR 'ultrasonic diagnosis' OR 'ultrasonic examination' OR 'ultrasonic scanning' OR 'ultrasonogram' OR 'ultrasonographic examination' OR 'ultrasonographic screening' OR 'ultrasonography' OR 'ultrasound diagnosis' OR 'ultrasound scanning') AND ('sucking'/exp OR 'sucking' OR 'sucking behavior' OR 'sucking behaviour' OR 'sucking movement' OR 'finger sucking'/exp OR 'breastfeeding'/exp)
Web of Science	('echography'/exp OR 'diagnostic ultrasonic examination' OR 'diagnostic ultrasonic imaging' OR 'diagnostic ultrasonic method' OR 'diagnostic ultrasound' OR 'duplex echography' OR 'scanning, ultrasonic' OR 'sonographic examination' OR 'sonographic screening' OR 'ultrasonic detection' OR 'ultrasonic diagnosis' OR 'ultrasonic examination' OR 'ultrasonic scanning' OR 'ultrasonogram' OR 'ultrasonographic examination' OR 'ultrasonographic screening' OR 'ultrasonography' OR 'ultrasound diagnosis' OR 'ultrasound scanning') AND ('sucking'/exp OR 'sucking' OR 'sucking behavior' OR 'sucking behaviour' OR 'sucking movement' OR 'finger sucking'/exp OR 'breastfeeding'/exp)
Scopus	echography (All fields) AND sucking (All fields)

The review included studies published from the date of insertion until April 2024.

Fig. 1 Individualized search strategy per database**.***The review included studies published from the date of insertion until April 2024*

Authors
Title of the article
Year of publication
Place
Objective
Sample number
Mean age
Profile of the sample (full-term, healthy infants, on breastfeeding or baby bottle)

Ultrasound model
Type of transducer
Software used to acquire images
Software used to analyze images
Ultrasound mode used

Positioning of the mother and baby (patient)
Positioning of the baby's head
Positioning of the transducer
Feeding route to assess sucking (only breastfeeding; breastfeeding and bottle; only bottle)
Assessment and guidance on how to feed the baby
Number of sucking cycles assessed
Settings used (outpatient clinic, home, research setting, hospital)
Biomarkers used to assess sucking
Software configuration used to acquire images (frames, speed, echogenicity...)
Reference points used to measure distance and amplitude

Units of measurement used
Software configuration used to analyze the images

Fig. 2 Data extracted from the studies selected to map the ultrasound assessment procedures of tongue movements during sucking in full-term infants

breastfeeding [12, 21]; between 1990 and 1997, they focused on the morphological evaluation of the nipple during sucking and tongue movements during sucking based on breastfeeding with a bottle nipple [22–24]; between 2001 and 2023, they evaluated the distance between the nipple and the hard/soft palate,

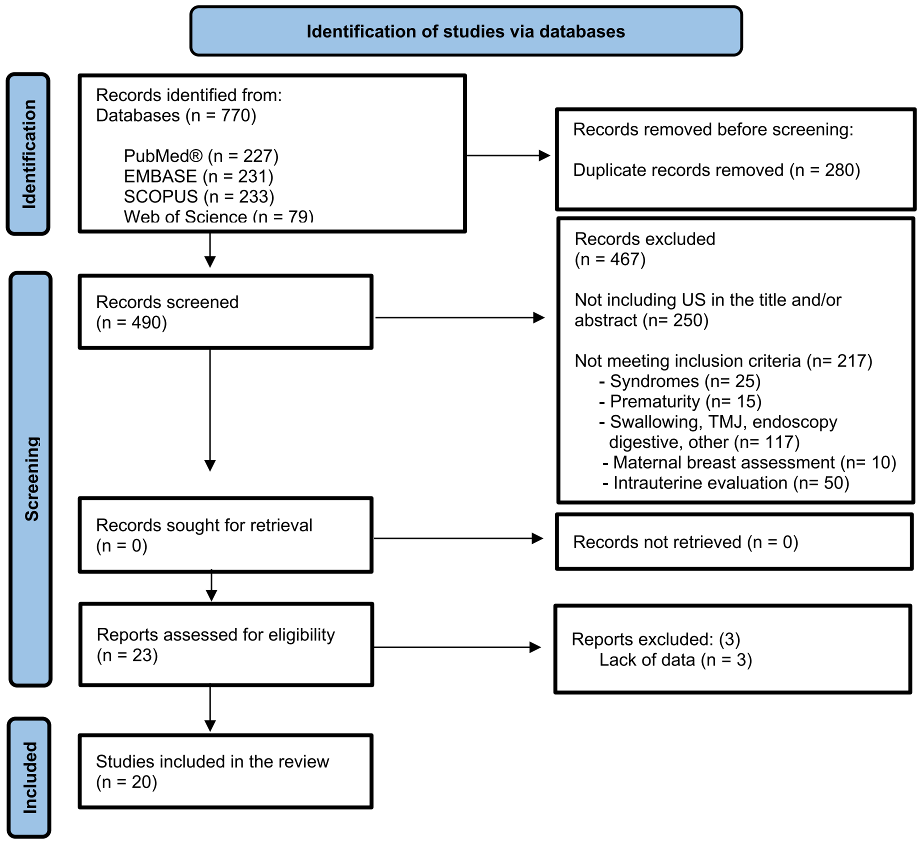

Fig. 3 Flowchart of the search and selection phases of the scoping review of ultrasound assessment of the tongue during sucking in infants

the movement of the tongue before and after lingual frenotomy, and the kinematics of the tongue during feeding in the mother's breast and bottle nipple [4, 6–10, 13, 15, 17–20]. The number of publications on the topic differed between countries; Australia had the most publications (48%), followed by the United States (28%), England (12%), Japan (8%), Turkey (3%) and Israel (1%).

The designs of the mapped studies consisted of observational (descriptive and analytical) [4, 7, 9, 13, 14, 17, 22, 25] and experimental (nonrandomized clinical trials) [8, 10, 15, 20, 23] However, seven studies did not present their methodological designs [6, 12, 16, 18, 19, 21, 24]. The studies analyzed samples ranging from four to 50 babies, aged 2 to 120 days, including healthy babies and those with ankyloglossia, and mothers who complained of pain during breastfeeding. They were assessed in the office/outpatient clinic and at home, although some studies did not inform the location.

Table 1 presents the general overview of the methodological procedures for acquiring and analyzing US images of the babies' sucking from different breastfeeding methods (only breastfeeding, breastfeeding and bottle, and only bottle). It also shows the equipment used to acquire US images, the acquisition method, previous instructions, positioning of the transducer, US image adjustments, analysis mode, and evaluation time.

The examinations were performed with different US equipment models (portable and mechanical). The endocavitary transducer was the most used for having a wide frequency range (4–10 MHz) and being more anatomically adjustable to the baby's submental region. Several studies do not describe the positioning when the baby was feeding. The ones describing it followed breastfeeding position protocols such as the LATCH and International Board Certified Lactation Consultant guidelines. Those that described bottle use suggested sitting the baby on the lap with the head reclined slightly back. The examination should use the transducer in the midline, centered in the submental region, in the sagittal plane, with the nipple to the left to obtain more accurate images. This enables better visualization of the anatomical structures of the baby's oral cavity and the dynamics of the tongue and nipple movements during suction.

