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Practice-based interpretation of ultrasound studies leads the way to more effective clinical support and less pharmaceutical and surgical intervention for breastfeeding infants

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ABSTRACT

Background: breastfeeding optimises health outcomes for both mothers and infants. Although most women want to breastfeed, they report commencing infant formula because of nipple pain, unsettled infant behaviour, and infant growth concerns. To date, existing approaches to fit and hold ('latch and positioning') have been demonstrated not to help breastfeeding outcomes, and women report widespread dissatisfaction with the quality of support and conflicting advice they receive. Breast and nipple pain, difficulty with latching and sucking, fussing at the breast, back-arching, marathon feeds, excessively frequent feeds, poor weight gain, breast refusal, and crying due to poor satiety often signal suboptimal positional instability and impaired milk transfer, but may be misdiagnosed as medical conditions. Over the past two decades, there has been an exponential increase in numbers of infants being treated with medications, laser or scissors frenotomy, and manual therapy for unsettled behaviour and breastfeeding difficulty. New approaches to clinical breastfeeding support are urgently required.

Method and results: we analyse the findings of a literature search of PubMed and MEDLINE databases for ultrasound studies measuring sucking in term and preterm infants. The findings demonstrate that the Stripping Action Model of infant suck during breastfeeding, and the resultant Structural Model of infant suck dysfunction, are inaccurate. Instead, ultrasound data demonstrates the critical role of intra-oral vacuum for milk transfer. We integrate these two-dimensional ultrasound results with clinical experience of the third dimension, volume, to propose a Gestalt Model of the biomechanics of healthy infant suck during breastfeeding. The Gestalt Model hypothesises that optimal intra-oral vacuums and breast tissue volumes are achieved when mother-infant positional stability eliminates conflicting intra-oral vectors, resulting in pain-free, effective milk transfer.

Conclusion: the Gestalt Model of the biomechanics of healthy infant suck during breastfeeding opens up the possibility of a new clinical method which may prevent unnecessary medical treatments for breastfeeding problems and related unsettled infant behaviour in early life.

Background

Parents resort to infant formula because of unsettled behaviour, breast and nipple pain, and growth concerns

Although 96% of Australian women want to breastfeed, by the end of three months only 39% are able to do so exclusively (Australian Institute of Health and Welfare, 2011). The most common reasons parents give for introducing infant formula are perceptions of low supply (usually because of unsettled infant behaviour), breast and nipple pain, difficulty with latching and sucking, unsettled infant behaviour, and infant weight concerns (Brown et al., 2014; Li et al., 2008; Odom et al., 2013; Redsell et al., 2010). Unsettled infant behaviour, breastfeeding difficulties, and lactation-related breast pain

Abbreviations: BSP, Breastfeeding support professional; ATLFF, Hazelbaker Assessment Tool for Lingual Frenulum Function; HSPJ, Junction of the hard and soft palate; BT, Intra-oral breast tissue; HP, Hard palate; SP, Soft palate

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also predispose to postnatal depression (Brown et al., 2015; Dias and Figueiredo, 2015; Howard et al., 2006; Radesky et al., 2013).

Unfortunately, women report dissatisfaction with the quality of support and conflicting advice they receive as they establish breastfeeding (Burns et al., 2012; Dykes, 2005; McInnes and Chambers, 2008; Schmied et al., 2011). There are serious gaps in health professional education concerning clinical breastfeeding support (Bernaix et al., 2010; Gavine et al., 2017; Holmes et al., 2012; Renfrew et al., 2012) and limited funding for translational research. That is, even though the use of infant formula is known to increase health risks for women and their babies and results in substantial cost to the health system, the health system itself inadequately supports breastfeeding women (Bartick and Reinhold, 2010; Pokhrel et al., 2014; Rollins et al., 2016; Smith and Ingham, 2001; Victora et al., 2016). Until more effective, evidence-based clinical approaches to both prevention of and early intervention for breastfeeding difficulties are available, scaling up breastfeeding support in health systems environments is unlikely to yield the hoped-for benefits (Perez-Escamilla and Moran, 2016).

Skills-based or hands-on clinical support do not improve breastfeeding outcomes

This analysis uses the term breastfeeding support practitioner (BSP) to refer to the various health professionals who offer clinical support to breastfeeding women, including but not limited to lactation consultants, midwives, and maternal and child health nurses. A 'skills-based' model of clinical breastfeeding support, in which the BSP actively helps the mother latch the baby on to her breast, has been prominent since the 1950s, and is also known as a 'hands-on' approach (Thompson et al., 2011).

In a related method, women are taught to shape their breast with a c-hold, scissors hold, or palmar grasp while using a cross-cradle hold, their other hand supporting the back of the infant's neck and head. This technique requires actively stimulating a gape in order to bring the baby on to the breast. In 2016, a study of 653 Australian women shows that this latter method, still commonly taught to mothers by BSPs, results in face-breast asymmetry and nipple malalignment, increasing the incidence of nipple pain fourfold (Thompson et al., 2016).

Biological nurturing and baby-led, mother-guided approaches are necessary, but not sufficient, to improve breastfeeding outcomes

The recognition that the infant has innate mammalian breastfeeding reflexes which drive him or her to self-attach to the breast and transfer milk has brought major advances in clinical breastfeeding support over the past decade. In an approach referred to as Biological Nurturing, a semi-reclined position is adopted by the mother for the release of primitive neonatal reflexes, which stimulate breastfeeding (Colson et al., 2008). A related approach known as Baby-Led Breastfeeding acknowledges the interactive nature of this process, with the mother encouraged to support her infant's state regulation by reading and responding to her infant's cues (Smillie, 2016). Skin-to-skin contact at birth has been demonstrated to promote breastfeeding, and is now widely implemented in maternity suits (Moore et al., 2016). In a randomised controlled trial of 103 mother-infant pairs with severe latching-on problems in the first 16 weeks post-birth, skin-to-skin contact didn't improve the number who achieved successful latch relative to usual clinical breastfeeding support, but did enhance maternal experience and time taken to successful latching (Svensson et al., 2013).

The physiologic approach to breastfeeding initiation, which includes skin-to-skin contact, Biological Nurturing, Baby-Led Breastfeeding, and activation of both maternal and infant instincts in the first hours after birth, is foundationally important for the facilitation of breastfeeding reflexes (Schafer and Watson Genna, 2015). It is, however, not enough to ensure ongoing pain-free and effective breastfeeding for many pairs (Brodribb et al., 2013). Complex sociocultural, environmental and anatomic factors impact on the breastfeeding relationship, including the effects of technologized birth environments on neonatal reflexes and lactogenesis (Brown and Jordan, 2013; Colson et al., 2008; Dewey et al., 2003; Lind et al., 2014; Sakalidis, Williams, Hepworth, et al., 2013; Smillie, 2016); the effects of chronic disease including diabetes and obesity on lactogenesis (De Bortoli and Amir, 2016; Nommsen-Rivers, 2016); and very importantly, the effects of obesity and other psychosociocultural factors on the way the maternal and infant body fit together (Amir and Donath, 2007; Thompson et al., 2011).

