# CHAPTER 3

# DEGLUTITION IN PREMATURE INFANTS

Aim: To provide an overview of the development of oral structures and feeding skills in normal infants and highlight the functioning of premature infants. The anatomical structures and the nerve supply needed in the feeding process are discussed as well as the different phases of deglutition. This information forms the basis of feeding assessment and intervention.

## 3.1 INTRODUCTION

Breathing and swallowing are two life-sustaining skills that an infant has to perform soon after birth (Brodsky, 1997). Oral feeding is one of the most complicated developmental tasks a newborn infant is required to master. The physical act of feeding is a complex physiological process. Sucking, swallowing and breathing form the cornerstones of the feeding process (Stevenson & Allaire, 1991; Wolf & Glass, 1991). For swallowing to be physiologically safe and effective, precise co-ordination of the pharyngeal and laryngeal musculature with the airway is required (Brodsky, 1997; Stevenson & Allaire, 1991). Another element of normal swallowing is the acquisition of adequate nutrition (Stevenson & Allaire, 1991) through good oral-motor and sucking skills. The ability of an infant to develop good oral-motor control as part of a well-integrated system depends on various anatomical, physiological, neuromotor, sensori-motor, cognitive and environmental factors (Alexander, 1987). Morris, Miller-Loncar, Landry, Smith & Denson (1999) add to the afore-mentioned, other factors such as gestational age, neurological status, medication, concurrent illnesses and congenital anomalies that may influence the infants' ability to feed orally. Bosma (1993) further states that the manner of arousal towards feeding and the competence in suckle feeding reflect the infant's general health and neurological status. The premature infant's immature neurological system, abnormal muscle tone, depressed oral reflexes and overall weak and irritable state, result in a decreased quality of oral motor skills and thus reduces the quantity of nutritional intake (Morris & Klein, 1987).

The same multiple anatomical structures needed for oral feeding are primarily needed for respiratory support. These structures are linked, anatomically and functionally, and interact to function in complex ways (Arvedson & Brodsky, 1993; Wolf & Glass, 1991). They also share the same neural supply. This implies that if a problem with any one of these systems is experienced, the others will be involved as well. It is therefore imperative that the **description** and the **comprehensive assessment** of the **feeding skills of premature infants** will take **all** the aspects of **oral feeding** as well as **respiratory status** into consideration.

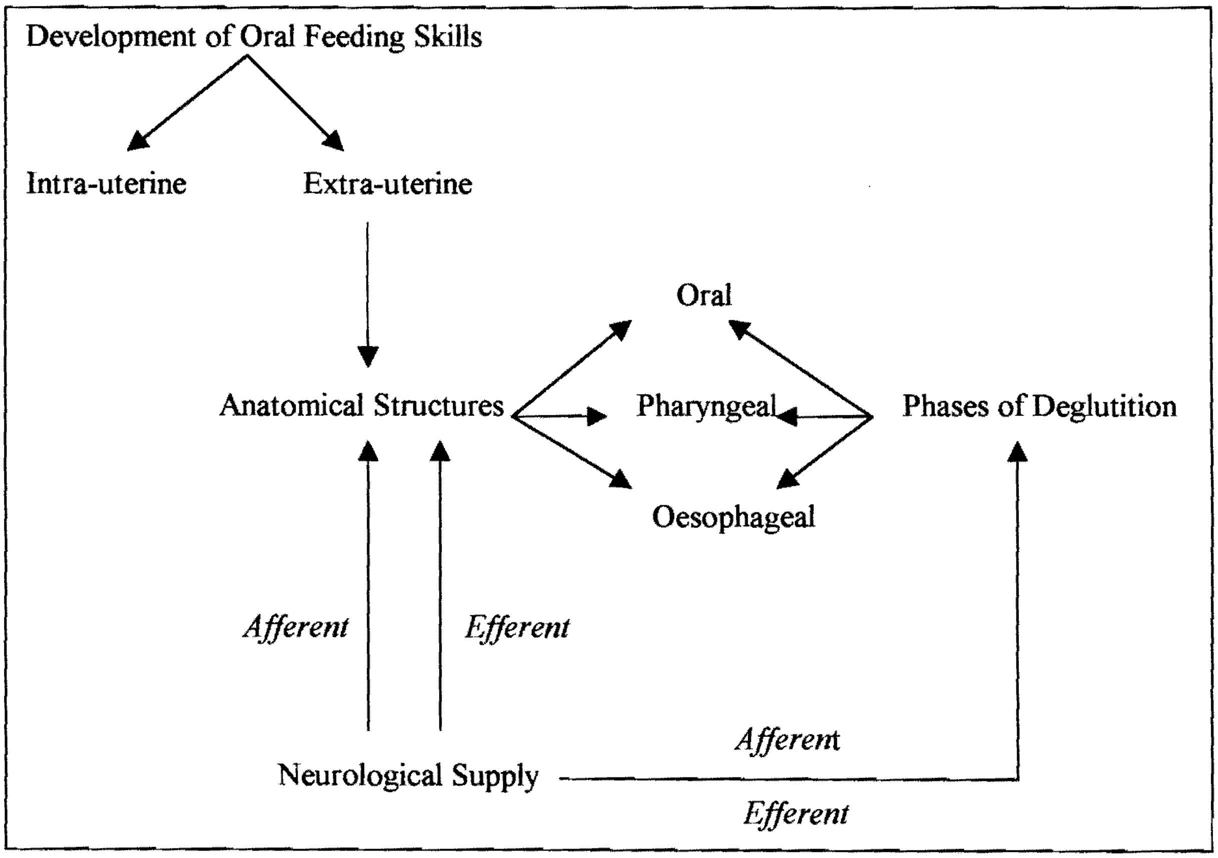



**Figure 3.1 Areas of discussion of deglutition in premature infants.**

A thorough understanding of the infant's (a) anatomy, embryology and physiology of the upper and lower aerodigestive tracts and related body systems, (b) the central nervous system, (c) the cardio-respiratory system, (d) the gastrointestinal tract and (e) normal development of feeding skills, is therefore needed to appreciate the magnitude of the assessment and management, involved in infants with feeding problems (Arvedson & Lefton-Greif, 1996; Brodsky, 1997; Wolf & Glass, 1991).

