Original Article - Prospective Study

Creation of Bone and Soft Tissue in Postmaxillectomy Patients Using Curvilinear Transport Distraction Osteogenesis

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Abstract

Background: Large surgical defects in the maxilla due to trauma or tumor are usually reconstructed with revascularized-free fibula flaps (RFFF). In the past, the use of curvilinear transport distraction osteogenesis (CTDO) has been shown to be an efficacious way in closing large defects in the maxilla, but it had limitations which have now been overcome by the present development. The present distractor is an improvement upon the previous three prototypes and employs the concept of tetrafocal distraction by means of hybridizing the bone with the tooth in the transport disc segment. This article aims to prove that tetrafocal distraction provides a viable alternative to the RFFF. **Materials and Method:** In a prospective cohort study of six postmaxillectomy patients, the method of CTDO was applied and investigated to ascertain the outcome. The regenerate bone was compared with the parent bone, using a new maxillary transport distractor. A linear bicortical fracture was created in the maxilla in a vertical direction (segmentally) to develop a mobile, vascularized transport disk. This transport disk underwent further subdivision to produce the concept of tetrafocal distraction. **Results:** After osseointegration of the dental implants, prosthetic rehabilitation of the dentition was successful. The authors report the successful outcome of two of the six cases subjected to CTDO to treat defects ranging from 25 mm (using bifocal distraction) to 80 mm along a curved trajectory (using tetrafocal distraction). **Conclusions:** The production of curvilinear bone and soft tissue along a horizontal plane has been demonstrated. From a clinical perspective, the new alveolar bone achieved the correct width and height to create a physiological vestibule and an esthetic zone for dental implants. In addition, the shape of the palatal vault is also reconstituted. The tetrafocal method of the CTDO is a reliable method of maxillary reconstruction.

Keywords: Distraction osteogenesis, maxillary reconstruction, maxillectomy defect, transport distraction

Introduction

Maxillary defects caused by trauma or tumor resection in the head-and-neck region can be devastating to the patient from a cosmetic and functional perspective.[1] The reconstruction of maxillary defects presents a significant challenge to both the surgeon and prosthodontist.[2,3] The esthetic needs that must be considered comprise the restoration of the mid-facial contour; for this, there needs to be proper anatomical restoration of the bony contours of the cheekbone or mala, the orbital rim, the zygomatic buttress, and the alveolar arch of the maxilla notwithstanding the vault of the hard palate.[4] The latter is germane to swallowing, speech, esthetics, as well as support for velopharyngeal valve competence.[5]

The revascularized free fibula flaps (RFFF) offer the most functional solution for postmaxillectomy rehabilitation, as the quality of the bone is ideal to house dental implants. In addition, the skin paddle of composite flaps can be used to obturate the palatal vault and close any associated defects.[6] This method of reconstruction can still be regarded as the gold standard in centers, where high expertise and technical facilities

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are available. Usually, donor-site morbidity and postoperative complications are not high in these units.[7] However, as the maximum height of the fibula bone is 14 mm, this presents problems in the esthetic zone of the mouth.[8,9] In addition, dental implants would support very high prosthetic superstructures to approximate the occlusal plane. These superstructures pose the risk of unfavorable bending movements and also implant overload. The latter may jeopardize the long-term survival of dental implants.[10,11] While skin does not do well with dental implants in the long term owing to the hyperplasia and inflammation that leads to pain and bleeding, the flatness of the skin paddle cannot reproduce an anatomical vault of the hard palate.[7]

The concept of transport distraction osteogenesis for the creation of new bone and soft tissue is well described.[12-17] However, the creation of bone and soft tissue along a curved trajectory has only recently been successfully accomplished in the maxilla.[18,19] The present distractor is an improvement on the previous three prototypes[14] and employs the concept of tetrafocal distraction by means of hybridizing the bone with the tooth in the transport disk segment [Figure 1]. This article describes the new design as well as the modification of the surgical protocol.