Health professional and peer interventions may improve breastfeeding initiation (Balogun et al., 2016), and individualised and regular support by trained or peer personnel in face-to-face settings improve breastfeeding outcomes overall (McFadden et al., 2017; Patnode et al., 2016; Sinha et al., 2015). However, existing interventions to help with fit and hold (commonly referred to as 'latch and positioning' or 'attachment and positioning'), including 'hands-off' or mammalian methods, are not demonstrated to improve breastfeeding outcomes, including in randomised controlled trials (De Oliveira et al., 2006; Forster et al., 2004; Henderson et al., 2001; Kronborg et al., 2012; Kronborg and Vaeth, 2009; Labarere et al., 2003; Wallace et al., 2006; Woods et al., 2016).

Emergent breastfeeding difficulties despite physiologic initiation may explain why many BSPs continue to resort to the older skills-based style of breastfeeding support. Importantly, once available clinical breastfeeding interventions fail, BSPs commonly resort to the medicalisation of breastfeeding difficulties (Douglas, 2013a; Douglas and Hill, 2011; Douglas, 2013b). There is also a trend for BSPs to refer breastfeeding difficulties that have not responded to available clinical approaches to chiropractic or osteopathic treatment, despite expense for parents and lack of methodologically reliable evidence of efficacy (Miller et al., 2016; Miller et al., 2009).

Signs of suboptimal fit and hold include nipple pain, difficulty latching and staying on, back-arching, fussiness at the breast, and excessive crying

This analysis uses the term 'fit and hold' to refer to the way a woman's highly anatomically variable breast and body and her infant's highly anatomically variable intra-oral cavity, face and body interact and fit together in breastfeeding. Optimal fit and hold supports the baby's positional stability, so that his or her breastfeeding reflexes are optimally activated, and effective pain-free sucking and milk transfer occurs.

Nipple pain commonly results from suboptimal fit and hold, and affects 34–96% of breastfeeding women (Berens et al., 2016; Joanna Briggs Institute, 2009; Tait, 2000). Nipple pain predisposes to engorgement, blocked ducts, mastitis, and premature weaning. A Cochrane Review of studies which combine typical approaches to fit and hold with various topical applications for nipple pain shows no convincing benefit, again emphasising the need for new clinical approaches (Dennis et al., 2014).

In addition to nipple pain and damage, suboptimal fit and hold results in difficulty latching onto and staying on the breast, back-arching, marathon feeds, excessively frequent feeds, excessive night-waking, fussiness at the breast, excessive crying, poor weight gain, and low supply. However, suboptimal fit and hold is often unidentified or misdiagnosed, because these signs are misattributed to gastro-oesophageal reflux disease, allergy, or, most recently, to oral connective tissue restrictions in the absence of classic tongue-tie (Douglas, 2013a; Douglas and Hill, 2011; Wattis et al., 2017).

The relationship between infant cry-fuss problems and suboptimal fit and hold are mediated by two neurobiological mechanisms. Firstly, poor satiety results from impaired milk transfer. A baby may be unsettled by hunger despite weight gains that have been considered normal in the past (and that are unremarkable if parents report no problems). The large World Health Organisation cohorts of breastfeeding infants show an average weight gain of 200 – 250 g/week in the first few months of life (De Onis et al., 2009). Infants with poor satiety feed excessively frequently or for excessively long periods, wake excessively at night, and cry and fuss a lot.

Secondly, a neurotypical baby who has repeated experiences of frustration at the breast due to an inability to maintain positional stability and transfer milk comfortably may develop a conditioned hyperarousal of the sympathetic nervous system and hypothalamic-pituitary-adrenal axis (referred to here as conditioned SNS hyperarousal), either when presented with the breast or as the feed progresses. This mechanism is elucidated in the neurobiological model of infant cry-fuss problems (Douglas and Hill, 2013). Conditioned SNS hyperarousal due to positional instability is evident in fussiness with latching, repeated pulling off the breast, back-arching, and crying, and may be referred to as 'aversive feeding behaviour', 'breast refusal' or 'oral aversion'.

Breastfeeding problems and associated unsettled infant behaviour are often inappropriately medicalised, risking unintended outcomes

The neurobiological model of unsettled infant behaviour also proposes that breastfeeding problems in the first days and weeks may re-set the stress thermostat, temporarily for most and long-term for some, during the neurologically sensitive first four months of life (Douglas and Hill, 2013). An upregulated sympathetic nervous system will result in increased frequency of reflux events, although these are not associated with oesophageal inflammation or pain in the first months of life and are not a cause for concern, once medical conditions such as pyloric stenosis are excluded (Gieruszczak-Bialek et al., 2015).

Inappropriate diagnoses of gastro-oesophageal reflux disease and unnecessary pharmaceutical treatment for unsettled infant behaviour and feeding problems remain widespread (Hua et al., 2014; Rimer and Hiscock, 2014) and have resulted, over the past few decades, in side-effects which include increased risk of infection and allergy (Freedberg et al., 2015; Merwat and Spechler, 2009; Orel et al., 2016; Trikha et al., 2013). Proton pump inhibitor use in the first 6 months of life has also been recently linked with a 22% increase in the risk of childhood bone fracture (Lyon, 2017). Similarly, inappropriate diagnosis of allergy in babies with unsettled behaviour and breastfeeding problems has resulted in increased risk of childhood allergy, due to the effects of unnecessary maternal elimination diets (Greenhawt, 2016; Ierodiakonou et al., 2016; Jensen et al., 2013; Skypala and Vlieg-Boerstra, 2014).

Proponents of surgery for oral ties in babies with breastfeeding problems hypothesise that poor latch results in aerophagia, which they argue worsens reflux (Ghaheri et al., 2017; Kotlow, 2011; Siegel, 2016). This hypothesis fails to consider the multiple mechanisms that underlie gastro-oesophageal reflux, including sympathetic nervous system up-regulation. The diagnosis of Aerophagia Induced Reflux mistakes functional lactose overload for aerophagia (Kotlow, 2016), exacerbates parental pressure for medical intervention (Scherer et al., 2013), and promotes unnecessary rituals such as burping and holding upright after feeds. By disrupting neurohormonally-induced drowsiness at the end of feeds, these rituals disrupt healthy function of the infant's biological sleep regulators (Whittingham and Douglas, 2014).

