X-RAY DENSITY OF BONE TISSUES OF THE DENTOGNATHIC APPARATUS IN CHILDREN WITH CONGENITAL UNILATERAL CLEFT LIP AND PALATE

Valerii Filonenko, Oleksandr Kaniura, Andrii Kopchak, Yuriі Kiriienko

1. Candidate of Medical Sciences, Associate Professor, Deputy Dean of Dental Faculty, Associate Professor of the Department of Orthodontics and Prosthodontics Propaedeutics, Bogomolets National Medical University, Kyiv, Ukraine
2. Doctor of Medical Sciences, Professor, Vice-Rector for Scientific-Pedagogical and Clinical Work, Professor of the Department of Orthodontics and Prosthodontics Propaedeutics, Bogomolets National Medical University, Kyiv, Ukraine
3. Doctor of Medical Sciences, Professor, Head of the Department of maxillo-facial surgery and innovative dentistry, Bogomolets National Medical University, Kyiv, Ukraine
4. Post graduate student of the Department of Orthodontics and Prosthodontics Propaedeutics, Bogomolets National Medical University, Kyiv, Ukraine

* Corresponding author: Valerii Filonenko, Candidate of Medical Sciences, Associate Professor, Deputy Dean of Dental Faculty, Associate Professor of the Department of Orthodontics and Prosthodontics Propaedeutics, Bogomolets National Medical University, Kyiv, Ukraine; e-mail: valerifilonenko@gmail.com

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Abstract

Relevance: Physico-mechanical characteristics of the bone tissue of the jaws, in particular its density, determine the efficacy of orthodontic interventions and are a determining parameter when calculating the forces acting on the tissue via orthodontic appliances. Hounsfield X-ray attenuation scale (HU) was used to quantify density during computed tomography.

The aim to analyze the X-ray density of bone tissue of the upper jaw in children with congenital unilateral cleft lip and palate using the method of computed tomography of the skull.

Materials and methods: The subject of the analysis were measurement data of the X-ray density of bone tissues of the upper jaw of 42 children in the areas that correspond to the maximum stress under the influence of orthodontic appliances.

Results: It was clinically established that among all patients included in the study group, cases with left-sided clefts quantitatively dominate over right-sided ones. The results of measurements in the younger age group at the points of intersection of the compact plates of the floor of the maxillary sinus and the zygomatic alveolar ridge (ZAS and ZAI) indicate that the density is 16.6% higher on the healthy side than on the cleft side; 17.6% higher on the healthy side in the most concave points of the nasolabial buttress (NS and NI); and 14.9% higher on the healthy side at the junction of the compact plate of the hump of the upper jaw and the sphenoid bone (TSS and TSI). The zygomatic process of the upper jaw at the level of the zygomatic-maxillary suture (ZZS and ZZI) is the only site where the results on the healthy side and the cleft side did not show a statistically significant difference.
In the older age group, a comparison of the averages of two independent samples at the NS and NI points revealed a prevalence of density values by 12.1% on the healthy side. No statistically significant differences in measurements were found at ZZS and ZSI, ZAS and ZAI, TSS and TSI points. At the same time, the average value on the healthy side for the younger age group is 7.6% more than for the older one.

**Conclusions:** Determination of the X-ray density of bone tissue allows to distribute the magnitude of force impact of orthodontic devices in the process of their activation and to obtain new data on the magnitude of external loads on the jaw bones.

**Keywords:** density of bone structures; computed tomography; congenital cleft lip and palate; Hounsfield scale.

**Introduction**

Bone tissue is a dynamic open system, and the processes of adaptive remodeling under different states of regulatory systems and operating conditions determine changes in its structure and properties. Digital methods of visualization and computer diagnostics are widely used for the study of bone structures. Its key tool is the analysis of data from multispiral or cone-beam computed tomography (CT) of the skull with subsequent 3D reconstruction of images in the given range of X-ray density.  