The authors used the following biomarkers: distance from the nipple to the HSPJ (mm); physical behavior of the nipple (nipple diameter, nipple compression, nipple stretching) (mm); tongue position during the sucking

Table 1 Parameters for acquisition and analysis of ultrasound images during feeding

Authors (year and country)	Objective	Participants' profiles and feeding routes		Type of transducer and frequency	Parameters for acquisition and analysis of ultrasound images during feeding				
					Acquisition mode and calibration parameters	Mother and baby positioning	Positioning of the transducer and reference points for acquisition	Instructions to the subject	Parameters assessed
Wilbur L. et al. (1988-USA) [11]	To describe the behavior of the nipple during feeding and the dynamics of normal baby feeding with US	Breastfeeding	16 mothers and babies Age: 60 to 120 days	Transducer not specified Frequency: 5 MHz	B mode Parameters not specified Measurements were taken from a display using a manual caliper	Not specified	The transducer was positioned in the horizontal transoral axial plane (under the cheek) to visualize nipple compression during sucking To visualize the length of the nipple, the transducer was positioned centrally under the baby's chin, in the sagittal plane under the submental region aligned with the nipple, which was positioned to the left The dietary pattern of each infant was observed by stop-frame visual analysis of nipple deformation and changes in shape and position of the tongue, cheeks, and palate Milk flow was visualized as hypoechoic fluid containing echogenic spots	The examination began when the baby latched onto the breast and ended when there was a decrease in milk intake seen on the ultrasound image Three complete suction cycles were performed	**Nipple Stretching (Submental Vision):** Nipple elongation (dark/gray region) was obtained with the ratio of the length at the end of sucking to the total extension of the intraoral nipple **Nipple compression (horizontal plane):** Lateral (transverse) compression of the nipple was also recorded as a ratio of the undeformed nipple width to the maximum deformed width **Maximum compression:** The height of the nipple is reduced by half due to compression between the tongue and palate. Milk ejection occurs after maximum nipple compression

Table 1 (continued)

Authors (year and country)	Objective	Participants' profiles and feeding routes		Type of transducer and frequency	Parameters for acquisition and analysis of ultrasound images during feeding				
					Acquisition mode and calibration parameters	Mother and baby positioning	Positioning of the transducer and reference points for acquisition	Instructions to the subject	Parameters assessed
Jacobs, AL et al. (2007-Australia) [12]	To assess the distance from the nipple to the junction of the hard and soft palate and the movement of the nipple during sucking in full-term babies using US	Breastfeeding	18 mothers and babies Age: 3 to 14 days (assessment); 25 to 65 days (reassessment)	1—Convex Endocavity Transducer (used in 65% of babies) Frequency: 7 MHz 2- Sector phased array transducer (used in 30% of babies) Frequency: 7 MHz 3- Linear array transducer (used in 5% of babies) Frequency: 7 MHz	B mode Gain: 50 dB Dynamic range: 50 to 57 dB It used a short, nipple-level depth and adjusted dynamic range to optimize soft tissue detail Software, ViewScan, was created and used to extract ultrasound images from videotape recording, record, and measure distances between manually selected anatomical points The investigator marked the anatomy on ultrasound images on the computer screen with a mouse pointer, and ViewScan recorded the distance between the marks in pixels that were converted into millimeters	The mother sat next to the US device and positioned and latched the baby as determined by the International Board Certified Lactation Consultant (IBCLC)	The transducer was positioned centrally under the baby's chin, in the sagittal plane under the submental region aligned with the nipple, which was positioned on the left The hard palate appears as an echogenic (white) line area, while the soft palate appears as a gray structure with an echogenic border. The nipple appears as a gray (cylindrical, "finger-like") structure and the milk ducts within the nipple appear as thin hypoechoic (black) tubular structures. Milk flow was visualized as hypoechoic fluid containing echogenic spots	They were advised not to breastfeed 2 h before the exam The exam started when the baby latched onto the breast and ended after about 5 min The 5 min were subdivided into T0 (first visible suction between the beginning of the feeding and the end of the first minute to record feeding events and nipple position before); T2 (second minute to record feeding events) and T5 (when sucking may be different because at least 80% of the volume of a breastfeed is consumed in the first 4 min)	**Nipple diameter:** Distance (mm) traveled by the entire gray structure presented cylindrically in the image **Distance from the beak to the hard-soft palate junction:** Distance (mm) between the tip of the nipple and the beginning of the hard-soft palate junction was measured from a transverse mark on the tip of the nipple to the transverse mark on the distal end of the hard palate adjacent to the soft palate in the sagittal plane The distance between the tip of the nipple and the hard palate and soft palate junction was measured in the midsagittal anatomical plane

Table 1 (continued)

Authors (year and country)	Objective	Participants' profiles and feeding routes		Type of transducer and frequency	Parameters for acquisition and analysis of ultrasound images during feeding				
					Acquisition mode and calibration parameters	Mother and baby positioning	Positioning of the transducer and reference points for acquisition	Instructions to the subject	Parameters assessed
Geddes DT et al. (2008 - Australia)[9]	To examine the relationship between tongue movement and intraoral vacuum generated during breastfeeding by the baby	Breastfeeding	20 mothers and babies Age: 3 to 24 weeks	1—Endocavity Convex Transducer Frequency: 7 MHz 2—PVT- 661 VT Convex Transducer Frequency: 8.8 MHz In some bigger and older babies, the transducer frequency was reduced (8.8 MHz to 7.3 or 5.8 MHz) for a better image	B mode 1—Gain: 50 dB Dynamic range: 57 dB 2 – Gain: 55 dB Dynamic range: 60 dB Two foci were used to narrow the ultrasound beam: One on the hard palate and the other on the nipple-tongue attachment Adjustments were made to gain, dynamic range, and timing during the acquisition	Not specified	The transducer was positioned along the midsagittal line of the baby's body and gentle pressure was used to maintain contact with the baby's chin The transducer was rotated until the image of the nipple was at its maximum length and diameter and a view of the junction of the hard and soft palate was achieved The position of the transducer was changed according to the baby's movement to maintain a midline sagittal view	The exam started when the baby latched on to the breast and ended when the baby finished breastfeeding At least three complete sucking cycles were performed during which milk flow was evident on the ultrasound image	**Tongue position during the sucking cycle:** Initially, the posterior region of the tongue is observed attached to the palate (upward position), and the anterior region of the tongue is attached to the lower edge of the nipple When the posterior region of the tongue is lowered to the maximum, the vacuum peak occurs. As the vacuum is released, the anterior region of the tongue is elevated slightly, and the milk passes under the soft palate. Both the back of the tongue and the soft palate rise, and milk continues to flow towards the pharyngeal region. When the posterior region reaches the palate (up position) the vacuum returns to basal levels **Nipple diameter:** Distance (mm) traveled by the entire gray structure presented cylindrically in the image **Distance from the nipple to the hard-soft palate junction:**

Table 1 (continued)

