**Different geometric patterns of pacifiers compared on the basis of finite element analysis**

L. LEVRINI, P. MERLO, L. PARACCHINI

**ABSTRACT.** **Aim** This study was carried out with the purpose to show on a virtual model of oral cavity the mechanical behaviour of different kinds of pacifiers with different pressure levels that can be likened to a condition of rest and deglutition. **Materials and methods** Three different types of dummies, orthodontic- (A), cherry- (B) and drop- (C) shaped from an anatomical point of view, were inserted between the palate and the tongue in a virtual system by means of a finite element simulation. The palatal structure was recreated through tridimensional laser scanning, while the tongue structure was reconstructed by a software suitable for reproducing solids. Also the image of the pacifiers was developed by computer-aided scanning and reproduction. Suitable constraints were inserted and high and low pressure levels were exerted on these systems. FEA simulation allowed us to distribute the strain on the palate according to the different geometrical structures of the objects. **Results** Dummy A shows a more uniform and wider crosswise stress distribution with also a lesser load on the anterior palatal crest. Dummy B and C, on the contrary, show a more dot-like behaviour inducing a higher stress due to contact on restricted points. **Conclusion** The characteristics of dummy A, although they have not been clinically investigated yet, seem to be the fittest ones to guarantee the maintenance of the transversal diameters of the premaxilla and reduce the risk of open bite.

**KEYWORDS:** Pacifiers, Finite Element Analysis, Maxilla.

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**Introduction**

The ability to suck represents the first coordinated muscular activity in the newborn baby. There are two forms of suction: the nutritive sucking, thanks to which the infant is nourished, and the non-nutritive one that gives the baby a feeling of peacefulness and safety. The non-nutritional suction consists in the habit of sucking the thumb and, even more often, a dummy.

The use of pacifier has increased more and more over the years and just its being widespread makes it a useful and much-discussed object. Since the first models appeared on the market up to now, many changes have been made in terms of size, geometry and production materials. With time new specific shapes have been designed, dimensions have been increasingly adapted to the baby’s age and materials such as caoutchou, or natural rubber, and silicone have been selected for production. The role of the pacifier has been scientifically studied over and over and not always with coherent outcomes. Several studies show, from an orthodontic point of view, how the early use of dummy does not affect the physiological development of the arches. In a study on 289 patients [Larsson, 1983] no significant differences were highlighted in the distribution of posterior cross bite between groups of babies used to thumb- or pacifier sucking and non-suckers. The same result was confirmed by a literature review [Farsi et al., 1997] aimed at pointing out the effects of pacifier use on primary dentition. In this case only a prevalence of open bite and not of cross bite could be found out in the suckers’ group. Conversely, an other research [Larsson, 1986] shows a prevalence of cross bite in 40 three-year-old children used to pacifier sucking, though with an unusual and different distribution according to sex. Similarly controversial results were achieved in further researches aimed at analysing the possible correlation between the use of dummy and the onset of malocclusions [Larsson, 1998] [Turgeon-
O’Brien, 1996]. More recently a longitudinal study carried out on 797 children followed up from the age of 0 to 8 years [Bishara and Warren, 2002] [Bishara et al., 2006] has underlined the importance of keeping correct premaxillary transversal relationships and has suggested that the onset of deviant contacts in the deciduous canine teeth should be accurately monitored in suckers. Two very recent studies [Lopez del Valle et al., 2006] [Viggiano et al., 2004] have come nearly to the same conclusions, besides confirming the influence, anyway disturbing, of the non-nutritive habits on the occlusion development.

Closer examinations of the influence of different kinds of pacifiers on the development of dental arches seem to be less frequent. Studies [Adair et al., 1992] [Adair et al., 1995] carried out on children aged 24 to 59 months underline how the use of orthodontic dummies can result in a reduced development of anterior open bite and posterior cross bite, while the outcomes related to overjet appear similar. The results achieved in 60 patients aged 36 to 60 months [Zardetto et al., 2002] appear less reassuring since they show a similar critical reduction in the intracanine distance in those babies who suck both conventional and physiological pacifiers. All the quoted studies have come to the same conclusions listed a posteriori on the basis of a direct observation of clinical parameters in the patient. What really seems to lack is a form of in vitro study of the pacifier that allows us to analyse its mechanical behaviour on an ideal model. Only in this way it seems possible to detect those features able to reduce the damaging impact on the arches for future dummies.

