RĪGAS STRADIŅA UNIVERSITĀTE

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MORPHORADIOLOGICAL EVALUATION OF MAXILLARY ALVEOLAR BONE IN DENTAL IMPLANT PATIENTS

Summary of the Doctoral Thesis
for obtaining the degree of a Doctor of Medicine

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CONTENTS

INTRODUCTION

Teeth loss due to various etiological factors has been known since the times of primitive men. Since ancient times there have been attempts to solve this problem as the loss of teeth leads to aesthetic, functional, as well as psychological problems. Edentulous jaws lead to a change of a person's facial features, lowering of facial height and degradation of soft tissue support. Functionally, it is more difficult for a person to digest food; he/she may experience malfunctioning of mandible joint and overloading of masticator muscles.

Alveolar bone atrophy after tooth loss tends to be rapid and irreversible. Atrophic alveolar bone fails to provide a stable support also for removable dentures. Therefore, osseointegration which was discovered in the middle of the past century set the era of dental implantology (Block, 1997). Sometimes posterior maxillary alveolar bone atrophy is very explicit, leaving only about 1 mm thin bone to separate an oral cavity from the maxillary sinus. Such a bone is unable to ensure primary stability for a dental implant. The first maxillary sinus floor augmentation surgery was performed in 1970s (Summers, 1998). Augmentation area of the maxillary cavity floor replaces the missing maxillary alveolar bone. Even though, the period of time since the first maxillary sinus lift surgery is quite considerable, still no conformity of opinions has been reached regarding the best biomaterial to be used for augmentation purposes. Autogenic bone grafts are still considered the "gold standard", though they are not the ideal choice. Synthetic, xenogenic or allogenic bone substitute biomaterials are used more frequently in one– or two–stage surgeries with insertion of dental implants.

In the recent years, three–dimensional imaging has been the most recommended technique for investigations before maxillary sinus lift surgeries with bone substitute biomaterials. Because of its reduced radiation, cone beam computed tomography (CBCT) has become the leading three–dimensional dental radiological imaging method (European Commission, 2012). In post–surgical evaluation of the results, cone beam computed tomography provides broader overview to the surgically treated field, an opportunity to assess dimensions of the augmented area and changes over the time, as well as an interaction with a maxillary sinus.

The study has evaluated patients' CBCT examinations before and after maxillary sinus lift (MSL) surgery with application of different biomaterials. Post–surgical imaging was performed at least one year after surgery, determining dimensions and grey level value of the elevated area. The study has evaluated condition of maxillary sinus at the surgically treated side both before and after surgery, radiologically detectable pathologies and the volume.

1. THE AIM OF THE STUDY, OBJECTIVES AND HYPOTHESIS TO DEFEND, SCIENTIFIC NOVELTY OF THE STUDY

1.1. The Aim of the Study

To provide radiological evaluation of maxillary structures before and after maxillary sinus lift surgeries with bone substitute biomaterials and of dental implantation in the long–term.

1.2. Objectives

1. To prepare literature review on planning of maxillary sinus lift surgery with application of bone substitute biomaterials, implementation of different materials, post–surgical and radiological evaluation of changes of the maxillary sinus.

2. To evaluate pre–surgical linear parameters of the residual alveolar bone of a patient's maxilla and grey level value, as well as to evaluate condition of a maxillary sinus in pre–surgical CBCT investigations.

3. To evaluate post–surgical linear measurements of the lifted site and grey level value measurements, as well as to evaluate condition of a maxillary sinus after sinus lift surgery.

4. To compare and to correlate data obtained from pre– and post–surgical CBCT investigations.

5. To compare results in relation with the use of different materials.

6. To identify effects of biomaterials on the residual bone, as well as changes of the biomaterial / bone hybrid over time.

7. To identify effects of metal artifacts on image distortion.

8. To summarize the results obtained and to elaborate recommendations for planning of maxillary sinus lift surgeries, as well as for radiological evaluation of post–surgical outcomes.

1.3. Hypothesis

1. Maxillary sinus lift surgery with application of bone substitute biomaterials shows no long–term pathological affect on the condition of maxillary sinus.
2. Calcium phosphate–containing biomaterials affect long–term mineralization of the residual alveolar bone.
3. Grey level value of the augmented biomaterial/bone hybrid tends to decrease in the long term.
4. Presence of metal dental implants creates artifacts affecting CBCT image.

1.4. Scientific novelty

1. This was the first in Latvia long–term radiomorphological study of maxillary sinus lift and dental implant patients before and after surgery.
2. The study focused on a complex radiological evaluation of residual alveolar bone and sinus of the maxilla both before and after maxillary sinus lift surgery.
3. Integration of biomaterials and mutual interaction with a patient’s tissue was radiologically evaluated.
4. Biomaterial/bone hybrid changes over time were radiologically evaluated.
5. Impact of maxillary sinus lift surgery on the condition of maxillary sinus was assessed.

2. MATHERIALS AND METHODS

2.1. Study design and study groups

The study included 59 patients/78 maxillary sinuses. During the period from 2008 to 2012 the above patients had undergone CBCT investigations before maxillary sinus lift (MSL) using biomaterials at the Department of Oral and Maxillofacial Radiology of the Institute of Stomatology of Riga Stradiņš University. Nineteen patients (32.2%) had undergone bilateral maxillary sinus lift surgery, but in none of the cases it was executed on both sides simultaneously. Maxillary sinus lift surgeries were carried out at the Clinic of Oral and Maxillofacial Surgery of the Institute of Stomatology. A total of 150 such patients at least one year after MSL surgery were selected for the study. The above mentioned 59 (37.1%) patients, out of 150, were the ones who responded to the invitation and thus were included in the study group. Seventy eight (78) maxillary sinuses which had undergone MSL surgeries with the application of bone substitute biomaterials were defined as research subjects.

The study did not address patient’s general health condition at the time of examination and surgery, as well as the elapsed time between tooth loss and MSL and the smoking factor.

As a control group, from the database of the Institute of Stomatology, were selected 24 patients who underwent placement of dental implants into posterior maxillary alveolar residual bone without maxillary sinus lift operation. Patients were included into a control group if CBCT examinations were performed before and after implantation surgery. In thirteen cases (54.16%), implantation was performed bilaterally; therefore the control group was represented by 37 cases of implants inserted into posterior maxillas.

2.2. Radiological investigations

Radiological investigation for pre–surgical planning and post–surgical evaluation purposes was performed using CBCT device I–CAT Next Generation, Imaging Science, USA, of the Institute of Stomatology.

All patients were investigated following a unified protocol. Patient's jaws were scanned with the following parameters: diameter – 16 cm, height – 13 cm, scanning time – 8 to 9 seconds, power – 120 kV, 5 mA. Images were obtained using 0.3 voxel (three–dimensional image volume unit) size. Images were processed and reconstructed by ExamVision 1.9, KaVo, Germany, software

Before taking measurements, an image was positioned so that the plane of the hard palate is parallel to the floor, while the sagittal plane is perpendicular to the floor. In pre–surgical examinations, the measurements were taken in coronal section, where physiological opening of the maxillary sinus is visible. The following linear measurements were taken: pre–surgical measurements of height and width of the alveolar bone. Measurements were recorded in millimetres (mm). In pre–surgical radiological investigations we determined grey level value of image voxels (VV) at the intended site of MSL.