Studies of bone quality are essential when planning surgical and orthodontic interventions. Different types of bone have different ability to absorb X-rays. This characteristic depends on the mineral saturation and is directly proportional to the density. To quantify the density of bone structures during CT, an X-ray attenuation scale, the Hounsfield (HU) scale, is used. X-ray density cannot be considered as a constant value. Depending on the type, bone tissues normally have different densities.

Various pathological conditions significantly affect bone density indicators. Thus, it is known that children with congenital cleft lip and palate (CLP) develop pronounced structural and functional changes in the facial bones, which are accompanied by changes in their anatomy, architectonics, physico-mechanical and biological properties. Almost 94% of them have dentognathic deformations that require complex treatment, including orthodontic support using various types of orthodontic devices. The physico-mechanical characteristics of the bone tissue of the jaws, in particular its density in various areas, determine the efficacy of orthodontic interventions and the determining parameters when calculating the forces acting on it from the side of orthodontic devices. However, systematic studies of X-ray density of bone tissue of the jaws in the specified category of children according to CT data were not found in the literature available to us.

The aim to analyze the X-ray density of bone tissue of the upper jaw in children with congenital unilateral cleft lip and palate using the method of computed tomography of the skull.

**Materials and methods**

The subject of the analysis was the measurement data of the X-ray density of bone tissues of the upper jaw of 42 children with unilateral CLP who underwent orthodontic treatment at the age of 4.5 to 13 years (average age 9.7±3.1 years). Surgical interventions to close the defect of the hard palate were performed at the age of 6 years, and bone plastic surgery of the alveolar process was performed at the age of 12-13 years. When planning the stages of surgical treatment, immediately before their implementation, all patients who underwent orthodontic treatment and were included in the study group underwent CT for the purpose of morphometric assessment of bone structures.

For a comparative analysis, taking into account the age-specific features of bite formation depending on the mixed dentition period, the younger (YAG) and older (OAG) age groups were selected. The 19 children were enrolled to the YAG, and 23 children were enrolled to the OAG.

Orientation of the tomographic sections was based on the standardized protocol of CT studies of the facial skull. A Planmeca ProMax 3DMid tomograph was used (slice increment, 0.625; pixel size, 0.488; matrix, 1024×1024; slice thickness, 0.625 mm; DLP, 250 mGy.cm).

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X-ray bone density (XRBD) of the jaws of patients with unilateral CLP was assessed in Hounsfield (HU) units, based on the determination of X-ray attenuation factors. For this purpose, the "Rectangle" tool of the software for viewing DICOM "Horos" files was used. Taking into account the individual morphological features of the bones of the facial skeleton, the component of the study was the measurement of minimum and maximum indicators. The density was determined in the areas that correspond to the maximum stress under the influence of the orthodontic appliances at the following points:

- on the zygomatic process of the upper jaw (processus zygomaticus), at the level of the zygomatic-maxillary suture (sutura zygomaticomaxillaris) – Zyg-Zyg (Sanitas) healthy side, Zyg-Zyg (Infirmus) cleft side: corresponding points ZZS and ZZI (Figure 1);
- at the intersection of the compact plates of the floor of the maxillary sinus (sinus maxillaris) and zygomatic alveolar ridge (crista zygomatico-alveolaris) – Zyg-Alv (Sanitas) healthy side, Zyg-Alv (Infirmus) cleft side: corresponding points ZAS and ZAI (Figure 2);
- at the junction of the compact plate of the hump of the upper jaw (tuber maxillae) and sphenoid bone (os sphenoidale) – TS (Sanitas) healthy side, TS (Infirmus) cleft side: corresponding points TSS and TSI (Figure 3);
- at the most concave point of the nasolabial buttress (nasofrontal patronam) – N (Sanitas) healthy side; N (Infirmus) cleft side: corresponding points NS and NI (Figure 4).

