RESEARCH PAPER

Study of Distracted Bone in Maxilla: A Comparative Analysis

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Abstract

Introduction Anterior maxillary distraction is one of the accepted modalities to treat hypoplastic maxilla. The study was undertaken to assess the maturation of the bone formed, which is measured by analyzing the amount of mineralization of the bone.

Materials and Methods For the study 29 patients were chosen, who were divided into three groups. First group consist of patients who had undergone distraction osteogenesis. Second group has cleft patients and third group is the control group. A bone biopsy using trephine drill is obtained from the subjects. This sample is subjected to Fourier transform infrared spectroscopy (FTIR).

Results From the results a mineral to matrix ratio is obtained which is then compared between the three groups. There is a statistically significant difference between the mineralization of the three groups. The distracted bone shows the lowest mineralization while mineralization of the cleft bone is also less than the normal bone.

Conclusion The study conclusively establishes that the distracted bone is not as mineralized as the normal bone. Although functionally the distracted bone is as good as the native bone and grafted bone as proved by the success rate of the implants placed. The study also highlights the use of FTIR for assessing the bone quality.

Keywords Distraction osteogenesis · Anterior maxillary distraction · Bone quality · FTIR

Introduction

Distraction Osteogenesis (DO) is the promotion of new bone formation by gradual, controlled and rhythmic application of force. The technique was first reported by Codivilla in 1905 but became widespread after the extensive studies published by Ilizarov [1].

The first reported use of DO in the management of craniofacial defect was by McCarthy in 1992 [2]. He treated a series of patients with congenital mandibular defects with DO. Following this there have been various reports of using DO is various cranio-maxillofacial defects [3–7].

Distraction Osteogenesis is said to be a very different form of fracture healing [8]. An objective analysis of the mineralization of the bone, post distraction is still lacking. The amount of mineralization indicates the relative maturation of the bone. This can be effectively measured using a spectroscopic analysis of the bone [9]. Fourier transform infrared spectroscopy (FTIR) is a technique which is used to obtain an infrared spectrum of absorption, emission, photoconductivity or Raman scattering of a solid, liquid or gas. This FTIR can be effectively used in the qualitative analysis of the maturation of the bone by measuring the distinct infrared absorption at the carbonated hydroxyapatite and collagen regions.

In this study the authors have compared the mineralization of the distracted bone in anterior maxilla with bone from corresponding region in cleft patients and normal patients.

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Aims and Objectives

1. To objectively analyze the quality of bone after anterior maxillary distraction.
2. To analyze the efficacy of trephine drill bone biopsy and spectroscopy in analyzing the quality of bone.
3. To assess the quality of bone in terms of mineralization in cleft patients.

Materials and Methods

The study population consists of patients reporting to the center. Ethical clearance has been obtained from the institute ethical committee.

The subjects were between the 18–22 years who were divided into three groups. The first group consisted of patients who had undergone an anterior maxillary distraction (AMD) for hypoplastic maxilla following primary cleft lip/palate repair. The second group had patients with cleft lip and palate but distraction was not performed. Third group was the control group in which the patients had no cleft or any other craniofacial anomalies. Nine patients were included in first group and ten each in second and third group.

AMD involves an anterior maxillary osteotomy which commences from the pyriform aperture connected to a vertical cut in the premolar region. In addition to this, lateral nasal osteotomy and septal osteotomy are performed. This is followed by down fracturing, mobilizing the anterior maxillary segment and placing an indigenously fabricated tooth borne appliance based on a Hyrax screw. After a latency period of six days the appliance is activated with two and a half turns per day. The distraction is carried out until the desired advancement is achieved. The appliance is then left in situ for a consolidation period of three months.

The amount of bone sample required is very minimal for spectroscopic analysis and a very small sample is sufficient for the analysis. A 3.0 mm diameter trephine drill was used to collect the bone samples from the patients in group I [Fig 1]. This was done in patients who were indicated for implant placement in the edentulous area formed after distraction was done. These samples were taken after a time period of one year post consolidation (Figs. 2, 3, 4, 5, 6, 7).