2.3. Pre–surgical CBCT image investigations

Condition of maxillary sinus was radiologically investigated, determining whether any of the following pathologies are radiologically detectable: mucosal thickening (mm), type of mucosal thickening (no thickenings, basal thickening, circular, irregular, cystic, total shadowing), functionality of physiological opening (functional/obstruction), additional opening (yes/no), *concha bullosa* (yes/no).

Volume of maxillary sinus (mm^3) was also measured before surgery. Sinus volume was measured using Dolphin Imaging 3D (Dolphin Imaging & Management Solutions, USA) software.

2.4. Post–surgical CBCT image investigations

Post–surgical radiological investigations were positioned analogous to those performed before surgery. Linear measurements in millimetres were taken of height, width and length of the maxillary sinus lift site. In five points around the implant: buccally in the bone (BK), buccally in the augmentation area (BAZ), apically (AP), palatally in the augmentation area (PAZ), palatally in the bone (PK) was recorded grey level value VV of the image. In case of a two–stage surgery with maxillary sinus lift followed by insertion of dental implant, measurements were taken at two points in coronal section, in the middle of augmentation area (AZ) and in the bone (K).

After surgery, condition of maxillary sinus was radiologically examined for any radiologically detectable pathologies: mucosal thickening (mm), type of mucosal thickening (no thickening, basal, circular, cystic, total shadowing), obstruction of physiological opening (yes/no), additional opening (yes/no), pneumatised middle turbinate of the nasal cavity – *concha bullosa* – yes/no. Volume of maxillary sinus (mm^3) was also measured after surgery.

2.5. Measurements of the control group

The control group included patients who had undergone radiological CBCT examinations before and after implantation surgery without maxillary sinus lift. Grey level value was determined before surgery (VV) and after surgery in 5 points around the implant – buccally bone side (BKM), buccally bone cranially (BKK), apically (AP), palatally bone cranially (PKK), palatally bone side (PKM). The control group was formed in order to evaluate impact of implants formative artifacts and bone substitute biomaterials on radiologically detectable changes of the surrounding tissue structures.

2.6. Clinical and demographic data extraction methods

The selection criteria were met only by those patients who underwent the second, repeated radiological investigation at least a year after the surgery. Time of the surgery was clarified through surgery registration journal of the Oral and Maxillofacial Surgery Clinic. Entries in those journals revealed patients' demographic data at the time of surgery, location of the surgically treated site and bone substitute materials applied.

2.7. Statistical analysis

Statistical processing of the data was performed using SPSS v.15.0 and Microsoft Office Excel v.11 softwares.

Patient parameters were described by conventional methods of descriptive statistics – summary tables with columns, bar graphs or histograms. Indicators of central tendency (mean, median) and dispersion parameters – standard deviation (SD), standard error (SE), as well as the 25th and 75th percentiles were assessed.

Significance of the test results was evaluated with a 5% statistical probability of errors, therefore, if a p–value was found to be less than 0.05, then test results were found statistically significant.

Difference was assessed by applying several statistical tests – when the proportional data were subjected to normal distribution, then analysis of variance (ANOVA) was used for analysis of quantitative differences between two or more groups, while Student's t–test was used for analysis of differences between two groups. If data were not subjected to normal distribution, non – parametric Mann – Whitney U – test was additionally applied for two – sample comparison or Kruskal – Wallis H – test was used for comparison of two or more samples. Equality of proportional data with normal distribution was determined by Kolmogorov –Smirnov test.

Qualitative difference of patient groups was evaluated by Pearson's chi – square (χ^2) test and the adjusted balances were calculated additionally, while in the analysis of 2·2 tables – Fisher's exact test was used (Bulman, 2000; Altman, 1996).

In order to determine link between variables, correlation analysis was applied. Method for calculation of correlation depended on the variable scale. If variables were measured on linear scale and correspond to normal distribution, relationship was determined by Pearson's correlation test. If one of the variables had the ordinal scale, nonparametric Spearman's rank correlation test was used. Correlation results were interpreted as follows: 0 = no correlation; 0–0.2 = very weak correlation, 0.2–0.5 = poor correlation; 0.5–0.7 = medium correlation, 0.7–0.9 = high correlation, 0.9–1.0 = very high correlation.

Correlation was found as significant when $p \leq 0.05$ (or ≤ 5%). Strength and significance of impact of independent variables was determined by linear regression (Altman, 1996).

3. RESULTS

3.1. Demographic and clinical results

Summarization of demographic data led to the conclusion that out of 78 maxillary sinuses included in the study 51 (65.4%) was female sinus and 27 (34.6%) were male sinuses.

At the time of maxillary sinus lift surgery, the mean age of patients was 50.88 SD ± 9.82 years. The lowest age was 28, but the oldest patient who was included in the study, was 78 years of age at the time of surgery. Mean age of females who were included in the study was 49.39 SD ± 10.16, while the mean age of males was 53.70 SD ± 8.63.

Selection criterion for inclusion of patients in the study was repeated control CBCT imaging at least one year after MSL with application of bone substitute biomaterials. The longest time recorded from post–surgery till CBCT re–examination was 3.92 years. The average time from post–surgery till CBCT re–examination was 2.06 ± SD 0.749 years. No statistically significant differences between genders and the elapsed time until control CBCT examinations were found (ANOVA, $p = 0.984$).

Bone replacement biomaterials included in the study can be divided into three groups: allogenic (Tutogen), xenogenic (Bio–Oss), synthetic materials (hydroxylapatite of RTU; Straumann BoneCeramic; 4Bone SBS). By grouping the cases, the division shows that allogenic materials were used in 9 (11.5%) maxillary sinus lift surgeries, xenogenic materials – in 45 (57.7%) cases and synthetic materials – in 24 (30.8%) surgeries (Figure 3.1.).

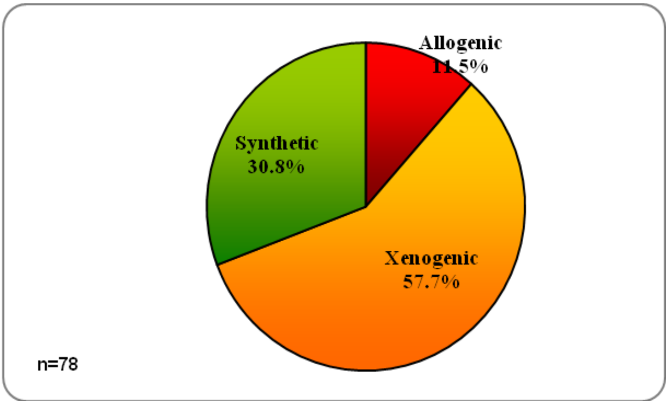

Figure 3.1. Grouping of biomaterials

Intercomparison of the three groups of the biomaterials and the elapsed time until CBCT re–examination showed statistically significant differences between xenogenic material group and synthetic material groups (ANOVA, $p = 0.031$). In the xenogenic group, the mean duration post surgery till the CBCT re–examination was 1.87 SD ± 0.64 years (median 1.75), in the group of synthetic materials – 2.28 SD ± 0.73 years (median 2.13) and in the group of allogenic materials – 2.37 SD ± 1.08 years (median 1.67).