Authors (year and country)	Objective	Participants' profiles and feeding routes	Type of transducer and frequency	Parameters for acquisition and analysis of ultrasound images during feeding				
				Acquisition mode and calibration parameters	Mother and baby positioning	Positioning of the transducer and reference points for acquisition	Instructions to the subject	Parameters assessed
						The hard palate appears as an echogenic (white) line area, while the soft palate appears as a gray (3–4 mm) structure with an echogenic border. The nipple appears as a gray (cylindrical) structure and the milk ducts within the nipple appear as thin hypoechoic (black) tubular structures. Milk flow was visualized as hypoechoic fluid containing echogenic spots. Echogenic spots are fat globules in milk		Distance (mm) between the tip of the nipple and the beginning of the hard-soft palate junction **Distance between tongue and palate:** Distance (mm) from the hard palate to the surface of the posterior region of the tongue. Its maximum distance corresponds with the vacuum peak

Table 1 (continued)

Authors (year and country)	Objective	Participants' profiles and feeding routes		Type of transducer and frequency	Parameters for acquisition and analysis of ultrasound images during feeding				
					Acquisition mode and calibration parameters	Mother and baby positioning	Positioning of the transducer and reference points for acquisition	Instructions to the subject	Parameters assessed
Geddes, DT et al. (2008-USA) [13]	To determine the effectiveness of frenotomy by measuring milk transfer and tongue movement during breastfeeding	Breastfeeding	24 mothers and babies Age: 4 to 131 days (assessment); 22 to 150 days (reassessment)	Endocavity Convex Transducer Frequency: 7 MHz	B mode Gain: 5 dB Dynamic range: 57 dB Single focus adjusted to nipple level Adjustments were made to gain, dynamic range, and timing during the acquisition	Not specified	The transducer was positioned along the midsagittal line of the baby's body The transducer was rotated until the image of the nipple was at its maximum length and diameter and a view of the junction of the hard and soft palate was achieved Measurements were taken at 2 points in each suction cycle. The first point on the tongue is most positioned in attachment to the hard palate, and the second with the tongue down, with evident milk flow	The exam started when the baby latched on to the breast and ended when the baby finished breastfeeding At least five complete sucking cycles were performed during which milk flow was evident on the ultrasound image	**Distance from the nipple to the hard-soft palate junction:** Distance (mm) between the tip of the nipple and the beginning of the hard-soft palate junction **Nipple diameter:** Distance (mm) traveled by the entire gray structure presented cylindrically in the image **Average range of nipple movement:** Difference in the junction of the nipple and hard/soft palate between the tongue up and tongue down positions for the 5 sucking cycles

Table 1 (continued)

Authors (year and country)	Objective	Participants' profiles and feeding routes		Type of transducer and frequency	Parameters for acquisition and analysis of ultrasound images during feeding				
					Acquisition mode and calibration parameters	**Mother and baby positioning**	**Positioning of the transducer and reference points for acquisition**	**Instructions to the subject**	**Parameters assessed**
Geddes, DT et al. (2010-Australia)[14]	To assess the sucking characteristics of normal infants	Breastfeeding	5 mothers and babies Age: 21 to 52 days	Endocavity Convex Transducer Frequency: 7 MHz	B mode Gain: 50 dB Dynamic range: 57 dB	Not specified	The transducer was positioned along the midsagittal line of the baby's body The transducer was rotated until the image of the nipple was at its maximum length and diameter and a view of the junction of the hard and soft palate was achieved The hard palate appears as an echogenic (white) line area, while the soft palate appears as a gray structure with an echogenic border. The nipple appears as a gray (cylindrical) structure	The exam started when the baby latched on to the breast and ended when the baby finished breastfeeding At least three complete sucking cycles were performed during which milk flow was evident on the ultrasound image	**Tongue position during normal breastfeeding:** The tongue is attached to the soft palate. The tongue compresses the nipple evenly. As the tongue is lowered inferiorly, the nipple expands in diameter and approaches the hard-soft palate junction. There is no nipple distortion **Tongue position during breastfeeding in a baby with ankyloglossia:** Tongue upward pattern, without nipple distortion. Tongue down, with compression of the base of the nipple. Tongue up, with compression of the tip of the nipple. Tongue down, without nipple distortion

Table 1 (continued)

Authors (year and country)	Objective	Participants' profiles and feeding routes		Type of transducer and frequency	Parameters for acquisition and analysis of ultrasound images during feeding				
					Acquisition mode and calibration parameters	**Mother and baby positioning**	**Positioning of the transducer and reference points for acquisition**	**Instructions to the subject**	**Parameters assessed**
McClellan HL et al. (2010-Australia)[15]	To measure the distance from the junction between the hard palate and the tongue up and down	Breastfeeding	30 mothers and babies Age: mean of 56.3 days	PVT- 661 VT Convex Transducer Frequency: 7.3 MHz to 8.8 MHz In some bigger and older babies, the transducer frequency was reduced (8.8 MHz to 7.3 or 5.8 MHz) for a better image	B mode Gain: 55 dB Dynamic range: 60 dB Two foci were used to narrow the ultrasound beam: One on the hard palate and the other on the nipple-tongue attachment Adjustments were made to gain, dynamic range, and timing during the acquisition	Not specified	The transducer was positioned along the mid-sagittal line of the infant's head and light pressure was used to maintain contact with the infant's chin The images were oriented so that the nipple was always on the left side of the image The transducer was rotated until the image of the nipple was at its maximum length and diameter and a view of the junction of the hard and soft palate was achieved The position of the transducer was changed according to the baby's movement to maintain a midline sagittal view	The exam started when the baby latched on to the breast and ended when the baby finished breastfeeding At least one suction cycle was included	**Depth:** Depth is measured as the internal distance from the hard palate to the tongue. The calipers measured the depth of the space in which the milk flowed into the pharynx **Tongue position during the sucking cycle:** **Tongue up:** when the tongue is raised as much as possible; the tongue is attached to the nipple, the hard and soft palate, and their junction. In this position, the shortest distance from the tip of the nipple to the hard and soft palate junction was obtained **Tongue down:** the tongue is lowered to its lowest level from the hard and soft palate junction. The tongue is attached to the nipple and soft palate, but not to the hard palate. In this position, the shortest distance from the tip of the nipple to the depth axis was obtained **Nipple diameter:**

Table 1 (continued)

Authors (year and country)	Objective	Participants' profiles and feeding routes	Type of transducer and frequency	Parameters for acquisition and analysis of ultrasound images during feeding				
				Acquisition mode and calibration parameters	**Mother and baby positioning**	**Positioning of the transducer and reference points for acquisition**	**Instructions to the subject**	**Parameters assessed**
						The soft palate appeared as a medium-gray structure with an echogenic upper border. The hard (bony) palate appeared as an echogenic white line Two calipers were used to measure the diameter of the nipple; the first measured the gap along the tip of the nipple (10 mm). The second caliper measured the outer diameter of the nipple at each interval		Distance (mm) traveled by the entire gray structure presented cylindrically in the image **Distance from the nipple to the hard-soft palate junction:** Distance (mm) between the tip of the nipple and the beginning of the hard-soft palate junction

Table 1 (continued)