**Figure 1.** Determination of XRBD on the zygomatic process of the upper jaw at the level of the zygomatic-maxillary suture

**Figure 2.** Determination of XRBD at the intersection of the compact plates of the floor of the maxillary sinus and zygomatic alveolar ridge

**Figure 3.** Determination of XRBD at the junction of the compact plate of the hump of the upper jaw and sphenoid bone
The study inclusion criteria were as follows: children with CLP, the age of orthodontic treatment from 4.5 to 13 years without distribution by gender, surgical interventions with the closure of a defect of the hard palate at the age of 6 and bone plastic surgery of the alveolar process at the age of 12-13, CT scan before surgical interventions at 6 and 12-13 years old, parental consent to participate in the study. Exclusion criteria: lack of complete documentation of the case, surgical interventions with closure of the hard palate defect before or after 6 years, bone plastic of the alveolar process before or after 12-13 years, CT scan before surgical interventions before or after 6 and 12-13 years, the presence of concomitant somatic diseases associated with a bone tissue metabolism disorder, mental disorders, a history of facial bone fractures, the presence of tumors, tumor-like and inflammatory processes that changed the bone architectonics of the upper jaw, refusal of parents to participate in the study.

Statistical analysis of the obtained data was carried out using the specialized software MedStat v. 5.2 (Ukraine, Free Software License) and Jamovi v. 2.3 (The Jamovi Project (2023), GNU Affero General Public License v3.0).

The distribution check for normality of all quantitative data was carried out using the Shapiro-Wilk test. Depending on the results of the test, parametric criteria (in the case of acceptance of the hypothesis on the distribution normality) or non-parametric criteria (in the case of a difference of the distribution from the normal) were used for further analysis. To present the descriptive statistical characteristics of measures of central tendency and measures of dispersion of variational series of data, in case of acceptance of the hypothesis on normality of distribution, the data are given with an indication of the value of the arithmetic mean (M) and the standard deviation (SD), i.e.: $M \pm SD$. In case of rejecting the hypothesis on normality of the distribution, the data are presented with an indication of the value of the median (Me), the interquartile range between the first quartile (Q1, 25th percentile) and the third quartile (Q3, 75th percentile), i.e. Me (Q1–Q3). Taking into account considerations of expediency, in some cases the minimum and maximum values of certain characteristics of objects of statistical observation and the 95% confidence interval (95% CI) are given. Qualitative indicators are used as grouping features with presentation in the form of acronyms.

To determine the statistical significance of differences, in cases of comparison of two independent groups of data against a normal distribution, the Student's t-test was used, and in the case of comparisons of three or more samples, the Scheffe’s method of multiple comparisons was used. Before conducting comparisons, the hypothesis of equality of variances in the respective groups was tested using Fisher's F-test (for a normal distribution law) and the Kruskal-Wallis test (in the case of a distribution difference from the normal).

Differences in the characteristics of objects of statistical observation are considered statistically significant at a significance level of $p<0.05$ (it is assumed that the critical value of the level of statistical significance is equal to 0.05).

Results

It was clinically established that among all patients included in the examination group (42), cases with left-sided cleft (LSC) quantitatively dominate over right-sided cleft (RSC). In total, LSC was detected in 33 children (79%) and RSC in 9 (12%). In total, LSC was detected in 33 children (79%) and RSC in 9...
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strains. pairs of difference points of higher points XRBD 17.6% level. were side, XRBD a value of TSI TSS NI NS ZAI ZZI ZZS measurement were statistically significantly different at the level of p=0.005. The XRBD value at the ZAS point, located on the healthy side, was 16.6% higher than at the ZAI point on the cleft side. XRBD values in YAG at NS and NI points were statistically significantly different at the p=0.005 level. At the same time, XRBD at the NS point was 17.6% higher than at the NI point. The results of XRBD measurements in the YAG at TSS and TSI points were statistically significantly different at the level of p=0.047. XRBD at the TSS point was 14.9% higher than at the TSI point. However, a comparison of the average XRBD values in YAG at ZZS and ZZI points did not reveal a statistically significant difference (p=0.395).