The control group was comprised of 20 (54.1%) women and 17 (45.9%) men with posterior maxillary atrophic outgrowth provided for insertion of dental implants. At the time of surgery, the mean age of the control group was 52.81 SD ± 9.97 years. The youngest patient was 36 years old and the oldest patient was 75 years old. The mean age of females, at the time of surgery, was 55.40 SD ± 11.16 years, while the mean age of males was 49.76 SD ± 7.58 years. No statistically significant differences were observed between the genders (ANOVA, $p = 0.087$).

3.2. Pre–surgical CBCT results

In pre–surgical CBCT imaging, the mean mucosal thickening was determined in mm and it was 3.95 SD ± 4,598 mm (median 3.00). In 28 (35.9%) pre–surgical cases mucosal thickening was not observed at all, 1 mm thickening was observed in 4 (5.1%) cases, 2 mm thickening was found in 5 (6.4%) cases, 3 mm thickening – in 7 (9.0%) cases and 4 and 6 mm thickening – in 6 (7.7%) cases.

Type of mucosal thickening was determined for all maxillary sinuses (Table 3.1.).

Table 3.1

Mucosal thickening type before surgery

Mucosa thickening type	Frequency	Percent
No	28	35.9
Basal	36	46.2
Cystic	7	9.0
Irregular	3	3.8
Circular	4	5.1
Totaly opacified	0	0
Total	78	100.0

In sixty nine (69) (88.5%) out of the 78 sinuses, pre–surgical CBCT imaging showed free, functioning opening. Statistically more frequently, obstruction of physiological opening was observed in the type of circular mucosal thickening (Chi^2 test, $p = 0.001$). In general, pre–surgical examinations showed additional openings in 17 (21.8%) sinuses, while pneumatisation of the middle nasal turbinate – *concha bullosa* – at the surgery site was found in 34 (43.6%) nasal passages.

The mean height of bone was 3.77 SD ± 2,227 mm, the mean width of bone was 7.13 SD ± 2,276 mm (median 7.00), grey scale intensity of bone was 141,08 ± SD 154.280 VV (median 111.5). The comparison of these parameters between the genders showed no statistically significant difference.

Statistically significant positive correlation was found between bone height and bone width before surgery ($r = 0.315$, $p = 0.005$) and statistically significant negative correlation between bone height and bone grey level value before surgery ($r = -0.285$, $p = 0.012$). When analysed these parameters by genders, males showed no statistically significant correlation. Females showed negative correlation between height and bone grey level intensity in their pre–surgical examinations (Spearman's correlation, $r = -0.422$, $p = 0.002$).

The mean grey level intensity of maxillary alveolar bone of the control group before insertion of implant was 165.16 SD ± 139.611 VV.

3.3. Post–surgical CBCT results

In post–surgical CBCT imaging, the mean mucosal thickening was determined in mm and it was 3.95 SD ± 4,637 mm (median 2.50). In twenty two (28.2%) sinuses mucosal thickening was not observed at all. Thickening up to 1 mm was found in 4 (5.1%) cases, 2 mm thickening was found in 13 (16.7%) cases, 3 mm thickening – in 7 (9.0%) cases and 4 mm thickening – in 4 (5.1%) cases.

As compared to pre–surgical examination results, statistically insignificant difference (the Wilcoxon test, $p = 0.642$) was detected. There was also found no statistical difference in mucosal thickening, depending on the group of bone substituting material used in surgery (Kruskal – Wallis H – test, p = 0.197).

Post−surgical examinations showed significant decrease of obstruction of physiological openings in a case of normal mucous membrane, while it tended to increase in a case of circular thickening and in a case of totally shadowed sinus (Chi^2 test, p = 0.001) (Figure 3.2.).

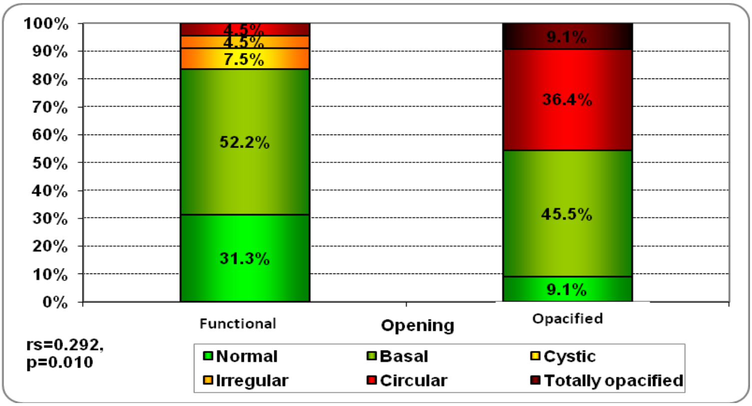

Figure 3.2. Physiological openings functionality and a mucosal thickening type after surgery

Correlation of the condition of the opening with mucosal thickening in post–surgery examinations led to finding positive correlation (Spearman's correlation r = 0.256, p = 0.024).

Identical amount of additional openings – 17 (21.8%) was found both in post–surgical examinations and in pre–surgical imaging.

Pneumatised middle turbinate of nasal cavity was detected in thirty–eight (48.7%) post–surgical cases. As compared to pre–surgical examinations, number of pneumatised turbinates has been increased and the Wilcoxon test showed statistically significant difference (p = 0.025). Spearman's correlation between post–surgical *concha bullosa* and mucosal thickening indicated weak negative correlation between the two readings ($r = -0.271$, $p = 0.017$).

Sinus volume of maxilla was measured in cubic millimetres (mm^3). Pre–surgical mean volume of maxillary sinus was 19030.23 SD ± 6664.577 mm^3, while post–surgical – 16643.12 ± SD 5705.934 mm^3. In both cases the variables comply with normal distribution. Comparing variables with paired t – test, statistically significant difference between sinus volumes before and after surgery ($p < 0.001$) was obtained.

Mean height in post–surgery examinations was 15.92 SD ± 2.900 mm (minimum 10, maximum 22); mean width was 12.91 SD ± 2.569 mm (minimum 8, maximum 19); mean length was 18.79 SD ± 5.097 mm (minimum 5, maximum 33). Comparing sizes of the augmented area between genders, no statistically significant difference was found (ANOVA, $p > 0.005$).

Correlating pre–surgical bone linear readings with linear readings of augmented area, correlation between width and length of the augmented area ($r = 0.396$, $p < 0.0001$) and width and height of the augmented area ($r = 0.332$, $p = 0.003$) was obtained. Correlating bone height and parameters of the augmented area, statistically significant negative correlation between bone height and width of the augmented area ($r = -0.282$, $p = 0.012$) and negative correlated between preoperative bone height and length of the augmented area ($r = -0.415$, $p < 0.0001$) was obtained. Negative correlation between preoperative bone height and width of the augmented area ($r = -0.380$, $p = 0.051$) and bone height and length of the augmented area ($r = –0.603$, $p = 0.001$) was found also in males. In females no correlation was detected.

Comparing size of the augmented area by biomaterials groups used, statistically significant differences were found between them ($p < 0.05$) (Table 3.2).