Bone samples from group II were collected while the patients underwent any major surgery which involved raising a flap. This includes late alveolar bone grafting, orthognathic surgeries and in some cases extraction. Bone samples were collected from the first and second premolar region either using the trephine drill or from the bony spicules obtained during the osteotomy.

Fig. 1 Trephine drill

Fig. 2 Pre op

Bone samples from group III were collected from patients who were indicated for extraction of upper 1st and 2nd premolar where bone filing was done post extraction to smoothen the sharp spicules.

Fig. 3 Post op

Fig. 4 Pre op lateral ceph

The samples were collected and preserved in formalin solution. Before spectroscopic analysis the samples were taken out and dried. These were then powdered and 50 mg of the sample was used for the analysis. The quantity of the sample bears no significance as the analysis is done on the quality of the sample.

Fig. 5 Post op lateral ceph

Fourier Transform Infrared Spectroscopy (FTIR) is a very good tool to characterize the bone matrix as its main components, carbonated hydroxyapatite and collagen, absorb infrared radiation at distinct, almost complimentary regions within the $500\text{--}400\text{ cm}^{-1}$ range [10].

The proportion between the mineral and organic content in the bone expresses its degree of mineralization and can be calculated from the ration of the integrated area due to phosphate bands (usually in the $900\text{--}1200\text{ cm}^{-1}$ region) to that of an amide band (Amide I in the $1600\text{--}1700\text{ cm}^{-1}$ region). This ratio gives a good idea about the maturation of the bone [10]. A higher ratio indicates increased mineralization and hence more maturation.

Results

A bone biopsy was performed on the patients and the sample was obtained. The samples are evaluated using spectroscopic analysis (Figs. 8, 9, 10). From the results a mineral to matrix ratio is obtained (Table 1). These ratios give an objective measurement of the bone mineralization. These values are compared between the groups. The values are checked for their statistical significance using ANOVA test (Table 2).

Fig. 6 Pre op OPG **Fig. 7** Post op OPG **Fig. 8** Distracted bone spectroscopy graph

Fig. 9 Cleft bone spectroscopy graph **Fig. 10** Normal bone spectroscopy graph **Table 1** Mineral to matrix ratio

Sl. no.	Group 1 (distracted)	Group 2 (cleft)	Group 3 (normal)
1	1.16	1.73	2.1
2	1.4	1.65	2.7
3	1.2	1.51	2.5
4	1.4	2	3
5	1.21	1.3	2.4
6	1.3	1.5	3.1
7	1.18	1.32	2.2
8	1.2	1.8	2.8
9	1.1	1.43	3.32
10		1.5	2.2

Post Hoc Tests

The ratios show low mineralization for the distracted bone than the cleft bone and the normal bone. There was a statistically significant difference between groups as determined by one-way ANOVA ($F(2,26) = 62.898$, $p < .005$). A Bonferri post hoc test (Table 3) revealed that groups are statistically significantly different. The statistical analysis of the mineral to matrix ratio shows a significant difference between the three groups. This is in not in accordance with the hypothesis of the study which stated that the distracted bone is comparable to the normal bone.

Table 2 ANOVA test

ANOVA					
VAR00001					
	Sum of squares	Df	Mean square	F	Sig.
Between groups	10.231	2	5.116	62.898	.000
Within groups	2.115	26	.081		
Total	12.346	28			

Table 3 Bonferri post hoc test

Multiple comparisons						
Dependent variable: VAR00001						
Bonferroni						
(I) Group	(J) Group	Mean difference (I–J)	SE	Sig.	95% Confidence interval	
					Lower bound	Upper bound
1	2	1.05800*	.12754	.000	.7316	1.3844
	3	1.39311*	.13104	.000	1.0578	1.7284
2	1	–1.05800*	.12754	.000	–1.3844	–.7316
	3	.33511	.13104	.050	–.0002	.6704
3	1	–1.39311*	.13104	.000	–1.7284	–1.0578
	2	–.33511	.13104	.050	–.6704	.0002

* The mean difference is significant at the .05 level

Discussion

It was McCarthy who first used this technique for craniofacial deformities wherein lengthening of mandible was performed by gradual distraction on young patients. His experiments showed that DO can be used as a viable alternative for the treatment of craniofacial deformities. Prior to that only osteotomies and bone grafts were the treatment modalities available which had their own inherent complications.