Authors (year and country)	Objective	Participants' profiles and feeding routes		Type of transducer and frequency	Parameters for acquisition and analysis of ultrasound images during feeding				
					Acquisition mode and calibration parameters	Mother and baby positioning	Positioning of the transducer and reference points for acquisition	Instructions to the subject	Parameters assessed
Sakalidis VS et al. (2013-Australia)[16]	To describe infant sucking patterns during breastfeeding at the time of secretory activation	Breastfeeding	15 mothers and babies Age: 3.2 to 16 days	Endocavity transducer Frequency: 5–8 MHz In some bigger and older babies, the transducer frequency was reduced (8.8 MHz to 7.3 MHz) for a better image	B mode Gain: 55 dB Dynamic range: 60 dB Two foci were used to narrow the ultrasound beam: One on the hard palate and the other on the nipple-tongue attachment Adjustments were made to gain, dynamic range, and timing during the acquisition	Not specified	The transducer was positioned along the mid-sagittal line of the infant's head, and light pressure was used to maintain contact with the infant's chin The transducer was rotated until the image of the nipple was at its maximum length and diameter and a view of the junction of the hard and soft palate was achieved The tip of the tongue could not be visualized using this method	The exam started when the baby latched on to the breast and ended when the baby finished breastfeeding Images from three consecutive cycles during NS and NNS were selected. Analysis done with the tongue up and tongue down First breastfeeding assessment carried out on the 3rd day postpartum (range 2–4), in the hospital or at the mother's home Second assessment of breastfeeding between days 10 and 45 postpartum (follow-up), carried out at the mother's home	**Suction cycle:** Defined as the beginning when the middle of the tongue was attached to the palate (tongue up), followed by a downward excursion of the tongue until when the middle tongue reached its lowest point (tongue down) and ending with the tongue attached to the palate again **Suction Rates:** Determined by counting the number of suctions per burst in the ultrasound record in the first 3 and last 3 min of feeding. A burst was defined as periods of sucking (tongue movement) between pauses (tongue rest) **Nutritive Suction (NS):** Suction cycles that resulted in the delivery of milk to the oral cavity, observed on US, in which the milk bolus appeared as a hypoechoic area (black) filled with echogenic spots (white) **Nonnutritive Sucking (NNS):**

Table 1 (continued)

Authors (year and country)	Objective	Participants' profiles and feeding routes	Type of transducer and frequency	Parameters for acquisition and analysis of ultrasound images during feeding				
				Acquisition mode and calibration parameters	Mother and baby positioning	Positioning of the transducer and reference points for acquisition	Instructions to the subject	Parameters assessed
								Suction cycles in which there was no milk on the ultrasound image **Tongue position in NS:** **Tongue up:** The nipple is evenly compressed from tip to base, and the tongue is in contact with the hard and soft palate **Tongue down:** The nipple expands evenly in size, approaching the hard-soft palate junction, the middle of the tongue low, allowing milk to flow into the intraoral space **Tongue position in NNS:** **Tongue up:** The nipple is less compressed compared to the same position in NS **Tongue down:** The nipple expands to a lesser extent, and the middle tongue lowers to a lesser extent in relation to NS **Depth of the intraoral space:** distance from the hard-soft palate junction to the posterior surface of the tongue and distance from the tip of the nipple to the hard-soft palate junction

Table 1 (continued)

Authors (year and country)	Objective	Participants' profiles and feeding routes		Type of transducer and frequency	Parameters for acquisition and analysis of ultrasound images during feeding				
					Acquisition mode and calibration parameters	Mother and baby positioning	Positioning of the transducer and reference points for acquisition	Instructions to the subject	Parameters assessed
Sakalidis VS et al. (2013-Australia)[17]	To measure sucking behavior in newborn infants born by cesarean section or vaginal delivery during secretory activation and after lactation	Breastfeeding	14 mothers and babies Age: 3 to 20 days	Endocavity transducer Frequency: 5 to 8 MHz	B mode Gain: 55 dB Dynamic range: 60 dB Two foci were used to narrow the ultrasound beam: One on the hard palate and the other on the nipple-tongue attachment Adjustments were made to gain, dynamic range, and timing during the acquisition	Not specified	The transducer was positioned along the mid-sagittal line of the infant's head and light pressure was used to maintain contact with the infant's chin The transducer was rotated until the image of the nipple was at its maximum length and diameter and a view of the junction of the hard and soft palate was achieved	The exam started when the baby latched on to the breast and ended when the baby finished breastfeeding At least three complete sucking cycles were performed during which milk flow was evident on the ultrasound image Breastfeeding assessments were carried out in two stages: The first in secretory activity (Day 3; interval, 2–4 days postpartum), carried out in the hospital or at the mother's home The second (monitoring), during established lactation (interval, 10–45 days postpartum), at the mother's home	**Tongue position during the sucking cycle:** Beginning when the middle tongue was attached to the palate (tongue up) followed by a downward excursion of the tongue until the middle tongue reached its lowest point (tongue down) and ending with the tongue attached to the palate again **Nutritive suction:** Suction cycles resulting in delivery of milk into the oral cavity as imaged by ultrasound where the milk bolus appeared as hypoechoic **Nonnutritive suction:** Defined as sucking cycles in which no milk was observed in the intraoral cavity on ultrasound

Table 1 (continued)

Authors (year and country)	Objective	Participants' profiles and feeding routes		Type of transducer and frequency	Parameters for acquisition and analysis of ultrasound images during feeding				
					Acquisition mode and calibration parameters	Mother and baby positioning	Positioning of the transducer and reference points for acquisition	Instructions to the subject	Parameters assessed
								In each session, ultrasound images of the infant's intraoral cavity were recorded during breastfeeding to determine tongue movement	
McClellan, HL et al. (2015-Australia)[18]	To analyze the intraoral shape of the nipple and tongue movement in babies of mothers with and without nipple pain	Breastfeeding	50 mothers and babies. (25 Control Group (CG) and 25 Pain Group PG) Age: CG 48 days (35–61) PG 46 days (30–70)	PVT- 661 VT endocavity convex transducer Frequency: 8.8 MHz	B mode Gain: 55 dB Dynamic range: 60 dB Two foci were used to narrow the ultrasound beam: One on the hard palate and the other on the nipple-tongue attachment The images were oriented so that the nipple was always on the left side and at the top of the image Two images were selected from each of the three sucking cycles: one when the middle tongue was raised to its highest level (tongue up), and the second when the middle tongue was lowered to its maximum (tongue down)	Babies breastfeeding with mothers sitting comfortably using a breastfeeding pillow	The transducer was positioned along the midsagittal line of the baby's body and gentle pressure was used to maintain contact with the baby's chin Infant's intraoral cavity with the outline of the tongue marked in white	The exam started when the baby latched on to the breast and ended when the baby finished breastfeeding At least three complete sucking cycles were performed during which milk flow was evident on the ultrasound image	**Depth of the intraoral space:** Distance from the hard-soft palate junction to the posterior surface of the tongue and distance from the tip of the nipple to the hard-soft palate junction **Tongue up:** The tongue moved inferiorly, with the middle tongue showing greater displacement as it moved away from the hard-soft palate junction **Tongue down:** The middle tongue was at its lowest point, the middle tongue elevated sequentially in an anteroposterior manner The soft palate followed the posterior tongue as it moved inferiorly with the middle tongue, and as the middle tongue returned to the hard palate, milk could be seen passing under the soft palate in two frames

Table 1 (continued)