Materials and Methods

Preoperative Planning

A three-dimensional (3D) stereolithographic model was fabricated from the computerized tomogram (CT) scan of a patient who had a Brown IIa postmaxillectomy defect.[2,3] In Figure 2a, the 3D model and the anatomical outlines of the teeth in the bone are illustrated. In Figure 2b, the adaptation of the baseplate to the model (to plan the position of the transosseous screws) can be seen. A "tandem" distractor would be placed to distract between the teeth in distinct phases. The design of the slot in the baseplate allows for deviation in dental root anatomy so that transosseous screws can be placed strategically to avoid the dental roots during fixation [Figure 3].

The fixing of the vertical distraction plates to the locomotive (bone transport carriage) was designed so that, after the first stage of distraction, by merely sectioning the small horizontal crossbars, the locomotive can be freed to continue with the second phase of distraction [Figure 4]. On the model in Figure 5a, it can be seen that the trajectory rail is adapted with the device to clear the zygomatic buttress. In Figure 5b, a mark was made for the area where bone is indicated for removal during surgery from the inferior aspect of the corpus malar.

Surgical procedure and installation of device

A general anesthetic was administered to the patient. The anterior maxillary bone was exposed through a circumvestibular incision [Figure 6a]. The baseplate was secured to the premaxillary bone, considering the position of the roots of the teeth. The insertion of 2.5 mm diameter titanium screws (Biomet™) ensured a good stability of the baseplate [Figure 6b]. Extra care was taken to ensure that the trajectory rail remained parallel to the occlusal plane of the mandible, and that the

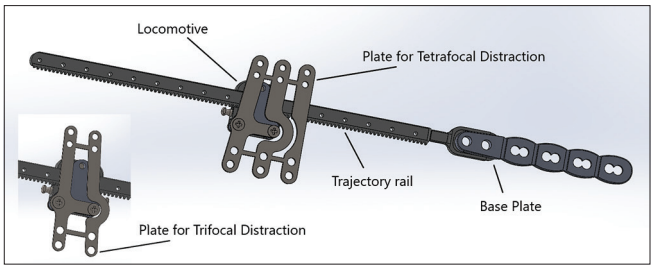

Figure 1: The curvilinear transport distraction osteogenesis distractor illustrating trifocal and tetrafocal distraction

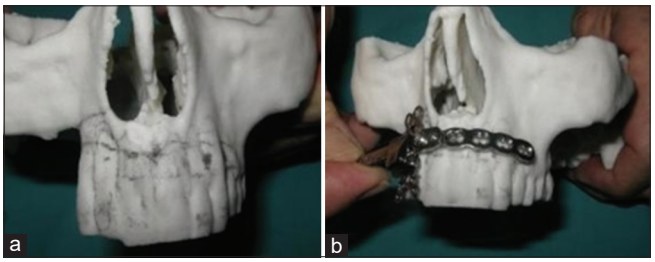

Figure 2: (a) The roots of the teeth are clearly seen. (b) Positioning of the device with reference to the roots of the maxillary teeth

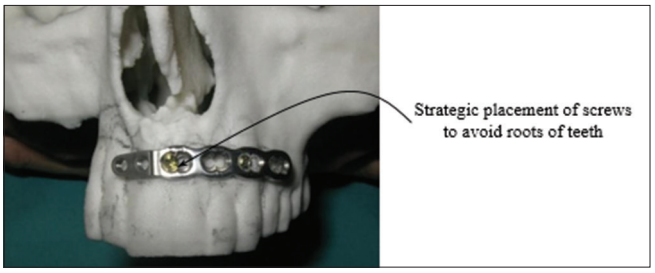

Figure 3: The baseplate prepared for attachment to the underlying bone

position of the locomotive and the vertical distraction plates coincided with the teeth below which make up the transport disk. Figure 7 confirms the correct relationship of the distraction plates and the underlying teeth. Intraosseous screws secured the vertical distraction plate to the alveolar bone superiorly.

In addition, care was taken to ensure that the trajectory rail be kept clear from any soft tissue, namely, cheek muscle or buccal mucosa, to allow free access to and mobility of the locomotive. Figure 8 shows the removal of bone from the corpus malar to allow unobstructed movement of the locomotive.

The crowns of the anterior teeth were prepared for bonding to the vertical plates of the transport disk. The surrounding environment was cordoned off from the anterior teeth by means of dry gauze to provide a desiccated environment. The crowns of teeth #12 and #13 were treated with acid etch gel and bonding agent which were cured with ultraviolet light. The transport disk was created by horizontal and vertical osteotomies in the bone [Figure 9].