Figure 5 presents a diagram of the range of results of XRBD measurements in YAG at four pairs of points with maximum gradients of equivalent strains.

For 23 YAG children with CLP, the XRBD data of the dentognathic apparatus, which were obtained using computed tomography, were also analyzed. Descriptive statistics of the results of XRBD measurements in OAG at four pairs of points with maximum gradients of equivalent strains are shown in table 2.

Table 1. XRBD measurement results in pairs of points ZZS and ZZI, ZAS and ZAI, NS and NI, TSS and TSI with maximum gradients of equivalent strains in YAG (n=19)

<table>
<thead>
<tr>
<th>Measurement points</th>
<th>XRBD, M ± SD, HU</th>
<th>XRBD, Min-Max, HU</th>
<th>XRBD, 95% CI, HU</th>
<th>Difference in pair, % (p&lt;0.05)</th>
</tr>
</thead>
<tbody>
<tr>
<td>ZZS</td>
<td>1126 ± 213</td>
<td>713-1422</td>
<td>1023-1229</td>
<td>-</td>
</tr>
<tr>
<td>ZZI</td>
<td>1189 ± 237</td>
<td>820-1782</td>
<td>1074-1303</td>
<td></td>
</tr>
<tr>
<td>ZAS</td>
<td>1164 ± 293</td>
<td>648-1665</td>
<td>1022-1305</td>
<td>16.6</td>
</tr>
<tr>
<td>ZAI</td>
<td>971 ± 207</td>
<td>603-1289</td>
<td>871-1070</td>
<td></td>
</tr>
<tr>
<td>NS</td>
<td>1356 ± 274</td>
<td>746-1741</td>
<td>1224-1489</td>
<td>17.6</td>
</tr>
<tr>
<td>NI</td>
<td>1118 ± 207</td>
<td>778-1532</td>
<td>1018-1218</td>
<td></td>
</tr>
<tr>
<td>TSS</td>
<td>1083 ± 262</td>
<td>653-1513</td>
<td>957-1210</td>
<td>14.9</td>
</tr>
<tr>
<td>TSI</td>
<td>922 ± 220</td>
<td>518-1209</td>
<td>815-1028</td>
<td></td>
</tr>
</tbody>
</table>

Comparison of the averages of two independent samples of the XRBD values in the YAG (n=19) at the ZAS and ZAI points using the Student's test revealed a difference at the significance level of p=0.025. The XRBD value at the ZAS point, located on the healthy side, was 16.6% higher than at the ZAI point on the cleft side. XRBD values in YAG at NS and NI points were statistically significantly different at the p=0.005 level. At the same time, XRBD at the NS point was 17.6% higher than at the NI point. The results of XRBD measurements in the YAG at TSS and TSI points were statistically significantly different at the level of p=0.047. XRBD at the TSS point was 14.9% higher than at the TSI point. However, a comparison of the average XRBD values in YAG at ZZS and ZZI points did not reveal a statistically significant difference (p=0.395).

For 23 YAG children with CLP, the XRBD data of the dentognathic apparatus, which were obtained using computed tomography, were also analyzed. Descriptive statistics of the results of XRBD measurements in OAG at four pairs of points with maximum gradients of equivalent strains are shown in table 2.
Comparison of the averages of two independent samples of the YAG values in OAG (n=23) at NS and NI points using the Student’s t test revealed a difference at the significance level of p=0.026. At the same time, XRBD at the NS point is 12.1% higher than at the NI point. However, the comparison of the average XRBD values in OAG did not reveal statistically significant differences in the results of measurements in pairs of points ZZS and ZZI (p=0.332), ZAS and ZAI (p=0.984), as well as TSS and TSI (p=0.874). Figure 6 presents a diagram of the range of the results of XRBD measurements in OAG in HU units in four pairs of points with maximum gradients of equivalent strains.