Authors (year and country)	Objective	Participants' profiles and feeding routes		Type of transducer and frequency	Parameters for acquisition and analysis of ultrasound images during feeding				
					Acquisition mode and calibration parameters	Mother and baby positioning	Positioning of the transducer and reference points for acquisition	Instructions to the subject	Parameters assessed
Cannon AM et al. (2016-Australia)[4]	To investigate the parameters of the infant's sucking cycle in relation to the volume of milk removed from the breast	Breastfeeding	19 mothers and babies Age: 36 ± 21 days (9–74)	PVT- 661 VT endocavity convex transducer Frequency: 8.8 MHZ	B mode Parameters not specified	Not specified	The transducer was positioned along the midsagittal line of the baby's body and gentle pressure was used to maintain contact with the baby's chin The transducer was rotated until the image of the nipple was at its maximum length and diameter and a view of the junction of the hard and soft palate and tongue was achieved	The exam started when the baby latched on to the breast and ended when the baby finished breastfeeding, on the first breast The first 4 min of the NS cycle were determined by the presence of milk in the infant's intraoral cavity identified in the ultrasound images, and multiple swallows identified in the breathing trace	**Tongue position during the sucking cycle:** During the first half of the cycle, the middle tongue is in contact with the palate, and a basal vacuum is applied. As the tongue lowers, the vacuum increases and milk flows into the oral cavity During the second half of the cycle, the vacuum decreases as the tongue moves upward and milk is eliminated from the oral cavity into the pharynx for swallowing and the vacuum returns to baseline levels, thus completing a sucking cycle
Alatalo D et al. (2020-USA)[6]	To investigate positive oral pressures exerted by the baby during breastfeeding and compare them with negative vacuum pressures from the same feeding	Breastfeeding	6 mothers and babies Age: 6 to 18 weeks	Endocavity Convex Transducer Frequency: 7 MHz In some bigger and older babies, the transducer frequency	B mode Gain: 55 dB Dynamic range: 60 dB Two foci were used to narrow the ultrasound beam: One on the hard palate and the other on the nipple-	All infants were successfully breastfed using a nipple shield The mother was asked to demonstrate how she would hold the baby and was instructed to bring the baby's	The transducer was positioned along the midsagittal line of the baby's body and gentle pressure was used to maintain contact with the baby's chin	The exam started when the baby latched on to the breast and ended when the baby finished breastfeeding At least three complete sucking cycles were performed during which milk flow was evident on the ultrasound image	**Tongue position during the sucking cycle:** The tongue, hard palate, and soft palate surround the nipple during milk ejection in a sucking cycle. The wave-like movement of the tongue anterior to the baby's palate was visualized. The nipple was visibly elongated and compressed when the babies moved their tongues up and down

Table 1 (continued)

Authors (year and country)	Objective	Participants' profiles and feeding routes		Type of transducer and frequency	Parameters for acquisition and analysis of ultrasound images during feeding				
					Acquisition mode and calibration parameters	Mother and baby positioning	Positioning of the transducer and reference points for acquisition	Instructions to the subject	Parameters assessed
				was reduced (8.8 MHz to 7.3 or 5.8 MHz) for a better image	tongue attachment Adjustments were made to gain, dynamic range, and timing during the acquisition	jaw, mandible, and lips closer together during sucking	The transducer was rotated until the image of the nipple was at its maximum length and diameter and a view of the junction of the hard and soft palate was achieved The position of the transducer was changed according to the baby's movement to maintain a midline sagittal view		**Nipple width and length:** Maximum nipple width and minimum nipple length were observed when the baby's tongue moved to the lowest position in nutritive sucking. A large portion of the areola must be pulled into the oral cavity so that the nipple reaches the junction of the soft and hard palate The nipple was assumed to be cylindrical in shape and pre-feeding and post-feeding measurements were used to calculate volume changes. The difference between pre-feed and post-feed volumes is reported as the volume change. Two separate measurements were averaged to calculate pre-feeding and post-feeding nipple width and length
Douglas PS et al. (2022- Australia)[8]	To investigate whether Gestalt intervention modifies nipple placement, tongue position and shape, and dimensions of the nipple and breast tissue during breastfeeding	Breastfeeding	4 mothers and babies Age: 2 to 20 weeks	Endocavity convex transducer 6V1/11 Frequency: 8.8 MHZ	B mode Gain: 55 dB Dynamic range: 60 dB Two foci were used to narrow the ultrasound beam: One on the hard palate and the other on the nipple-tongue attachment	First moment: babies breastfed with support from a breastfeeding consultant Second moment: Gestalt intervention between 5 and 10 min	The transducer was positioned along the midsagittal line of the baby's body and gentle pressure was used to maintain contact with the baby's chin	The exam started when the baby latched on to the breast and ended when the baby finished breastfeeding At least three complete sucking cycles were performed during which milk flow was evident on the ultrasound image	**Tongue position during the sucking cycle:** Initially, the posterior region of the tongue is observed attached to the hard palate, the hard-soft palate junction, and the soft palate (positioned upwards), and the anterior region of the tongue attached

Table 1 (continued)

Authors (year and country)	Objective	Participants' profiles and feeding routes		Type of transducer and frequency	Parameters for acquisition and analysis of ultrasound images during feeding				
					Acquisition mode and calibration parameters	**Mother and baby positioning**	**Positioning of the transducer and reference points for acquisition**	**Instructions to the subject**	**Parameters assessed**
					Adjustments were made to gain, dynamic range, and timing during the acquisition		The transducer was rotated until the image of the nipple was at its maximum length and diameter and a view of the junction of the hard and soft palate was achieved		to the lower edge of the nipple, sealing the oral cavity and pharynx, generating the basal vacuum **Intraoral space:** It is limited distally by the tip of the nipple, proximally by the soft palate attached to the base of the tongue, superiorly by the hard palate, and inferiorly by the dorsal surface of the tongue, and does not contain air **Distance from the beak to the hard-soft palate junction:** Distance (mm) between the tip of the nipple and the beginning of the hard-soft palate junction **Distance between the tongue and hard palate:** Distance (mm) from the hard palate to the surface of the posterior region of the tongue. Its maximum distance corresponds to the vacuum peak
Alan A et al. (2023- Turkey) [19]	To compare the position and movement of the tongue during sucking in babies with and without ankyloglossia	Breastfeeding	30 mothers and babies without ankyloglossia 30 mothers and babies with ankyloglossia Age: 5 to 15 days	8 C-RS micro-convex transducer. To acquire 2D images Frequency: 6–10 MHz	B and M modes Gain: 55 dB Dynamic range: 60 dB Two foci were used to narrow the ultrasound beam: One on the hard palate and the other	Not specified	The transducer was positioned along the midsagittal line of the baby's body and gentle pressure was used to maintain contact	The exam started when the baby latched on to the breast and ended when the baby finished breastfeeding	**Tongue position during sucking:** Initially, the posterior region of the tongue is observed attached to the palate (upward position), and the anterior region of the tongue attached to the lower edge of the nipple. When the posterior region of the tongue

Table 1 (continued)