In this upgraded distractor, the locomotive could be removed and replaced repeatedly. This two-part system facilitated the process of installation, in which the trajectory rail could be attached and removed as needed. Figure 10 shows the distraction plates

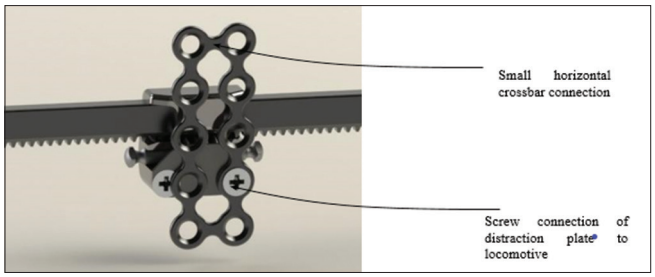

Figure 4: The inner aspect of the locomotive. The vertical plates are joined to each other above and below by a crossbar. A screw fixes the vertical plates to the locomotive

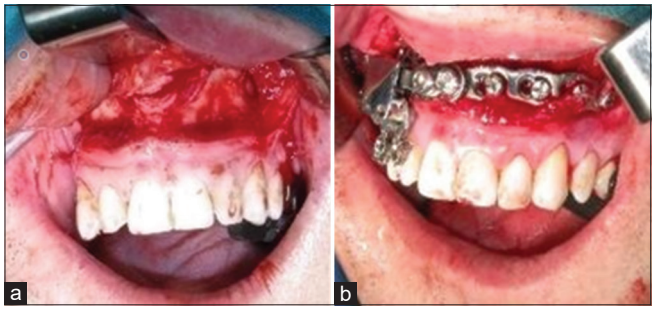

Figure 6: (a) The exposed premaxilla. (b) Fixation of the baseplate

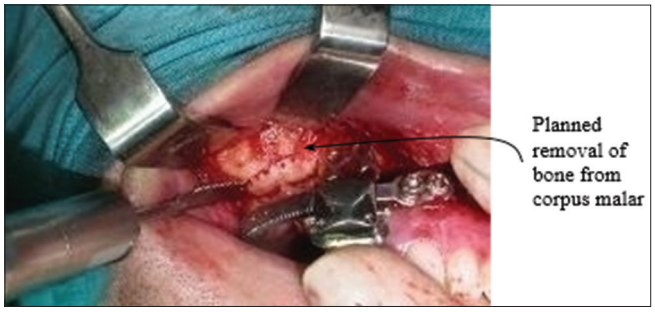

Figure 8: Planned removal of the bone from the zygomatic corpus malar

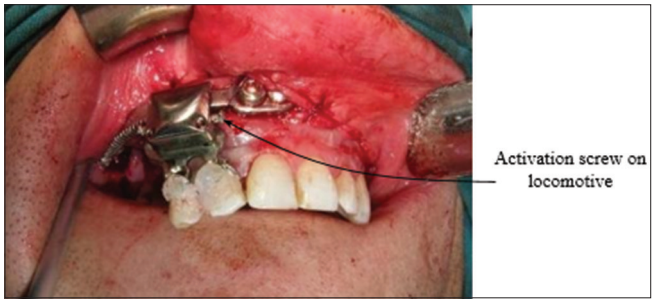

Figure 10: The locomotive firmly attached to the crowns of the teeth inferiorly and to the bone superiorly by two transosseous screws

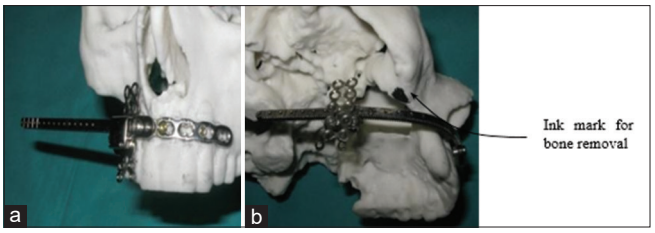

Figure 5: (a) The attached device and the distraction plate clearing the zygomatic buttress. (b) The proposed bone removal is marked in black ink