The aim of the below presented study was to assess the stress condition exerted during the phase of suction (weak and strong) by three different kinds of dummies in contact with the palatal arch. The biomechanical behaviour, quantified by the level of strain at the interface palate-pacifier, was reproduced by means of finite element analysis (FEA). The different stress distribution during the phases of rest and suction was worked out by comparing three different pacifiers called as following: orthodontic (dummy A), cherry (dummy B) and drop (dummy C). In order to obtain the maximum representatives of the ideal situation the mathematical model developed to compare stress conditions has taken into account the space occupied by the tongue.

**Materials and methods**

FEA analysis requires, in the process setting phase, tridimensional mathematical models of the examined bodies. As for the palate the solid model was measured from a 3-D laser scan (scanner 3Shape R250) of an impression of a newborn baby’s palate. The point cloud obtained by the tridimensional laser scanning was converted through Rapidform 2006 (Inus Technology) into surfaces that afterwards were closed and turned into a solid model by means of Solidworks Office Professional 2006 SP0 (Solidworks Corporation). As for the tongue the solid model was constructed through Solidworks Office Professional 2006 SP0 by using curves and geometrical dimensions available in the international literature.

With regard to the pacifiers dummy A was drawn starting from a 3-D laser scan, performed by scanner 3Shape R250, of a dummy whose point cloud, as for the palate, was transformed into surfaces and solids. As regards dummies B and C the final mathematical models were processed by means of Solidworks Office Professional 2006 SP0 through operations of extrusion, cutting and revolution. Once all the solid bodies had been produced, in order to perform FEA simulation it was necessary to join the pacifier, palate and tongue as shown in figure 1 a-c. The three different

![Fig. 1 - a) dummy A, palate and tongue; b) dummy B, palate and tongue; c) dummy C, palate and tongues.](image-url)
groups of solids were obtained through Solidworks Office Professional 2006 SP0. After optimising the 3-D geometrical models we had to add loads and constraints. In figures 2 a-c we can see the loads involved during the phase of suction (weak and strong). As it is possible to notice the three pressures were applied to the tongue (p1), pacifier (p2) and palate (p3). The values of pressure were drawn from an analysis of the international literature [Wen-hua Ruan et al., 2003]. For a better understanding of these values data were reported in Table 1 (Fig. 2-3). Regarding constraints the following aspects were considered: in order to fix the tongue a fixed constraint was placed on the side opposite to the contact with the dummy, whereas for the palate the constraint was inserted near the base. Contact constraints were arranged among the dummy, palate and tongue (fig. 3 a-c). Subsequently the three systems were discretised into finite elements and the joint and contact constraints were adjusted by ANSYS V10.0 SP0 (ANSYS Corporation). In figure 4 a-c we can see the mesh constructed by using 10-node tetrahedral parabolic elements (fig. 4). FEA simulation of the three different systems was carried out taking into account linear, homogeneous and isotropic materials.

<table>
<thead>
<tr>
<th>Pressure</th>
<th>Weak suction</th>
<th>Strong suction</th>
</tr>
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<tbody>
<tr>
<td>p 1</td>
<td>93 MPa</td>
<td>1253 MPa</td>
</tr>
<tr>
<td>p 2</td>
<td>37 MPa</td>
<td>1679 MPa</td>
</tr>
<tr>
<td>p 3</td>
<td>148 MPa</td>
<td>1009 MPa</td>
</tr>
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TABLE 1 - Data concerning the pressure levels on the tongue, pacifier and palate during the phases of weak and intense suction.
As to the employed materials table 2 shows the chemical-physical properties of the constitutive elements. The tongue and palate features were drawn from the analysis of the international literature, while those of the three pacifiers were obtained by means of laboratory tests (mechanical crushing tests) performed on three dummies of material taken from the ring (Youngs’ modulus E for the three dummies equals the mean that results from the assessment of the three outcomes).

