Alveolar distraction osteogenesis: a systematic literature review

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Abstract

Objective: Alveolar distraction osteogenesis is a viable clinical alternative for vertical, horizontal and interdental alveolar ridge augmentation, and mostly used to regenerate bone for the placement of dental implants, closure of the defect and creation of new bone. This review was performed to analyze the most commonly followed protocols for, and clinical outcomes of, alveolar distraction osteogenesis.

Materials and methods: A PUBMED search was carried out to list articles published on alveolar distraction osteogenesis between January 1996 and May 2010. Although 180 articles were identified, only 101 human clinical case reports were included. Out of 101 only 59 fulfilled the criteria for the study. These studies covered 209 cases and were analyzed for indication, distraction protocol and amount of regenerated bone.

Results: Alveolar distraction was generally indicated in cases of vertical bone deficiency and interdental distraction was mainly applied to patients with clefts. The mean latency period applied was 6.26 days, rate of distraction per day was 0.81 mm, and the consolidation period was 79 days. The mean amount of regenerated bone was 11.34 mm (range, 2 to 26 mm).

Conclusions: Alveolar distraction osteogenesis is effective in increasing alveolar bone volume with simultaneous lengthening of the surrounding soft tissues for implant placement. The application of different treatment modalities were beneficial to the patient in enhancing the quality of distracted bone, shortening the overall treatment period and improving the performance of dental implants placed in the distracted alveolar ridges.

Key words: Alveolar distraction osteogenesis, interdental distraction, alveolar cleft, distraction protocol, distraction distractor, regenerated bone

Introduction

Distraction osteogenesis is the bone formation of new bone formation between the surfaces of bone segments that are gradually separated by incremental traction. This process is initiated when a traction force is applied to the bone segments and it continues as long as the callus tissues are stretched. This traction force, in turn, generates tension within the tissue that connects the bone segments, which stimulates new bone formation parallel to the vector of distraction.

In 1905, Codivilla first performed lengthening of a femur using external skeletal traction after an oblique osteotomy. Later, several surgeons modernized Codivilla’s “continuous extension” procedure by modifying the osteotomy technique, distraction protocol, and the device for bone fixation. Significant contributions in the development of distraction osteogenesis were made by a Russian orthopedic surgeon named Gavril Ilizarov. In 1951, Ilizarov developed an external device and bone lengthening method. Based on his clinical experience, in 1989, Ilizarov discovered two biologic principles of distraction osteogenesis known as the “Ilizarov effects”- (a) the tension-stress effect on the genesis and growth of tissues, and (b) the influence of blood supply and loading on the shape of bones and joints.

Following the basic principles of Ilizarov, in 1992, McCarthy and colleagues were the first to clinically apply distraction osteogenesis in the craniofacial skeleton. McCarthy and colleagues used extra-oral distraction osteogenesis on four children with congenital craniofacial anomalies. Following the basic principles of Ilizarov, in 1992, McCarthy and colleagues were the first to clinically apply distraction osteogenesis in the craniofacial skeleton. McCarthy and colleagues used extra-oral distraction osteogenesis on four children with congenital craniofacial anomalies.

Since the clinical application of the craniofacial distraction osteogenesis, a number of experimental and clinical investigations have demonstrated that gradual mechanical traction of bone segments at an osteotomy site created in the craniofacial region also generated new bone parallel to the direction of traction and allowed adaptation of the surrounding soft tissue to the new dimensions, with complete preservation of function and without relapse. This phenomenon opened up new possibilities in the correction of severe craniofacial deformities. The application of distraction osteogenesis offers novel solutions for surgical-orthodontic management of developmental anomalies of the craniofacial skeleton. Distraction osteogenesis provides a means whereby bone may be molded into different shapes to more adequately address the nature of skeletal deformities and asymmetries. Similar to distraction osteogenesis in the long bones, craniofacial distraction osteogenesis evolved from skeletal traction, osteotomy techniques, and external fixation methods.

The clinical evolution of extra-oral distraction began with the use of miniaturized orthopedic devices for small bone lengthening. One of the first clinical applications of midface distraction was reported in 1995 by Polley and Figueroa, who used an externally fixed cranial halo to distract the midface. The advantages of a rigid external distraction device (RED) are that it is fairly simple to apply intraoperatively, it is easy to activate for patients, and can be removed without the need for a second operative procedure at the completion of consolidation.