After decades of neglect, it is now accepted in clinical practice that classic tongue-tie, often referred to as 'anterior' tongue-tie, but which we define in this paper as Type 1–2 in the Coryllos typing, may cause nipple pain and fussy behaviour with breastfeeding. Classic tongue-tie commonly requires a simple scissors frenotomy. However, breastfeeding babies in Western societies without classic tongue-tie are experiencing an epidemic of oral tie diagnoses and resultant frenotomies (Joseph et al., 2016; Kapoor et al., 2017; Walsh et al., 2017; Wattis et al., 2017). In the first author's clinical experience as a medical doctor-lactation consultant in a specialist breastfeeding clinic, diverse variants of normal oral connective tissue are now frequently labelled by BSPs as posterior tongue-tie, upper lip-tie, or even buccal ties in the presence of breastfeeding difficulties. These patients are referred by BSPs for frenotomy, often by laser surgery, in the absence of reliable evidence demonstrating benefit, and despite risk of unintended outcomes including oral aversion (Douglas et al., 2017; Francis et al., 2015; O'Shea et al., 2017; Power and Murphy, 2015). We suggest that the trend to diagnose oral ties when mother-baby pairs have breastfeeding difficulty, in the absence of classic tongue-tie, demonstrates that current approaches to fit and hold are failing BSPs.

Women persist courageously with breastfeeding in the face of formidable obstacles, including inadequate role modelling of breastfeeding; institutionalised disrupters to neurohormonal synchrony between mother and baby from birth onwards, impacting negatively on both neonatal breastfeeding reflexes and maternal neurohormones; conflicting and confused advice from BSPs; and clinical interventions that do not demonstrate efficacy. It is not surprising that breastfed babies cry and fuss more than formula-fed babies in Western societies (de Lauzon-Guillain et al., 2012).

Oral surgery and manual therapy are based upon the Stripping Action Model of infant suck during breastfeeding

In the absence of classic tongue-tie, surgical interventions for diagnoses of restricted oral connective tissues (posterior tongue-tie and upper lip-tie) derive from a model of suck dysfunction that attributes functional changes to structural abnormalities. We refer to this as the Structural Model of suck dysfunction. Similarly, infant chiropractic and osteopathic interventions for breastfeeding problems, and the most popular assessment tool for identifying the need for frenotomy, the Hazelbaker Assessment Tool For Lingual Frenulum Function (ATLFF), derive from the Structural Model of suck dysfunction.

The Structural Model has been developed from the Stripping Action Model of infant suck during breastfeeding. The Stripping Action Model proposes that the primary mechanism of milk removal during breastfeeding is tongue movement, which compresses and strips the breast (Woolridge, 1987). The Stripping Action Model arose from the mid-twentieth century assumption that the biomechanics of breastfeeding must be the same as the biomechanics of removing milk from a bottle or sucking on the examiner's finger. Studies of infants with feeding difficulties, who cannot be viewed as normative, also contributed to the development of the Stripping Action Model.

The Stripping Action Model of infant suck proposes that some or all of the following mechanisms are required for effective milk transfer: a grasping action of the tip of the tongue on the breast; active longitudinal tongue grooving or cupping which supports the length of the nipple and surrounding areola, stabilising it in the mouth and channelling the milk bolus for swallowing; compression of the breast by the superior ridge of the mandible; peristaltic movement from the anterior to the posterior tongue that strips the breast of milk and propels the milk bolus into the oesophagus; and flanging of the upper lip which applies both a seal and pressure to the breast (Watson Genna, 2016).

The Structural Model of suck dysfunction proposes that (even in the absence of classic tongue-tie) structural deficits in the oral connective tissue impair tongue mobility and flanging of the upper lip, and result in the following problems: poor gape, shallow latch, over-use of the upper lip, sucking blisters, a sweeping motion of the upper lip during feeds, posterior humping of the tongue, nipple pain, oromotor muscle tightness, and impaired milk transfer (Watson Genna, 2016). A high and narrow palate is also viewed as a sign of a lingual tie, because the architecture of the infant palate is proposed to be shaped by intra-utero tongue movements.

From the point of view of the Structural Model of suck dysfunction, surgically releasing 'tight' oral connective tissue under the tongue and upper lip either by frenotomy, or by manual therapy which massages, stretches and relaxes related muscle groups and connective tissue, is necessary to improve breastfeeding outcomes, and to protect from impaired developmental outcomes such as underdevelopment of the maxillofacial skeleton, oromyofacial dysfunction, speech and swallowing impediments, and breathing disorders during sleep (Watson Genna, 2016).

However, there is no credible evidence-base for these claims, which frighten parents into compliance with surgical intervention. The association between breastfeeding and optimal orthodontic outcomes (Peres et al., 2015) is confused with the unproven assumption that oral connective tissue surgery (despite absence of classic tongue-tie) will improve breastfeeding outcomes. Studies concerning efficacy of frenotomy are seriously methodologically flawed (Douglas, 2017), in large part due to definitional confusion after the introduction of the poorly defined diagnosis of posterior tongue-tie from 2004 (Coryllos et al., 2004 Summer).

Aim

New approaches to fit and hold are urgently required, in order to prevent, or provide effective early intervention for, breastfeeding problems and associated unsettled infant behaviour in neurotypical mother-baby pairs. We analyse existing ultrasound studies to determine the accuracy of the Stripping Action Model of infant suck and the resultant Structural Model of suck dysfunction, which give rise to popular interventions for breastfeeding problems. From this analysis, we aim to elucidate an updated model of infant suck during effective pain-free breastfeeding, in order to facilitate the development of new clinical approaches to fit and hold.

Methods

In a 2016 literature review, the second author searched PubMed and MEDLINE databases for original studies measuring sucking in term and preterm infants. This search combined variations of the following keywords: sucking, vacuum, ultrasound, feeding, and infant feeding, in association with breastfeeding and bottle feeding and term or pre-term infants. Papers were limited to English and human infants. Studies measuring both breastfeeding and bottle feeding were included, and letters, commentaries, case studies, and reviews were excluded. The methodologies and results of the original studies were then analysed (Geddes and Sakalidis, 2016).

Interpretation of the overall findings of these existing ultrasound studies is required in order to elucidate implications for clinical practice. The first author is a medical doctor who first qualified as an International Board Certified Lactation Consultant in 1994, and is currently Medical Director of a specialist breastfeeding clinic in Brisbane, Australia. Many of the mother-baby pairs who present at this clinic with breastfeeding problems have previously consulted multiple BSPs. The clinic has developed an innovative clinical approach to fit and hold, Gestalt Breastfeeding, which helps breastfeeding pairs achieve optimal intra-oral breast tissue volume and positional stability, for pain-free effective milk transfer (Douglas and Keogh, 2017). We interpret existing ultrasound data through the lens of the first author's clinical experience.