Table 3.2

Augmented areas parameters in biomaterials groups

Parameters	Biomaterials	N	Mean (mm)	SD
Height	Allogenic	9	14.67	2.828
	Xenogenic	45	17.04	2.730
	Synthetic	24	14.29	2.293
	Total	78	15.92	2.900
Width	Allogenic	9	10.89	2.667
	Xenogenic	45	13.73	2.562
	Synthetic	24	12.13	1.872
	Total	78	12.91	2.569
Length	Allogenic	9	18.33	5.099
	Xenogenic	45	20.44	4.993
	Synthetic	24	15.88	3.993
	Total	78	18.79	5.097

Fisher's Least Significant Difference test showed statistically significant difference between height of the augmented area among xenogenic and allogenic biomaterials ($p = 0.015$) and among xenogenic and synthetic materials ($p < 0.0001$). Width of the augmented area statistically significantly differed between xenogenic and allogenic materials ($p = 0.002$), as well as between xenogenic and synthetic materials ($p = 0.009$). Length of the augmented area statistically significantly differed between xenogenic and synthetic materials ($p < 0.0001$).

Intercomparison of five grey level value measurements using MANOVA test led to finding statistically significant difference between all those five points of measurement ($p < 0.0001$).

During sinus lift surgeries, implants were not inserted into thirteen sinuses – 2–stage MSL with insertion of dental implants on the second stage of the surgery. The obtained grey level measurements of bone (K) and augmented area (BZ) have been batched in the Table 3.4.

Table 3.4

Mean grey level value of bone and augmented in two–stage surgery cases

	K	BZ
N	13	13
Mean	335.38	876.62
SD	278.847	181.905
Median	213.00	891.00
Minimum	−35	614
Maximum	912	1129

In the control group, grey level value of the bone around implant was measured at five points. (Table 3.5).

Table 3.5

Descriptive statistics of grey level measurements of X–ray images in the control group

		BKM	BKK	AP	PKK	PKM
N	Valid	33	37	31	37	N
	Missing	4	0	6	0	
Mean		867.85	817.35	434.87	645.27	908.46
Median		782.00	779.00	384.00	667.00	878.00
SD		357.801	382.190	317.112	275.976	313.512
Minimal		97	–110	–192	91	222
Maximal		1696	1686	1151	1135	1668

In the course of the study, three following groups were formed: control group with dental implant inserted in the maxillary bone (control group); study group without implants, due to two–stage surgery performed; study group with dental implants inserted during the course of maxillary sinus lift. The control group was comprised of 37 individuals, the study group without implants – of 13 individuals and the study group with implants – of 65 individuals. In post–surgical investigation we compared increase of grey level value in all groups. For comparison in the study group with implants, there were selected measurements in PK and BK points; in the study group without implants – in K measuring point, while in the control group – in BKM and PKM measurement points. Increase of grey level value was calculated as follows: in the study group with implants BK it was 994.18 SD ± 336.478 VV, PK 845.55 SD ± 369.285; in the study group without dental implant, at the measurement point K it was 194.69 SD ± 264.768 VV; in the control group at the BKM measurement site it was 697.58 SD ± 369.279 VV, PKM 743.30 SD ± 339.479 VV (Figures 3.3 and 3.4).

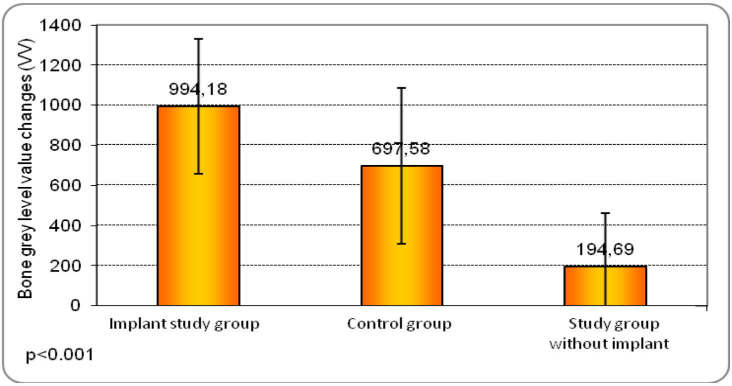

Figure 3.3. Grey level value changes in PK, PKM and K measurement points

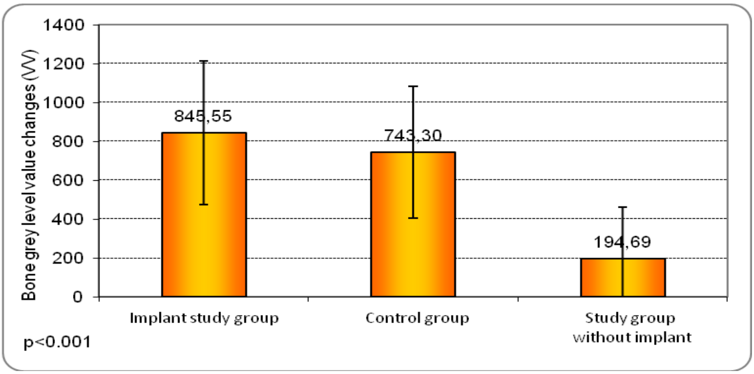

Figure 3.4. Grey level value changes in BK, BKM and K measurement points

Increase of grey level intensity around implant in the control group is clinically unexplainable. Presumably, "fake" increase of grey level values of tissue has been affected by metal artifacts. Similarly we can presume about the explicit increase of grey level values in the study group with implants. Impact of biomaterials on changes in grey level intensity is explainable both clinically and histologically. Presence of biomaterials indicates weak correlation with increase of bone grey levels in BK, K and BKM measurement sites ($r = 0.208$, $p = 0.029$), and no correlation with PK, K and PKM ($r = 0.012$, $p = 0.896$). However, the presence of implants showed correlation close to moderately high correlation both with PK, K, PKM and BK, K, BKM measurements: accordingly $r = 0.458$, $p <0.0001$ and $r = 0.486$, $p <0.0001$.

After obtaining positive correlation data, analysis of linear regression was performed separately for BK, K, BKM and PK, K, PKM groups depending on predicators – biomaterials and implants. Model of linear regression established by BK, K, BKM group proved to be statistically significant and is applicable to practice (ANOVA, $p <0.0001$) (Table 3.6).

Table 3.6

Dependence of grey level value in BK, K, BKM measurement areas on the presence of implants and biomaterials in linear regression

Model	Unstandard coefficient		Stand. coef.	t	p	Colinearity	
	B	Std error	Beta			Tolerance	VIF
1	–101.917	121.188		–0.841	0.402		
Biomater	296.609	73.976	0.316	4.010	0.000	0.944	1.059
Implant	799.492	105.151	0.599	7.603	0.000	0.944	1.059

Presence of biomaterials and implants leads to the increase of grey level values in CBCT images, which are more explicit in BK, K and BKM group. Results of linear regression show that the presence of implants in CBCT images increases grey level value in the bone buccally from the implant by 799.492

VV, while the presence of biomaterials increases grey level value by 296.609 VV. Thus, in order to obtain precise increase of changes in a bone buccally from the implant, which was not caused by implant artifacts, taking measurements of grey level values with CBCT, 799.492 VV should be subtracted from the indicated result.

Model of linear regression formed by PK, K, PKM groups has proved to be was statistically significant and is applicable in practice (ANOVA, p <0.0001) (Table 3.7).