In several reports, Polley and Figueroa’s group demonstrated that full correction of the midface deficiency, including both skeletal and soft tissue deficiencies, was possible with their technique. In 1995, Molina and Ortiz-Monasterio simplified the methods established by McCarthy. They were the first to use bidirectional distraction osteogenesis in the mandible. In 1998, Molina and Ortiz-Monasterio used distraction osteogenesis as an alternative technique in patients with cleft lip and palate with associated maxillary hypoplasia and mixed dentition. In an attempt to simplify distraction
in patients needing simultaneous maxillomandibular correction, the same authors introduced a technique for simultaneous mandibular and maxillary distraction using only a mandibular device. The technique involved an incomplete Le Fort I osteotomy and a mandibular corticotomy. As the mandible was elongated, the maxilla moved with it.\textsuperscript{17}

Although bone transport has been less commonly employed in the craniofacial region relative to the previously mentioned techniques, nowadays its use has increased for the correction of large mandibular defects, reconstruction of neocondyles, cleft lip and palate, and alveolar defects for dental implants. Bone transport consists of resection of a pathologic bone followed by gradual transport of an osteotomized healthy bone segment (transport disk) via a distraction device across the area of the defect. As the transported bone segment is advanced, new bone tissue is generated, gradually filling the defect. After the transport disk reaches the opposite host bone segment, the intervening fibrous tissue is removed followed by application of compression between the transport and host bone segments at the docking site.\textsuperscript{8,18}

The first report of the clinical application of bone transport was presented in 1995 by Costantino and colleagues, who successfully applied transport distraction to restore the continuity of a mandibular defect formed as a result of cancer resection following radiation therapy.\textsuperscript{19} A year later, Block presented the results of four cases with bone transport using a Synthes lengthening device.\textsuperscript{20} After these reports, bone transport has been sporadically used to treat bone defects caused by trauma or bone resection. Importantly, mandibular distraction recreates the alveolar ridge with its attached mucosa.

An intriguing application of the bone transport technique is the augmentation of the maxillary and mandibular alveolar ridges. Alveolar deformities and defects may result from a variety of pathologic processes including (a) developmental anomalies, such as cleft palate and congenital tooth absence, (b) maxillofacial trauma, which often involves damage to the teeth and associated jaw structures, and (c) periodontal disease leading to bone and tooth loss from the alveolar process. These deformities may be managed by a variety of surgical techniques, such as autogenous onlay bone grafting, alloplastic augmentation, connective tissue grafting, or guided tissue regeneration. However, each of these modalities has its limitations.\textsuperscript{21,22} These grafts do not provide an increase in osseous volume. Guided tissue regeneration is restricted in the volume of generated bone, often resulting in unpredictable results. Alternatively, distraction osteogenesis of the alveolar process may provide superior reconstruction of these types of defects. In 1996, Chin and Toth reported the first clinical application of vertical mandibular alveolar distraction osteogenesis.\textsuperscript{21} Since the clinical introduction of alveolar ridge distraction by Chin, the use of the technique, as well as the number of available devices, has increased tremendously. Alveolar distraction devices and techniques have recently been established as a viable treatment modality for correction of severe alveolar bone defects and maxillary/mandibular alveolar ridge augmentation.\textsuperscript{21} In recent years it has become quite accepted in oral and maxillofacial surgery and has been used for narrowing of large alveolar clefts before grafting.\textsuperscript{23} This method is based on distracting a dento-osseous segment created posterior to the cleft site and narrowing the large alveolar defect with mesial movement of the segment.\textsuperscript{23,24} New alveolar bone and soft tissue can be generated by this technique. Thus, the alveolar cleft can be more easily repaired.
with a bone graft, which makes an ideal soft tissue closure possible using newly generated attached gingiva.24

In 2000, Liou and colleagues first reported a new technique “Interdental distraction osteogenesis” (IDO). They used distraction osteogenesis as the basis of a new method for lengthening of the dental arch, minimizing the alveolar cleft/fistula and, thus, reducing the need for large surgical reconstructions of the maxillary dento-alveolar defects. IDO and rapid orthodontic tooth movement were used on patients with wide alveolar clefts or bony defects.25 The technique displayed many advantages, including minimizing the need for extensive alveolar bone grafting, eliminating tooth extraction in cases of dental crowding, and maintaining velopharyngeal function.