Result and discussion

Two-dimensional ultrasound imaging elucidates the biomechanics of a healthy suck cycle

Analysis of existing ultrasound studies of healthy term infants during breastfeeding demonstrate that the mechanisms upon which the Stripping Action Model of healthy infant suck and the Structural Model of infant suck dysfunction are based are inaccurate (Geddes and Sakalidis, 2016).

Varying definitions have confused interpretation of ultrasound studies

Confusion of definitions has affected the way ultrasound studies of breastfeeding pairs have been interpreted to date.

The term ‘peristalsis’ means ‘alternate waves of constriction and dilation of a tubular muscle system or cylindrical structure’ and is not appropriately applied to discussions of the biomechanics of the infant oral cavity and tongue movements.

We use the term ‘intra-oral breast tissue’ to refer to all the breast tissue, including the nipple, which is located within the intra-oral cavity. We propose that the elongated tissue labelled as ‘nipple’ in ultrasound studies includes a varying amount of breast tissue in addition to the nipple. Some intra-oral breast tissue is obscured by the inability of the ultrasound to penetrate the mandible.

The tongue has three parts, the anterior, mid and posterior tongues. Earlier ultrasound studies used ‘posterior’ to describe what is more accurately referred to in recent studies as the mid-tongue. The tongue shaping popularly referred to as ‘posterior’ humping is actually mid-tongue elevation. We propose that the diagnoses of posterior tongue-tie and upper lip-tie are unhelpful, since they pathologise the wide range of diverse but normal anatomic variants of lingual and labial frenula (Douglas, 2013b; Douglas et al., 2017). For that reason, we do not use those terms in this discussion.

The seal creates a base-line vacuum

As the lips and lower face contact the breast tissue around the nipple and areolar, a mouth-opening reflex is activated. The tactile sensation of breast tissue in the oral cavity triggers reflex mandibular excursion, as firm contact between the lower half of the face and the breast creates a seal. In this way, an initial or baseline vacuum is generated, which varies between infants. This variation may relate to variations in nipple and breast morphology and elasticity, and also to the presence of conflicting vectors of force applied to the intra-oral breast tissue.

Ultrasound studies show that the tip of the anterior tongue rests over the inferior alveolar ridge, evidenced by the tongue not being retracted away from the mandibular shadow, but not protruding beyond the outer edge of the alveolar ridge during effective seal and sucking. The anterior tongue does not actively grasp or apply itself to the breast (Geddes and Sakalidis, 2016) (Fig. 1).

Transfer of milk occurs because depression of the mandible generates intra-oral vacuum

Movements of the tongue and mandible are coupled (Steele and Van Leishout, 2008). Downward excursion of the mandible drops the infant's anterior and mid-tongue inferiorly; the anterior and mid-

Fig. 1. Ultrasound image superimposed on an infant sucking normally to demonstrate intra-oral structures.

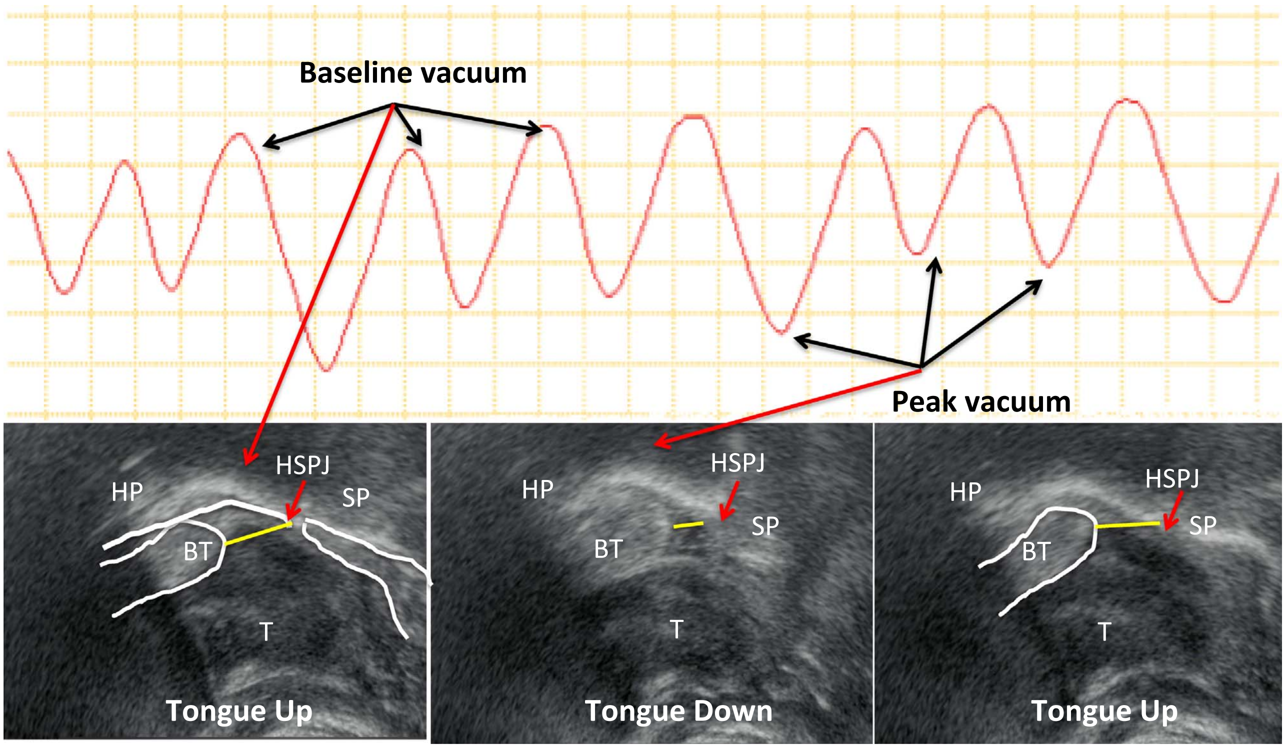

Fig. 2. Intra-oral vacuum and ultrasound images of the infant oral cavity during breastfeeding.

tongue move downwards together as a single 'rigid' unit, following the mandible (Elad et al., 2014; Geddes and Sakalidis, 2016). The tongue is observed to have substantial inferior-superior range of movement during breastfeeding because it is coupled with and follows the inferior and superior movements of the mandible, not because of independent movement. The tongue does not move laterally during the suck cycle, and effective sucking does not require the tongue to lift independently. For example, the tongue tip does not need to lift to the equivalent of the mid-oral cavity when the mouth is open. The capacity for inferior-superior excursion of the mandible, which couples with passive inferior-superior tongue movements, is not affected by the lingual frenulum.