Traditionally radiographs were used to assess the quality of the distracted bone. Assessment is done by measuring the amount of new bone formation seen in the radiographs before and after distraction, also by comparing the trabecular pattern with the normal bone of the same area [11–13]. Radiographic assessment still remains the time tested method to analyze the quality of the distracted bone. Although this method is quite simple and easy, it is subjective and may be biased to operator errors. So an objective method to assess the quality of the bone is essential.

The histological aspects of the distracted bone have been studied extensively in animal models and mandibles in humans, mostly for vertical distraction of the alveolar ridge while placing implants [14–17]. The reason for low number of such studies in maxilla may be attributed to the fact that in maxilla the osteotomy cuts are placed either in the third

molar region or in the pterygomaxillary area where occlusal rehabilitation is not indicated. Histological analysis was not done in our study as we collected only a lesser sized sample which was deemed inadequate for the same.

In CLP patients with severe maxillary hypoplasia DO appears to be superior to conventional orthognathic surgery [18]. Anterior maxillary distraction (AMD) is a viable option in such patients considering the disadvantages of other systems. RED and internal distractor systems are also expensive when compared to the relatively inexpensive AMD. Besides, the appliance for AMD is easy to fabricate and offers better patient compliance [19].

The bulk of the new bone formed after performing an AMD is in the alveolar ridge which retains the buccopalatal dimension at the premolar region (Figs. 4, 5, 6, 7). As one goes cranially the alveolar bone forms the floor of the maxillary antrum. Here the distracted bone is formed along the thin walls of the antrum. Hence we concentrated our study to the new alveolar bone formed after distraction. Some authors reported a relapse or resorption of the distracted bone in vertical distraction of the alveolar bone [20]. They advocate an over correction of 20% to overcome this reduction of vertical height.

Post distraction, the patients have an edentulous alveolar ridge in the maxillary premolar region which has to be rehabilitated. The patients we chose were to be rehabilitated by dental implants. A bone biopsy was performed at

the location using a trephine drill before placing the implant. However, the sample obtained was inadequate for histological study.

Hence in our study we objectively assessed the maturation of the new bone formed after AMD by analyzing the mineral content of the bone. Mineralization of the bone is directly influenced by age, nutrition, hormonal equilibrium and health condition [15]. They also vary according to the location of the sample taken, highlighting the extreme sensitivity of measuring the mineral content as a function of the bone quality. In a study done by Gamsjaeger et al. [21], the Raman spectroscopy was used to assess bone mineral and matrix components. They also came to the same conclusion that the mineralization of the bone is a good indicator in terms of bone quality. They also concluded that the spatial orientation of the mineral crystals with respect to the collagen fibril axis also plays an important aspect in the mechanical abilities of the bone. The mineral to matrix ratio which gives the amount of mineralization in relation to the organic matrix is taken as the basis for our study. This ratio gives an objective measure of the amount of mineralization.

We took samples from 29 patients in our study. The patients were classified into three groups as mentioned before. ANOVA test was used to statistically analyze the ratios. This analysis showed that there was a statistically significant difference between the three groups. This conclusively proves that there was low mineralization in the distracted bone.

We compared this bone with the cleft bone from patients who had not undergone DO and the control group. The new bone formed after distraction was not as mineralized as normal bone or normal bone of those affected with cleft. Moreover the cleft bone was also found to be less mineralized in comparison to the control group. This is an unprecedented finding as comparative analysis on cleft maxilla had not been studied histologically or for its mineralization. There is no literature evidence available to corroborate with this finding. Since the sample size is inadequate to derive a definitive conclusion further evaluation is essential.