Table 3.7

Dependence of grey level values in PK, K, PKM measurement areas on the presence of implants and biomaterials in linear regression

Model	Unstandard coefficient		Stand. coef.	t	p	Colinearity	
	B	Std error	Beta			Tolerance	VIF
1	92.436	120.897		0.765	0.446		
Biomater	102.257	72.074	0.120	1.419	0.159	0.940	1.064
Implant.	650.862	106.329	0.517	6.121	0.000	0.940	1.064

Presence of implants gives an increase of tissue grey level values on CBCT images also in PK, K, PKM group. Results of linear regression allow to conclude that the presence of an implant in CBCT images increases grey level value of tissues palatally from the implant by 650.862 VV. Increase of presence of biomaterials is statistically insignificant. In order to determine precise increase of bone level palatally from the inserted implants, 650.862 units to be subtracted from grey level measurement obtained from CBCT.

For evaluation of grey level changes in augmented areas of the two research groups, grey level value of biomaterials was subtracted from the mean volume obtained from the post–surgical measurements. Grey level value of biomaterials was obtained by scanning materials originally packed by CBCT (Table 3.8). Tutodent was excluded from the statistical analysis as it was unavailable.

Table 3.8

Biomaterial–determined grey level value

Biomaterial	Grey level value
Bio–Oss	−130
Straumann BoneCeramic	163
RTU HAp/TCP	1434
4Bone SBS	−71

Correlation of the obtained results with the period of time elapsed from lift surgery showed no correlation between the two variables in the study group without implants. In the study group with implants, negative correlation was found in all three (BAZ, AP, PAZ) measurement points with regard to time. Pearson’s correlation was used for analysis and the results obtained are as follows: BAZ $r = -0.509$, $p < 0.0001$, AP $r = -0.274$, $p = 0.0454$, PAZ $r = -0.313$, $p = 0.018$. Comparing correlation data by genders, there were obtained even stronger correlation data in females, while in male group no correlation was found.

Parametric Pearson’s correlation with xenogenic and synthetic material groups after the lapse of time since MSL, negative correlation was found in the group of synthetic materials in all measurement points of augmented area: BAZ $r = -0.573$, $p = 0.003$, AP $r = -0.433$, $p = 0.050$; PAZ $r = -0.393$, $p = 0.050$. In xenogenic material group – only in BAZ point ($r = -0.407$, $p = 0.019$). Due to the small size of the group, allogenic material group was not included in the analysis.

4. DISCUSSION

Oral health status in middle–aged adults has been studied in many European countries. All studies find that the socioeconomic status of an individual is linked to his or her dental health. The wealthier and better educated is a patient; the better is his or her oral hygiene, dental condition and patient's satisfaction with his or her oral cavity both in the sense of functionality and aesthetics. The studies indicate that the skills learned in childhood and the habits regarding oral health maintenance, as well as the socioeconomic situation of the family are key factors in the maintenance of oral health condition throughout life. In countries with higher standards of living, oral health is in better shape throughout life and patients are more satisfied with their dental condition (Shen, 2013; Singh, 2013; Kengne Talla, 2013). In Latvia, dentistry for adult patients is a paid service. Presumably, patients of the study represent the economically secured and educated part of the population of Latvia. Such a survey of patients was not executed within this paper.

Demographic data of the doctoral research group showed that maxillary sinus lift surgeries with bone substitute biomaterials were more frequently performed among female patients. Females In our study were on average slightly younger than the males. These results do not suggest that MSL surgeries for women are more necessary than for men. This rather suggests that women care more about themselves and therefore they more to agree to more extensive surgical manipulations. This is confirmed by studies conducted in Latvia comparing men's and women's oral health condition in middle–aged and elderly patients in nursing homes. Studies showed no statistically significant differences between male and female oral cavity conditions (Vidzis, 2012). Studies conducted in other European countries confirm the fact that women are more concerned about their health (Tseveenjav, 2012; Kengne Tall 2013).

Gender distribution in the control group was practically equal, and the average age was close to the average age of the study groups. In the control group, the average age of women was lower, but the average age of men – higher, however, with no statistically significant difference between the genders.

MSL in the study group was performed using bone substitute biomaterials with calcium phosphates as a key structured element. These were five different materials, dividable into three groups according to their origin: allogenic, xenogenic and synthetic materials. Comparing time from post–surgery to re–examination with CBCT, it was found that the longest time had elapsed in allogenic and synthetic material groups, while the mean time in the xenogenic material group was shorter by about 6 months. This can be explainable by individual competence, views and reasoning of surgeons performing MSL, as well as by patients' preferences, economic considerations and other individual factors. Histological and histomorphological results of evaluation of maxillary sinus lift surgeries, available in the literature, are usually limited to the first 12 months after surgery (Barone, 2013). Long–term studies more often are studies focusing on clinical evaluation of implants (Cavalli, 2012) and radiological studies with no re–intervention in the augmented area. Long–term studies analysing large research groups are also difficult to find due to the fact that selection criteria are hard to meet.

4.1. Radiological findings in the maxillary sinuses

Three–dimensional imaging is the most recommended technique for evaluation of a maxillary sinus. Compared to two–dimensional, conventional imaging, 3–D images allow more accurate evaluation of pathologies (Nemec, 2009). The European Position Paper on Rhynosinusitis and Nasal Polyps issued by the European Academy of Allergology and Clinical Immunology indicates that radiological examinations should be carried out only in cases where clinical findings are suspicious or applied therapy has proven to be infective (Thomas, 2008). Also, this paper states that conventional radiological methods for visualization of the maxillary sinus are ineffective.

In our study we used three–dimensional imaging, which is the most accurate imaging method for the visualization of maxillary sinuses. Radiologically assessable changes of the maxillary sinus were mostly related to the changes in Schneider membrane. Thickening of maxillary mucous membrane was measured in millimetres in coronal sections of CBCT image. In twenty–eight sinuses mucosal thickening was not found at all. In sixteen sinuses mucosal thickening was found in one to three millimetre ranges. We can allege that mucosal thickening in 44 sinuses or 56.4 % was within the normal range. This is the case if we assume that mucosal thickening up to 3 mm is considered as norm. Literature shows no consensus about how many millimetre mucosal thickening should be considered as normal. The number varies between 1 to 5 millimetres. Similar results of mucosal thickening measurements can be found in the literature. The study where thickening from 2 mm was viewed as pathological, such a thickening was found in 60.62% of patients (Shanbhag, 2013). The literature points out mucosal thickening as the most common radiologically detectable pathology of the maxillary sinus (Ritter, 2011). The study where retrospectively were surveyed 500 patients and thuswise 1000 maxillary sinuses, 3 mm margin was set as the criterion for pathological mucosal thickening before maxillary implantation surgery. Mucosal thickening over three millimetres was found in 62.6 % cases (Lana, 2012). In our study, the most common radiologically detectable pathology of the maxillary sinus was mucosal thickening with percentage that did not much differ from the data of similar studies available in the literature. One might assume that mucosal thickening depends on smoking, season, periodontal condition or time elapsed from tooth extraction. However Janner et al (Janner, 2011) has found no such a relationship. The authors found statistically significantly thicker mucosa membrane in male patients and in cases where periapical changes were found in neighbouring teeth. Mucosal thickening is also more common in patients over 60 years of age (Lu, 2012). In the retrospective radiological study, mucosal thickening was found in 25.1% of cases, while cystically thickened mucous membrane was found in 5.75% of cases (Gracco, 2012). They also found statistically significant difference between male and female patients. Cystically thickened mucous membrane was found in males almost twice as often as in female patients and radiological changes in the maxillary sinus were more common in patients aged 40 to 60. The study included 258 patients. Our research group was smaller which could explain the reason why no statistically significant difference was found between the genders. Post–surgical radiological imaging showed mucosal thickening similar to pre–surgical findings, which may suggest that in long–term the MSFL surgery does not affect the condition of maxillary sinus. Post–surgical imaging showed mucosal thickening similar to pre–surgical findings suggesting that MSL surgery has no long–term affect on the condition of maxillary sinus. One patient after surgery showed completely shadowed sinus which radiologically indicates acute sinusitis. However, it might have had different cause, such as mucocele that completely opacifies maxillary sinus. Therefore, in the present case, etiological factor of the sinus obscuration should be evaluated. Completely shadowed sinus is visible also in the case of perforation of the Schneider membrane, while in this case symptoms would have been observed immediately after surgery. More often, acute post–surgical change is swelling of the Schneider membrane – a temporary phenomenon which disappears shortly after surgery. Studies show that such a swelling disappear within one to four weeks after MSL using bone substitute biomaterials, and the swelling affects entire sinus membrane, rather than just surgery site (Quirynen, 2012). Statistically more often, inflammations (including belated one) of maxillary sinus are found in cases where patients in pre–surgical imaging show maxillary sinus inflammations or mucosal thickening (Manor, 2010). Thickening of the sinus mucous membrane is also more often in patients with asthma (Tezer, 2006).