## 3.2 DEVELOPMENT OF ORAL FEEDING SKILLS

Feeding development is a dynamic and interactive process which involves physiological factors, neurodevelopmental progression, respiratory and nutritional status and the effects of body positioning and movement on the upper respiratory tract (Arvedson & Lefton-Greif, 1996). Feeding problems can occur as a result of abnormal development of the mouth or pharynx during the initial development of the embryo (Bosma, 1993). An assessment can then be made on the basis of the difference from what is expected (Arvedson & Lefton-Greif, 1996). The development of oral feeding and the relevant structures will be discussed in two phases, namely the embryological stage (intra-uterine) and after (premature) birth (extra-uterine).

### *3.2.1 EMBRYOLOGICAL DEVELOPMENT OF ORAL MOTOR SKILLS (INTRA-UTERINE)*

The development of the anatomical and neural structures begins in utero. Normal embryological development from conception until birth, as it relates to the dynamic processes of oral-motor functioning, swallowing and respiratory functioning, will be discussed briefly.

*26 days* after conception, the respiratory and swallowing systems, begin their own path of development (Wolf & Glass, 1991). The tracheoesophageal septum divides into a ventral and dorsal portion. The ventral part develops into the larynx, trachea, bronchi and lungs, the dorsal part into the oesophagus. The branchial arches contribute to the formation of the face, neck, nasal cavities, mouth and larynx. The mandible is one of the first structures to be completed at *4 weeks*, the maxilla soon follows and the development of the palate at *5 weeks* (Arvedson & Brodsky, 1993).

At *7-8 weeks* a mouth opening can be observed and taste buds detected. The oesophagus has reached its relative length (Arvedson & Brodsky, 1993). Breathing movements and jaw opening occur at *10 weeks* (Wolf & Glass, 1991). The first motor responses in the pharynx for a pharyngeal swallow have been detected between the $10^{th}$ and $11^{th}$ week (Arvedson & Brodsky, 1993; Arvedson & Lefton-Greif 1996). From 10-18 weeks and in the last 3 months the brain tissue is especially susceptible to damage, from toxic substances, nutritional deprivation or disruption of oxygen flow. A spurt in brain growth occurs around 14 weeks (Wolf & Glass, 1991).

The first sucking movements can be detected by *11-12 weeks* (Wolf & Glass, 1991). By *12-13 weeks,* oral reflexes can be elicited and tongue protrusion begins. There is also response to sound at this age. Swallowing of amniotic fluid has been observed with ultrasound as early as 13 weeks (Arvedson & Lefton-Greif, 1996; Bosma, 1985). The swallowing during this time plays an important role in the balance of the amniotic fluid. Half of the amniotic fluid is swallowed daily (Cherney, 1994; Wolf & Glass, 1991). Dysphagia can be expected if polyhydramnios (excessive amniotic fluid) occurs (Harris, 1986; Kramer & Eicher, 1993.) Polyhydramnios can also occur as a result of a tracheoesophageal fistula (TOF), congenital diaphragmatic hernia (Alper & Manno, 1996) or oesophageal atresia (Wolf & Glass, 1991). Between *15 and 18 weeks* more sucking movements occur, which Arvedson & Lefton-Greif (1996) consider to be true sucking. Wolf & Glass (1991) state that strong gagging occurs at 18 weeks, but Arvedson & Brodsky (1993) are of the opinion that there is only evidence of a gag reflex by 26-27 weeks, while Harris (1986) says that the gag reflex only evolves around 32/33 weeks. Clinical experience has indicated that the gag reflex is weak in most of these infants except in cases where they were exposed to extensive unpleasant procedures, such as recurrent suctioning and intubation. They then usually exhibited hyperactive gag reflexes. It is therefore unreliable to try to estimate a gestational age based upon the maturity of the gag reflex.

Pouting of the lips can be observed at *22 weeks* (Hack, Estabrook & Robertson, 1985; Harris, 1986). Life in infants under 24 weeks gestational age, or with a weight of less than 500 g, is unlikely. Significant development in the respiratory and central nervous systems (CNS) occurs between 24 and 32 weeks (Arvedson & Brodsky, 1993).

By *26-28 weeks,* single sucking movements and long variable pauses during non-nutritive sucking (NNS) appear (Arvedson & Lefton-Greif, 1996; Cherney, 1994; Harris, 1986; Wolf & Glass, 1991). This is important to know, because if the infant is born at this stage, non-nutritive sucking (NNS) should be encouraged to maintain the natural need and ability to suck and to reap the benefits of NNS until the infant can feed orally. The CNS can be mature enough to direct rhythmic breathing movements and control body temperature (Arvedson & Brodsky, 1993). By 28 weeks, the phasic bite reflex and transverse tongue movements are observed (Arvedson & Brodsky, 1993). A sucking rhythm is present, but the infant becomes exhausted easily as more calories are spent on sucking and swallowing than can be ingested. Rooting is also present, but is of a lesser quality than that of a full-term infant. Breathing and swallowing is not in synchrony yet (Morris & Klein, 1987). During the next 3 weeks, the infant will also begin with mouthing.

### 3.2.2 DEVELOPMENT OF ORAL MOTOR SKILLS (EXTRA-UTERINE)

A considerable number of infants may survive should they be born at this stage (28-39 weeks) and the development of the oral structures and oral motor functioning continues. These premature infants have to function differently in the environment after birth (extra-uterine) than in a fluid-filled intra-uterine environment, also in regard to their oral motor skills. Their oral motor skills differ from those of the infant who is born at full-term

If the infant was born at *30-32 weeks*, his sucking movements during NNS show some intrinsic rhythm (Hack et al., 1985). The NNS will still be weak and will occur less often than in a full-term infant. The organisation of the sucking burst pattern, which is necessary for successful nipple feeding, becomes evident (Arvedson & Lefton-Greif, 1996; Tuchman, 1989; Wolf & Glass, 1991). These sucking bursts are short but stable in length although the pauses may be long and irregular (Arvedson & Brodsky, 1993; Wolf & Glass, 1991). Swallowing occurs before or just after the short sucking burst (Wolf & Glass, 1991). The co-ordination between the sucking, swallowing and breathing also improves (Morris & Klein, 1987).

