Transport Distraction Osteogenesis for Maxillomandibular Reconstruction: Current Concepts and Applications

R. S. Neelakandan · Darpan Bhargava

Received: 26 September 2011 / Accepted: 5 December 2011 / Published online: 29 December 2011
© Association of Oral and Maxillofacial Surgeons of India 2011

Abstract Reconstruction of the facial skeleton remains a herculean task for a reconstructive surgeon, even with the availability of ample reconstructive options. Transport distraction osteogenesis is a novel reconstructive modality in the armamentarium of a maxillofacial reconstructive surgeon with obvious advantages of osteogenesis and histogenesis from the residual host tissues after tumor ablative surgeries or trauma and also, precludes donor site morbidity. This paper reviews the current concepts, principles involved and applications of transport distraction osteogenesis in maxillomandibular reconstruction.

Keywords Maxilla · Mandible · Maxillofacial surgery · Distraction osteogenesis · Transport distraction · Osteogenesis · Mandibular reconstruction

Introduction

Reconstruction of the facial skeleton remains a herculean task for a reconstructive surgeon, even with the availability of ample reconstructive options. The mandible, in particular, which is considered the major aesthetic highlight of the face, poses complex reconstructive confront. Mandible remains an important component of the facial skeletal framework as it assists in speech, oral competence,

mastication, deglutition, airway support, and maintains the facial projection. This vital position of the mandible mandates its anatomic, functional, and aesthetic restoration following resective surgeries or trauma. Transport distraction osteogenesis (TDO) is a novel reconstructive modality in the armamentarium of a maxillofacial reconstructive surgeon with obvious advantages of osteogenesis and histogenesis from the residual host tissues after tumor ablative surgeries or trauma and also, precludes donor site morbidity [1]. This paper reviews the current concepts, principles involved, and applications of TDO in maxillo-mandibular reconstruction.

Definition

Distraction osteogenesis may be defined as the biological process of new bone formation between the surfaces of bone segments that are gradually separated by incremental traction. TDO can be best explained as a creation of bone and soft tissue to fill a defect by moving a disk of bone and formation of new tissues behind it until the disk docks the receiving host bone [2] (Fig. 1).

Distraction osteogenesis for maxillo-mandibular reconstructive need can be classified into: monofocal distraction osteogenesis and TDO [3]. TDO can be achieved by incremental movement of one (bifocal distraction), two (trifocal distraction) or three (quadrifocal distraction) viable bone segments (transport disks) across a defect [4] (Fig. 2).

Historical Perspective

Distraction osteogenesis was first popularized by Ilizarov in the mid-20th century to correct long bone defects

R. S. Neelakandan · D. Bhargava
Department of Oral and Maxillofacial Surgery, Meenakshi
Ammal Dental College & Hospital, Alapakkam Main Road,
Maduravoyal, Chennai 600 095, Tamil Nadu, India

D. Bhargava (✉)
H-3/2, BDA Colony, Airport Road, Lalghati,
Bhopal 462 032, Madhya Pradesh, India
e-mail: emaildarpan@gmail.com

Fig. 1 Line diagram depicting process of TDO in a mandible requiring reconstruction for a segmental defect

following which its application was extended to the distraction of the membranous bones of the craniofacial skeleton by Snyder et al. in 1973. The mandibular distraction was further developed by Michieli and Miotti. They also first suggested the operative protocol in humans for mandibular distraction, which included: latency period of 1 week after osteotomy, an activation rate of 1-mm on alternate days, and a minimum consolidation period of 45 days for every 15-mm of distraction. The first clinical case of DO in the human mandible was reported by McCarthy et al. in 1992. Costantino et al. were the first to report bifocal distraction (TDO) of the mandible by using an external custom made distraction device to regenerate a segmental defect of 40-mm. Since then there have been rapid advancements in the field of TDO, which has now become an important tool for the reconstruction of composite defects [4].