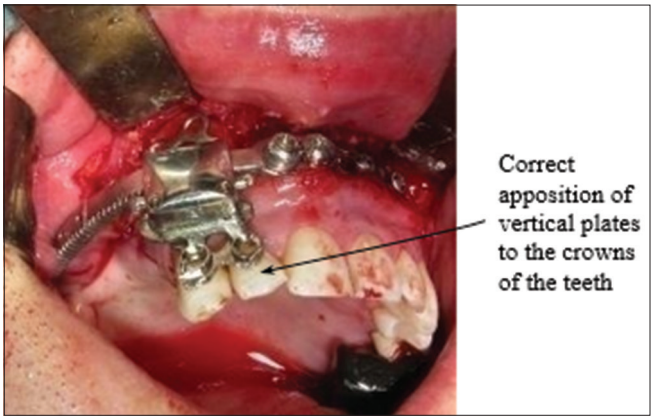

Figure 7: The correct placement of the locomotive and distraction plates in relation to teeth #12 and #13

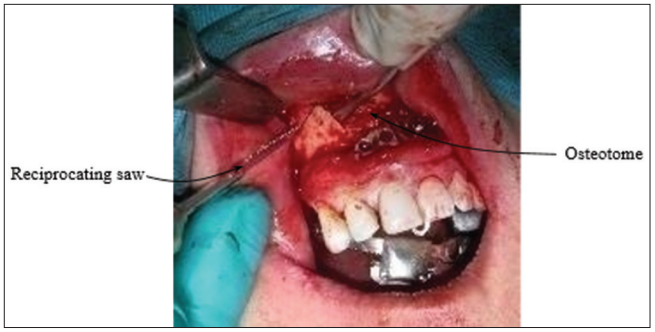

Figure 9: The transport disk created by a reciprocating saw and osteotome

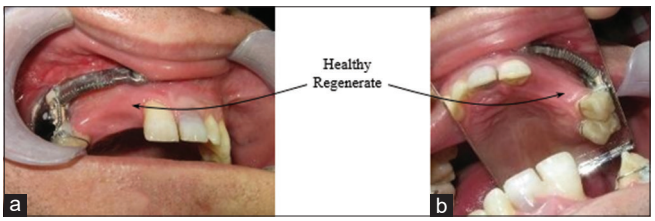

Figure 11: (a) Healthy regenerate. (b) Palatal vault with rugae created from this regenerate

cemented to the crowns of the teeth with glass ionomer cement. The baseplate was submerged under the soft tissue of the upper lip, taking care not to obstruct access to the activation screw on the locomotive. The exposed trajectory rail is also evident.

Commencement of distraction

After a latency period of 5 days, distraction was commenced. Distraction was carried out at a rate of 1 mm/day and a rhythm of 0.5 mm twice daily.[20,21] After 20 days, the first phase of distraction was terminated. As shown in Figure 11a and b, the healthy new regenerate in the premaxillary region measured approximately 20 mm with a curvilinear appearance. In the hard palate, the presence of a palatal vault was visible and rugae replication was also noted in the palatal mucosa. Once distraction reached the cornerstone of the maxilla, it

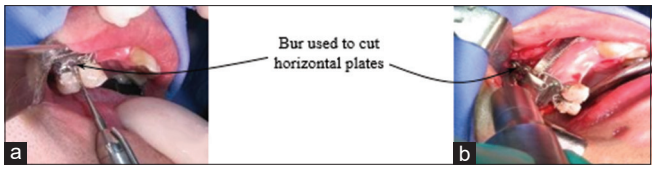

Figure 12: (a) The separation of the transport disk by cutting the crossbar between the vertical plates inferiorly. (b) The cutting of the crossbar superiorly, thus allowing the locomotive to advance freely to continue the distraction process