Authors (year and country)	Objective	Participants' profiles and feeding routes	Type of transducer and frequency	Parameters for acquisition and analysis of ultrasound images during feeding				
				Acquisition mode and calibration parameters	**Mother and baby positioning**	**Positioning of the transducer and reference points for acquisition**	**Instructions to the subject**	**Parameters assessed**
				on the nipple-tongue attachment Adjustments were made to gain, dynamic range, and timing during the acquisition		with the baby's chin Visibility of the tip of the tongue on ultrasound is impaired by mandibular superposition The hard palate appears as an echogenic (white) line area, while the soft palate is observed as an intermediate gray structure with a distinct echogenic upper border. The nipple appears as a gray (cylindrical) structure **B-Mode ultrasound images:** Used to examine various features to locate the nipple in the oral cavity during breastfeeding **M-mode ultrasound images:** Anatomical ultrasound images were used to evaluate tongue movement during sucking		is lowered to the maximum, the vacuum peak occurs. As the vacuum is released, the anterior region of the tongue is elevated slightly, and the milk passes under the soft palate. Both the back of the tongue and the soft palate rise, and milk continues to flow towards the pharyngeal region. When the posterior region reaches the palate (upward position) the milk is introduced into the pharynx **Distance from the nipple to the hard-soft palate junction:** Distance (mm) between the tip of the nipple and the beginning of the hard-soft palate junction **Nipple position during breastfeeding:** The nipple is positioned so that it rests against the anterior region of the tongue, while the tip of the anterior tongue is elevated above the inferior alveolar ridge

Table 1 (continued)

Authors (year and country)	Objective	Participants' profiles and feeding routes		Type of transducer and frequency	Parameters for acquisition and analysis of ultrasound images during feeding				
					Acquisition mode and calibration parameters	Mother and baby positioning	Positioning of the transducer and reference points for acquisition	Instructions to the subject	Parameters assessed
Weber F et al. (1986-England)[20]	To describe events that occur in the baby's oral cavity during breast-feeding using US	Breastfeeding and bottle	6 mothers and babies (mother's breast) 6 babies (bottle) Age: 2 to 6 days	Transducer: Not specified Frequency: not specified	B mode Depth 6.6 cm Other parameters not specified	Bottle: baby held by the mother, who supported and slightly tilted his head Maternal breast: baby placed in the usual position	The transducer was positioned along the midsagittal line of the baby's body and gentle pressure was used to maintain contact with the baby's chin The image is best seen when tilted 45º so that the baby's head is vertical The hard palate appears as an echogenic (white) line area, while the soft palate appears as a gray structure with an echogenic border. The nipple appears as a gray (cylindrical) structure. The structures seen at the back of the mouth, behind the tongue, are assumed to be the upper margin of the larynx	The examination began when the baby took the breast and bottle and ended when the baby finished feeding	**Coordination of sucking and swallowing:** Sucking is evident from the beginning of the tongue indentation of the nipple or bottle nipple. Sucking is the isolated action of tongue movement without laryngeal movement and"suction-swallowing"for sucking accompanied by swallowing **Tongue position during the sucking cycle:** Maternal breast: tongue movement was wavelike; and in the resting position of the tongue, the nipple was recessed Baby bottle: the movement seemed to be due to compression, and in the resting position of the tongue the nipple was expanded

Table 1 (continued)

Authors (year and country)	Objective	Participants' profiles and feeding routes		Type of transducer and frequency	Parameters for acquisition and analysis of ultrasound images during feeding				
					Acquisition mode and calibration parameters	**Mother and baby positioning**	**Positioning of the transducer and reference points for acquisition**	**Instructions to the subject**	**Parameters assessed**
Geddes DT et al. (2012-Australia)[7]	To determine the action of the infant's tongue during breastfeeding and bottle feeding using US	Breastfeeding and bottle	12 mothers and babies (mother's breast) 6 babies (trial bottle) Age: 49.4 days (+ – 19.9) mother's breast 56 days (+ – 18.3) bottle	Transducer: endocavity convex (PVT-661 VT) Frequency: 3.6–9 MHz	B mode Parameters not specified Two foci were used to narrow the ultrasound beam: One on the hard palate and the other on the nipple-tongue attachment Adjustments were made to gain, dynamic range, and timing during the acquisition	Bottle: offered by the mother Breast: baby placed in the usual position	The transducer was positioned along the midsagittal line of the baby's body and gentle pressure was used to maintain contact with the baby's chin The transducer was rotated until the image of the nipple was at its maximum length and diameter and a view of the junction of the hard and soft palate was achieved The position of the transducer was changed according to the baby's movement to maintain a midline sagittal view The hard palate appears as an echogenic (white) line area,	Mothers were asked to measure 24-h milk production in their own homes Mothers and babies attended to the laboratory in two moments with an interval of 15 days between them The examination began when the baby took the breast and bottle and ended when the baby finished feeding	**Tongue position during the sucking cycle:** In the first half of the sucking cycle, as the tongue lowered, the intraoral vacuum increased, and milk flowed into the mouth during breastfeeding and experimental bottle feeding In the second half of the sucking cycle, as the tongue rose, milk was eliminated from the oral cavity (the anterior tongue rose a little earlier than the rest of the tongue) towards the palate, and the vacuum decreased To compare tongue movement, the relationship between nipple diameter and the interaction between tip distance, tongue position, and type of feeding was considered; 5 mm was designated as the reference level **Distance from the nipple to the hard-soft palate junction:** Distance (mm) between the tip of the nipple and the beginning of the hard-soft palate junction

Table 1 (continued)

Authors (year and country)	Objective	Participants' profiles and feeding routes		Type of transducer and frequency	Parameters for acquisition and analysis of ultrasound images during feeding				
					Acquisition mode and calibration parameters	Mother and baby positioning	Positioning of the transducer and reference points for acquisition	Instructions to the subject	Parameters assessed
							while the soft palate appears as a gray structure with an echogenic border. The nipple appears as a gray (cylindrical) structure and the milk ducts within the nipple appear as thin hypoechoic (black) tubular structures visible when the tongue is lowered in breastfeeding		**Nipple diameters:** Distance (mm) traveled by the entire gray structure presented cylindrically in the image Measured at intervals of 2, 5, 10, and 15 mm from the tip of the nipple to the base of the nipple. Such measurements were made with two calipers: one to measure the intervals along the nipple from the tip and the other to measure the external diameter of the nipple at each interval. There was an increase in the diameter of the nipple and the bottle nipple, except for the tip of the nipple with the tongue pointing upwards
Nowak AJ et al. (1994-USA)[22]	To compare differences in deformation of the bottle nipple with the human nipple and compare the suction mechanism used by the infant using US	Bottle feeding	35 babies Age: 6–12 weeks	E8 C-RS endocavity transducer Frequency: 5 MHz	B mode Parameters not specified	Not specified	The transducer was positioned in the coronal plane, along the midsagittal line of the baby's body, submental region, with minimal interference to the baby's chin The transducer was positioned in the axial plane (transoral approach through the cheek) In this axis, the nipple was observed just after its full extension. The echogenic material at the tip of the nipple is milk and air extracted from the nipple Several 3-s ultrasound cine-clips were recorded as soon as the baby began nutritive sucking	The examination began when the baby took the bottle and ended when the baby finished feeding At least three complete sucking cycles were performed during which milk flow was evident on the ultrasound image	**In the axial plane:** The ratio of the length of the nipple during full suction to the length of the nipple at rest The ratio of the nipple width at full suction to the nipple width at rest provides a measurement of lateral (side-to-side) compression **On the coronal axis:** Measuring the degree of flattening of the nipple is equivalent to the ratio between the height of the nipple at maximum compression and the height of the nipple at rest