In 2001, Yen reported a case of closure of a large alveolar cleft by bony transport of a posterior segment using orthodontic arch wires attached to bone.26 This technique is effective in reducing the palatal fistula and closing the alveolar cleft. An increasing number of reports note that bony transport of a premaxillary segment provides space for dental implants,27 and the anterior transport of a posterior segment was developed as a strategy for closing clefts with autogenous bone grafts.26 In 2003, Dolanmaz et al28 reported management of alveolar cleft using dento-osseous transport distraction osteogenesis. They developed an efficient device to repair small or large alveolar clefts without bone grafts. In 2006, Suzuki and Suzuki28 developed a new alveolar distraction device that allowed three-directional movement of the osteotomized segment. The device allowed simultaneous maxillary advancement, wide cleft closure and creation of edentulous alveolar bone.

This technique corrected severe craniofacial deformities with fewer surgical interventions and, consequently, resulted in less total treatment time than with current techniques.28 With the development of distraction devices and techniques, distraction osteogenesis is widely employed for vertical augmentation of alveolar ridge following failed grafting procedures29,30 and for segmental bone grafting,31 prior to orthognathic surgery,32 and for anterior advancement of maxillary segments for closure of alveolar clefts.26,33

However, there is a lack of evidence regarding appropriate distraction osteogenesis protocols, maximum possible augmentation distance and application of various devices. This review analyzed studies published on the application of distraction osteogenesis for alveolar ridges and assessed the current state of knowledge.

Materials and methods

The review of the literature on alveolar distraction was based on a PUBMED search, covering the period from January 1996 to May 2010. The key words searched were alveolar distraction osteogenesis, interdental distraction osteogenesis and alveolar cleft. Although the search listed 179 articles, 101 human clinical case reports were included in this review. Individual case reports (43 articles) and animal studies (36 articles) were excluded from the data analysis. The 101 human articles included 60 articles (554 cases, 72%) on vertical alveolar distraction, 23 articles (184 cases, 21%) on horizontal alveolar distraction and 18 articles (56 cases, 7%) on interdental distraction (Table 1). The data from all publications were analyzed, despite the possibility of some results being reported in more than one publication, which was not possible to verify in all cases.

The identified studies were searched for defined inclusion criteria. These included indications for alveolar distraction osteogenesis, total number of alveolar distractions per patient, protocol parameters and type of
distractor used. The specific protocol parameters recorded were: duration of the latency period before the active phase of distraction, the rate and rhythm of activation, the mean and maximum distraction distance achieved, the duration of the consolidation phase and the quality of regenerated bone.

The statistical analysis was performed using SPSS for Windows (Release 13.0, standard version; SPSS, Chicago, IL, USA). Data analysis methods included the X text and the independent Student’s t-test for evaluation of statistical significance. A p-value less than 0.05 was considered as significant.

**Results**

Although many studies on alveolar distraction osteogenesis have reported data on the study outcome, only a limited body of literature was available to validate the methodology. In several studies the exact protocol parameters or the amount of new bone created were not reported for a standard time interval, but as a range. These data were not acceptable for the present analysis. A total of 59 articles (219 cases) that met the criteria were reviewed, including interdental distraction osteogenesis (10 articles) \(^{23-25,26,33-38}\), horizontal alveolar distraction (13 articles) \(^{39-51}\) and vertical alveolar distraction (36 articles), \(^{52-87}\) covering a total of 219 distractions in 209 patients.

Alveolar distraction osteogenesis was generally indicated in cases of alveolar bone deficiency with an unfavorable implant-to-crown relation, collapsed dental arches and aesthetically compromised rehabilitation.\(^{30,81,88}\)

The most frequent diagnosis was bone atrophy (Table 2).\(^{81,82,89}\) Interdental distraction was performed for lengthening the dental arch while minimizing the alveolar cleft/fistula or reconstructing maxillary/mandibular dentoalveolar defects (Table 3).\(^{24-26}\) IDO was commonly used for patients with clefts.

**Table 1** Literature review of alveolar distraction osteogenesis

<table>
<thead>
<tr>
<th>Alveolar distraction osteogenesis</th>
<th>No. of article</th>
<th>%</th>
<th>No. of cases</th>
<th>%</th>
</tr>
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<tbody>
<tr>
<td>1. Vertical alveolar distraction</td>
<td>60</td>
<td>59</td>
<td>554</td>
<td>70</td>
</tr>
<tr>
<td>2. Horizontal alveolar distraction</td>
<td>7</td>
<td>7</td>
<td>26</td>
<td>3</td>
</tr>
<tr>
<td>Bucco-lingual</td>
<td></td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>Mesiodistally</td>
<td>16</td>
<td>16</td>
<td>158</td>
<td>20</td>
</tr>
<tr>
<td>3. Interdental distraction osteogenesis</td>
<td>18</td>
<td>18</td>
<td>56</td>
<td>7</td>
</tr>
<tr>
<td><strong>Total</strong></td>
<td>101</td>
<td>100</td>
<td>794</td>
<td>100</td>
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**Table 2** Indications for alveolar distraction osteogenesis