In the groups of XRBD, measurement results in all eight points: ZZS and ZZI, ZAS and ZAI, NS and NI, TSS and TSI in YAG (n=19) and OAG (n=23) patients with unilateral CLP there are sufficiently high coefficients of variation of values (VC =SD/M*100%). The VC of XRBD varies from 17.1% to 30.6% (95% CI 20.0-24.0). A pairwise comparison of XRBD values at all eight control points in YAG and OAG (eg, the value at the ZZS point in YAG against the value at the ZZS point in OAG) did not reveal statistically significant differences at any point, and therefore did not demonstrate differences in the results between the two different age groups.

An alternative approach to the XRBD comparison in YAG and OAG made it possible to identify certain significant trends. Under the conditions of availability of the XRBD measurements data at ZZS, ZAS, NS, TSS points on the healthy side and on the cleft side, it is reasonable to calculate and further analyze the average value (AV) of XRBD on each side, i.e. AV-S and AV-I.

Accordingly, the average values of AV-S YAG and AV-S OAG, as well as AV-I YAG and AV-I OAG were calculated for YAG and OAG patients with unilateral CLP. Descriptive statistics of the average values of the XRBD measurement results AV-S YAG and AV-S OAG, as well as AV-I YAG and AV-I OAG by age groups are shown in Table 2.

### Table 2. XRBD measurement results in pairs of points ZZS and ZZI, ZAS and ZAI, NS and NI, TSS and TSI with maximum gradients of equivalent strains in OAG (n=23)

<table>
<thead>
<tr>
<th>Measurement points</th>
<th>XRBD, M ± SD, HU</th>
<th>XRBD, Min-Max, HU</th>
<th>XRBD, 95% CI, HU</th>
<th>Difference in pair, % (p&lt;0.05)</th>
</tr>
</thead>
<tbody>
<tr>
<td>ZZS</td>
<td>1123±280</td>
<td>723-1672</td>
<td>1001-1244</td>
<td>-</td>
</tr>
<tr>
<td>ZZI</td>
<td>1046±249</td>
<td>531-1565</td>
<td>938-1153</td>
<td>-</td>
</tr>
<tr>
<td>ZAS</td>
<td>1055±279</td>
<td>626-1581</td>
<td>934-1175</td>
<td>-</td>
</tr>
<tr>
<td>ZAI</td>
<td>1053±322</td>
<td>546-1691</td>
<td>914-1192</td>
<td>-</td>
</tr>
<tr>
<td>NS</td>
<td>1221±240</td>
<td>866-1617</td>
<td>1117-1325</td>
<td>12,1</td>
</tr>
<tr>
<td>NI</td>
<td>1073±191</td>
<td>845-1455</td>
<td>990-1156</td>
<td>-</td>
</tr>
<tr>
<td>TSS</td>
<td>999±170</td>
<td>749-1346</td>
<td>925-1073</td>
<td>-</td>
</tr>
<tr>
<td>TSI</td>
<td>991±193</td>
<td>677-1359</td>
<td>907-1074</td>
<td>-</td>
</tr>
</tbody>
</table>

Figure 6. Diagram of the range of the results of the XRBD measurements (HU) in patients of OAG (n=23) in four pairs of points ZZS and ZZI, ZAS and ZAI, NS and NI, TSS and TSI

Table 3. Statistics of the average values of the XRBD measurement results AV-S YAG and AV-S OAG, as well as AV-I YAG and AV-I OAG by age groups

<table>
<thead>
<tr>
<th>Average values in YAG and OAG</th>
<th>XRBD, M ± SD, HU</th>
<th>XRB, Min-Max, HU</th>
<th>XRBD, 95% CI, HU</th>
<th>Difference in pair, % (p&lt;0.05)</th>
</tr>
</thead>
<tbody>
<tr>
<td>AV-S YAG</td>
<td>1182±278</td>
<td>648-1741</td>
<td>1119-1246</td>
<td>7.6</td>
</tr>
<tr>
<td>AV-S OAG</td>
<td>1099±256</td>
<td>626-1672</td>
<td>1046-1152</td>
<td>7.6</td>
</tr>
<tr>
<td>AV-I YAG</td>
<td>1050±240</td>
<td>518-1782</td>
<td>995-1104</td>
<td>-</td>
</tr>
<tr>
<td>AV-I OAG</td>
<td>1041±243</td>
<td>531-1691</td>
<td>990-1091</td>
<td>-</td>
</tr>
</tbody>
</table>

