A Facial Growth Analysis Based on FEM Employing Three Dimensional Surface Measurement by a Rapid Laser Device

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Summary: Although there have been several studies of finite element method (FEM) analysis on two dimensional (2D) facial growth with cephalometric X-rays, there has been little FEM analysis on three dimensional (3D) facial growth of long term observation. Therefore the objective of our study is to use FEM model by 3D surface measurement of rapid laser device from human dried skull and to analyze the changes of facial growth based on FEM by the volume and the direction of strain in each stage.

Samples were taken from each human dried skull for 5 stages; about 0, 3, 6, 9, 12 and 18 years of age, a total of 6 normal human dried skulls. (No abnormal skeletal growth patterns were selected and age was supposed by tooth development and eruption.)

After measuring each human dried skull by 3D rapid device, we selected the clearest 16 anatomical reference points from about 70,000 points on face image to form accurate FEM shells. The study utilized Cosmos/M (SRAC) for FEM analysis, on a PC(NEC). From the strain analyses, it was revealed that (1) The vale of growth strain from 0 to 3 years of age and from 3 to 6 years of age gradually increased from condylar area toward mental area and the most vale of growth strain was showed at mental area. The vale of growth strain of corpus area was bigger than other areas. (2) As a whole the vale of growth strain of other areas except mental, corpus and nasal area were almost equal. These results indicate especially the growth change of mandible were predominantly showed in the early stages, and the direction of growth strain changed backward and above from mental area to condylar area.

Materials and Methods

Specimens in this study were taken from human dried skulls of the following ages: about 0 year of age (no teeth), about 3 years of age (milk teeth development and eruption), about 6 years of age (first molar development
and eruption), about 9 years of age (first molar root development), about 12 years of age (second molar development and eruption), and about 18 years of age (third molar development and eruption), for a total of 6 normal human dried skulls. (Abnormal skeletal growth patterns were avoided, and age was estimated by tooth development and eruption.) These human dried skulls were obtained from the Department of First Oral Anatomy, Showa Dental University.

Rapid laser device using 3D measurements was composed of both measuring equipment and an imaging personal computer (Fig. 1). The beam line of a semiconductor laser was projected around the specimen, and the reflected line was scanned by two CCD cameras located ±30° from the projection (Fig. 2).

To minimize the error of measurements, all materials were set to pass through the top of the parietal bone perpendicularly to the ground so that it would be parallel to the ground at the Frankfort horizontal plane. The center line from nasion to menton was set up to be symmetrical in the frontal image. After measuring each human dried skull by the 3D rapid device (Fig. 3), the clearest 16 anatomical reference points in accordance with modified Martin's measurements (Martin, 1957) were selected from about 70,000 points on face image to form 3D shell models composed of 17 elements (Fig. 4).

The FEM model of 0 year of age and FEM model of 3 years of age were superimposed as were the FEM model of 3 years of age and FEM model of 6 years of age, those of 6 years of age and 9 years of age, those of 9 years of age and 12 years of age, and those of 12 years of age and 18 years of age. Thus, 5 FEM models were prepared and compared, based on the detailed growth strains.

Results

The growth rates in the 5 FEM models from 0 year to 18 years of age were evaluated. The growth rates were designated as magnification of 6 levels from maximum to minimum.

(1) Growth rates on the FEM model from 0 to 3 years of age (Fig. 5)

The FEM model aged 3 years was 4.2-5 times as great as the model aged 0 year in the mental area and was 2.6-3.4 times as big as that in the corpus area and was 1-1.8 times as big as that in the other areas.

(2) Growth rates on the FEM model from 3 to 6 years of age (Fig. 6)

The FEM model aged 6 years was 4-4.75 times as great as the model aged 3 years in the mental area and was 2.5-3.3 times as big as that in the corpus area and was 1.5-1.75 times as big as that in the alveolar mandible and maxilla and was 1-1.75 times as big as that in other areas.

(3) Growth rates on the FEM model from 6 to 9 years of age (Fig. 7)

The FEM model aged 9 years was 1.6-1.75 times as big as the model aged 6 years in the maxilla of the nearest nasal spina and was 1.15-1.3 times as big as that in the zygoma and maxilla, and was 1-1.5 times as big as that in other areas.

Fig. 1. 3D rapid laser device, measuring device and personal computer.
(4) Growth rates on the FEM model from 9 to 12 years of age (Fig. 8)

The FEM model aged 12 years was 1.8–2.6 times as big as the model aged 9 years in the nasal area and was 1–1.8 times as big as that in the other areas.