Indications for TDO in Maxillofacial Region

The chief goal that can be achieved by TDO is best described by Sacco and Chepeha [5] as “to restore bony continuity through the use of in situ bone in an attempt to create an anatomically correct regenerate that is better than bone grafting or revascularized free-tissue transfer.” It is well documented in orthopedic literature that TDO is a reliable method for simultaneous treatment of composite

bone and soft tissue defects, which also is one of the most important indications of TDO [6]. It still remains a question to the TDO experimentation and research, as to what the ideal length of the defect that can be reconstructed with this modality should be. Although various authors have reported reconstruction of large defects, Zhang and Zhang [7] have described 3–12 cm defects to be optimal for considering TDO. Currently TDO for facial skeleton finds its applications for segmental defects of the mandible, neocondyle regeneration, distraction for calvarial defects, achieving alveolar height for prosthesis, and even for the maxillary alveolar defects. Segmental defects may be a result of ablative surgery for odontogenic tumors, surgical removal of cancers, chronic bone infections, blast injuries, gunshot wounds, etc. [4]. When indicated, TDO has its own advantages over high failure rates in non-vascularized bone grafts and high complication rates of highly demanding techniques of vascularized bone grafts [8]. The surgical trauma is reduced and the need for the donor site is excluded, the new bone regenerated with TDO is enclosed in a sleeve of healthy mucosa with well-formed lingual and buccal sulci, making it ideal for dental restoration and rehabilitation [8].

Linear Vectors in Mandibular Reconstruction with TDO

It remains important for the operating surgeon to understand the vectors that the mandibular anatomy follows to reconstruct the various mandibular segmental defect. The base of the mandible is constituted by five linear vectors. The two linear vectors run parallel to the base of the mandible, one on either side in the body region, two linear vector lie parallel to the base of the mandible in the parasymphysis region, and one horizontal linear vector again run parallel to the base of the mandible in the mid symphyseal region. Ideal mandibular reconstruction should follow five linear planes. For all practical reconstructive purposes, it may be concluded that the defect along a single vector is best reconstructed with straight regeneration and when there is a defect involving more than a single vector, it should be reconstructed with arched regeneration and can

Fig. 2 Types of TDO:
a Bifocal, b Trifocal.
c Tetra focal. 1, 2, 3: Number of transport segments

Fig. 3 Neocondyle regeneration with TDO

be best executed with multi-vectorial transport distraction devices [9].

In the authors' experience, vector control in cases requiring neo-condyle regeneration for reconstruction of TMJ, remains intricate. In such cases, it is recommended to fix a minimum of two screws, both in the transported neocondyle and the caudal mandibular segment, to secure the device and have an appropriately directed transport segment towards the glenoid fossa (Fig. 3). Although to target the neo-condyle to the preplanned glenoid fossa remains difficult, TDO in such cases have an additional advantage of a fibrocartilaginous capping between the transported bone segment and the glenoid fossa [2, 5].

Vector control remains an important aspect in reconstruction of the maxillofacial defects with TDO. In a study by Heffez and Kirton [30] on vector control in transportation osteogenesis, it is emphasized that in the clinical cases where proper vector control is achieved, the advantages of diminishing the volume of bone graft required or achieving final bony reconstruction can far outweigh the few disadvantages that may be associated with TDO.

Classification of Mandibular Defects for Reconstruction with TDO

Mandibular segmental defects for reconstruction with TDO may be classified as central and lateral defects. Central defects can be either symmetrical or asymmetrical depending on extension of tumor/defect on either side of

the midline. Lateral defects can either be straight when a defect is posterior to the 2nd premolar (involving only one mandibular vector), or arched when the defect is from anterior to 2nd premolar (Involving >1 vector), as the linear parasymphysial vector unites with the vector of the corpus (body) in this region.

Surgical Principles for TDO

Transport distraction involves creating a transport disk in the residual host bone stump, adjacent to a discontinuity defect or a resection site. The transport disk is then advanced 1.0-mm per day to span the discontinuity defect [9]. As this transport disk advances towards the target host bone segment, callus forms at its trailing end, which gradually matures and calcifies. Regardless of the surgical site, adherence to the following basic Ilizarov principles are the key to surgical success in TDO- Osteotomy of the bone site with minimal periosteal stripping, latency period of 5–7 days before activation, distraction rate of 1.0-mm per day, twice a day distraction rhythm, and consolidation until a cortical outline can be seen radiographically across the distraction gap, usually 6 weeks [9]. Once the transport disk reaches the docking site, the segment is held in neutral fixation until a cortical outline is seen in the regenerate. At the time of distractor removal, a small bone graft may need to be positioned between the transport disk and the docking site because the transport disk becomes rounded and encased with a fibrocartilaginous cap on the advancing front. Osseous union between the disk and docking site necessitates removal of this intervening fibrocartilaginous cap (Fig. 4).

