Two-Dimensional Cephalometric Analysis of the Effects of Subperiosteal Palatal Soft-Tissue Expansion in Growing Cats

Philip A. Van Damme, M.D., D.M.D., Ph.D., Jaap C. Maltha, Ph.D., Anne Marie Kuijpers-Jagtman, D.M.D., Ph.D., Hans Peter M. Freihofer, M.D., D.M.D., Ph.D., and Martin A. Van't Hof, Ph.D.

Nijmegen, The Netherlands

The feasibility and possible effects of palatal soft-tissue expansion in palatal repair were studied. A prospective longitudinal animal experiment was performed in 75 growing cats assigned to 5 groups. In 31 cats, a midline defect was made, and bipedicled flaps were raised at the age of 8 weeks (simulated Langenbeck operation) in order to create palatal scars. At the age of 14 weeks, custom-made tissue expanders were inserted palatally in 61 animals. Tissue expansion was performed by weekly inflation in 33 cats (16 without and 17 with scars) for an 8-week period. The remaining 28 cats (14 without and 14 with scars) served as sham groups. A control group was formed by 14 animals (without scars and without tissue expanders). Soft-tissue gain and its effects on maxillofacial growth and development were measured in the midsagittal plane on tracings from standardized lateral radiographs. The effects of the experimental interventions were evaluated for 8 weeks after removal of the tissue expanders. Not all the cats yielded results at all time periods.

This study showed that soft-tissue expansion of palatal mucoperiosteum is feasible. The surgically induced scars did not cause significant differences between the different groups in the midsagittal plane, and the data from both expansion and sham groups could be pooled. Significant soft-tissue gain was achieved by the tissue-expansion technique. Iatrogenic side effects were significant anteroposterior growth retardation at the level of the bony palate and an increase in vertical growth of the anterior nasomaxillary height and the posterior skull height during active tissue expansion. After removal of the tissue expanders, some accelerated growth was found in the tissue expansion in the scarred tissue group, with initial correction of the abnormal growth at the cranial base level.

It is concluded that palatal soft-tissue expansion is possible in growing cats. This technique, however, impaired maxillofacial growth and development. (Plast Reconstr Surg. 99: 1960, 1997.)

The use of soft-tissue expansion for facilitating the closure of palatal defects in cleft lip and palate is new and has seldom been reported. The usual techniques for closure of oronasal communications in cleft lip and palate are summarized by Millard. Secondary fistulas are reported to occur as failures in 5 to 30 percent of cases after primary cleft repair. Recent reported closure techniques are various located pedicled mucoperiosteal flaps, such as tadpole flaps, buccal musculomucosal flaps, buccal fat pad flaps, different linguopalatal flaps, and temporal muscle and/or fascial flaps, as well as other techniques. The flaps do not always yield good results. For instance, with the buccal musculomucosal flap, complete closure can be achieved in 35 to 70 percent of secondary fistulas at first attempt, depending on the size and site of the defects. Closure generally becomes more difficult as the techniques become less reliable when multiple closure attempts have been made.

There are several disadvantages to these flaps. Some of them are two-stage procedures, create a donor-site defect, and use tissue of different origin, texture, and characteristics for the repair. The techniques may result in temporary functional disturbances. Lingual flaps, for example, cause temporary impairment of tongue function with speech interference, an
FIG. 1. Schematic drawing of modified Langenbeck operation. Excision of lenticular part of the palatal mucoperiosteum in the midline (left) and bilateral relaxation incisions. Elevation of the mucoperiosteum and closure of the midline defect (right). Three scars are created: one healed per primam in the midline and two by secondary intention laterally on both sides.

Free microvascularized flaps, such as the radial forearm fasciocutaneous flap, are hazardous, time-consuming, and bulky and often cause donor-site morbidity and visible scars.\textsuperscript{16,17} Also, each surgical intervention has a negative effect on subsequent growth and development of the dentomaxillofacial complex.\textsuperscript{18-27} A reduction in the number of palatal operations and subsequent scarring is therefore a desirable goal.