Table 1 (continued)

Authors (year and country)	Objective	Participants' profiles and feeding routes		Type of transducer and frequency	Parameters for acquisition and analysis of ultrasound images during feeding				
					Acquisition mode and calibration parameters	Mother and baby positioning	Positioning of the transducer and reference points for acquisition	Instructions to the subject	Parameters assessed
									Deformation of the nipples and changes in the shape and position of the tongue, cheeks, and soft palate were observed by stop-frame analysis during each infant's feeding pattern
Nowak AJ et al. (1995-USA)[21]	To compare the sucking and swallowing patterns of infants while feeding with a new bottle nipple during breastfeeding	Bottle feeding	15 babies Age: 2 to 15 weeks (mean of 7.2)	Transducer: angled Frequency: 5 MHz	B mode Parameters not specified	Supine in a crib or on a plank table with the neck in slight hyperextension	The transducer was positioned in the coronal plane, along the midsagittal line of the baby's body, submental region, with minimal interference to the baby's chin The transducer was positioned in the axial plane (transoral approach through the cheek) In this axis, the nipple was observed just after its full extension. The echogenic material at the tip of the nipple is milk and air extracted from the nipple	Parents were asked to use the new tricut bottle nipple and return after 1 week of successful feeding Serve milk in a bottle for 2 min At least three complete sucking cycles were performed during which milk flow was evident on the ultrasound image	**In the axial view:** Length of the anterior to posterior region of the tongue and compression of the nipple were observed The ratio of the nipple width at full suction to the nipple width at rest provides a measurement of lateral (side-to-side) compression **In the coronal view:** Medial compression of the nipple was observed. Length, anteroposterior compression, and medial compression of the beak were measured
Hayashi N et al. (1997-Japan) [23]	to observe morphological and suction pressure analysis simultaneously using US in M and B modes	Bottle feeding	15 babies Age: 5 to 6 days	Transducer: Not specified Frequency: 5 MHz	B and M modes Parameters not specified	Not specified	The transducer was positioned along the midsagittal line of the baby's body, the submental region	The examination began when the baby took the bottle and ended when the baby finished feeding	**Tongue position during the sucking cycle:** Initially, the anterior portion of the tongue pressed the nipple upward and the medial portion pressed the nipple when the anterior portion moved downward The posterior portion moved upward in order, pressed against the palate again, and then moved downward and separated from the palate

Table 1 (continued)

Authors (year and country)	Objective	Participants' profiles and feeding routes	Type of transducer and frequency	Parameters for acquisition and analysis of ultrasound images during feeding				
				Acquisition mode and calibration parameters	Mother and baby positioning	Positioning of the transducer and reference points for acquisition	Instructions to the subject	Parameters assessed
								In B-mode ultrasound: The space surrounded by the posterior portion of the tongue, palate, and nipple disappeared when the tongue was attached to the palate and increased in size when the tongue moved downward and separated from the palate **In M-mode ultrasound:** In the line that includes the posterior portion of the tongue and the palate, a linear pattern was observed while the tongue was attached to the palate. When the tongue was separated from the palate and moved downward, the distance between the posterior portion of the tongue and the palate became greater With the anteroposterior wave movement, the tongue rose again, and the distance between the posterior portion of the tongue and the palate became smaller

Table 1 (continued)

Authors (year and country)	Objective	Participants' profiles and feeding routes		Type of transducer and frequency	Parameters for acquisition and analysis of ultrasound images during feeding				
					Acquisition mode and calibration parameters	Mother and baby positioning	Positioning of the transducer and reference points for acquisition	Instructions to the subject	Parameters assessed
									This distance changed moment by moment, and sequential changes in distance were observed as a rectilinear pattern With the letdown of milk, the posterior portion of the tongue moves downwards and releases the palate and the space surrounded by the posterior portion of the tongue. The nipple and palate appear, and the nipple increases in size
Lagarde L et al. (2021-the Netherlands)[24]	To measure nipple compression and tongue movements using US in healthy infants during bottle feeding	Bottle feeding	12 babies Age: 2 to 5 months Mean: 11.5 weeks Range: 8.8–13.5 weeks	C8 convex transducer Frequency: 5 MHz	B mode Parameters not specified	The babies were held by one of the parents in a semi-recumbent position on a surface	The transducer was positioned along the mid-sagittal line of the baby's body, submental region, without pressure from the oral cavity The mandible, tongue, submental muscles, nipple, and hyoid bone were visualized. The nipple was visualized as midsagittal as possible	Serve in a bottle, nipple 1, until the best possible recording quality was obtained, the bottle was empty, or the infant stopped drinking	**Tongue position during sucking:** Tongue displacement (lifting and lowering) along four evenly distributed lines and anterior and posterior displacements. The contour of the nipple and the tongue surface was referenced to the position of the edge of the mandible **Nipple diameter during compression:** Average difference in diameter (mm) of the nipple during suction. Gray structure presented cylindrically in the image

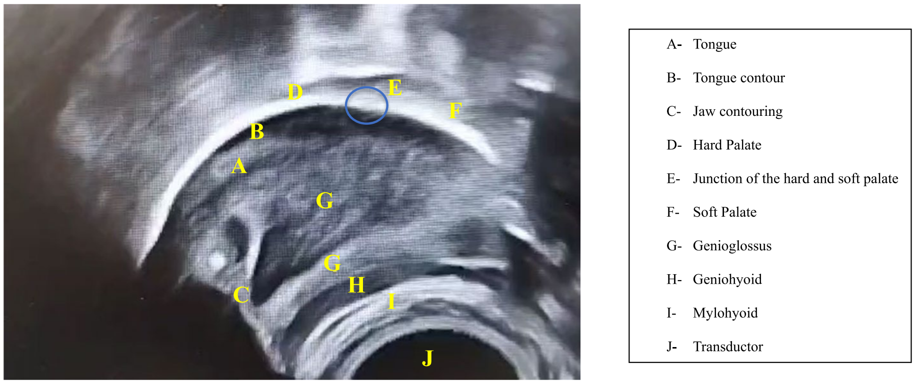

Fig. 4 Ultrasound imaging of the tongue at rest to identify anatomical structures

cycle (tongue up and down, nutritive and nonnutritive suction); suction rates; distance between tongue and palate. Even though the studies addressed the same biomarkers, analyzing all or some, the results may differ according to the evaluator's expertise in applying the technique, identifying the target biomarkers during the examination, associating them, and analyzing data Fig. (4)

The authors aimed to investigate the distance from the tip of the nipple to the HSPJ; the physical behavior of the nipple during sucking; the correlation with intraoral vacuum [6–9, 12, 13, 16, 19, 25] and tongue movement during breastfeeding before and after lingual frenotomy [14]; tongue kinematics and morphology during breastfeeding in babies with and without ankyloglossia [20, 21, 24]; sucking patterns during breastfeeding over time; secretory activation [4, 7, 8, 10, 16–18] and tongue action during breastfeeding and bottle feeding [7, 22, 23].