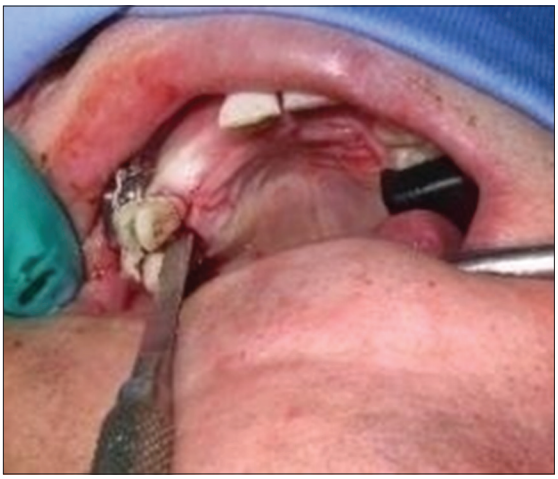

Figure 14: Use of a fine osteotome to separate the coronal interseptal bone

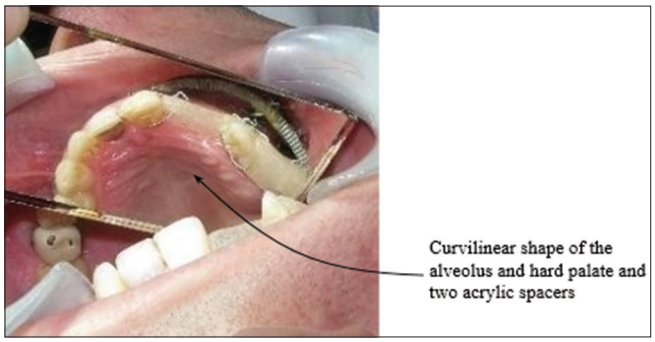

Figure 16: The superlatively recreated palatal vault with rugae in the palate. Note also the depth of the palatal vault and the creation of a vestibule. The two acrylic interdental spacers are wired to the abutment teeth

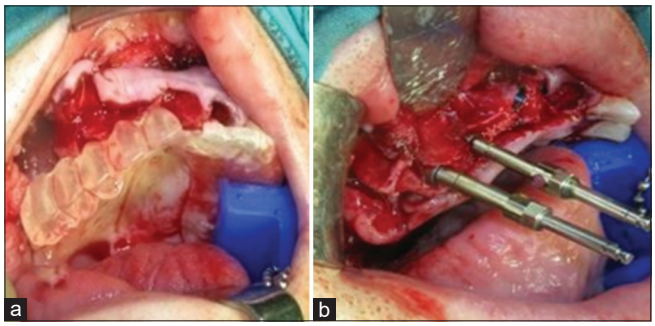

Figure 18: (a) The acrylic splint for implant placement. (b) Placement of the four dental implants

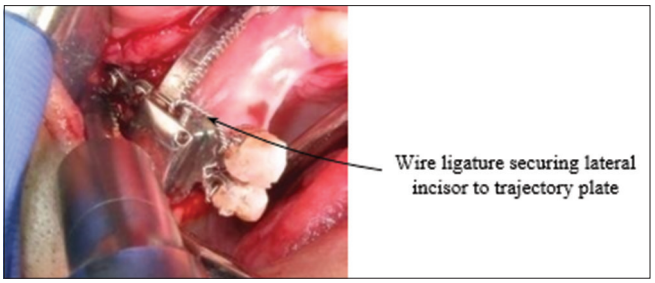

Figure 13: A reciprocating saw was used to create an osteotomy for the second transport disk. A wire ligature was used to secure the lateral incisor to the rail. The bone was also secured superiorly by means of the vertical distraction plate

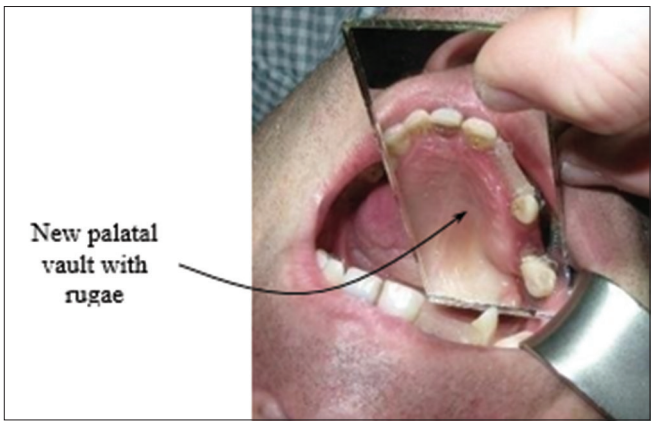

Figure 15: The second part of the distraction process. The shape of the bone is anatomical, with a palatal vault and a "tuberosity" appearance