Basics of a TDO Device

A myriad of bone transport devices are being developed and are being used for regenerating bone in surgical or traumatic defects [4]. A prototype custom made device for TDO is described for explanation. This custom made distraction device is developed by Department of Oral and Maxillofacial Surgery in technical collaboration with Department of Biomedical Engineering at Meenakshi Ammal Dental College and Hospital, Chennai, India and approved by the institutional ethics committee (IEC), Meenakshi Academy of Higher Education and Research, India.

The transport distraction device may be divided into three basic components: the reconstruction plate for stability, distractor component for mobilizing the transport disk on activation, and the screws for assembling and securing the device (Fig. 5). Fig. 6 shows a transport

Fig. 4 Panoramic radiographs showing TDO

Fig. 5 TDO Device

Fig. 6 Transport distraction device adapted on a stereolithographic model for pre-operative planning

distraction device adapted on a stereolithographic model for pre-operative planning in a patient requiring TDO for reconstruction of mandibular continuity defect after resection of the tumor.

Table 1 Results of a clinical study evaluating the bone transport as a reconstructive modality for regeneration of bone in the mandibular continuity defects following tumor ablative surgery

Variable	Group-I Mean $\pm$ S.D	Group-II Mean $\pm$ S.D	<i>P</i> Value*
T. S Width (mm)	22.0 $\pm$ 4.5	21.0 $\pm$ 6.5	0.84 (Ns)
Clinical defect	57.0 $\pm$ 14.4	93.6 $\pm$ 23.7	0.008 (Sig)
Regenerate (mm)	49.4 $\pm$ 14.8	73.4 $\pm$ 12.9	0.03 (Sig)
% Regenerate	86.7 $\pm$ 15.6	79.8 $\pm$ 8.9	0.55 (Ns)

Group-I: Straight mandibular regeneration; Group-II: Multivectorial mandibular regeneration. *T.S* Transport segment. *P* values based on Mann–Whitney's μ test for significance

In a clinical study done by the authors at Meenakshi Academy of Higher Education and Research, India evaluating the bone transport as a reconstructive modality for regeneration of bone in the mandibular continuity defects following tumor ablative surgery between 2001 and 2010, the results obtained were convincing to incorporate TDO as an important reconstructive tool in the maxillofacial surgeon's armamentarium. A total of 20 patients were enrolled for the study. Out of the 20 patients, 50% patients required straight regeneration of the mandible as the defect was limited distal to the 2nd premolar region in the body of the mandible. Bone regeneration in the remaining 50% patients was done to reconstruct the arched mandible, as the defect involved more than one mandibular vector for reconstruction. The results of the study are summarized in Table 1. Conclusions of the study indicate that a better length of regenerate is possible with TDO in cases requiring straight regeneration of the mandible. The length of regenerate was

comparatively less when reconstruction of the mandible was attempted in cases involving multiple vectors (arched regeneration).

Vascular Dynamics in TDO

The process of TDO induces tensile stretching of the osteoblast-like cells that alters the local regulation of bone formation and increases the expression of the growth factors [10]. This entire process is vascular dependent and requires the maintenance of an adequate blood supply [11]. DeCoster et al. [12] in their animal experimental model on TDO used injection angiography to study the arterial response of the bone undergoing transport distraction. The angiographic techniques revealed that the transport segment had an intact arterial supply after the osteotomy cut was completed (adhering to surgical principles of TDO) and also, after transport distraction was activated. They also showed an extensive increase in vessels in distracted limbs of the experimental animals with proximal stretching and distal kinking of the major artery in that limb. Such studies involving major facial vessels during TDO are awaited to be added to maxillofacial literature. Formation of callus can be detected with ultrasonography, where it appears as a mixed to hyper echoic area depending upon the degree of maturation. The color doppler study of the callus demonstrates the quantum of vascularity in the regenerate before maturation (Fig. 7).

Radiology

Regular plain film radiographs remain the mainstay for screening the TDO during active distraction and consolidation period. Panoramic radiograph, submento-vertex view, lateral oblique mandibular projections, posteroanterior, and lateral skull views may all aid in planning and screening the TDO. These radiographs have their limitation of 2D view of the multivectorial 3D procedure.

Ultrasound is a non-invasive method that can be used for assessing callus healing after distraction osteogenesis. The distraction gap appears as an echolucent window which narrows progressively and subsequently produces a hyper-reflecting line which after further consolidation could not be assessed as the calcification increases [13, 14].