A comparison of XRBD average values on the healthy side for YAG and OAG, that is, AV-S YAG and AV-S OAG, using the Student's test, revealed a difference at the significance level of p=0.046. At the same time, XRBD average value on the healthy side was 7.6% higher for YAG than for OAG. However, a comparison of XRB average values of the cleft side for YAG and OAG, i.e., AV-I YAG and AV-I OAG, did not reveal a statistically significant difference (p=0.811).

Figure 7 presents the diagram of the range of AV results of XRBD measurements (in HU units) in YAG and OAG: AV-S YAG and AV-S OAG, AV-I YAG and AV-I OAG.

Figure 7. Diagram of the range of AV results of XRBD measurements (HU) in YAG and OAG: AV-S YAG and AV-S OAG, AV-I YAG and AV-I OAG

Applying Scheffe's method of multiple comparisons revealed that the difference between the mean AV-S YAG and AV-I YAG, as could be predicted on the basis of the presented XRBD analysis in YAG patients, is statistically significant (p=0.02).

Discussion

Considering the importance of changes in the structure of bone tissue that occur in the process of adaptive remodeling, determination of X-ray density indicators in children with unilateral CLP using CT of the skull with subsequent 3D reconstruction of images is an important diagnostic criterion in planning surgical and orthodontic interventions.

The use of the Hounsfield scale (HU) allowed to quantitatively assess the degree of morphological changes in dentognathic deformations, which are widespread among children of the younger and older age groups with unilateral CLP with changes in anatomy, architectonics, physico-mechanical and biological properties of the bone tissue on the healthy side and on the cleft side.

The statistical significance of the difference in the XRBD average values in the areas that correspond to the maximum strain under the influence of orthodontic appliances should be taken into account when choosing their activation modes in order to prevent complications and optimize treatment.

Conclusions

The results of measurements in patients of the younger age group at the points at the intersection of the compact plates of the floor of the maxillary sinus and the zygomatic alveolar ridge indicate that the X-ray density of bone tissue is 16.6% higher on the healthy side than at the points on the cleft side; 17.6% higher on the healthy side in the most concave points of the nasolabial buttress; and 14.9% higher on the healthy side at the junction of the compact plate of the hump of the upper jaw and the sphenoid bone. The
zygomatic process of the upper jaw at the level of the zygomatic-maxillary suture is the only site where the results of the comparison of the average values of the X-ray density of bone tissue on the healthy side and the cleft side did not show a statistically significant difference.

A comparison of the average of two independent samples in the older age group at the points of the nasolabial buttress revealed a 12.1% prevalence of X-ray bone density values on the healthy side. A comparison of the average values of X-ray density of bone tissue in the older age group did not reveal statistically significant differences in the results of measurements in pairs of points on the buccal process of the upper jaw at the level of the zygomatic-maxillary suture, at the intersection of the compact plates of the floor of the maxillary sinus and the zygomatic alveolar ridge, as well as at the junction of the compact plate of the hump of the upper jaw and sphenoid bone.

The average value of X-ray density of bone tissue on the healthy side for the younger age group was 7.6% higher than for the older age group. However, a comparison of the average values of X-ray density of bone tissue from the cleft side for the younger age group and the older age group did not reveal a statistically significant difference.

Determination of the X-ray density of bone tissue allows to distribute the magnitude of force impact of orthodontic devices in the process of their activation and to obtain new data on the magnitude of external loads on the jaw bones.