### Table 2 - Mean tooth size of both groups.

<table>
<thead>
<tr>
<th>Material</th>
<th>Youngs’ Modulus E</th>
<th>Poisson ratio</th>
</tr>
</thead>
<tbody>
<tr>
<td>Tongue</td>
<td>5 and 5 MPa</td>
<td>0.45 (non dimensional)</td>
</tr>
<tr>
<td>Palate</td>
<td>2 and 6 MPa</td>
<td>0.45 (non dimensional)</td>
</tr>
<tr>
<td>dummy A</td>
<td>1.25 and 5 MPa</td>
<td>0.49 (non dimensional)</td>
</tr>
<tr>
<td>dummy B</td>
<td>9.3 e 5 MPa</td>
<td>0.49 (non dimensional)</td>
</tr>
</tbody>
</table>

Results

The purpose of FEA simulation on the three systems was to achieve the distribution of stress on the palate during the phase of weak and strong suction. The evaluation of stress intensity, computed by means of von MISES, is shown in figures 5 a-b, 6 a-b, 7 a-b. The palate is represented in occlusal projection with a very small lateral angle. For a comparative analysis of the three different systems the same scale was used to measure the phase of both weak and intense suction.

Discussion

Looking closely at figures 5-7 some remarks can be made from a biomechanical point of view.

A first clarification concerns the impossibility to compare the phase of weak suction with that of strong suction on account of the different pressure conditions. Anyway comparisons for the same condition can be

Fig. 4 - a) mesh of the system dummy A, palate and tongue; b) mesh of the system dummy B, palate and tongue; c) mesh of the system dummy C, palate and tongue.

Fig. 5 - a) stress distribution on the palate during the phase of weak suction using dummy A; b) stress distribution on the palate during the phase of strong suction using dummy A.
drawn demonstrating how pacifiers with different geometrical shapes cause different stress distribution on the palate.

Observing the strain that occurs during the phase of weak suction it is possible to notice how dummy A stresses a lateral part of the palate leaving the central region almost unaltered; conversely dummies B and C concentrate the stress on the central zone. As for the phase of strong suction dummy A shows a biomechanical behaviour, in terms of stress distribution, completely different from dummies B and C.

The strain reproduced by FEA simulation on the palate, tongue and pacifier system is concentrated in a wide palatal area and does not extend to the anterior crestal region much. On the contrary, the systems with dummies B and C activate stress mainly in the central and crestal area.

The differences in terms of stress distribution, computed by von MISES and shown in figures 5-7, are strictly connected with the geometrical position of the pacifier inside the palate.

Looking at figure 2, where some sections of the systems with their respective loading conditions have been represented, it is easy to guess how the strain generated during the phase of strong suction of dummy A is present, to a greater extent, in the palatal region where the dummy and palate are in contact. With respect to this we can claim that the wider the contact area between pacifier and palate is, the greater both the developed stress and surface area. Conversely, if the dummy is in contact only with a small surface, as
for dummies B and C, both strain intensity and the concerned area will be limited. An inevitable consequence of this aspect is the concentration of high stress levels due to contact in limited points. The load transfer with stress induction at the interface depends a lot also upon the geometrical pattern of the pacifier and upon its production material.

Regarding the dummy production material, the lower the modulus of elasticity E is, the more elastic the material is. This results in greater deformability and therefore in a wider surface of strain distribution in the contact area, avoiding, as already said, concentration. Stress optimisation should be achieved trying to improve the features of the materials of dummies depending on their geometrical shape. But the pacifier position inside the palate is still a variable: it is not completely controllable and describable and it inevitably affects the strain at the interface dummy-palate.

Conclusion

In light of the above explained issues correlations between mathematical analysis and clinical condition of the child are evident.

The data in literature underline the key role of an adequate intracanine distance for the physiological premaxillary development and the maintenance of the mandible centring. FEA analysis highlights how one of the three dummies (dummy A) shows a biomechanical behaviour more suitable for the reported anatomical requirements. This statement cannot disregard long-term evaluation of the real power the object has to keep transversal diameters more than any other geometrical shape of pacifier. But definitely, at least in laboratory, the force distribution of dummy A is the closest to the one the clinician could accept.

The width and uniformity of the contact area are associated with a reduced cristal impact and this could possibly lead to a lesser pressure impact on the alveolar component and therefore to the development of a more physiological overbite, besides leaving the transversal dimension unaltered.

References