Soft-tissue expansion has been used in cranio-maxillofacial surgery since 1981.\textsuperscript{28} More recently, the use of a soft-tissue expander for closure of palatal fistulas has been advocated.\textsuperscript{1,2} Few studies have reported on the effects of tissue expansion on growth and development in growing individuals.\textsuperscript{29,30} In order to quantify the positive and/or negative effects of subperiosteal palatal soft-tissue expansion on the anteroposterior and vertical growth of the maxilla, a prospective longitudinal animal experiment was performed and maxillary growth was evaluated radiographically.

The present study evaluates the feasibility and effects of tissue expansion on the palatal mucoperiosteum of growing cats with and without preexisting scars.

** MATERIALS AND METHODS**

Seventy-five domestic tomcat kittens aged 8 weeks were assigned to five groups: group I, tissue expansion group ($n = 16$); group II, sham group ($n = 14$); group III, tissue expansion in scar tissue group ($n = 17$); group IV, sham in scar tissue group ($n = 14$); and group V, control group ($n = 14$). The animals were housed under normal laboratory conditions in the Central Animal Laboratory, University of Nijmegen, and received a diet consisting of granules, canned meat, and drinking water ad libitum. The cats were weighed every week and prior to any intervention.

All interventions were performed under standard general anesthesia, induced by 30 mg/kg ketamine HCl intramuscularly (Nimeta 100 mg/ml, A.U.V. Cuijk, The Netherlands) with 0.5 ml atropine intramuscularly (atropine sulfate 0.5 mg/ml) and maintained after endotracheal intubation with a mixture of $O_2$ (1 liter/min), $N_2O$ (2 liters/min), and 0.5% to 4.0% enflurane (Ethrane, Abbott B.V., Amstelveen, The Netherlands).
For the first week after surgery, or when indwelling catheters were inserted, the animals were placed in full-body contoured plastic casts. For the subsequent 6 weeks, the casts were removed. The wounds were inspected daily.

Fig. 2. Left: standard view of custom-made hemispheric cast, with isoflurane inhalation. The wound was inspected daily to monitor infection and complications related to the surgery, as well as the healing process. The casts were removed after 6 weeks, and the wounds were inspected weekly to ensure proper healing.

Prophylactic antibiotics were administered, as is standard practice. The casts were left in place for 6 weeks, until the animals were fully healed. The casts were then removed to allow for proper healing and to monitor the healing process. The casts were removed after 6 weeks, and the wounds were inspected weekly to ensure proper healing.

A simulated Langenbeck operation was performed for the first week after surgery, or when indwelling catheters were inserted. The casts were removed after 6 weeks, and the wounds were inspected daily to monitor infection and complications related to the surgery, as well as the healing process. The casts were removed after 6 weeks, and the wounds were inspected weekly to ensure proper healing.
cephalostat. The animals were fixed in the
cephalostat with two ear rods and a pin in the
midsagittal plane. Kodak diagnostic film Min-r
(Eastman Kodak Company, Rochester, N.Y.)
was used. A Philips Practix x-ray machine (Phil-
ips, The Hague, The Netherlands) was used
and set at 20 mA and 100 kV with an exposure
time of 10 seconds. The focus-film distance was
4.5 m, and the object-film distance was 9 cm.

Thirteen cats had to be excluded from the
study as a result of technical failures. Sixty-two
cats were followed until the age of 20 weeks,
and 52 cats were followed for the entire infla-
ation period up to 24 weeks. Forty animals were
studied during the 8 weeks after removal of the
tissue expander.

All radiographs were examined independ-
ently by two investigators. The following anat-
omic reference points were identified and
marked on the tracings (Fig. 4): P, most pos-
terior point of the bony palate; F, center of the
optic foramen; O, most posterior point of the
occpit; C, intersection of the coronal suture and
the external cortical bone plate; N, most an-
terior point of the nasal bone; and I, inter-
section of the labial contour of the central
incisor and the alveolar bone. The contour of
the tissue expander also was traced.

The points and structures were digitized
independently by both observers using an X-Y
digitizing tablet (Hitachi HDG-1111B, Man-
udax Nederland B.V., The Netherlands),
which was connected to a computer (IBM-PC
PS 2, Model 70 386) with a mathematical co-
processor. The projections of the points P, O,
C, and I on the line NF were denoted P*, O*,
C*, and I*.