On US, the hard palate appears as an echogenic line visualized in white. Although the articles have not described it, the contour of the hard palate on US is visible when the tongue presses against it, as in swallowing/sucking milk, and is no longer visible when the tongue moves away from it. Because it is a rigid structure, the hard palate can be used as a reference point to eliminate noise induced by non-breastfeeding movements[10]. The HSPJ location on the polar coordinates was identified where the band becomes wider than 5 pixels[10]. The soft palate appears as a gray structure (3–4 mm) with an echogenic border and was identified where the band widens. The nipple appears as a gray, soft tissue structure, and the ducts within the nipple appear as hypoechoic (black), shaped like tubular structures. Milk flow was visualized as a hypoechoic fluid containing echogenic spots [14, 16]. Echogenic spots are described as fat and globules in milk [14, 16].

Other landmarks were used as measurement markers, such as distance (mm) between the tip of the nipple and the beginning of the HSPJ was measured from a transverse mark on the tip of the nipple to the transverse mark on the distal end of the hard palate adjacent to the soft palate in the sagittal plane; distance (mm) the nipple traveled in the entire gray structure presented cylindrically in the image; the sucking cycle, from when the middle of the tongue was attached to the palate (tongue up), followed by a downward tongue excursion, the middle tongue reaching its lowest point (tongue down), until the tongue attached to the palate again. Some authors measured with a caliper on the device's screen, whereas others used the device's measurements (which can bias the analysis of the results).

Discussion

This scoping review aimed to map the procedures for acquiring and analyzing US images of tongue movements during sucking of full-term infants at the mother's breast and bottle. It presents the possibilities of US assessment of sucking, based on the analysis of acquisition methods, image modes, milk ejection and flow, association with the evaluation of intraoral vacuum, weight gain, and limitations inherent to the exam. In this way it will help understand US image acquisition methods and guide the basic principles for examinations of full-term infants' sucking. Hence, studies should indicate the oral cavity structures that can be evaluated in this population. Moreover, the mapped studies show that examiners must know how US images are formed, tissue differences, and structure echogenicity.

Real-time US is a lower-cost imaging modality free from ionizing radiation and other associated risks [5, 26]. It has been used since the 1980 s to describe events that occur in full-term babies' oral cavity and nipple behavior during breastfeeding [12, 21]. The most recent studies explore the validity and reliability of new US technologies for morphometric and kinematic assessment of the tongue [4–6];distance from the nipple to the HSPJ [8, 9]; physical behavior of the nipple and bottle nipple[8, 12, 13], associating milk ejection [17, 18] and intraoral vacuum [9] during the sucking of infants at the mother's breast and bottle, seeking to establish the temporal sequences of the events of suction identified with US in the wave-like movement of the tongue during breastfeeding [4, 6–10, 12–25]. It makes it possible to understand patterns considered typical of sucking and the possible variations of these patterns [27, 28] and correlate tongue movements before and after lingual frenotomy and maternal pain scale to verify the effectiveness of the surgical technique [14] and the displacement of the hyoid bone as a marker for swallowing and reference for sucking cycles [4].

US provides more detailed, static, and dynamic images of the soft tissues of the infant's mouth, human nipple, and bottle nipple, showing the milk flow in the oral cavity with various US devices, such as B-mode, endocavity transducer, at 7 MHZ, with a gain of 55 dB and a dynamic range of 60 dB [6, 7, 9, 13, 15, 19]. Such parameters can be adjusted according to the baby's age by reducing the frequency to 5 MHz [6, 9, 16, 17], using two foci to narrow the US beam, one on the hard palate and the other on the nipple-tongue attachment [6–9, 13, 14, 16–20].

Currently, the infant's sucking patterns are clinically assessed through visual and digital inspection (with a gloved finger while the baby sucks), using protocols with qualitative and empirical measures [3, 25], with no objective method to assess tongue movement during sucking on the mother's breast or bottle for clinical speech-language-hearing pathologists to more accurately assess tongue movements and draw up a more assertive and individualized therapeutic plan. Thus, more studies are needed to understand the reliability, sensitivity, and specificity of US for this objective. This corroborates the need to develop a protocol for evaluating tongue movements during sucking in full-term babies during breastfeeding and bottle feeding.

Even though the US is a potential evaluation instrument likely used in these individuals' clinical follow-up, the studies do not address the challenges faced in acquiring and analyzing US images. They must detail the evaluator's experience and training and whether the intrarater and interrater reliability was analyzed. Most articles do not mention the preparation of the mother and baby for the assessment, the position of the baby for milk supply, the place where babies were assessed, the details of the acquisition mode, and US calibration parameters. There was variability in the parameters and methods of US image analysis to determine the quantitative measures and interpret the qualitative ones. Furthermore, for the same variable, the authors differ between units of measurement in millimeters [12] and percentages [23].

Moreover, some standardization difficulties are expected in US assessment of sucking, such as the change in the sucking rhythm that occurs naturally according to the baby's alert state and sucking time, anatomical differences between nipples in the breastfeeding assessment, variations in the entry and exit movement of the bottle nipple during sucking [22], the difficulty in maintaining the transducer stabilized, centered, and positioned in the submandibular region without interfering with the natural breastfeeding process, and the quality of US image resolution to enable more accurate analysis.

This scoping review observes a need for detailing the US image acquisition method to make the studies more robust and homogeneous. It also found that they overvalued sonographic analysis results but undervalued the biases from image formation.

Conclusion

The studies mapped in this review present the acquisition and static analysis of US images of the tongue muscles, hard and soft palate, nipple, and bottle nipple, and kinematic measurements of the tongue, nipple, bottle nipple, and hyoid bone. They assessed quantitative and qualitative parameters, mostly amplitude (mm), distance (mm), duration (number of sucking cycles), and description of the displacement of the tongue, nipple, and bottle nipple. They used endocavitary transducers at various frequencies, depending on the depth and the child's age. B-mode was the most used among the studies. Babies were generally placed reclined on their mother's lap to breastfeed or feed from a bottle, and mothers were instructed to breastfeed on demand and/or until the bottle was emptied. The brightness, depth, and gain settings were modified to acquire quality images according to the equipment's and the baby's characteristics. However, there is a significant gap in knowledge, such as detailed information on the evaluator's training and expertise, standardized mother-infant management during feeding, methodological accuracy in acquiring images and identifying and analyzing biomarkers. Clinical practice can use US to assess infants, identify the cause of feeding difficulties, and define individualized care plans. Thus, more detailed and standardized studies are needed, as well as the development of a US protocol to evaluate tongue movements while sucking on the bottle or the mother's breast.

Abbreviations

CG	Control Group
dB	Decibels
DSW	Digital Swallowing Workstation
IBCLC	International Board Certified Lactation Consultant
JBI	Joanna Briggs Institute
MeSH	Medical Subject Headings
Mm	Milimeter
NOMAS	Neonatal Oral Motor Assessment Scale
NNS	Nonnutritive Sucking
NS	Nutritive Suction
OSF	Open Science Framework
PG	Pain Group
PCC	Population, Concept, Context
US	Ultrasonography

Supplementary Information

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Supplementary Material 1
Supplementary Material 2
Supplementary Material 3
Supplementary Material 4
Supplementary Material 5
Supplementary Material 6
Supplementary Material 7
Supplementary Material 8

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