Between 30 and 34 weeks, white fat forms 8% of the body weight. The presence of white fat is a developmental milestone for normal feeding, because it shows some potential for nutritional reserves. More rooting is noted by 32 weeks (Arvedson & Brodsky, 1993; Morris & Klein, 1987). The gag reflex evolves around *33 weeks* (Harris, 1986). This implies that an infant is not equipped to protect his respiratory system effectively before 33 weeks. Oesophageal peristalsis is poorly co-ordinated due to a lack of smooth peristaltic movement (Wolf & Glass, 1991). A significant improvement in oral motor patterns and stronger sucking is seen after 33 weeks (Arvedson & Lefton-Greif, 1996; Morris & Klein, 1987). This implies that an infant may become ready to feed orally from this age onwards. The premature infant is also maturationally and neurologically better prepared for survival (Morris & Klein, 1987).

From *34 weeks* the link between sucking and swallowing becomes better, as well as the co-ordination with breathing (Comrie & Helm, 1997; Dreier et al., 1979), but if any problems arise, apnea may occur (Tuchman, 1989). The initial continuous sucking burst lasts at least 30 seconds (generally closer to 70 seconds) and 30% of their feeding is taken during this time (Wolf & Glass, 1991). An infant with respiratory difficulties will not be able to sustain such a long sucking burst. Gryboski (1969) and Wolf & Glass (1991) are of the opinion that breast-fed infants have better co-ordination of sucking and swallowing than bottle-fed infants. Meier & Pugh (1985) support this idea by stating that infants born at this age may be ready for breastfeeding. Many abnormal or disorganised tongue and jaw movements during sucking still occur up to 34 weeks. This results in poor intake per suck which leads to a longer feeding time (Wolf & Glass, 1991). The WHO (1989) stated that organised oesophageal activities occur if effective sucking can be maintained. Wolf & Glass (1991) state that oesophageal peristalsis is smooth and propagative at 34 weeks gestational age. However, regular breathing is often still disturbed (Bu'Lock et al., 1990). The frequency of respiration reduces because the co-ordination between sucking, swallowing and breathing is not well developed yet and the haemoglobin oxygen saturation levels tend to drop during oral feeding. This has the effect that infants tire more quickly (Wolf & Glass, 1991). It is, therefore, important to monitor the infants on a saturation monitor when oral feeding is introduced and to interrupt oral feeding when necessary, to reduce stress and allow low oxygen levels in the infant to return to baseline values.

The co-ordination between sucking, swallowing and breathing begins to stabilise to the ratio of 1:1:1 and will consistently increase with maturity (Bu'Lock et al., 1990). Arvedson & Brodsky (1993) feel that the suckle and swallowing of these infants may now be developed enough to sustain nutritional needs and adequate weight gain via the oral route. As the infant matures, more sucking actions per sucking burst occur. Swallowing does not occur simultaneously with sucking, but afterwards. Sucking inhibits swallowing, which is another mechanism to protect the airway (Logan & Bosma, 1967; Gryboski, 1969; Bernbaum et al., 1983; Harris, 1986). At this stage, the sleep-wake cycle emerges and an alert state enhances oral feeding.

By *35-36 weeks,* fewer abnormal tongue movements occur, but Bu'Lock, et al. (1990) found that these infants seem to block the hole of the nipple more often at this stage. According to them, mainly mouthing occurs for the first three days. For the next four days, short sucking bursts occur and after that, long deep sucking is observed (Gryboski, 1969). A full-term infant displays almost no abnormal tongue movements (Bu'Lock et al., 1990). Hack et al., (1985) state that as the infant gets older, the tempo of the sucking bursts increase and the frequency of pausing and mouthing decreases. Bottle-feeding can be maintained at this age irrespective of the weight of the infant. Co-ordination between sucking, swallowing and breathing is achieved in most premature infants when they reach 37 weeks gestational age (Bu'Lock et al., 1990). Feeding experience interplays with maturation to improve efficiency of oral feeding (Wolf & Glass, 1991).

Knowledge of the development of sucking and swallowing skills will enable the feeding specialist to assess the oral feeding skills of the premature infant efficiently and to plan appropriate feeding intervention strategies.

The anatomic structures, essential to oral feeding, continue to grow after birth and change their physical relationship to one another, which therefore affects their function. The functional skills depend on the integrity of the anatomic structures. These structures also undergo neurological maturation and experiential learning (Stevenson & Allaire, 1991). The feeding specialist should also have a sound knowledge of these maturational changes to be able to assess and manage premature infants' feeding problems appropriately and safely.

## 3.3 ANATOMICAL STRUCTURES RELEVANT FOR FEEDING

The aerodigestive tract provides a conduit for passage of both air and food (Cherney, 1994; Wolf & Glass, 1991). The upper aerodigestive tract comprises the oral cavity, pharynx, larynx, trachea and oesophagus. The lower aerodigestive tract comprises the airway; the lungs, and digestive; the stomach and small intestines (Arvedson & Brodsky, 1993).

### *3.3.1 ORAL CAVITY (LIPS, TONGUE, CHEEKS, PALATE, VELUM, MANDIBLE AND MAXILLA)*

The anatomy of the oral structures of a full-term infant is well adapted for sucking. The basic constitution is similar to that of an adult, but the tongue, velum, arytenoid mass and vocal cords of the infant are relatively bigger than the surrounding structures and have a close proximity to each other (Miller, 1986; Stevenson & Allaire, 1991). The premature infant's oral structures also differ from those of the full-term infant. This is briefly set out in Table 3.1 and is fully discussed in the following paragraphs.

**Table 3.1. Differences between oral structures of the premature and full-term infant.**

| Premature infant | Full-term infant |
|---|---|
| ▪ No sucking pads – poor cheek stability | ▪ Sucking pads – cheek stability |
| ▪ No facial fat | ▪ Facial fat |
| ▪ Open lips & jaw at rest | ▪ Closed lips and jaw at rest |
| ▪ Decreased lip seal | ▪ Adequate lip seal |
| ▪ Tongue relatively small for oral cavity | ▪ Tongue relatively big for oral cavity |
| ▪ Tongue in elevated position to stabilise | ▪ Tongue fills cavity, against palate |
| ▪ Mandible relatively small – insufficient stability | ▪ Mandible normal size – jaw stability |
| ▪ Palate often high and narrow | ▪ Normal palate |
| ▪ Muscles of body and face weak and underdeveloped | ▪ Stronger facial and body muscles |

| | |
|---|---|
| ▪ Decreased oral reflexes | ▪ Intact oral reflexes |
| ▪ Anatomically at sucking disadvantage | ▪ Anatomically ready to suck |
| ▪ Weakened suck | ▪ Strong suck |

(Source: Morris & Klein, 1987; Wolf & Glass, 1991)

The lips and mouth of the premature infant remain in an open position when at rest, in contrast to the full-term infant whose lips and jaw are closed (Wolf & Glass, 1991). The mandible of the premature infant is relatively small for the oral cavity. The position of the neck extensors contributes to a greater amount of jaw opening and reduces stability that would be provided by the flexor tone. This strong extension can cause cheek retraction, which can influence the lipseal (Morris & Klein, 1987).