Downward excursion of the mandible and the coupled anterior and mid-tongue depression cause the oral cavity to enlarge and the intra-oral vacuum to increase (Geddes et al., 2008; Sakalidis and Geddes, 2016; Sakalidis et al., 2013). A small intra-oral space is created between palate and mid-tongue as this downward movement occurs. The breast tissue that has been drawn into the oral cavity, and the milk ducts within it, expand evenly as the vacuum is applied. The tongue, which moulds under the intra-oral breast tissue; the enveloping buccal and palatine mucosa; and rhythmic application of peaks of vacuum bathe the breast tissue and nipple in warmth, moisture, and a deep drawing sensation, stimulating oxytocin release and contraction of the alveolar myoepithelial cells. Milk flows into the intra-oral space, as the mandible and tongue continue to drop inferiorly to peak vacuum (Geddes and Sakalidis, 2016; Sakalidis et al., 2013).

That is, intra-oral vacuum is the primary mechanism of milk removal, not tongue action (Elad et al., 2014; Geddes and Sakalidis, 2016). The negative pressure of the intra-oral vacuum is most effective in milk removal when combined with the positive pressure of maternal milk ejection (Kent et al., 2003). Vacuum variability may relate to changes in this positive pressure, which may reflect volume of milk in the breast, or to changes in the intra-oral breast tissue volume, or both (Geddes and Sakalidis, 2016).

As the mandible returns towards neutral, the tongue, being coupled with the mandible, lifts superiorly, and the intra-oral breast tissue is compressed, but there is no milk flow (Geddes et al., 2008; Sakalidis and Geddes, 2016). Although wave-like movements of the anterior and mid tongue are observed with digital and teat sucking, during normal breastfeeding the infant tongue does not perform wave-like stripping of the intra-oral breast tissue.

In non-nutritive sucking, minimal breast tissue compression is observed, and the excursion of the infant's mandible is shorter and more rapid compared to during nutritive sucking. Nutritive sucking occurs at an average rate of 90 sucks per minute, compared to 100 sucks per minute in non-nutritive sucking (Sakalidis et al., 2013).

The anterior tongue has slight independence of movement as the mandible returns superiorly, but this does not relate to milk extraction (Geddes and Sakalidis, 2016). In pain free effective breastfeeding the range of inferior-superior movement of the anterior tongue averages three millimetres. This small range of anterior tongue movement observed at the base of the intra-oral breast tissue most likely relates to the anterior tongue's involvement in moulding under and stabilising the intra-oral breast tissue, and also the anterior tongue's minor contribution to the face-breast bury, which creates the baseline vacuum seal (Sakalidis and Geddes, 2016).

The mid-tongue shows double the range of inferior-superior movement compared to the anterior tongue, on average six millimetres. The mid-tongue contacts the palate at the end of the suck cycle. When the mid-tongue lowers to its most inferior point, the anterior tongue begins its slight rise. The mid-tongue follows superiorly until it is in contact with the palate again.

In general, stronger intraoral vacuums are associated with more effective and efficient feeding (Geddes and Sakalidis, 2016). Stronger peak volumes are associated with larger volumes of milk collected in the oral cavity (Cannon et al., 2016). Weak peak intra-oral vacuums are associated with reduced feeding effectiveness (Mizuno et al., 2004). The baseline vacuum is also predictive of the strength of peak vacuum, emphasising the importance of an effective face-breast seal.

Baseline vacuum levels remain consistent overall throughout the first ten weeks of lactation for an individual breastfeeding pair. However, baseline vacuums are also observed to strengthen throughout a breastfeed, which may be a compensatory mechanism for increased pliability of the breast as it empties of milk (Cannon et al., 2016) (Fig. 2).

The shape of the posterior tongue does not alter significantly during swallowing

Movement of the posterior tongue, like movement of the anterior and mid-tongue, is coupled to movement of the mandible. Posterior tongue movement cannot be felt during digital sucking and is not easily observed, since it occurs beyond the hard palate. The soft palate, too, drops inferiorly with the downward movement of the tongue, in apposition with the posterior tongue. The posterior tongue slopes downward towards the vertical during sucking, and does not have any independent movement associated with milk transfer, only with swallowing.

As the mandible rises superiorly, the intra-oral vacuum decreases, the mid-tongue rises, and simultaneously the milk bolus passes over the posterior tongue and under the soft palate. The soft palate rises to meet the walls of the pharynx, sealing the nasal airway. A swallow occurs when milk stimulates the numerous sensory receptors in the posterior oral cavity; both posterior tongue and soft palate rise, milk flows toward the pharyngeal region, where it pools; a pharyngeal swallow is initiated, and breathing is briefly interrupted (McClellan et al., 2010; Sakalidis and Geddes, 2016; Sakalidis et al., 2013). The shape of the posterior tongue does not alter significantly during a swallow. However, a subtle wave like motion may be observed because of time lag, as the bolus passes between the part of the posterior tongue which is closest to the junction of the hard and soft palate (HSPJ) and the soft palate, then passes between the more proximal portion of the posterior tongue closest to the pharyngeal area and the soft palate (Elad et al., 2014).

Latch problems do not result in the swallowing of air

Large volumes of air are not normally observed in the stomachs of breastfeeding infants (Gridneva et al., 2017). There is no evidence of air being swallowed during ultrasound assessments of successful breastfeeding, of breastfeeding with tongue-tie, or of breastfeeding with nipple pain (Geddes et al., 2008; McClellan et al., 2015). White flecks displayed on ultrasound during sucking are due to the reflection of sound by fat globules in the milk, not air (Torres, 2014). During non-nutritive sucking, the intermittent swallows are most likely of small amounts of saliva, and do not appear to contribute to the ingestion of air.

The second author, a sonographer, regularly uses ultrasound to image the contents of breastfeeding infants' stomachs in her laboratory, including the stomachs of infants with breastfeeding problems. Air in the stomach creates artefacts that impede imaging and obscure stomach contents (Holt et al., 1980), but this is not typically observed. Air in stomachs of enterally fed preterm infants is also rarely seen on ultrasound (Perella et al., 2013).

Suck-swallow-breath ratios are highly variable

Breastfeeding problems have been attributed to suck-swallow-breath co-ordination problems in neurotypical infants. However, suck-swallow-breathe co-ordination is dynamic and variable, both across varying infant ages and throughout the temporal sequence of the breastfeed. Suck-swallow-breath ratios during effective nutritive sucking in ultrasound studies are highly variable, ranging from ratios of 1:1:1 to 12:1:14 (Sakalidis and Geddes, 2016; Sakalidis, 2013).