The following distances and angles were cal-
culated (see Fig. 4): PI direct distance, PI indi-
direct distance (along the oral outline of the
tissue expander), NF, I*F, P*F, O*F, II*, PP*,
CC*, OO*, and angle NF/PI.

The error of the cephalometric procedures
was determined by measurements on repeated
exposures of 15 cats of different ages. The
animals were removed and then replaced in the
tissue expander between the exposures.

Means and standard deviations were calcu-
lated for the increments of all variables in all
groups. Increments were defined as differ-
ces between two time periods. Comparison
between the groups was carried out by one-way
analysis of variance (ANOVA) and analysis of
covariance, and if significant differences be-
tween groups were found, Tukey’s multiple-
comparisons test was used for evaluation of
these differences.

Analysis was performed for the period from
14 to 20 weeks of age for 62 cats and for the
period from 14 to 24 weeks of age for 52 cats.
Also, a period of 8 weeks after removal of the
tissue expanders was evaluated in 40 animals.
Intraobserver and interobserver variability tests
were performed to check the accuracy and
reproducibility of the procedures.

RESULTS

Error Analysis

The total error of the cephalometric proce-
dure is composed of an error in the positioning
of the animals in the cephalostat, the tracing
procedure, including the definition of points
and structures on the lateral cephalo-
grams, and the measuring procedure. The dup-
icate exposures at different ages showed a
mean total error of 0.23 mm. The angle NF/PI showed a mean total error of 0.92 degrees. Based on these results, the accuracy and reproducibility of the methods were considered to be acceptable.

Effects of the Interventions

Mutual comparison of all groups by one-way ANOVA revealed no significant differences between comparable scarred and nonscarred groups for any of the parameters until removal of the expander. Additional analysis of covariance supported that scarring of the tissue itself was not decisive for the effects of tissue expansion on maxillofacial growth and development in the sagittal plane. This meant that pooling of groups I and III as well as of groups II and IV was allowed. Pooling resulted in a tissue-expansion group TE, consisting of 26 (20) cats, and a sham group SH, consisting of 22 (18) animals (Tables I and II). The pooled groups TE, SH, and CO (controls, n = 14) were mutually compared by one-way ANOVA, and significant differences, if any, were subsequently explored by Tukey’s multiple-comparisons test.

The differences caused by the interventions were more pronounced for the period from 14 to 24 weeks of age than for the period from 14 to 20 weeks, indicating time-related effects.

The changes in distance PI direct, which are a measure of palatal growth, indicated that tissue expansion, as expressed by the distance PI indirect, increased, as expected, significantly faster in the TE group than in the others (Fig. 6). Measurements along the “cranial base,” defined as the line NF, indicated a relative posterior change in the position of point I* due to the tissue expansion, as expressed by the distance PI*. The vertical dimensions in the anterior