Premature infants have diminished sucking pads and facial fat, resulting in an increased oral cavity (Wolf & Glass, 1991). Sucking pads are densely compacted masses of fatty tissue within the masseter muscles (Stevenson & Allaire, 1991). These sucking pads stabilise the lateral walls of the oral cavity and decrease the oral cavity in full-term infants (Kramer & Eicher, 1993). The absence of sucking pads and poor lipseal can greatly reduce the mechanical efficiency of sucking (Morris & Klein, 1987).

The tongue of the full-term infant fills the whole oral cavity and rests more anteriorly than in adults. The tongue of the premature infant is relatively small and does not fill the oral cavity (Morris & Klein, 1987; Wolf & Glass, 1991). The oral cavity is relatively bigger because of the diminished sucking pads. The tongue has therefore less stability and moves freely in the mouth or is elevated in an attempt to stabilise it and to oppose the palate. The feeding specialist should have knowledge of this because the nipple can easily be placed under the tongue of the premature infant and inaccurate assessment of sucking, swallowing and the flow rate can be made. The development of normal tongue movements will be inhibited (Wolf & Glass, 1991). Since the oral cavity is relatively bigger, a very small nipple may not necessarily be needed.

The palates of the premature infants are often high and narrow. That may be due to the fact that the tongue has less constant pressure on the palate, because of the open mouth position tendency in these infants (Wolf & Glass, 1991). NNS may not be implemented regularly when an infant is not ready for nipple feeding yet and less pressure is applied to the palate, as would have occurred in a full-term infant who is exposed to regular nipple feeding. Continuous pressure from oral tracheal tubes, used in infants with BPD, and the lack of contact between the tongue and palate, can also cause a high narrow palate (Wolf & Glass, 1991). The muscles and ligaments of the premature infants are still weak. This has the implication that sucking may be weak and endurance low. The close proximity of the tongue, velum and pharynx to the larynx facilitates nasal breathing (Arvedson & Brodsky, 1993). That implies that if the infant experiences any form of nasal obstruction, feeding may be influenced.

### *3.3.2 PHARYNGEAL CAVITY (OROPHARYNX, NASOPHARYNX, HYPOPHARYNX)*

An understanding of the anatomy of the pharynx is essential for a thorough understanding of the feeding process (Stevenson & Allaire, 1991). There does not seem to be a difference between the anatomy of the pharynx of the premature infant and that of the full-term infant. Development of feeding occurs in a caudal–cephalic direction (Gryboski, 1969). Adequate pharyngeal functioning is needed for adequate oral functioning (Wolf & Glass, 1991). The pharynx consists of 3 muscles, e.g. the superior, medial and inferior constrictors, which are involved in swallowing (Arvedson & Brodsky, 1993). The pharynx can be separated into 3 areas, the oro-, naso- and hypopharynx.

The *oropharynx* extends from the palate (superior) to the base of the tongue (inferior) and includes the valleculae (Stevenson & Allaire, 1991). The position of the velum of the infant is relatively low in the oropharynx, can be in contact with the tongue and is close to the tip of the epiglottis. The epiglottis may even lie over the velum and protects against aspiration by diverting fluids down on both sides of the laryngeal opening (Jolley et al., 1995; Stevenson & Allaire, 1991; Wolf & Glass, 1991). The larynx and hyoid bone are both placed more anterior and superior, and closer to the mandible than those of the adult (Brodsky, 1997; Kramer & Eicher, 1993; Stevenson & Allaire, 1991). The larynx of the infant is on the level of the third cervical vertebra ($C_3$) whereas that of an adult is at $C_7$ (Kramer & Eicher, 1993). The high position of the larynx near the base of the tongue diminishes the size of the pharyngeal cavity relatively to that of the adult and it also assists in the closure of the laryngeal vestibule. It is considered to be a natural protection of the airway in infants.

The *nasopharynx* extends from the base of the skull to the roof of the velum (Stevenson & Allaire, 1991). The velum elevates to form a nasopharyngeal closure. This prevents the bolus from entering the nasal cavity. Plaxido & Loughlin (1981) name nasopharyngeal reflux as one of the causes of neonatal apnea. Premature infants tend to be hypotonic (Sheahan & Brockway, 1994). If the hypotonia extends to the muscles in the velum, nasopharyngeal reflux may be a problem in premature infants.

The *hypopharynx* extends from the valleculae to the cricopharyngeus. The larynx opens into the hypopharynx anteriorly (Stevenson & Allaire, 1991). The larynx serves three basic functions, in order of priority, protective (during swallowing), respiration and phonation. The larynx is suspended by suprahyoid muscles from the hyoid bone superiorly and anteriorly. If the head is not in a stable, anterior position, the larynx may not be in a position to protect the airway. Premature infants tend to move their heads backwards into cervical extension, because of dominance of the extension pattern to facilitate respiration and possible tube placement (Cherney, 1994). That is why positioning of the head and head control later on is so important during oral feeding. Protection of the airway is carried out on three levels: (a) the epiglottis descends forward to close the superior inlet of the larynx, (b) The false vocal cords close and (c) the true vocal folds close (Arvedson & Brodsky, 1993). Infants suck and breathe simultaneously, but during swallowing a brief co-ordinated pause in respiration occurs (Brodsky, 1997). However, the CNS of the premature infant may still be immature, and this co-ordination may then not be well developed yet and feeding problems will be experienced. From this point onwards the respiratory and feeding pathways separate. For the sake of this study, only the feeding pathway, namely the oesophagus, will be discussed further.