<table>
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<tr>
<th>Indication</th>
<th>No. of case</th>
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<tbody>
<tr>
<td>1. Alveolar cleft</td>
<td>15</td>
<td>7</td>
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<tr>
<td>2. Trauma</td>
<td>19</td>
<td>9</td>
</tr>
<tr>
<td>3. Bone atrophy</td>
<td>137</td>
<td>62</td>
</tr>
<tr>
<td>4. Tumor resection</td>
<td>22</td>
<td>10</td>
</tr>
<tr>
<td>5. Crowding</td>
<td>26</td>
<td>12</td>
</tr>
<tr>
<td><strong>Total</strong></td>
<td>219</td>
<td>100</td>
</tr>
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</table>
Distraction osteogenesis protocol

The mean latency period applied was 6.26 days (range, three to 14 days). A latency period of seven days was used in 15 cases to permit healing of mucoperiosteum and to reduce the risk of wound dehiscence. The mean rate of distraction per day was 0.81 mm (range, 0.3 to 1.5 mm/day). A total of 25 cases (76%) were distracted up to 1 mm/day, while two cases (6%) were distracted over 1 mm/day. In the other 6 cases (18%) continuous force was applied. The rhythm of distraction ranged from one (17 cases, 52%) to three (one case, 3%) times daily. In 9 cases (27%) distraction was used twice daily. In the other 6 cases (18%) continuous force was applied. The mean consolidation period was 79 days (range, 30 to 161 days). In 6 cases (18%) the consolidation period was not reported. (Table. 4) The mean amount of distraction achieved was 21.15 mm (range, 4 to 65 mm).

Distraction device

Similar to the intra-oral distraction devices, the alveolar ridge distraction devices can be classified as tooth-borne, bone-borne, and hybrid, based on their fixation points. In this study, the application of various devices in alveolar distraction osteogenesis was also analyzed. All of the vertical alveolar distraction devices were bone-borne. Most of the

Table 3  Indications for IDO

<table>
<thead>
<tr>
<th>Indication</th>
<th>No. of case</th>
<th>%</th>
</tr>
</thead>
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<tr>
<td>1. Cleft</td>
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<td>68</td>
</tr>
<tr>
<td>2. Trauma</td>
<td>3</td>
<td>14</td>
</tr>
<tr>
<td>3. Bone atrophy</td>
<td>1</td>
<td>4.5</td>
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<tr>
<td>4. Tumor resection</td>
<td>1</td>
<td>4.5</td>
</tr>
<tr>
<td>5. Crowding</td>
<td>2</td>
<td>9</td>
</tr>
<tr>
<td><strong>Total</strong></td>
<td><strong>22</strong></td>
<td><strong>100</strong></td>
</tr>
</tbody>
</table>

Table 4  Protocol of IDO

<table>
<thead>
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<th>Protocol</th>
<th>Data</th>
<th>No. of cases</th>
<th>%</th>
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<tr>
<td>Latency</td>
<td>Up to 7 days</td>
<td>66</td>
<td>96</td>
</tr>
<tr>
<td></td>
<td>Over 7 days</td>
<td>2</td>
<td>3</td>
</tr>
<tr>
<td></td>
<td>Not specified</td>
<td>1</td>
<td>1</td>
</tr>
<tr>
<td>Rate</td>
<td>0.3mm/day -0.5mm/day</td>
<td>36</td>
<td>52</td>
</tr>
<tr>
<td></td>
<td>0.5mm/day -1mm/day</td>
<td>28</td>
<td>41</td>
</tr>
<tr>
<td></td>
<td>1mm/day -1.5 mm/day</td>
<td>2</td>
<td>3</td>
</tr>
<tr>
<td></td>
<td>Not specified</td>
<td>3</td>
<td>4</td>
</tr>
<tr>
<td>Rhythm</td>
<td>1 time/day</td>
<td>40</td>
<td>58</td>
</tr>
<tr>
<td></td>
<td>2 times/day</td>
<td>26</td>
<td>38</td>
</tr>
<tr>
<td></td>
<td>Not specified</td>
<td>3</td>
<td>4</td>
</tr>
<tr>
<td>Consolidation</td>
<td>Up to 3 months</td>
<td>61</td>
<td>89</td>
</tr>
<tr>
<td></td>
<td>Over 3 months</td>
<td>3</td>
<td>4</td>
</tr>
</tbody>
</table>

*Table 3: Indications for IDO*

*Table 4: Protocol of IDO*
horizontal alveolar distractions used bone-borne devices, whereas 78% of interdental distractions employed tooth-borne devices (Table 5).