Two-dimensionality is a limitation of ultrasound studies of breastfeeding mother-baby pairs

Ultrasound studies of breastfeeding pairs have limitations (Geddes and Sakalidis, 2016). They are largely limited to two-dimensional submental midsagittal ultrasound views of the structure and function of the oral cavity-breast interface, tracked over the fourth dimension of time. They are also descriptive in nature, though one longitudinal observational cohort study had two time points, one in early lactation and the other in established lactation (Sakalidis et al., 2013). Sample sizes are low, of fifty or less. Currently, comparisons of infants with dysfunction (maternal pain) or oral anomalies (tongue tie) either lack control groups, are not randomised, or consist of small sample sizes (Geddes et al., 2008; McClellan et al., 2015).

Burton et al. used three-dimensional ultrasound to analyse movement of the superior tongue surface. Although the authors reported peristaltic action, they could not provide a reliable analysis, because they were unable to adequately image the nipple, hard and soft palates, and milk flow. Their study did highlight, however, the importance of a true midsagittal plane (Burton et al., 2013). Elad et al. (2014) have since used advanced computerised modelling of two dimensional ultrasound images to confirm that the tongue does not remove milk from the breast by a stripping action.

Despite these limitations, ultrasound studies constitute a major advance in our understanding of the biomechanics of effective pain-free milk transfer in breastfeeding.

Interpreting two-dimensional ultrasound imaging through the lens of three-dimensional clinical observation elucidates the biomechanics of a healthy suck cycle (the 'Gestalt Model')

When we integrate clinical observations of the significance of the third dimension, volume, into analyses of recent ultrasound data from breastfeeding pairs, new understandings emerge. We use 'gestalt' (pronounced *ger-shtolt*) to describe this emergent new biomechanical model of infant suck, because 'gestalt' means a whole that is more than the sum of its parts.

Intra-oral breast tissue volume is optimised when conflicting vectors are eliminated

When an infant is positionally stable, intra-oral breast tissue is optimised, because intra-oral breast tissue is no longer subjected to a vector or force that conflicts with the indrawing vector generated by intra-oral vacuum. Conflicting intra-oral vectors affect available breast tissue volume, altering placement of the nipple, and risking nipple damage and decreased milk transfer.

The weight of the breast responding to gravity may create a conflicting vector. Similarly, the way the baby's face and body are fitted against the woman's breast and body may drag the breast tissue in another direction (for example, in the direction of her arm closest to the feeding breast), creating a conflicting vector. Although some breastfeeding mother-baby pairs may have enough anatomic flexibility or breast tissue elasticity to adapt in the presence of conflicting vectors, many don't.

In Gestalt Breastfeeding, derived from the Gestalt Model of the biomechanics of healthy infant suck, positional stability is achieved by symmetrical face-breast contact or 'bury'. Gestalt Breastfeeding proposes that optimal intra-oral breast tissue volume does not depend upon initial fit (or 'latch' or 'gape'), but upon the subsequent dynamics of fit and hold, which secure positional stability and facilitate a gradual increase in intra-oral breast tissue volume in the early part of the breastfeed. Increases in intra-oral breast tissue volume cause the mandible to depress incrementally lower with each suck, until optimal intra-oral breast tissue volume and maximal mandible excursion are achieved.

In Gestalt Breastfeeding, women are empowered to experiment with the semi-reclined biological nurturing position in order to activate their baby's mammalian breastfeeding reflexes; to find a stable mother-baby body interface across their highly diverse anatomic configurations so that conflicting vectors are minimised; and, importantly, to experiment with micro-movements and attention to breast sensation in order to achieve optimal intra-oral breast tissue volume (Douglas and Keogh, 2017).

Intra-oral breast tissue volume depends upon positional stability and face-breast symmetry, not oral connective tissue structure

We have observed clinically that intra-oral breast tissue volume determines the range of mandible excursion and efficiency of milk transfer, not the initial gape and latch, nor oral connective tissue configurations (in the absence of classic tongue-tie). Intra-oral breast tissue volume is optimised by positional stability and symmetrical face-breast bury, so that conflicting vectors are eliminated. Lip flanging is not necessary for, or relevant to, effective, pain-free breastfeeding, and visible lips are a sign that intra-oral breast tissue volume is suboptimal.

Ensuring positional stability and optimal intra-oral breast tissue volume facilitates adaptation between the infant's unique facial and intra-oral anatomies, including tongue length, palate height and width, and chin morphology, and the mother's unique breast morphology and breast tissue elasticity. A positionally stable infant is relaxed at the breast, without signs of back-arching and fussing, unless conditioned sympathetic nervous system hyperarousal is already in effect.

Tongue movement and nipple tip distance from the junction of the hard and soft palates adapt to variations in intra-oral breast tissue volume

Although the word ‘rigid’ has been used to emphasise the way the anterior and mid-tongue move as a single unit, the breastfeeding tongue is most accurately conceptualised as an adaptive, supple organ that moulds to fit around available intra-oral breast tissue, cushioning it.

The tip of the tongue rests stably against the inner lower lip and breast, as incrementally increasing volumes of breast tissue fill up the oral cavity and depress the mid-tongue. This gradual increase in intra-oral breast tissue volume occurs in response to the intra-oral vacuum created by reflex mandible depressions.

The mid-tongue tends to lower more with downward mandible excursions as infants develop over the first four weeks. Although this may in part result from increased milk in the breasts as lactation establishes, it is also likely to be a response to increasing intra-oral breast tissue volumes, as the neural pathways of stable position and effective breastfeeding habituate (Sakalidis et al., 2013). Infants may also modify the range of inferior-superior mid-tongue movement to adapt to changes in milk flow during milk ejection as the breast empties (Cannon et al., 2016; Sakalidis et al., 2013).

The overall distance between the nipple tip and the HSPJ is similar throughout the first six months in successful breastfeeding pairs, suggesting that there is a particular position conducive to both effective milk removal and swallowing. The nipple tip does not quite reach the HSPJ in both nutritive and non-nutritive sucking, probably because the gag reflex is stimulated if the nipple tip touches the soft palate, which has a large number of sensory cells. Also, a space is required for the milk bolus to collect in the oral cavity.

The more breast tissue that is drawn into the mouth by the intra-oral vacuum, the closer the tip of the nipple reaches to the HSPJ. The closest distance to the HSPJ is variable, perhaps affected by nipple length and elasticity, but most importantly, by positional stability (Geddes and Sakalidis, 2016). At the conclusion of the suck cycle, when the mandible is elevated, the nipple tip is at its furthest from the HSPJ. As a positionally stable feed progresses, upward movement of the mandible is constrained by the greater intra-oral breast tissue volume. The greater the intra-oral breast tissue volume, the closer the nipple reaches to the HSPJ when the mandible is depressed.