Multi-slice computed tomographic scans provide a better preview but have the limitation of excessive radiation exposure and scatter due to the distraction device when it is in situ (Fig. 8). Elsalanty et al. [8] at Medical College of Georgia Dental School (Augusta, USA) have extensively experimented on cone-beam CT densitometry and three-dimensional histomorphometry in mandibular bone defects reconstructed with bone transport and found that the physical dimensions and architectural parameters of the new bone regenerated remain comparable to the contralateral normal bone in TDO. In their study, the radiographic density comparison was done by studying the radiographic attenuation of the regenerate measuring in hounsfield units (HU) and comparing it to the outer, inner, and inferior cortices of the bone on opposite side of the

Fig. 7 Color doppler study showing vascularity of the distraction callus

Fig. 8 Computed tomography showing the regenerated bone with TDO (Right mandible)

mandible (normal bone). Their results showed that the density of the distraction regenerate was comparable to the inner and outer cortices of the control bone, whereas the lower border of the control side of the mandible showed higher density than the regenerate at 1 month of consolidation. The HU value of the regenerate by TDO was towards the 2,000 mark (2,000 HU) after a month of consolidation.

Micro computed tomography based three-dimensional histomorphometry used to assess percent bone volume, bone mineral density, degree of anisotropy, trabecular thickness, trabecular number, trabecular pattern factor, and trabecular separation showed no significant differences between the regenerate and the normal bone after 1 month consolidation in all parameters except percent bone volume, and the trabecular separation. Percent bone volume is reported to be significantly less while trabecular separation is significantly higher in the regenerate [8].

Histology

Garcia et al. [15] studied the histology of the regenerate and docking site in bone transport in the tibial diaphyseal defect of adult sheep model and concluded that there is a marked difference between the ossification of the docking site and of the regenerate. Intramembranous ossification plays a major role in the regenerate, with bone forming from the host bone segment to the target segment. The ossification of the docking site shows endochondral and intramembranous ossification simultaneously but intramembranous ossification is limited to rare and small foci.

In a study conducted at Mercer university (USA) on the architecture and microstructure of cortical bone regenerated with TDO, it was found and concluded through their

study that at 12 weeks of consolidation, bone created during bone TDO was comparable to native bone in microstructure, architecture, and mechanical properties and when appropriate time has lapsed, the properties of the regenerate bone were identical to the host bone [16].

Çakır-Özkan et al. [17] in their study on immunohistochemical analysis of reconstructed sheep mandibles by TDO reported strong positive staining for BMP-2, -4, and TGF- β in the cells and matrix components. These growth factors are believed to enhance the osteogenesis in TDO.

Role of Exogenous Growth Factors and Platelet-Rich Plasma (PRP) in TDO

Studies have highlighted that the transforming growth factor-beta, basic fibroblast growth factor, and insulin-like growth factor I are the chief up-regulated factors during TDO. These factors are present in the bony matrix and the cytoplasm of the cells, osteoblasts, and in a few mesenchymal cells. Distraction at faster rate show stronger presence of the growth factors but clinically a poor regenerate. An optimum distraction rate, presence of the growth factors, and strict adherence to the biomechanical principles of DO, remains the key to successful clinical outcome [18]. Currently, external administration of the exogenous growth factors remains controversial and is a subject of further research, with evidences both for and against it [19, 20]. Present clinical evidence is more against the use of exogenous transforming growth factor-beta in DO [21]. It may be concluded that the optimum TGF-beta1 is present during the distraction phase in vivo, and its exogenous administration may not be recommended based on the evidences from future research [22].

Injection of platelet-rich plasma (PRP) is found to have more favorable clinical outcome to enhance bone healing during distraction osteogenesis [11, 23, 24].

Platelet-Rich Plasma releases platelet-derived growth factor and transforming factors (TGF-1 and 2). Platelet-derived growth factors are the initial growth factors present in a wound and initiate connective tissue healing, bone regeneration, and repair [25, 26]. A definite protocol needs to be devised for the use of PRP in TDO.