Studying 3–D images of orthodontic patients, Pazer et al (Pazer, 2011) found that the most frequent asymptomatic and random radiological finding in the maxillary sinus is basal mucosal thickening. It was found in 23.7% of cases of their study. While, cystic thickening of mucous membrane was found in 19.4% of cases. Since this study analyzed radiological investigations of orthodontic patients, this could explain slight difference from the results of our study. The above mentioned study showed no statistically significant link to the season when radiological imaging was performed (Pazer, 2011).

Type of the mucosal thickening of the doctoral research was determined as impact on functionality of physiological opening of the sinus may vary in different types (Carmel, 2011). The authors of the research indicate that the obstruction of the opening of maxillary sinus is more often in cases of circularly, irregularly and completely shadowed sinuses. In our study, circular, irregular mucosal thickenings and completely shadowed sinuses were found rarely, and pre–surgical imaging showed sinus obstruction in case of basal mucosal thickening more often than in case of circularly thickened mucous membrane. It should be noted that before surgery, obstruction of physiological opening was found only in 9 sinuses. In post–surgical CBCT examinations, obstruction of the opening was also rare. Obstruction was found only in 11 cases. Post–surgical examinations with CBCT showed increased number of those obstructions that were found in case of circularly thickened mucous membrane and completely shadowed sinus. Type of mucosal thickening did not depend on the biomaterial used in MSL surgery. Post–surgical investigations revealed weak correlation between mucosal thickening and obstruction of physiological opening of the maxillary sinus. That means – the greater is the mucosal thickening in post–surgery examinations, the more often obstruction of sinus opening was observed. Both signs – obstruction of the opening and mucosal thickening are considered as radiological signs of chronic rhynosinusitis indicating inflammatory process at the time of the examination. Investigations were conducted at least a year after surgery, which, however, indicates that the inflammatory process has been triggered by some other cause, for example, a virus.

Pneumatisation of middle nasal turbinate or *concha bullosa* is considered a risk factor of inflammatory pathology of the maxillary sinus. Large pneumatised turbinates can narrow or block opening of the sinus accordingly obstructing drainage of the sinus (Farina, 2010). However, retrospective examinations of CT images of 1095 patients showed no link between *concha bullosa* and radiological finding of maxillary sinus sinusitis. It is considered that physiological mobility of epithelial cilia which is lining sinuses is the key factor in prevention of sinusitis. Anatomical variations, such as *concha bullosa*, are not considered to be predisposing factors (Tsai, 2012). In our study, number of pneumatised turbinates increased in post–surgical investigations. Subjectively their size also increased. Weak negative correlation was also found between *concha bullosa* findings and mucosal thickness in millimetres, which means that in case of finding of *concha bullosa* in post–surgical examinations, less thickened mucous membrane was found, which runs contrary with the assumption pneumatisation of turbinate can impede drainage of the sinus and contribute to the inflammatory process. Finding of our study confirm that *concha bullosa* has no negative impact on physiological drainage of the sinus and pneumatised middle nasal turbinate is not a predisposing factor of maxillary sinus inflammation.

Volume of maxillary sinus was measured both in pre–surgical and post–surgical investigations. Statistically significant differences were found between the two measurements. Drop of post–surgical volume is statistically significant. In our study, the median maxillary cavity volume before and after surgery slightly differed from the data available in the literature, where the mean volume is stated as 15700 ± 5300 mm^3 (Sahlstrand – Johnson, 2011), while in another study, (Deeb, 2011) sinus volume was 24100 ± 9700 mm^3. The difference could have arisen due to different methods applied for determination of volume. We were unable to locate any study in the literature revealing estimation of maxillary sinus volumes before and after floor lift surgeries using Dolphin Imaging software. In addition, patients of our study were with missing teeth, where, probably, were not just atrophic alveolar overgrowths, but also pneumatised maxillary sinuses, thus increasing volume of the sinus. The doctoral study found no difference between volumes of male and female maxillary sinuses. Presumably, this also was caused by the loss of teeth, different age groups and different methods for taking measurements (Vidya 2013). Although volume differences between the two of our measurements are statistically significant, the mean indices in both cases are close to the norm. This suggests that the augmentation surgery have resulted in no significant change of maxillary sinus volume and no change in its homeostasis.

4.2. Alveolar bone and maxillary sinus floor augmentation area measurements

Pre–surgical imaging identified bone dimensions at the site provided for augmentation. No statistically significant difference was found between genders regarding residual bone height and width readings. Measurements of bone grey level value in the pre–surgical site also showed no statistically significant differences between the genders. The study group showed statistically significant correlation between bone height and width, which means, the higher is the alveolar bone, the wider the bone is. It is found that in cases of lower residual bone, perforation of the Schneider membrane is observed more often (Deepthi, 2012), which is explainable by thinner bone and smaller cavities. In our study, no such links were found.

The negative correlation between bone height and grey level value of a bone indicates that the higher residual bone has lower grey level. Grey level value decreases because radiation is retained less. Denser objects are better radiation retainers. Higher residual alveolar bone has lower grey level value which indirectly suggests that such a bone has lower density. Dimensions of residual alveolar bone are likely to remain higher as teeth extraction has been performed relatively recently. This would also explain the fact why bone density, which is radiographically visible as reduced bone shadowing, is lower. Interestingly, when correlating grey levels and bone height, negative correlation recurred in females, while in males it was not detected. However, comparison of bone pre–surgical height, width and grey level with biomaterials used in surgery, no differences were found. Presumably, surgeons tend to follow other prerequisites regarding selection of bone substitute biomaterials in the process of planning MSL surgeries.