When milk is being transferred effectively, a greater range of inferior-superior movement of the mid-tongue is observed, which we propose reflects greater intra-oral breast tissue volume. Also, the breast tissue may become more pliable and compressible as the milk flows and the breast empties.

Excessive intra-oral vacuums and nipple pain occur as the infant adapts to suboptimal intra-oral breast tissue volumes

Nipple and breast pain during breastfeeds, in the absence of classic tongue-tie, is associated with excessive intra-oral vacuums, both at peak and at baseline, and with decreased milk transfer. We propose this occurs because a conflicting vector is acting to minimise intra-oral breast tissue volume. Baseline intra-oral vacuum in the context of nipple pain is twice that measured in the absence of nipple pain, most likely because the infant reflexively increases the intra-oral volume in an unsuccessful attempt to draw more breast tissue into the mouth, contributing to the mother's pain (McClellan et al., 2015).

McClelland et al. used ultrasound imaging to compare 25 breastfeeding pairs in a control group with 25 pairs with maternal nipple pain (in the absence of tongue-tie). This study demonstrated that both the mandible and mid-tongue were lower at peak vacuum, the intra-oral space was larger, and the tip of the nipple was closer to the HSPJ in pain-free effective breastfeeding. There was also greater breast tissue expansion when the mandible was depressed in pain-free effective breastfeeding, and a greater range of inferior-superior movement of the mid-tongue (2015). These ultrasound observations are consistent with the greater intra-oral breast tissue volumes observed to be associated with pain-free effective breastfeeding in the clinical context.

In one case study, the nipple pressed through the holes in the tip of the mother's nipple shield while the infant was sucking, most likely due to breast tissue elasticity, nipple length, or fit and hold problems. This infant's intra-oral vacuum was measured as extremely high during sucking. It is more likely that the high vacuum resulted from compensatory attempts by the infant to extract milk in the presence of blockage, than that an idiopathically high intra-oral vacuum resulted in the blockage (Perrella et al., 2015) (Fig. 3).

Intra-oral breast tissue shape alters after frenotomy for classic tongue-tie

An ultrasound study of 24 mothers with persistent unspecified breastfeeding difficulties in the presence of tongue-tie observed sucking dynamics before and after frenotomy (Geddes et al., 2008). The study states that for all participants, ‘using sterile iris scissors, a small cut was made at the anterior portion of the frenulum extending just passed the genioglossus muscle.’ Since the study was published in 2008, prior to widespread popularity of the diagnosis of posterior tongue-tie, this is most likely a description of frenotomy for classic tongue-tie, although the diagnostic criteria and classifications are not specified.

The study found two groups of breast tissue compression prior to frenotomy: ‘point’ or nipple tip compression, and ‘base’ compression. In the group with ‘point’ compression, the tip of the nipple was double the distance from the HSPJ compared to the ‘base’ compression group. It is possible that the ‘base’ compression group were women with more elastic breast tissue whose breast tissue was drawn more readily with vacuum application, stretching and narrowing the breast tissue at the base. This is likely to occur in the context of suboptimal fit and hold, conflicting vectors, inabiity to achieve optimal breast tissue volume, and compensatory raised vacuums. The tongue shape then conforms to the stretched and distorted base of the intra-oral breast tissue. Pinching of the base or tip of the nipple was shown to be reduced post-frenotomy, and increased milk intake was observed.

This study did not measure intra-oral vacuum simultaneously so it is not known whether intra-oral vacuum changed (Geddes et al., 2008).

Altered suck dynamics post-frenotomy (in the absence of classic tongue-tie) may have multiple explanations other than the effects of connective tissue release

Altered suck dynamics post-frenotomy may have multiple explanations other than the effects of connective tissue release, in the absence of classic tongue-tie. In a 2013 pre- and post-frenotomy single case study, scissors frenotomy was performed at 7 weeks of age for a palpable lingual frenulum in the absence of a diagnosis of either anterior or posterior tongue-tie. The need for frenotomy was determined by the signs of poor weight gain, an unusual pointy appearance of the tongue despite good extension, weak suck and cup on digital examination, inability to elevate tip of tongue to palate, and a frenulum of normal appearance that felt ‘tight’ on palpation. Post-frenotomy, there was no longer pinching at the base of the nipple, the nipple tip

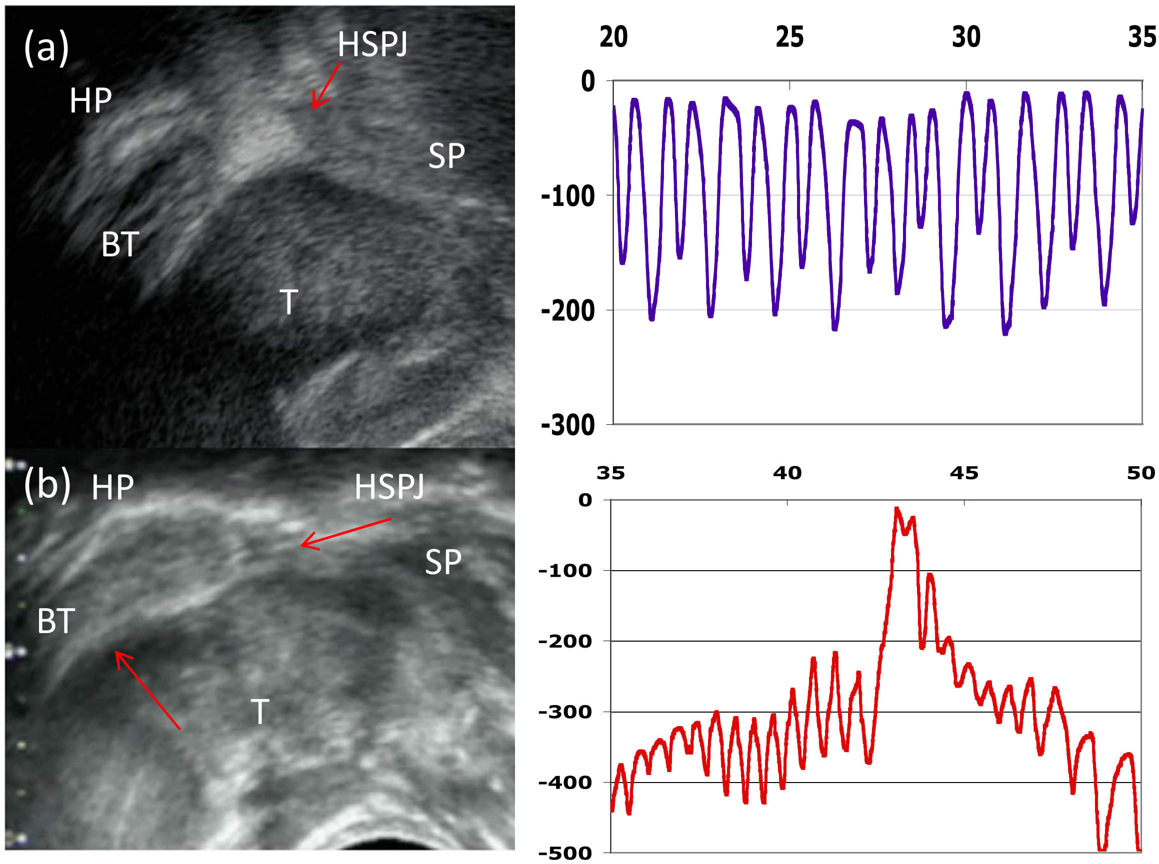

Fig. 3. Ultrasound and intraoral vacuum traces in an infant with pain-free breastfeeding, and an infant with painful breastfeeding.