Declarations

Conflicts of interest and financial disclosures
The author declares that he has no conflict percent and there was no external source of funding for the research in question.

Ethical approval
The study was approved by the University ethics committee and was conducted in accordance with the Declaration of the World Medical Association.

Informed consent
Informed consent was obtained from all individual participants included in the study.

Source of funding
The work was not funded.

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4.3.2. Более высокий процент появления ортодонтических паттернов


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РЕНТГЕНОВСКАЯ ПЛОТНОСТЬ КОСТНЫХ ТКАНЕЙ ЗУБОЧЕЛЮСТНОГО АППАРАТА У ДЕТЕЙ С ВРОЖДЕНОЙ ВОДАСТОРОННЕЙ РАСЩЕПЛИННОЙ ГУБЫ И НЕБА

Валерий Филоненко,1 Александр Каниора,2 Андрей Копчак,3 Юрий Кириенко4

1. Кандидат медицинских наук, доцент, заместитель декана стоматологического факультета, доцент кафедры ортодонтии и пропедевтики ортопедической стоматологии, Национальный медицинский университет имени Богомольца, Киев, Украина
2. Доктор медицинских наук, профессор, проректор по научно-педагогической и лечебной работе, профессор кафедры пропедевтики ортодонтии и ортопедической стоматологии, Национальный медицинский университет имени Богомольца, Киев, Украина
3. Доктор медицинских наук, профессор, заведующий кафедрой челюстино-лицевой хирургии и инновационной стоматологии, Национальный медицинский университет имени Богомольца, Киев, Украина
4. Аспирант кафедры ортодонтии и пропедевтики ортопедической стоматологии, Национальный медицинский университет имени Богомольца, Киев, Украина

Абстракт

Актуальность: Физико-механические характеристики костной ткани челюстей, в частности ее плотность, определяют эффективность ортодонтических вмешательств и являются определяющим параметром при расчете сил, действующих на ткани посредством ортодонтических аппаратов. Шкала ослабления рентгеновских лучей Хаунсфилда (HU) использовалась для количественной оценки плотности во время компьютерной томографии.

Цель: Проанализировать рентгенологическую плотность костной ткани верхней челюсти у детей с врожденной односторонней расщелиной губы и неба методом компьютерной томографии черепа.

Материалы и методы: Предметом анализа послужили данные измерения рентгенологической плотности костных тканей верхней челюсти 42 детей в зонах, соответствующих максимальной нагрузке под воздействием ортодонтических аппаратов.

Результаты: Клинически установлено, что среди всех пациентов, включенных в основную группу, случаи с левосторонними расщелинами количество преобладают над правосторонними. Результаты измерений в младшей возрастной группе в точках пересечения компактных пластинок дна верхнечелюстной пазухи и скулового альвеолярного отростка (ZAS и ZAI) свидетельствуют о том, что плотность на здоровой стороне на 16,6% выше, чем на здоровой, расщелина сбоку; на здоровой стороне на 17,6% выше в наиболее вогнутых точках носогубного выступа (NS и NI); и на 14,9% выше на здоровой стороне в месте соединения компактной пластинки верхней челюсти и клиновидной кости (TSS и TS1). Скуловой отросток верхней челюсти на уровне скулово-верхнечелюстного шва (ZAS и ZAI) — единственный участок, где результаты на здоровой стороне и стороне расщелины не показали статистически значимой разницы. В старшей возрастной группе сравнение средних значений двух независимых выборок в точках NS и NI выявило преобладание значений плотности на 12,1% на здоровой стороне. Статистически значимых различий в измерениях в точках ZZS и ZZI, ZAS и ZAI, TSS и TS1 обнаружено не было. При этом средний показатель на здоровой стороне для младшей возрастной группы на 7,6% больше, чем для старшей.

Выводы: Определение рентгенологической плотности костной ткани позволяет распределить величину силового воздействия ортодонтических аппаратов в процессе их активации и получить новые данные о величине внешних нагрузок на кости челюсти.


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