Literature data show that MSL with application of bone substitute materials has been chosen in cases where height of the residual alveolar bone is reduced disabling to cover the length of the implant. Uncovered implants in maxillary sinus may cause mucosal thickening and also inflammatory processes in the sinus (Jung, 2007). Depending on the bone height, one may choose dental implantation simultaneously with maxillary augmentation or implantation as a second surgery approximately 6 months after augmentation. The data indicate that no dental implantation and augmentation diminish implant osseointegration even in cases of explicit bone losses (Fenner, 2009). The authors indicate that opting for two–stage surgery when bone height is less than 5 mm is not scientifically justified. In addition, the second, repeated surgery increases the risk of the maxillary sinus inflammation (Manor, 2010). A small residual bone height is not a risk factor for consolidation of the site augmented by the bone tissue substitute biomaterials and osseointegration of dental implant (Avila – Ortiz, 2012). On the other hand, primary stability is the prerequisite for a successful osseointegration of the dental implant, which is determined not only by height and width of the residual alveolar bone, but also by its density.

Taking linear measurements in the augmentation area, positive correlation was obtained between the width and the length and the width and the height of the augmentation area. Correlation of parameters of the augmentation site with pre–surgical readings showed that lower bone height leads to creation of higher and wider augmentation site of maxillary sinus floor. It is understandable that in cases of small amounts of bone, when an adequate amount of material is needed to cover and to support an implant vertically, it is necessary to have an adequate width horizontally. Therefore contact with the bone gets increased, which improves blood supply to the augmentation area ensuring cell migration and stable formation of biomaterial/tissue hybrid. Sagittal dimension of the augmentation site, which is visible in readings as length of augmentation site, is dependent both on the height and width of the augmentation site and on number of dental implants planned. Similar study showed that the volume of the augmented area increases with the increase of the height of the augmented area (Krennmair, 2006), which coincides with findings of our research. As it was found in the above study, the increase of height of the augmented area by 5 mm, volume of the zone doubles.

Comparing linear parameters of the augmented area separately between the groups of biomaterials used in study, it can be concluded that largest biomaterial/tissue hybrids were radiologically visible specifically in xenogenic material group. Xenogenic materials group was comprised only by Bio–Oss, Geistlich Biomaterials, Switzerland. Data available in the literature indicate that the resorption of Bio–Oss granules is slow or unobserved at all (Tadjoedin, 2003). Histological evaluation of tissue of the augmented area from the study where the tissue were harvested both 6 months and 11 years after MSL surgery using Bio–Oss, showed that, although the biomaterial granules were well integrated into the newly formed bone, no changes of sizes in both histological investigations were observed (Mordenfeld, 2010). This could explain the largest bone – hybrid zones found. Re–examination in xenogenic material group was performed relatively earlier than in other groups, therefore xenogenic material group was shorter exposed to potential resorption, remodelling and pressure of the maxillary sinus re–pneumatisation. Not to mention that the surgeon's individual surgical tactics can add to dimensions of xenogenic augments.

In cases of application of synthetic materials in MSL, all linear parameters of augmentation area differed from linear parameters of xenogenic material group. As mentioned above, materials of the xenogenic group show biocompatibility (Ramirez – Fernandez, in 2013 (1)) while re–sorption and re–modelling is weak or unobserved at all. Synthetic material group was given a longer time for integration and resorption. In addition, it is found that remodelling of the area augmented by synthetic materials occurs within first six months and its decrease may reach up to 20% (Kuhl, 2013), which can be explained by both the healing and remodelling processes and the initial resorption of biomaterials.

4.3. Grey level value of the bone and the augmented area measurements

Grey level value mirrors ability of tissue or a material to retain x–ray photons, to alter their direction or energy. The denser is tissue or a material, the greater is their ability to alter quality of x–ray beam. In radiological image it is visible as brighter image – a shadowing. In turn, lower–density tissue and a material is visible in an image as darker image – lighting. Thus, grey level intensity is higher when more X–ray photons are retained or altered, which, in turn, means that the tissue or a material has higher density. In our study, grey level value around the implant was determined in five points in order to compare the results of MSL according to the different materials used, their impact on the residual bone, as well as changes over time, determining dynamics of radiological changes in regard to biomaterials applied. Thus, it was found that synthetic and xenogenic materials and bone/hybrid in the augmented zone show higher grey level compared to allogenic materials. For comparison, we performed CBCT imaging of a sterile packages of biomaterials and determined their grey level values. The highest grey level value was found RTU synthetic hydroxylapatite granules, which, with a significant difference, was followed by other materials. Xenogenic Bio–Oss showed the second lowest grey level value, which was lower than grey level value of water. To exclude impact of packaging and the amount of material on the measurement results, all biomaterials were re–examined by CBCT and this time all the biomaterials, at identical amounts, were placed in identical containers. In case of Bio–Oss, we need smaller amount and also mass to fill up the container compared to Straumann BoneCeramics and RTU synthetic hydroxylapatite. Re–examination of grey level value of both Straumann BoneCeramics and RTU synthetic hydroxylapatite showed similar results to the previous ones. In case of Bio–Oss, grey level value dropped even more reaching 400 VV. Decrease of value in the re–examination, as well as the low grey value in the first imaging we explain by a number of factors. The required smaller quantity of Bio–Oss material indicates that Bio–Oss granules *in vitro* do not sit tightly to each other. This may be affect by the irregular shape of granules, which tend to form lots of free space. It is observable also in microscopic images of materials (Fig. 4.1.), where 2.5x magnification shows macroporosity of granules and surface irregularities. Bio–Oss granules have irregular structure with many small internal ductuli as in a natural trabecular bone. Bio–Oss material *in vitro* contains lot of air between and inside the granules, and, presumably, due to lengthy keeping in an original packing, pellets were settled more compact.

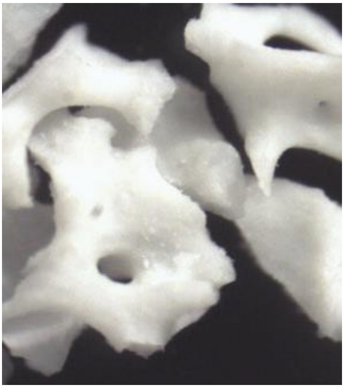

Figure 4.1. Microscopic image of Bio–Oss granules (bictel.ulg.ac.be)

This explains the low grey level value of the material which in the original packaging with higher weight was higher. In post–surgical examinations, canals filled with granular air and the free space between granules initially are filled by blood and later by connective tissue and bone tissue. In addition, wetness helps to form more compact mass, where granules sit closer to each other. Therefore, post–surgical evaluation of grey level value of the biomaterial/tissue hybrid shows substantial increase of the grey level value.

Straumann BoneCeramic is a synthetic biomaterial. Microscopic image shows that the granules sit relatively close to each other; macropores and crystal–like structure of granules are visible (Fig. 4.2).

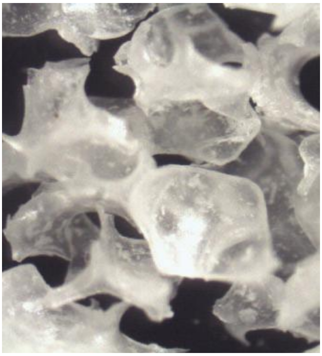

Figure 4.2. Image of Straumann BoneCeramic granules (bictel.ulg.ac.be)

Hydroxylapatite is a synthetic biomaterial with the surface pattern and internal structure microscopically less explicit compared to Bio–Oss (Figure 4.3).