was noted to be closer to the HSPJ, and vacuum pressures halved. Four days later, the infant took most breastmilk from the breast instead of from a bottle (Garbin et al., 2013).

An alternate explanation of the immediate improvements could be the effects of post-frenotomy sympathetic nervous system upregulation on fit and hold, and therefore on intra-oral breast tissue volume. That is, infant pain or distress post-intervention alter the way a woman and her baby fit together, for behavioural and psychological reasons, which would be expected to impact upon intra-oral vacuum, breast tissue volume and therefore tongue shape. Frenotomy and particularly the more painful experience of laser frenotomy, or any experience that makes the infant cry, could be expected to alter intra-oral vacuum, intra-oral breast tissue volume, resultant tongue shape, and maternal experience of the infant's breastfeeding immediately afterwards. The dramatic change to feeding from the breast rather than from a bottle of expressed breast milk could have multiple explanations in this single case, such as maternal confidence and resultant change of feeding patterns, leading to adaptation of the breast. There is no evidence that breast milk production increased.

The Hazelbaker Assessment Tool for Lingual Frenulum Function is not a reliable tool for decision-making concerning frenotomy

Digital suck assessments and visual inspection of tongue action are not functionally relevant and do not reliably assess capacity for pain-free effective milk transfer, with the likely exception of severe functional impairment posed by a classic tongue-tie.

Observed bumps, humps, and furrows of the tongue, and notches in the tongue tip, are not signs of limitations in the tongue's capacity to play a moulding, cushioning, responsive role during breastfeeding, other than in the case of classic tongue-tie. A wide range of lingual frenulum anatomic variation and elasticity is congruent with effective pain-free breastfeeding, once classic tongue-tie is addressed. Infants may also have anterior membranes visible under the tongue which do not impact functionally on either the tongue or breastfeeding, and are therefore not a tongue-tie.

Given the findings of ultrasound studies discussed in this paper, it is unsurprising that the Hazelbaker Assessment Tool for Lingual Frenulum Function (ATLFF) has not proven to be a reliable tool for clinical decision making concerning frenotomy (Amir et al., 2006; Madlon-Kay et al., 2008; Ricke et al., 2005). It has, however, pioneered systematic examination of an infant's oral cavity and oromotor function. Assessment of oromotor tongue function, frenulum structure, and tongue tip tethering is one important part of clinical assessment for classic tongue-tie and the potential benefits of scissors frenotomy.

Suck-swallow-breath dyscoordination is a marker of positional instability in neurotypical infants

Healthy suck-swallow-breath coordination results from optimal activation of the suck reflexes in the context of optimal fit and hold. In neurotypical babies, difficulty with suck-swallow-breath co-ordination is a marker of positional instability resulting from suboptimal fit and hold, rather than the cause of breastfeeding dysfunction. There is no evidence to suggest that suck-swallow-breath dyscoordination indicates structural oral connective tissue problems, other than in the case of severe classic tongue-tie.

Conclusion

Although most women want to breastfeed, parents resort to infant formula because of the distressing problems of unsettled infant behaviour, nipple pain, and growth concerns. Skills-based or ‘hands on’ clinical support has been largely deficient in preventing or repairing these problems. The advances of Biological Nurturing and baby-led, mother-guided approaches, recently referred to as the physiologic approaches to breastfeeding initiation, help empower both women and their BSPs, and are now widely applied in breastfeeding initiation. However, physiologic approaches are not enough to ensure successful breastfeeding for many women in the weeks and months post-birth.

In the absence of classic tongue-tie, the signs of suboptimal fit and hold in breastfeeding are commonly misdiagnosed as signs of medical conditions (gastro-oesophageal reflux or allergy) or congenital anatomic abnormalities (oral ties). Widespread medicalised interventions for breastfeeding problems risk unintended outcomes.

Recent ultrasound studies demonstrate that breastmilk is transferred by the intra-oral vacuum generated by reflex downward mandible and tongue excursion, in conjunction with the positive pressure of milk ejection. These studies show that the Structural Model of infant suck, used to rationalise both frenotomy in the absence of classic tongue-tie and manual therapy interventions for breastfeeding problems, is inaccurate.

Interpreting the findings of ultrasound studies through the lens of clinical experience, we propose a Gestalt Model of infant suck in breastfeeding. In the Gestalt Model, maximum mid-tongue depression and minimum nipple-tip proximity to the HSPJ with excursion of the mandible are interpreted as ultrasound markers of optimal intra-oral breast tissue volume. Optimising positional stability, with associated symmetrical face-breast bury and nipple alignment, and elimination of conflicting vectors, are critical for achieving optimal intra-oral vacuums and breast tissue volumes and suck-swallow-breath co-ordination in neurotypical infants. An innovative clinical approach, Gestalt Breastfeeding, which applies a range of strategies to optimise intra-oral breast tissue volume in breastfeeding pairs, has been made available for use by parents and health professionals (http://www.possumsonline.com/gestalt-breastfeeding-online-program), and is undergoing evaluation.

Future studies investigating the efficacy of frenotomy and manual therapies should aim to compare those interventions with the effects of optimal fit and hold.

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Not applicable.

Conflict of interest

Dr Pamela Douglas is Medical Director of Possums for Mothers and Babies, a registered charity which sells the Gestalt Breastfeeding Online Package http://www.possumsonline.com/programs/gestalt-breastfeeding-online-program.

All revenue raised from the sale of this product is directed back into research and development of educational materials.

Associate Professor Donna Geddes has no competing interests to declare.

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Authors' contributions

Dr Pamela Douglas is the principal author, who is responsible for conception, design, and drafting of the manuscript. She analysed and interpreted the data, wrote the manuscript, approved the final manuscript for submission, and acts as corresponding author. Associate Professor Donna Geddes made critical revisions and editing recommendations, added text and citations, and approved the final manuscript for submission.

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