### *3.3.3 OESOPHAGUS*

The oesophagus is a muscular tube lined with mucosa, which links the pharyngeal chamber with the stomach. The oesophagus lies in the neck, anterior of the cervical vertebrae, posterior to the trachea and between the cardiac arteries. The recurrent laryngeal nerves are on either side of the oesophagus (Arvedson & Brodsky, 1993). During swallowing food is propelled from the hypopharynx to the stomach. At the superior end, the Cricopharyngeus sphincter or Upper oesophageal sphincter (UES) can be found and at the lower end the gastro-oesophageal sphincter (LES). These two sphincters keep the oesophagus empty between swallows (Arvedson & Brodsky, 1993). The UES and upper third of the oesophagus are composed of striated voluntary muscles and the LES and lower two thirds of the oesophagus, of smooth involuntary muscle (Arvedson & Brodsky, 1993; Wolf & Glass, 1991). The pharynx and oesophagus are the only two organs in the body with striated muscles which are not under voluntary neural control (Arvedson & Brodsky, 1993).

Gryboski (1969) believed that sucking in the premature infant would be inhibited if the peristalsis in the oesophagus were not efficient yet, because development follows a caudal–cephalic direction. It is thought that the oesophagus is in this way protected until it can handle large boluses. According to Gryboski (1969), peristaltic movements in the oesophagus are only well developed by 37 to 40 weeks gestational age. The WHO (1989), on the other hand, stated that the oesophagus can (at a young age of 34 weeks), be activated and organised if the infant can maintain sucking. It may be true that inefficient peristalsis may inhibit sucking, but it is known from the literature (Arvedson & Brodsky, 1993; Bu'Lock et al., 1990; Comrie & Helm, 1997) and clinical experience that sufficient sucking can occur before 37 weeks gestational age. If it is true that the peristalsis is only efficient a little later, it may explain the high frequency of regurgitation clinically seen in premature infants. They suck efficiently, but because the peristalsis is not well developed yet, the oesophagus overfills and the infant regurgitates. This can be misinterpreted as gastro-oesophageal reflux or vomiting. The fact remain that as the premature infant matures, the peristalsis in the oesophagus becomes more consistent and of higher amplitude (Bosma, 1993), but until it functions efficiently, appropriate management is necessary. Appropriate management can only be carried out after a proper assessment of the oesophageal functioning has been made.

An abnormal oesophagus can have deleterious effects on both the breathing and feeding simultaneously. For example, in the case of a tracheoesophageal fistula (TOF) there is communication between the trachea and the oesophagus and the contents of the oesophagus may spill into the trachea, causing major aspiration. Any mass in the oesophagus can press against the posterior wall of the trachea and compromise breathing (Brodsky, 1997). Oesophageal atresia in an infant can already be suspected in utero if polyhydramnios is detected, because the infant is unable to swallow the amniotic fluid. Hypertrofic stenosis in the oesophagus can cause projectile vomiting. A comprehensive medical and prenatal history should be included in the assessment procedure to plan intervention efficiently.

In conclusion, it may be stated that the anatomical structures of premature infants differ from those of the full-term infant and those of the adult. Abnormalities in these structures may cause feeding difficulties in premature infants.

## 3.4 NEUROPHYSIOLOGY OF DEGLUTITION

Deglutition or swallowing is a dynamic process. The sensory control of the swallowing process requires widespread involvement. If the CNS is immature, the infant cannot organise or integrate the stimuli that are part of a typical oral feeding environment. The areas from the lips (anterior), the pharynx (posterior), the velopharynx (superior), to the oesophagus (inferior), are involved. Good neural co-ordination of both the cranial and spinal nerve systems is required for efficient swallowing. The peripheral nerves, central nuclei and neural centres are involved, e.g. medulla oblongata, midbrain and cerebellum. The extensive neural network co-ordinates, integrates and determines the sequence of the voluntary and involuntary activities of the swallowing process (Lass et al., 1988). The premature infant's neurological system is still immature. The overall effects of the neural immaturity and the inability to integrate sensory information on the infant's state and behaviour, was described in chapter 2. It can therefore be expected that a process such as feeding, which involves such widespread and integrated neurological participation, will equally be affected by an immature nervous system.

The swallowing centre involves three levels or subsystems which are discussed below.

### *3.4.1 AFFERENT SYSTEM*

The afferent sensory fibres provide the swallowing centre with sensory information for swallowing. Four *cranial nerves*, $V_2$, VII, IX and X (of which the last two are the most important), synapse with tractus solotarius (NTS) in the *brainstem* and with the adjacent *reticular formation* to provide the sensory information to initiate swallowing (Stevenson & Allaire, 1991; Wolf & Glass, 1991).

*Cranial nerve* $V_2$ provides information from the face. It plays an important role in the elicitation of the rooting, suckling and tonic biting reflexes in infants. It provides feedback during sucking and the information from the soft palate facilitates swallowing (Rogers, 1996; Wolf & Glass, 1991). *Cranial nerve* VII provides sensory information (taste) from the anterior two thirds of the tongue and influences sucking behaviour (Wolf & Glass, 1991). Sensory information from the mucosa of the tongue and palate, the soft palate, and pharyngeal folds, is carried by *CN* IX (Rogers, 1996; Wolf & Glass, 1991). Sensory innervations to the lower portions of the pharyngeal wall come from *CN* X. It also carries sensory information from the pharyngeal and laryngeal mucosa, vocal folds and crycothyroideus (Bosma, 1993). It influences swallowing and breathing (Wolf & Glass, 1991). Immaturity of the cranial nerves may have an effect on the oral reflexes and the sensory elicitation of a swallow in premature infants.

It is known that the *reticular formation* controls alertness. The premature infant has problems with maintaining an alert state. If this was due to an immature reticular formation and the reticular formation is also involved with swallowing, it is understandable why feeding problems in premature infants occur and why an alert state facilitates oral feeding. This also illustrates that feeding problems in premature infants are complex and are not merely an inability of the oral structures to perform an activity.