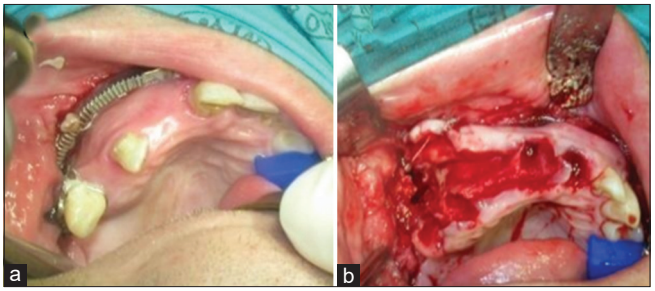

Figure 17: (a) The favorable curvilinear shape of the new maxilla. (b) The thick and deep new regenerated maxillary bone and healthy dental sockets

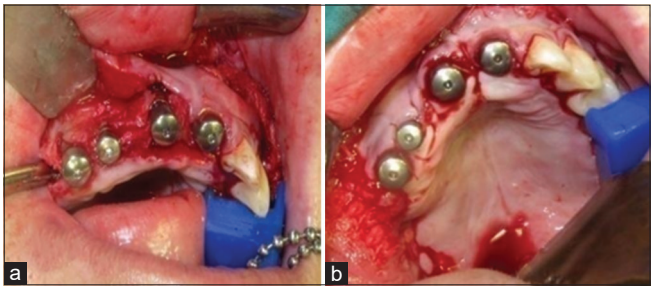

Figure 19: (a) The placement of four dental implants with healing abutments. (b) Primary closure of soft tissue around the dental implants

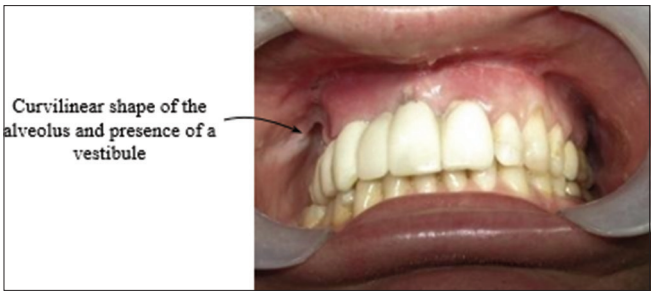

Figure 20: The esthetically constructed temporary bridge *in situ*

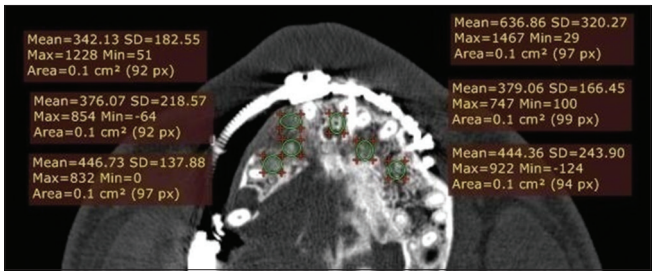

Figure 22: The first phase post distraction at 3 months with regenerate (left column) versus parent bone (right column) and regions of interests expressed in Hounsfield units

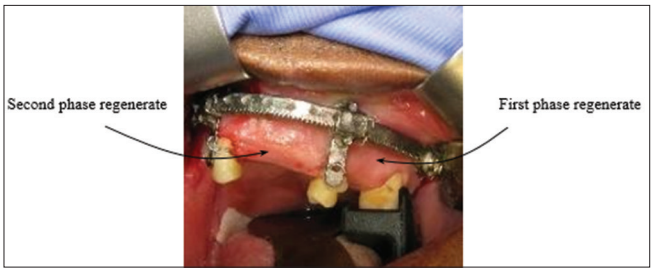

Figure 24: The regenerated trifocal curvilinear bone supported by the trajectory rail