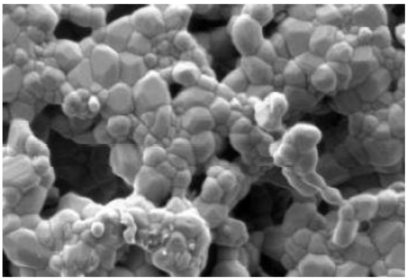

Figure 4.3. Image of RTU hydroxylapatite granules (Salma, 2009)

Presumably, grey level value of biomaterials *in vitro* depends on the granular form and the internal and external structures.

In the study group without inserted dental implants simultaneously with MSL surgery, grey level value was determined before and after surgery. Post–surgical imaging showed increase of grey level value in residual bone by an average of 200 VV, suggesting greater ability of the bone to retain x–rays. This indirectly indicates increasing density of the residual bone. Such an increase can be explained by increase of mineralization of the residual bone resulting through mutual interaction between the bone and the augmented biomaterial. Such a relationship was found and patented by the Patent LV14171of the Republic of Latvia (B) (Skagers, 2010). The enduring researches analysing the atrophic maxillary bone and the adjacent augmented area resulted with the conclusion that mineral density in the area of biomaterials decreases over years, but in the atrophic maxillary alveolar bone – increases. Similar conclusions on increase of bone mineralisation and diffusion of calcium ions both in the residual bone and in the newly formed bone were found by other authors though histological researches (Kuhl, 2012; Ramirez – Fernandez 2013 (1) Ramirez – Fernandez 2013 (2)). These histological studies were able prove the above findings in a short post–surgical time, respectively, five and nine months after surgery. Therefore, presumably, gradual increase of grey level value in the residual bone in our study indicates an increase of bone mineralisation. Alike research with a smaller group resulted with a similar conclusion (Neimane, 2012).

When x–ray beam passes through dense tissue and materials, there is where beam hardening manifests. This means, when the beam passes through metal, e.g. implant, part of beam–forming photons with lower energy gets absorbed and redirected (Schulze, 2011). The created artifacts can alter measurements of the bone grey level value and also distort the image (Figure 4.4). Artifacts can be visible in all its dimensions around the dense object.

Figure 4. 4. Coronal section of CBCT. The arrows mark artifacts from beam hardening

In order to determine existence of such alterations and their impact on grey level value, we selected, from the database, a control group of patients with dental implants inserted in the maxillary alveolar bone without application of bone substitute materials. Post–surgical grey level value in the control group in all measurement sites has increased in comparison with pre–surgical measurements. In order to estimate the true impact of artifacts created by the implant and bone substitute biomaterial on the residual bone, we compared three groups: the control group, the study group with implants and the study group without implants. The control group showed increase in bone measurements on both sides in coronal section at the bone side by an average of 700 VV and came nearer the results of the study group with implants. There the increase was found on an average by 900 VV. The most minor alterations were found in the study group without implants. Correlation analysis showed that the presence of an implant affects the grey level value of the implant in the area of the residual bone both buccally and palatally. Clearly, such a relationship cannot be caused by physiological affect of the implant onto the surrounding tissue. Most likely they manifested due to distortion of an image caused by alterations of the x–ray beam and beam hardening. Linear regression resulted in finding that, due to artifacts created from the implant, when measuring grey level value of the residual bone, on average of 800 VV (799, 492 VV) in buccal bone and on average of 650 VV (VV 650.862) palatally are to be subtracted from the volume produced by the device. Therefore, in order to accurately determine grey level value of the residual bone, the above mentioned volumes are to be subtracted the result produced by the device, accordingly separating image distortions caused by interactions of the implant and x–ray beam and obtaining the true grey level value.

Biomaterials affect grey level value of the residual bone buccally from the implant. Linear regression showed that biomaterials affect increase of grey level value of the buccal residual bone side by on average of 300 VV (VV 296.609). Such an increase of bone grey level value is caused by increase of bone mineralisation. The possibility of impact of artifacts from biomaterials is small given the low grey level value of the materials themselves and the fact that no convincing image distortions were found. Data available in the literature confirm increase of residual bone mineralisation after MSL with calcium phosphate–containing materials (De Lange, 2014; Ramirez – Fernandez, in 2013 (1) Kuhl, 2012).

Grey level value of bone substitute materials in the augmented area later shows negative correlation between all three measurement sites in the augmented area. Therefore, over time it tends to change in the augmented areas. There are histological and histomorphological studies were resorbtion and replacement of biomaterials with tissue takes place (Handschek, 2009; Soardi, 2011, Wagner, 2012). Interestingly, that comparison of correlations between the genders showed that among men no correlation was detected, while among women strength of the correlation increased.

When comparing grey level value between synthetic and xenogenic materials, no correlation was found for the last ones. While in the group of synthetic materials, decrease of the grey level value was observed over time. Presumably, resorption of synthetic materials occurs over time and is detectable also through radiological imaging. Granules of synthetic materials resorbe and gets replaced by body's tissues with lowered density. Remodelling and formation of a new bone more actively occurs in MSL with synthetic materials (De Lange, 2014).

5. CONCLUSION

1. Maxillary sinus lift surgery has no long–term affect on radiologically identifiable functionality of the maxillary sinus and it homeostasis remains unaffected.
2. Pneumatisation of the middle nasal turbinate – *concha bullosa* – is not a predisposing factor in the inflammatory pathology of the maxillary sinus.
3. Obstruction of the physiological opening of the maxillary sinus more often is observed in cases of circularly thickened mucous membrane in the sinus, completely shadowed sinus, as well as in cases of greater mucosal thickening.
4. The maxillary residual alveolar bone with a greater height has usually greater width with lower grey level value.
5. Height of the residual maxillary alveolar bone is a predominant factor for the size of the augmented area. When pre–surgical imaging shows lower height of the alveolar bone, than maxillary sinus lift surgery covers dimensionally larger area. Such an augmented area visualises greater height, width and length.
6. The largest dimensional parameters of the augmented areas were observed in cases of surgeries with application of xenogenic material.
7. Titanium dental implant alters CBCT images due to beam hardening and reflection caused by artifacts. Size of artifacts in the residual palatal bone is 650 VV, in the residual buccal bone – 800 VV.
8. In the long term, bone substitute biomaterials affect mineralisation of the alveolar bone. Bone mineralisation tends to increase by 200–300 VV of grey level value units.
9. Grey level value of the biomaterial/tissue hybrid of the augmented area tends to decrease over time.

6. PRACTICAL RECOMMENDATIONS

1. Cone beam computed tomography is an optional imaging technique in planning maxillary sinus lift surgery and in evaluation of long–term results.
2. When planning maxillary sinus lift surgery, height and width of the maxillary residual alveolar bone must be radiologically evaluated in order to foresee amount of the required biomaterial.
3. Condition of the maxillary sinus must be evaluated before surgery. Mucosal thickening, obstruction of the physiological opening and inflammations or signs of other diseases are considered as temporary contraindications to surgery.
4. Since the maxillary sinus lift using bone substitute biomaterials do not deteriorate condition of the maxillary sinus in the long term, than in the case of negative finding, one must evaluate probability of other diseases or complications in the augmented area.

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8. RESEARCH PUBLICATIONS AND REPORTS

8.1. Scientific research papers

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8.2. Scientific research abstracts

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