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**TABLE I**

Increments 14 to 20 Weeks: Initial 6 Weeks after Insertion of Tissue Expander

<table>
<thead>
<tr>
<th>Variable</th>
<th>I and III (TE n = 52)</th>
<th>II and IV (SH n = 22)</th>
<th>V (CO n = 14)</th>
<th>Pooled SD</th>
<th>Intergroup Difference (p &lt; 0.05)</th>
</tr>
</thead>
<tbody>
<tr>
<td>1 PI direct</td>
<td>1.29</td>
<td>1.95</td>
<td>2.32</td>
<td>0.49</td>
<td>TE &lt; CO</td>
</tr>
<tr>
<td>2 PI indirect</td>
<td>1.79</td>
<td>2.25</td>
<td>2.32</td>
<td>1.39</td>
<td>TE &gt; SH, CO</td>
</tr>
<tr>
<td>3 NF</td>
<td>3.07</td>
<td>3.07</td>
<td>2.94</td>
<td>0.38</td>
<td>TE &lt; CO</td>
</tr>
<tr>
<td>4 PI*</td>
<td>1.08</td>
<td>1.20</td>
<td>0.99</td>
<td>0.46</td>
<td>TE &lt; CO</td>
</tr>
<tr>
<td>5 I*F</td>
<td>1.23</td>
<td>1.19</td>
<td>1.15</td>
<td>0.43</td>
<td></td>
</tr>
<tr>
<td>6 O*F</td>
<td>1.38</td>
<td>1.06</td>
<td>1.17</td>
<td>0.34</td>
<td>TE &gt; SH</td>
</tr>
<tr>
<td>7 H*</td>
<td>1.38</td>
<td>1.06</td>
<td>0.74</td>
<td>0.32</td>
<td>TE &gt; SH</td>
</tr>
<tr>
<td>8 PI*</td>
<td>0.68</td>
<td>0.60</td>
<td>0.17</td>
<td>0.41</td>
<td></td>
</tr>
<tr>
<td>9 O*</td>
<td>0.32</td>
<td>0.38</td>
<td>0.81</td>
<td>0.69</td>
<td>TE &gt; SH</td>
</tr>
<tr>
<td>10 OD*</td>
<td>1.02</td>
<td>0.81</td>
<td>0.05</td>
<td>0.79</td>
<td>TE &gt; CO</td>
</tr>
<tr>
<td>11 &lt;NF/PI</td>
<td>0.69</td>
<td>0.17</td>
<td>0.23</td>
<td></td>
<td></td>
</tr>
</tbody>
</table>

Note: Values in mm resp. degrees per month; increments = differences between two time periods.
region, as represented by the distance $II^*$, increased faster in the TE group than in the SH or CO groups (Fig. 7). This also resulted in a significantly larger increase in the angle $NF/PI$ in the TE group than in the SH and CO groups after 24 weeks.

The distance $OO^*$, which is an indication of the posterior skull height, appeared to increase faster in the TE group than in the CO group when the period up to 24 weeks of age was considered.

The increments in the first 4 weeks after removal of the tissue expanders showed three significant differences, two of which seemed to
be temporary and one ($P*F$) persistent (Tables III and IV).

The measurements in the period from 4 to 8 weeks after removal of the tissue expanders revealed some significant differences in the increase of distances related to point $F$ (see Table IV). The increase in the distances anterior to point $F$ ($NF$, $I*F$, and $P*F$) was significantly larger in group III than in the unscarred groups. The distances $NF$ and $P*F$ in group I increased significantly less than in the scarred groups III and IV. Only two parameters of the control group showed significant differences with any of the experimental data: $P*F$ in-

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**Fig. 6.** Plotted diagram of mean values of $PI$ indirect versus time. Time is on the horizontal axis and $PI$ indirect on the vertical axis.
creased more in the control group than in group I, and $I^*F$ increased less in the control group than in group III.

In the 8 weeks after removal of the tissue expander, group III was significantly different from the other groups for the parameters $NF$, $I^*F$, and $P^*F$, with significant increases in group III (Table V). Furthermore, $P^*F$ increased significantly more in group IV compared with group I.

**Discussion**

This study has tried to evaluate the effects and further possibilities of tissue expansion of...
the palatal mucoperiosteum in growing cats with and without preexisting scars. Since extrapolation to the human clinical situation is important, an animal model was chosen with a deciduous and permanent dentition. Beagle dogs, although apparently suitable for study, were not selected for this experiment because of their non-human-like palatal anatomy. The morphology of the palate of the domestic cat appears to be suitable for comparisons with humans.

It is still impossible to breed nonrodent mammals with identical congenital clefts. Creating an artificial palatal cleft by surgery has major negative effects on growth and development of the dentomaxillary complex. This means that no reliable starting point exists after surgery.

To be able to check the validity of the soft-tissue expansion technique in scarred tissue, as is usually present in cleft lip and palate situations, a simulated Langenbeck operation was performed. The effects of this surgical intervention are well documented for dogs and assumed to be more or less the same for cats. The most prominent growth disturbances due to this type of operation were found in the transverse dental arch measures, which are beyond the scope of the present study. Only minor temporary changes in the anteroposterior dimensions were found. Also, the present study revealed no significant effect of the simulated Langenbeck operation on any of the parameters in the sagittal plane during tissue expansion. As a consequence, the Langenbeck and non-Langenbeck groups were pooled.