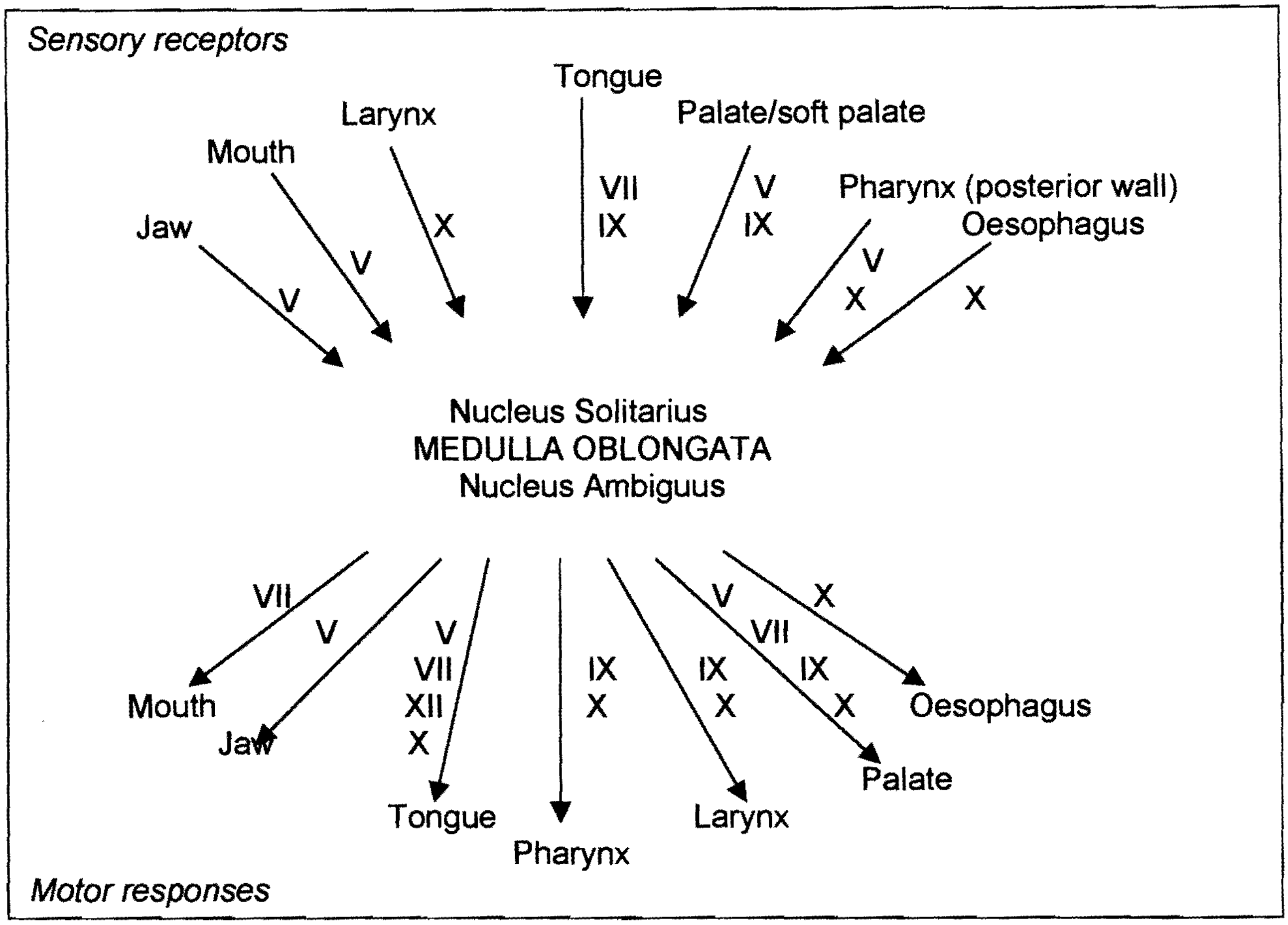
### *3.4.2 EFFERENT SYSTEM*

The efferent motor fibres convey motor commands from the nucleus ambiguus (NA) and the adjacent ventral *reticular formation* and are distributed to *cranial nerves* $V_3$, VII, IX, X, XII and two of the *cervical peripheral nerves* $C_1$ -$C_3$, to supply the oral structures (Wolf & Glass, 1991).

*Cranial nerve* $V_3$ is involved with the motor actions of sucking and swallowing. The muscles of the lower jaw help with sucking and palatal elevation and initiate swallowing (Wolf & Glass, 1991). *CN* VII provides the buccinator and stylohyoid muscles involved in sucking and swallowing (Wolf & Glass, 1991). The motor fibres in the soft palate, pharynx, larynx, trachea and oesophagus are provided by *CN* X (Bosma, 1993; Rogers, 1996; Wolf & Glass, 1991) and it is involved with swallowing and breathing (Wolf & Glass, 1991). The dorsal motor nucleus of CN X in the *medulla* is responsible for the integration of swallowing, respiration, phonation, emesis and cardiovascular responses (Rogers, 1996). An immature nervous system may have widespread influence on the feeding skills and associated behaviour of a premature infant, as it may affect the motor actions needed for sucking and swallowing. The coordination with breathing may also be compromised by an immature medulla.

### *3.4.3 ORGANISING LEVEL*

An inter-neural network co-ordinates the two systems mentioned above, programmes the whole motor sequence of swallowing and determines the patterns of pharyngeal and oesophageal muscle contractions needed for swallowing (Wolf & Glass, 1991). Figure 3.2 provides a visual representation of the neural network involved in the whole swallowing process.




(Source: Bosma, 1993; Rogers, 1996; Wolf & Glass, 1991)

**Figure 3.2 Neural Network for Swallowing**

The swallowing centre is situated in the medulla oblongata in the brainstem and modifies all neural input from the pons, limbic and hypothalamic systems, the cerebellum and the frontal cortex (Stevenson & Allaire, 1991; Wolf & Glass, 1991). Centres for respiratory control and feeding are developed simultaneously in the brainstem (Bosma, 1993). This fact may explain why Rosen et al., (1984), Shivpuri et al., (1983) and Solomano (1986) all found that apnea during feeding occurred as often and even more often in premature infants than sleep apnea did, which highlights the importance of including the monitoring of apnea during the assessment and management of feeding skills in these infants. The brainstem integrates and processes different signals from the oropharyngeal fibres and the higher central nervous system and orchestrates the whole swallowing process.

The sensory information received from the receptors of the oral cavity, tongue and pharynx acts as the main trigger for swallowing. In older infants, children and adults, the motor reaction that should follow is determined by the cortex and depends on the size and characteristics of the bolus, the head and neck position and orientation towards gravity (Stevenson & Allaire, 1991). Feeding in the *premature* and very young infants is reflexive, without any supra-bulbar involvement. The older infant develops, through a process of encephalization and experience, the ability to evaluate the physical properties of the food and to manipulate the bolus effectively, and the oral preparatory phase, oral phase and swallowing becomes voluntary.