In cases of osteoporosis there is a high turnover rate associated with low mineralization causing bone resorption [22]. Also in patients of postmenopausal osteoporotic women transiliacal bone biopsies were found to have mostly lower mineralization densities than normal, which were partly associated by an increase of bone turnover, but also caused by calcium and Vit-D deficiency [23].

Literature suggests an overcorrection of 20% to counter the relapse rate for distraction [20, 24]. The relapse could possibly be attributed to the lower mineralization of the distracted bone as found in our study.

This low mineralization of distracted bone can be explained based on the histologic picture of the distracted

bone. Chiapasco et al. did a histologic study on vertical distraction of mandible in humans. They also used a trephine drill to get a bone sample before placing an implant. The histological picture obtained by them showed the formation of a woven bone reinforced by parallel-fibered bone and altered trabecular pattern [14].

This is also consistent with another study which assessed the orthodontic tooth movement into the distracted bone in a canine model. The authors established that rapid tooth movement is possible into the distracted bone due to the low resistance offered. They also concluded that the distracted bone does not have sufficient strength or resistance as native bone. The rapid orthodontic movement of teeth without any complications proves this point [15]. In a study which analyzed the long term follow up of distracted mandible in canine model, it was found that the distracted mandible attains only 77% of the strength of the corresponding normal bone after a period of 12 months [25]. The reason for this may be attributed to low mineralization found in our study.

The low mineralization does not render the distracted bone nonfunctional in any way. Studies have been done to compare the success rate and survival of dental implants in the distracted bone [15, 26]. They found that the survival of the implants in the distracted bone is comparable to the normal bone and even to bone grafts. Bone grafts are considered to be the gold standard in reconstruction and this undoubtedly puts DO as a viable alternative to generate functional bone.

The amount of mineral was thought to determine the stiffness of the material, but studying the bone at a nano level suggests that the properties of organic matrix as well as the spatial arrangement have an important influence on the mechanical aspects of the bone [27]. Bone strength can also be increased by mechanical loading, which is a potent stimulus for bone cells. These cells will improve the bone strength and inhibit bone loss with progressing age [28]. Hence the distracted bone will have better mechanical properties if it is mechanically stimulated by placing implants or by orthodontic movement of teeth into the edentulous ridge.

The study also highlights the use of Fourier Transform Infrared Spectroscopy (FTIR) in objectively analyzing the bone. Various studies have been done on characterization and mineralization of bone, bone substitutes and other tissues [29–37]. FTIR uses the unique bonds present to identify the compounds which are present in the given sample. In the context of bone, a ratio between the regions of phosphate band to the region of amide band is used to determine the amount of mineralization. The amount of mineralization gives a good idea about the maturation of the bone. This technique can also be used to determine various conditions affecting the bone. The effects of various drugs, toxins, pathology and mechanical trauma may be elicited from the spectroscopy values [36].

Further experiments are required to validate the FTIR results in the head and neck region. An age and sex controlled study is required to determine its effect on mineralization. With the advent of FTIR, response of the bone after grafts or osteotomies can also be objectively assessed. The main advantage of this technique is that only a minute sample is required for the analysis. This sample gives the data on all the bonds and minerals present in the bone. The applications of this technique are elaborate.

Limitations of the study are smaller sample size and the functional aspects of the distracted bone not correlated with the FTIR values. Spatial organization of the organic matrix, an indicator in terms of strength needs an electron microscopic evaluation was not done in this study. The samples in the three groups are not gender matched.

Conclusion

- From the study it can be concluded that the distracted bone is less mineralized than the bone in normal individuals and those affected by cleft.
- Bone from the cleft maxilla is also less mineralized in comparison with the bone from normal individuals.
- Traditionally radiographs were used as a tool in order to assess the quality of the distracted bone however FTIR is a viable investigation technique and also an alternate to assess the bone quality objectively by analyzing the mineralization.

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