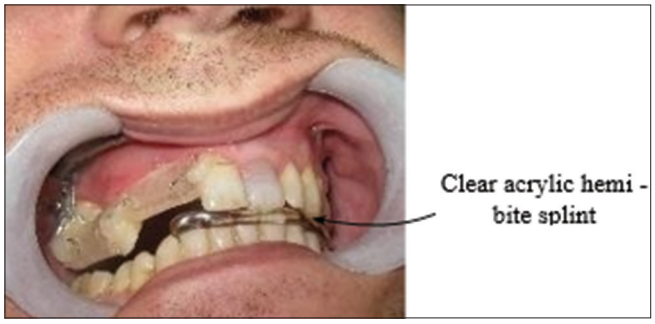

Figure 26: The jaws in occlusion; the insertion of a lower hemibite plate helped to protect the regenerate and abutment teeth from the traumatic occlusal forces

was terminated so that a blended curvature could be arrived during the second phase of distraction. The latter images show excellent reproduction of regenerate with anatomical replication of parent alveolar and palatal bone. This proved to be the ideal in optimizing function and esthetics. The immature bone was allowed to consolidate for 10 weeks.[22-27]

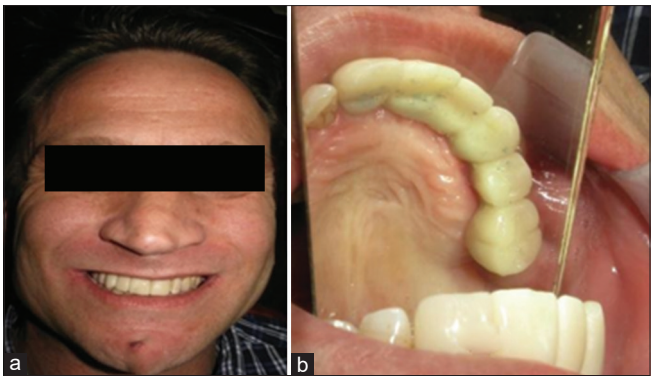

Figure 21: (a) The patient with a most esthetic and functional temporary bridge *in situ.* (b) The anatomical recreation of the hard palate, alveolus, and vestibule (mirror view); (consent obtained)

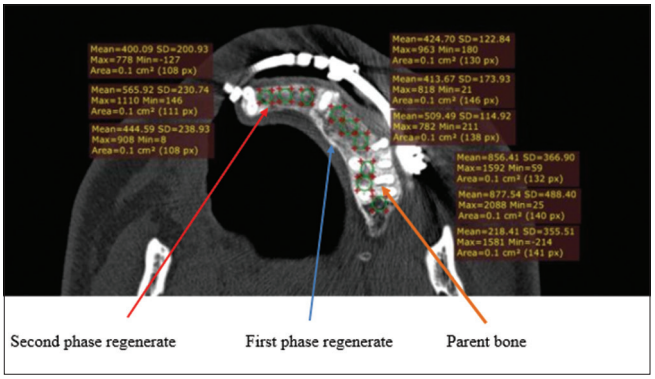

Figure 23: The posttrifocal distraction situation at 6 months with the regenerate versus parent bone and regions of interests expressed in Hounsfield unit

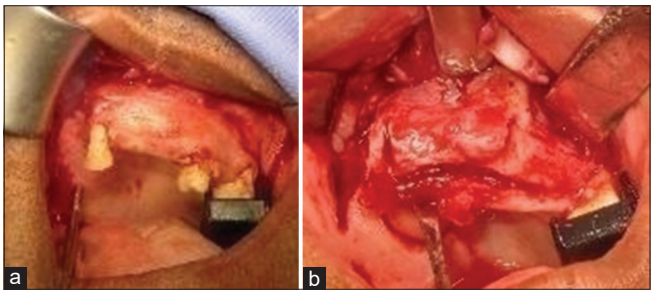

Figure 25: (a) The trifocal favorable curvilinear shape of the new maxilla. (b) The thick and deep new regenerated maxillary bone and healthy dental sockets

Second phase of distraction

Under general anesthesia, the soft tissue was elevated, and the transport disk was exposed. The horizontal metal bars supporting the two vertical plates of the distraction apparatus were cut using a tungsten carbide burr (SS White™ #702) [Figure 12a and b]. A reciprocating saw was used at the bone interface, and a new osteotomy was performed in a vertical fashion between the remaining teeth in the transport disk. After tooth #22 was secured to the trajectory rail by means of a wire ligature [Figure 13], the mobile segment (transport disk) created by means of an osteotome [Figure 14] was tested for

unhindered movement and then returned to its original position for another period of latency.