It is clear that the neurological supply system needed for effective oral feeding is widespread and involves multiple cranial nerves as well as the brainstem for sensory and motor pathways and the organisation of the neural input. As discussed earlier, premature infants have immature neurological systems and problems with oral feeding are therefore to be expected.

## 3.5 PHASES OF DEGLUTITION (SWALLOWING)

Swallowing or deglutition can be defined as the semi-automatic motor action of the muscles of the respiratory and gastro-intestinal tracts to propel food from the oral cavity to the stomach (Stevenson & Allaire, 1991). It is a physical process which requires the co-ordination of a series of steps. In young infants, it means progression from reflexive oral management, swallowing reflexes and involuntary oesophageal peristalsis, to (as in older children and adults), voluntary oral management, swallowing reflexes and involuntary oesophageal peristalsis. The process involves the autonomic nervous system, striated and smooth muscles as well as sensory input (Rosenthal et al., 1995).

Swallowing occurs in four phases. The anatomical structures and their neural supply will be further described in terms of these phases.

### *3.5.1 ORAL PREPARATORY PHASE*

In this phase, fluids and solid food are prepared into a bolus small enough to swallow safely. In young infants (0-6 months), this phase consists almost exclusively of sucking fluids (Wolf & Glass, 1991). The infants rouse, exhibit a rooting response and start to suckle. Coordination of the tongue, hyoid and mandibular muscles and the lower lip is required. Milk is expressed by rhythmic compressing movements of the tongue against the palate and a negative intra-oral pressure in the oral cavity. This posterior moving, suction-compression wave expresses the bolus towards the pharynx with the medial part of the tongue (Bosma, 1993). If more than one suckle precedes the swallow, a bolus is formed and accumulated in the reservoir between the tongue and velum, or the tongue and valleculae (Stevenson & Allaire, 1991; Kramer & Eicher, 1993; Rosenthal et al., 1995). The soft palate is in a lowered position, helping to prevent a bolus of liquid from entering the pharynx before swallowing. This is accomplished by the contraction of the palatoglossus muscle. The pharynx and larynx are at rest and nasal breathing continues (Arvedson & Brodsky, 1993).

This phase becomes more important as the infant grows older and solid food needs to be chewed before it is swallowed. However, in the case of the premature infant, this phase is very short and forms a close unit with the next phase, namely the oral phase.

### 3.5.2 ORAL PHASE

The bolus is captured for a moment between the tongue and the velum. In infants it can also be captured in the pharynx, as low as the epiglottis (Logan & Bosma, 1967; Bosma, 1993). The bolus is maintained as a cohesive mass, so the liquid does not leak into the pharynx prior to the triggering of a swallow (Wolf & Glass, 1991). The tongue grooves to channel the bolus and the medial part of the tongue lifts (due to genioglossus) in a vertical wave movement to project the bolus into the pharynx (Bosma, 1993). The buccal and mandibular muscles also contract and the lips form a tight seal to prevent loss of bolus. The velum lifts to prevent the bolus from entering the nasopharynx (Bosma, Hepburn, Josell & Baker, 1990; Stevenson & Allaire, 1991).

The premature infant's muscles are generally weak, so the contraction of the buccal and mandibular muscles may also be weak. This is also true of the lipseal around the nipple and loss of liquid can be observed in these infants. Nasopharyngeal reflux often occurs in the premature infant, which can lead to apnea (Plaxido & Loughlin, 1981). It has been postulated that this may be one of the reasons that feeding apnea occurs more often in premature infants than sleep apnea. That is why it is important to monitor an infant's physiological functions during oral feeding as well.

The oral motor skills of an infant are represented in the two phases discussed above.

### 3.5.3 PHARYNGEAL PHASE

This phase is initiated when swallowing is triggered, when the bolus reaches the anterior faucial arches (Logeman, 1983; Helfreich-Miller, Rector & Straka, 1986). Logan & Bosma (1967) believed that in infants, the bolus can move beyond this point before swallowing is triggered (Wolf & Glass, 1991). Glass & Wolf (1994) support this viewpoint by stating that triggering of the swallow is dependent on the sensory feedback from various areas, namely faucial arches, the uvula, velum, posterior tongue and the pharynx. As the velum elevates for the velopharyngeal closure, the hyoid bone elevates anteriorly and superiorly through the shortening of the thyrohyoid and suprahyoid muscles. The tongue is then pressed posteriorwards to propel the bolus into the pharynx, thus making the tongue part of the pharyngeal phase (Bosma, 1993). Peristaltic contractions of the posterior and lateral walls of the pharynx descend from the level of C1 (supra pharyngeal constrictors) (Bosma, 1993). The peristaltic wave of the infant, to propel the bolus from the oral cavity to the oesophagus, is similar to that of an adult. The larynx lifts towards the epiglottis to seal off the airway (Bosma, et al., 1990; Brodsky, 1997; Harris, 1986; Stevenson & Allaire, 1991). The infant with a tracheostomy finds this phase difficult because the larynx is often fixed and elevation of the larynx cannot occur (Brodsky, 1997). The epiglottis moves downwards and the true and false vocal cords close (Jolley et al., 1995). The closure of the true vocal cords is the first event to occur in oropharyngeal swallow. A brief co-ordinated stop of respiration is seen as soon as swallowing is initiated (Bosma, 1993; Brodsky, 1997). During suckle feeding respiration is incorporated into the rhythm. Pairs of inspiration and expiration are interposed between swallows. Premature infants tend to omit respiration during the first sucking bursts, which results in feeding apnea. If it continues, hypercapnia and hypoxemia may occur secondary to bradycardia (Bosma, 1993). It is thus important for the feeding specialist to monitor the cardiorespiratory status of the infant closely whilst giving feeding therapy. This can be done by attaching a saturation monitor to the infant.

Minimal spillage into the laryngeal aperture is common in infants because of the laxity of the epiglottis and the large size of the arytenoid cartilage, but this spillage is easily squeezed out of the pharynx with consecutive swallows. Wolf & Glass (1991) wrote that liquid in the laryngeal area is the most effective stimuli to trigger swallowing. If the larynx is not cleared, a cough reflex should be triggered, but premature infants' cough reflexes are not well developed yet and they would rather respond with apnea, or aspiration. The feeding specialist should be aware of this and not be satisfied that an infant is swallowing safely just because he is not coughing. Cervical auscultation is an instrumental help in evaluating the quality of the pharyngeal swallow in premature infants.