Discussion
Distraction osteogenesis is effective in endochondral and craniofacial bone lengthening and augmentation. It was originally used in the treatment of mandibular deficiency and, subsequently, used to treat hypoplastic maxilla, zygoma, and midface. In the dento-alveolar region, the application of distraction osteogenesis includes vertical height augmentation of the alveolus, creation of an edentulous alveolar ridge for rapid orthodontic tooth movement through the regenerated bone and dental distraction for rapid orthodontic tooth movement into freshly extracted sockets. Segments of new alveolus and attached gingiva are created during dento-alveolar distraction osteogenesis, without grafting of alveolar bone or free gingiva.

The closure of a wide alveolar cleft and fistula in patients with clefts and the reconstruction of a maxillary dento-alveolar defect in patients with trauma are challenging for both orthodontists and surgeons, because of the difficulty in achieving complete closure by using local attached gingiva and the greater volume of bone required for the graft. IDO for the treatment of a wide alveolar cleft and oronasal fistula or a maxillary defect has proven to be an effective treatment modality. This technique creates new alveolar bone and attached gingiva at a site distant to the fistula or defect, and the fistula or defect is approximated by native local alveolar bone and attached gingiva. The principle of this technique is a modification of bifocal distraction osteogenesis, that has been used successfully in long bones and, recently, also in the correction of mandibular defects.

The rate and rhythm of distraction are two major parameters of critical importance, which influence the treatment results. The results of Ilizarov’s experimental studies demonstrated that the latency period should be at least five days. The benefit of seven days of latency was demonstrated in a long-bone distraction in a rabbit model, but the results from other studies in long bones and in the craniofacial region have questioned the need for a latency period. A latency period of seven days reduces the risk of bone exposure to the oral environment and, thus, is probably the optimal choice in the majority of cases of IDO. A slower rate could result in premature union, while non-union can occur if the rate is too rapid. As with the distraction rate, it seems that the rhythm of distraction in IDO tends to be chosen empirically, perhaps reflecting a lack of experimental findings on distraction.

Compared with conventional orthodontic and orthognathic surgical treatment, distraction osteogenesis has the advantage of producing new bone in the palate and the alveolar ridge for dental implants and tooth movement. Displaced teeth can then be moved into the

<table>
<thead>
<tr>
<th>Table 5 Application of distraction device</th>
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<tbody>
<tr>
<td>Tooth-borne</td>
</tr>
<tr>
<td>-------------</td>
</tr>
<tr>
<td>1. Vertical alveolar distraction</td>
</tr>
<tr>
<td>2. Horizontal alveolar distraction</td>
</tr>
<tr>
<td>Bucco-lingual</td>
</tr>
<tr>
<td>Mesiodistally</td>
</tr>
<tr>
<td>3. Interdental distraction osteogenesis (IDO)</td>
</tr>
<tr>
<td>Total</td>
</tr>
</tbody>
</table>
newly created bone rather than having to be extracted. In comparison with conventional alveolar bone grafting, there is no need for alveolar bone grafting and further gingivoperiosteoplasty with IDO. One of the potential advantages of IDO is that the soft palate is not distracted forward; it is left at the same sagittal position, before, during, and after distraction. This has the benefit of avoiding possible disturbance to the velopharyngeal function of those patients with clefts who need distraction of the entire maxilla.25

However, IDO also has some disadvantages that influence the outcome of treatment, including (a) technique sensitive surgery, (b) equipment-sensitive surgery, (c) possible need of a second surgery to remove distraction devices, (d) patient compliance, and (e) experience with the technique is limited.

In conclusion, alveolar distraction osteogenesis is effective in increasing alveolar bone volume with simultaneous lengthening of the surrounding soft tissues for implant placement. IDO is a variation of alveolar distraction osteogenesis and can successfully be applied to patients with clefts.

The application of different treatment modalities are beneficial to the patient in enhancing the quality of distracted bone, shortening the overall treatment period and improving the performance of dental implants placed in the distracted alveolar ridges.

However, there is a need for further evaluation of appropriate distraction osteogenesis protocols, effective distractors and augmented distance.

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Conflict Interest: None declared

Ethic approval: None (Systematic review)

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