Palatal soft-tissue expansion may interfere with food intake by mechanical hindrance and expansion-related discomfort. This is reported to occur during and shortly after inflation. To examine this possible effect on nutrition,

### TABLE III

<table>
<thead>
<tr>
<th>Group (n = 40)</th>
<th>I TEXP (n = 9)</th>
<th>II SEXP (n = 7)</th>
<th>III TSCA (n = 6)</th>
<th>IV SAGA (n = 6)</th>
<th>V CONT (n = 12)</th>
<th>Pooled SD</th>
<th>Intergroup Difference</th>
</tr>
</thead>
<tbody>
<tr>
<td>Variable</td>
<td>Mean</td>
<td>Mean</td>
<td>Mean</td>
<td>Mean</td>
<td>Mean</td>
<td></td>
<td></td>
</tr>
<tr>
<td>1 PF direct</td>
<td>0.88</td>
<td>0.83</td>
<td>0.79</td>
<td>0.71</td>
<td>0.97</td>
<td>0.28</td>
<td></td>
</tr>
<tr>
<td>2 PF indirect</td>
<td>0.80</td>
<td>0.83</td>
<td>0.79</td>
<td>0.71</td>
<td>0.97</td>
<td>0.28</td>
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</tr>
<tr>
<td>3 NF</td>
<td>1.10</td>
<td>1.01</td>
<td>1.39</td>
<td>1.00</td>
<td>1.20</td>
<td>0.44</td>
<td></td>
</tr>
<tr>
<td>4 IF</td>
<td>1.24</td>
<td>1.41</td>
<td>1.78</td>
<td>1.09</td>
<td>1.48</td>
<td>0.37</td>
<td>I &lt; III</td>
</tr>
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<td>5 PIF</td>
<td>0.39</td>
<td>0.54</td>
<td>0.97</td>
<td>0.43</td>
<td>0.49</td>
<td>0.35</td>
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</tr>
<tr>
<td>6 OF</td>
<td>0.45</td>
<td>1.07</td>
<td>0.58</td>
<td>0.54</td>
<td>0.94</td>
<td>0.41</td>
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</tr>
<tr>
<td>7 II*</td>
<td>0.43</td>
<td>-0.09</td>
<td>0.42</td>
<td>0.17</td>
<td>0.39</td>
<td>0.49</td>
<td></td>
</tr>
<tr>
<td>8 PPI*</td>
<td>0.20</td>
<td>0.14</td>
<td>0.50</td>
<td>-0.16</td>
<td>0.46</td>
<td>0.47</td>
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</tr>
<tr>
<td>9 CC*</td>
<td>0.10</td>
<td>0.21</td>
<td>0.05</td>
<td>-0.13</td>
<td>-0.02</td>
<td>0.50</td>
<td></td>
</tr>
<tr>
<td>10 O0*</td>
<td>0.99</td>
<td>0.36</td>
<td>0.44</td>
<td>0.27</td>
<td>0.11</td>
<td>0.69</td>
<td></td>
</tr>
<tr>
<td>11 &lt;NF/PI</td>
<td>0.13</td>
<td>-0.48</td>
<td>-0.36</td>
<td>0.32</td>
<td>-0.37</td>
<td>1.15</td>
<td></td>
</tr>
</tbody>
</table>

Note: Values in mm resp. degrees per month; increments = differences between two time periods.