Role of TDO in Maxilla

TDO is an established reconstructive modality for mandibular continuity defects. Although, at present the applications of TDO are limited for mandibular reconstruction owing to its complex anatomic architecture, it is emphasized that the maxillary bone with its multiple vascular perfusion, rich periosteal supply, and abundant cancellous

component is expected to biologically respond even better to the distraction force [27]. The maxillary alveolar reconstruction is demonstrated in Fig. 9. Although as the

collagen fibers of the regenerate are stretched in a linear fashion between two points along the maxillary midline, the regenerate obtained is flattened, as depicted in Fig. 9 and this remains a commonly encountered problem in anterior maxillary regeneration.

Fig. 9 Anterior maxillary ridge formed with TDO

Complications

With regard to the complications arising during the distraction osteogenesis, Ilizarov has commented that “there are no complications with the technique, there are only inexperienced surgeons causing problems for their patients” [28]. Most of the complications arise from poor patient preparation and compliance, inadequate preoperative planning, and inaccurate surgical execution [29]. Risk of intra or post-operative anesthetic and surgical complications with TDO remain at par with any major maxillo-facial surgical procedure done under general anesthesia.

Fig. 10 Complications: **a** Drifted teeth after TDO. **b** Lingually deviated callus. **c** Hour-glass deformity showing hypotrophic callus (arrow)

Fig. 11 Commonly encountered complications with TDO in a clinical study on 20 patients. (Group-I: Straight mandibular regeneration; Group-II: Multivectorial mandibular regeneration)

Commonly encountered complications with TDO include misdirected vectors due to faulty adaptation of the device, hypotrophic or fibrous regenerate, drifting of teeth with distraction, and infection (Fig. 10). In author's experience with TDO in 20 clinical cases, the commonly encountered complications were misdirected vector (presented as sagittal and coronal deviation of the regenerate), early consolidation in long span distraction gaps, infection, and plate/hardware exposure, summarized in Fig. 11.

Conclusion

Although TDO seems a promising modality of reconstruction of maxillo–mandibular defects with excellent clinical results, it has the disadvantage of prolonged duration of treatment, follow up, and use of bulky transport devices. The future of bone transport relies on innovations that would accelerate mineralization of new bone regenerate and biomechanical developments in the device design, may it be an automated miniature transport device for better patient compliance. Improvisation in techniques involved in controlling the vectors during the TDO remains critical, as the technique usually is utilized to reconstruct long span defects of the bone [30].