(5) Growth rates on the FEM model from 12 to 18 years of age (Fig. 9)

The FEM model aged 18 years was 1.8–2 times as big as the model aged 12 years in the nasal area and 1.6–1.8 times as big as that in the process of maxilla and was 1.4–1.6 times as big as that in the alveolar of maxilla and was 1–1.2 times as big as that in the zygoma.

The present analyses of growth rates (Table 1) reveal that

(1) The most rapid growth rate was in the mental area in the early stages.
Anatomical reference points and elements

1. Nasion
2. Rhinion
3. Lateral Nasale
4. Nasospinale
5. Point A
6. Point B
7. Menton
8. Medial orbitale
9. Orbitale
10. Lateral orbitale
11. Supra orbitale
12. Gonion
13. Zygomare
14. Retromolare
15. Kondillion
16. Frontomolare

(1) Nasal area
(2)–(3) Nasal and maxillary area
(4)–(7) Maxillary area
(8) Maxillary and corpus area
(9)–(10) Corpus area
(11)–(12) Ramus area
(13)–(14) Zygomatic area
(15)–(16) Temporal area
(17) Frontal area

Fig. 4. Anatomical reference points and elements in the 3D FEM model.

Growth rates between the two FEM models from skulls aged 0 and 3 years.

Growth rates between the two FEM models from skulls aged 3 and 6 years.
Fig. 7. Growth rates between the two FEM models from skulls aged 6 and 9 years.

Fig. 8. Growth rates between the two FEM models from skulls aged 9 and 12 years.

Fig. 9. Growth rates between the two FEM models from skulls aged 12 and 18 years.

(2) The growth rate in the corpus area was more rapid than those in all other areas except for the mental area in the early stages.

(3) The growth rates in the nasal area were higher than those in the other areas in the later stages.

(4) As a whole, the values of growth rates were almost equal in the later stages.

Discussion

(1) Advantages of 3D surface measurement by the rapid laser device

It is difficult to cope with data produced by using a computer with Moiré photography (Meadow, 1970) Stereoscopy (Burke and Bread, 1967; Savara, 1965) also requires high level techniques for contour line preparation.

The advantages of the rapid laser device (Chen, 1993) include a non-contact system which produces no deformity and a short measurement time (4.3 seconds). The time needed to reconstruct the 3D image on personal computer is about 5 seconds, and it uses safelight. The device is designed to light up for only 0.03 second of photographic time, and there is no danger to the eyes or the skin, because the energetic density is lower than $2\text{mW} \times 0.03\text{ second} = 0.00006\text{ J}$ due to the enlargement of the length to 400 mm at the facial position, although the point of the semiconductor laser is 2mW. This device was clinically accurate; the error of the visual field of height (250mm)xwidth (250mm) is about 0.4%.

(2) The analytical results

The highest growth rate was found at the mental area in the early stages. The mental foramen is known as most rapid growth site in early youth (Moss, 1970). A single ossification center is reported to arise for each half of the mandible in the region of bifurcation of the inferior alveolar nerve and artery into the mental and incisive branches (Geoffrey, 1989).

Our results confirm that the mental area is one of the
origins of growth in the mandible, and early secondary growth was clearly found in the corpus area.

There is a definite increase in growth in the length of the face, especially of the mandible. The growth changes in the lower facial area are faster than those of the middle and upper facial area in the early stages (Margolis, 1955). Our results suggested that the facial growth from 0 to 6 years of age gradually slows down. After 6 years of age almost all areas showed growth rates of 5–25% per year. These data correspond with the report (Dockrell, 1960) that more than 80% of facial growth is generally completed by 5 years. Most of the facial growth is completed to the adult (85–90%) by 9 years; the subsequent growth changes from 9 years of age are generally only 10% to 15% of the total (Graber, 1966). We also showed that facial growth was only slight in later stages. Moderate growth rates were found in the nasal area from 9 to 12 years of age and from 12 to 18 years of age. We considered that these rates were caused by enlargements of the maxillary sinus and ethmoid sinus, which are reported to be occasionally irregular as late as 17 years of age (Salzmann, 1966).

Conclusions

The 3D growth analysis of the upper, middle, and lower facial areas based on FEM from 3D images was first investigated in this study. Individual growth factors at several domains in craniofacial area were quantitatively analyzed without setting of any registration points or orientation lines.

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References