### TABLE IV

<table>
<thead>
<tr>
<th>Variable</th>
<th>I TEXP (n = 9)</th>
<th>II SEXP (n = 7)</th>
<th>III TSCA (n = 6)</th>
<th>IV SAGA (n = 6)</th>
<th>V CONT (n = 12)</th>
<th>Pooled SD</th>
<th>Intergroup Difference</th>
</tr>
</thead>
<tbody>
<tr>
<td></td>
<td>Mean</td>
<td>Mean</td>
<td>Mean</td>
<td>Mean</td>
<td>Mean</td>
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</tr>
<tr>
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<td>1.11</td>
<td>0.70</td>
<td>0.68</td>
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<td>0.64</td>
<td>0.24</td>
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</tr>
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<td>0.70</td>
<td>0.68</td>
<td>0.50</td>
<td>0.64</td>
<td>0.24</td>
<td></td>
</tr>
<tr>
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<td>0.68</td>
<td>1.26</td>
<td>1.03</td>
<td>0.82</td>
<td>0.35</td>
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</tr>
<tr>
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<td>0.65</td>
<td>1.48</td>
<td>0.96</td>
<td>1.02</td>
<td>0.30</td>
<td>I, II, IV, V &lt; III</td>
</tr>
<tr>
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<td>-0.01</td>
<td>0.02</td>
<td>0.88</td>
<td>0.51</td>
<td>0.41</td>
<td>0.30</td>
<td>I, II, III, IV; I &lt; V</td>
</tr>
<tr>
<td>6 OOF</td>
<td>0.75</td>
<td>0.36</td>
<td>1.04</td>
<td>0.72</td>
<td>0.52</td>
<td>0.43</td>
<td></td>
</tr>
<tr>
<td>7 II*</td>
<td>0.25</td>
<td>0.71</td>
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<td>0.67</td>
<td>0.29</td>
<td>0.77</td>
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<tr>
<td>8 PPI*</td>
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<td>0.40</td>
<td>0.07</td>
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<tr>
<td>9 CC*</td>
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<td>0.01</td>
<td>-0.07</td>
<td>0.50</td>
<td>0.62</td>
<td></td>
</tr>
<tr>
<td>10 O0*</td>
<td>0.07</td>
<td>0.83</td>
<td>-0.17</td>
<td>0.58</td>
<td>0.83</td>
<td>1.04</td>
<td></td>
</tr>
<tr>
<td>11 &lt;NF/PI</td>
<td>-0.41</td>
<td>0.47</td>
<td>-1.15</td>
<td>0.29</td>
<td>0.18</td>
<td>1.39</td>
<td></td>
</tr>
</tbody>
</table>

Note: Values in mm resp. degrees per month; increments = differences between two time periods.
weight gain was monitored and recorded carefully on a weekly basis. No decrease or abnormal weight changes were found.

Complications of soft-tissue expansion in the head and neck area are well established. Complication rates vary from 0 to 69 percent depending on surgeon, time, technique, and anatomic site. Most authors reported high complication rates early in their experience, with a subsequent decrease. In a pilot study, the various techniques were practiced in order to accrue enough experience to start the experimental intervention became more prominent some of the abnormal growth in the maxillo-mandibular region and not in the parameters involved in the palatal length and nasomaxillary height. This phenomenon was quite unexpected, and we can forward no explanation for it.

In the first weeks after removal of the tissue expanders, nearly all increments in the experimental groups returned to the normal, control values. Later on, some significant differences between the groups developed. All these differences were found in the cranial base region and not in the parameters involved in the maxillary length and nasomaxillary height. This means that although the growth rates in that area soon after removal of the tissue expander returned to normal, it still is questionable whether real catch-up growth takes place beyond the period of 8 weeks after removal of the tissue expander. These findings indicate that some of the abnormal growth in the maxillofacial complex induced by tissue expansion can persist after tissue expander removal.

A limitation of this study is the fact that it provides only two-dimensional information about effects in the midsagittal plane. Three-dimensional data are needed to elucidate the positive and negative effects of tissue expansion.

From this study it can be concluded that tissue expansion of the palatal mucoperiosteum in young growing cats is possible, with
and without scars of the palatal tissues. During growth, however, tissue expansion interferes with the anteroposterior growth of the bony structures at the palatal level. In the vertical direction, the anterior facial and posterior skull heights are altered by tissue expansion. It also interferes with dental development as the incisors become more inferiorly and posteriorly located. This may be due to interference with occlusion and traction in the soft tissues overlying the subperiosteally located tissue expander. Some of these effects, however, seem to be temporary, since there is a relatively accelerated growth at the cranial base after removal of the tissue expander in the scarred tissue expansion group.

Philip A. Van Damme, M.D., D.M.D., Ph.D.
Department of Oral and Maxillofacial Surgery
University Hospital Nijmegen St. Radboud
P.O. Box 9101, 421
6500 HB Nijmegen
The Netherlands

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