Conflict of interest None

References

1. Neelakandan RS, Bhargava D (2011) Transport distraction along the mandibular midline: conceptual analysis. *J Stomat Occ Med* 4:123–126
2. Spagnoli D (2008) Mandible reconstruction with transport distraction osteogenesis. *Atlas Oral Maxillofac Surg Clin N Am* 16:287–307
3. Wang X, Lin Y, Yi B, Liang C, Li Z (2002) Mandibular functional reconstruction using internal distraction osteogenesis. *Chin Med J* 115:1863
4. Zapata U, Elsalanty ME, Dechow PC, Opperman LA (2010) Biomechanical configurations of mandibular transport distraction osteogenesis devices. *Tissue Eng Part B Rev* 16(3):273–283
5. Sacco AG, Chepeha DB (2007) Current status of transport-distraction osteogenesis for mandibular reconstruction. *Lancet Oncol* 8(4):323–330
6. El-Alfy B, El-Mowafi H, El-Moghazy N (2010) Distraction osteogenesis in management of composite bone and soft tissue defects. *Int Orthop* 34(1):115–118
7. Zhang GL, Zhang M (2008) Advance on the bone transport distraction osteogenesis for the treatment of bone defects. *Zhongguo Gu Shang* 21(12):950–952
8. Elsalanty ME, Zakhary I, Akeel S, Benson B, Mulone T, Triplett GR, Opperman LA (2009) Reconstruction of canine mandibular bone defects using a bone transport reconstruction plate. *Ann Plast Surg* 63(4):441–448
9. Miloro M (2004) Peterson's principles of oral and maxillofacial surgery, 2nd edn. Peoples Medical Publishing House, USA
10. Cillo JE Jr, Gassner R, Koepsel RR et al (2000) Growth factor and cytokine gene expression in mechanically strained human osteoblast-like cells: implications for distraction osteogenesis. *Oral Surg Oral Med Oral Pathol Oral Radiol Endod* 90:147
11. Robiony M, Polini F, Costa F, Politi M (2002) Osteogenesis distraction and platelet-rich plasma for bone restoration of the severely atrophic mandible: preliminary results. *J Oral Maxillofac Surg* 60(6):630–635
12. DeCoster TA, Simpson AH, Wood M, Li G, Kenwright J (1999) Biologic model of bone transport distraction osteogenesis and vascular response. *J Orthop Res* 17(2):238–245
13. Eyres KS, Bell MJ, Kanis JA (1993) Methods of assessing new bone formation during limb lengthening. ultrasonography, dual energy X-ray absorptiometry and radiography compared. *J Bone Jt Surg Br* 75:358–364
14. Babatunde OM, Fragomen AT, Rozbruch RS (2010) Noninvasive quantitative assessment of bone healing after distraction osteogenesis. *HSSJ* 6:71–78
15. Garcia FL, Picado CH, Garcia SB (2009) Histology of the regenerate and docking site in bone transport. *Arch Orthop Trauma Surg* 129(4):549–558
16. Zapata U, Halvachs EK, Dechow PC, Elsalanty ME, Opperman LA (2011) Architecture and microstructure of cortical bone in reconstructed canine mandibles after bone transport distraction osteogenesis. *Calcif Tissue Int* 89(5):379–388. doi:10.1007/s00223-011-9529-6
17. Çakır-Özkan N, Eyibilen A, Özkan F, Gülbahar MY, Kabak YB (2011) Immunohistochemical analysis of reconstructed sheep mandibles: transport distraction osteogenesis versus autogenous bone grafting. *J Oral Maxillofac Surg* 69(4):1248–1254
18. Farhadieh RD, Dickinson R, Yu Y, Gianoutsos MP, Walsh WR (1999) The role of transforming growth factor-beta, insulin-like growth factor I, and basic fibroblast growth factor in distraction osteogenesis of the mandible. *J Craniofac Surg* 10(1):80–86
19. Ozkan K, Eralp L, Kocaoglu M, Ahishali B, Bilgic B, Mutlu Z, Turker M, Ozkan FU, Sahin K, Guven M (2007) The effect of transforming growth factor beta1 (TGF-beta1) on the regenerate bone in distraction osteogenesis. *Growth Factors* 25(2):101–107
20. Sciadini MF, Dawson JM, Banit D, Juliao SF, Johnson KD, Lennington WJ, Schwartz HS (2000) Growth factor modulation of distraction osteogenesis in a segmental defect model. *Clin Orthop Relat Res* 381:266–277
21. Rauch F, Lauzier D, Travers R, Glorieux F, Hamdy R (2000) Effects of locally applied transforming growth factor-beta1 on distraction osteogenesis in a rabbit limb-lengthening model. *Bone* 26(6):619–624
22. Yeung HY, Lee KM, Fung KP, Leung KS (2002) Sustained expression of transforming growth factor-beta1 by distraction during distraction osteogenesis. *Life Sci* 71(1):67–79
23. Latalski M, Elbatrawy YA, Thabet AM, Gregosiewicz A, Raganowicz T, Fatyga M (2011) Enhancing bone healing during distraction osteogenesis with platelet-rich plasma. *Injury* 42(8):821–824
24. Swennen GR, Schutyser F, Mueller MC, Kramer FJ, Eulzer C, Schliephake H (2005) Effect of platelet-rich-plasma on cranial distraction osteogenesis in sheep: preliminary clinical and radiographic results. *Int J Oral Maxillofac Surg* 34(3):294–304
25. Whitman DH, Berry RL, Green DM (1997) Platelet gel: an autologous alternative to fibrin glue with applications in oral and maxillofacial surgery. *J Oral Maxillofac Surg* 55:1294
26. Marx RE, Carlson ER, Eichstaedt RM et al (1998) Platelet-rich plasma: growth factor enhancement for bone grafts. *Oral Surg Oral Med Oral Pathol Oral Radiol Endod* 85:638
27. Neelakandan RS, Mathew PC (2009) Intraoral maxillary transport distraction: a case report. *J Oral Maxillofac Surg* 67(8):1751–1755

28. Cherkashin AM, Samchukov ML (2001) Potential mistakes and complications during distraction osteogenesis. In: Samchukov ML, Cope JB, Cherkashin AM (eds) Craniofacial distraction osteogenesis. St. Louis, Mosby, pp 583–594
29. Troulis MJ, Kaban LB (2003) Complications of mandibular distraction osteogenesis. *Oral Maxillofac Surg Clin N Am* 15:251–264
30. Heffez LB, Kirton M (2005) Vector control in transportation osteogenesis. *J Oral Maxillofac Surg* 63:737–746