In this phase, the motor movement in the pharynx seems to be more prominent, more contractions of the posterior walls occur and the frequency and speed of the peristalsis is higher in the infant (Jolley et al., 1995; Kramer & Eicher, 1993). This phase ends when the bolus reaches the Cricopharyngeal sphincter, which will relax and open to allow the bolus to pass and the airway reopens as the hyoid, larynx, soft palate and tongue return to their resting places (Wolf & Glass, 1991; Helfreich-Miller et al., 1986). The duration of this phase is about 1 second (Rosenthal et al., 1995; Wolf & Glass, 1991).

The pharynx and larynx are richly supplied by chemoreceptors, which are slow adapting stretch/pressure and temperature receptors with the purpose of initiating and modifying swallowing (Wolf & Glass, 1991). The sensory information is conducted by cranial nerves IX (Glossopharyngeus), X (Vagus) and V (Trigeminus) to be integrated by nucleus ambiguus and the Nervi vagus dorsalis (Lass et al., 1988; Wolf & Glass, 1991). The motor nuclei initiate and send the motor information via cranial nerves V, IX, X, XII and the cervical nerves $C_{1-3}$ to initiate the peristaltic wave (Bosma, 1993). The sensory and motor components are combined and co-ordinated in a centre which probably lies in the medullar reticular formation. This centre also regulates the muscles involved in respiration, which ceases once the swallowing is initiated, so that this phase can be completed uninterrupted (Logan & Bosma, 1967; Helfreich-Miller et al., 1986; Kramer & Eicher, 1993; Lass et al., 1988; Stevenson & Allaire, 1991).

There seems to be a difference of opinion in the literature regarding the number of muscles needed to swallow effectively. Comrie & Helm (1997) state that 20 pairs of muscles and 5 cranial nerves are involved, whereas Glass & Wolf (1994) mention that 26 muscles and six cranial nerves have to be co-ordinated to ensure safe and effective swallowing. Stevenson & Allaire (1991) state that 31 pairs of striated muscles are involved in the whole swallowing process. Whatever the number, it is clear that a vast number of muscles must be used and coordinated to swallow effectively. It follows, therefore, that a premature infant with an immature neurological system and weak muscles might find co-ordinated swallowing during the pharyngeal phase problematic.

The premature infant is also especially prone to respiratory problems. This phase is very closely involved with breathing and therefore makes it a very important aspect of the premature infant's oral feeding abilities. This phase is often overlooked in the evaluation of the premature infant's oral feeding abilities, if only the oral motor skills are being evaluated. It is crucial that the pharyngeal phases should be included in a comprehensive evaluation of the feeding skills of the premature infant.

### 3.5.4 OESOPHAGEAL PHASE

This is the final phase in the transfer of nutrients from the oral cavity to the stomach (Wolf & Glass, 1991). It consists of an autonomic peristaltic wave which carries the bolus to the stomach (Brodsky, 1997). Co-ordination and relaxation of two sphincters (superior/rostral: cricopharyngeus and inferior/caudal: gastro-oesophageal) is needed to complete the process: The oesophageal sphincter (or upper oesophageal sphincter/UES) relaxes to let the bolus pass through from the pharynx to the oesophagus (Brodsky, 1997). The sphincter remains open until the whole bolus has reached the oesophagus. It then closes tonically to prevent any reflux back into the pharynx (Glass & Wolf, 1994; Kramer & Eicher, 1993; Jolley et al., 1995). The bolus moves with peristaltic movements of the oesophagus's longitudinal and circular muscles towards the lower gastro-oesophageal sphincter. It also relaxes to allow the bolus to pass through to the stomach and will close immediately after the bolus is through to prevent any reflux, like the cricopharyngeal sphincter, but this time from the stomach into the oesophagus. This phase lasts 8-20 seconds (Stevenson & Allaire, 1991). As the infant matures the phase shortens. The swallowing process is completed at this stage (Logeman, 1983; Rosenthal et al., 1995).

Even though peristalsis in the young infant is present and the sucking has stabilised, accumulation of milk in the oesophagus still occurs. This happens because the peristalsis in the pharynx is faster than the peristalsis in the oesophagus. The rapid successive pharyngeal swallows may result in accumulation of bolus in the oesophagus (Arvedson & Lefton-Greif, 1996). During suckle feeding each pharyngeal swallow briefly inhibits oesophageal peristalsis. Boluses of consecutive swallows may also accumulate in the oesophagus (Bosma, 1993), but usually the oesophagus will empty itself with the last swallow (Kramer, 1989). It might be necessary to give the premature infant extra time between sucking bursts to allow the oesophagus to empty, otherwise overfilling can result in regurgitation, which can be mistaken for reflux.

Sensory feedback from the bolus itself as it progresses through the oesophagus is an important component in the initiation of oesophageal peristalsis (Wolf & Glass, 1991). Sensory and motor neural control of the oesophagus is mainly provided by cranial nerve V (Vagus) and it remains immature in the premature and young infant. That is another reason why gastro-oesophageal reflux (GER) or regurgitation occurs so easily and often in these infants (Gryboski, 1969; Bosma et al., 1990). GER is also commonly seen in cerebral palsy and mentally retarded children. This phase also causes difficulties with feeding in the premature infant and is often neglected in the evaluation of their feeding skills. A comprehensive evaluation of the premature infant's oral feeding skills will be incomplete if the oesophageal phase of deglutition is not included.

## 3.6 CONCLUSION

The ability of an infant to feed orally efficiently depends partly on the development of intact oral anatomic structures from the embryological stages until well after birth. These structures are linked anatomically and functionally and they share the same neurological supply. The development of effective oral feeding skills of the premature infant is also dependent on the intact neural supply to the structures involved in feeding and the maturation of the central nervous system. Deglutition or swallowing can be divided into four phases. All these phases pose problems to the premature infant and should be included in a comprehensive evaluation of their feeding skills. Such an evaluation should enable the feeding specialist to describe the oral feeding patterns and oral motor skills of the premature infant in such a way that an appropriate, accountable and, most importantly, a safe therapy strategy can be planned.

## 3.7 SUMMARY

The development of the oral feeding skills and the anatomical structures needed for oral feeding in the premature infant were discussed. The extent of the neurological supply during deglutition or the total swallowing process, were explained with reference to the sensory and motor pathways, as well as their interaction. Finally, the four phases of deglutition, with special reference to the skills of the premature infant, were described.