After a latency period of 5 days, the locomotive was activated at a rate of 1 mm/day and a rhythm of 0.5 mm twice daily. An acrylic spacer was wired to the abutment teeth to maintain the newly created space and provide stability [Figure 15]. The latter also showed the recreated palatal vault with rugae and a "tuberosity" appearance. A further 18 mm was added to the maxilla which amounted to a total distraction of 38 mm. The amount of new regenerate bone and soft tissue was sufficient for the placement of dental implants. Figure 16 shows the secured acrylic spacer in position, and the newly created regenerate which is on a curvilinear trajectory.

Final phase: Surgical exposure of regenerate and placement of dental implants

A general anesthetic was administered. In Figure 17a, the new maxilla can be seen before removal of the distraction apparatus. The trajectory rail and the rest of the distraction device were removed. The incisor and canine teeth were carefully removed so that the sockets of the teeth could be preserved for the placement of dental implants [Figure 17b].

A clear acrylic splint was fabricated by a prosthodontist using a CT scan of the maxilla. The splint fitted accurately during the placement of dental implants into the new maxilla. The availability of this thick regenerate made it possible to place four dental implants with good primary stability into the new maxilla. Figure 18a shows the acrylic splint *in situ* and Figure 18b shows placement of the dental implants. As can be seen in Figure 19a, the dental implants were well placed with healing abutments. Bone scrapings were taken from the areas of excess tissue and placed into the sockets around the dental implants to accelerate osseointegration. There was good bony union between the regenerate and the malar corpus, and hence, no interpositional bone grafting was required in this case. Figure 19b shows primary soft tissue closure around all the dental implants.

There was sufficient torque at implant placement for an immediate esthetic temporary bridge to be constructed. Figure 20 shows the implant-supported temporary bridge.

Results

The use of curvilinear transport distraction osteogenesis (CTDO) has created not only new alveolar bone with its attendant depth creating a vestibule but also a palatal vault. The shape, depth, and anatomical accuracy of the regenerated maxilla are evident. Figure 15 shows the superlatively recreated palatal vault with rugae in the palate.

In Figure 18b, the regenerated bone can be seen as well as the preserved sockets of the anterior teeth. The quality of the regenerated bone with its thick buccal plate as well as the healthy tooth sockets, made it conducive to the placement of dental implants. A temporary bridge was constructed onto the implants, [Figures 20 and 21a and b].

Bone density of second-phase regenerate

The bone density of the new regenerate at 3 months, compared favorably with the bone density of the regions of interests seen within the parent bone. The CT scan of the maxilla, Figure 22, shows the 3-month state of the new bone expressed in Hounsfield units.[28]

A CT scan of the maxilla [Figure 23] shows tetrafocal distraction (of another patient) at the 3-month and 6-month intervals of new bone formation, expressed in the HU. The second phase of regenerate compared favorably with the first phase, which, in turn, compared favorably with the parent bone. This clinical situation is shown in Figure 24.

Discussion

The development of the current distractor was due to the paucity of teeth available for the creation of bone stock, which led to the concept of hybrid distraction. Concurrently, the new design of the distractor allows the mobile component to be split into segments; hence, the term "Tandem distractor." This concept eliminated the problem of the weak anchoring of the transport disk onto its cradle as previously described by Boonzaier *et al*. in 2015.[18]

The current device caters for a distraction length of up to 100 mm including a minimum bend radius of 25 mm. This means that in severe cases, the device can distract from one side of the maxilla to the other, transcending the premaxilla, and centerline of the maxilla.

As shown by Neelakandan amd Bhargava in 2012, it is not possible to grow bone on a curvilinear trajectory in a horizontal plane.[29] The regenerate will follow the shortest distance between two points, hence creating a straight line, which is known as the "rubber band" effect. With the "tandem distractor" eliciting tetrafocal distraction, as shown in Figure 24, the bone was grown following the curvature of the premaxilla, using the method of creating a second (and possibly a third) transport disk from the first one.

The quality of the newly created bone was found to be more than satisfactory, and the teeth that were transported were eventually extracted, and dental implants were placed into their respective sockets. The results of the bone that was produced are shown in Figures 24, 25a and b.

During distraction and transport of the teeth, it was noted that premature contacts with the mandibular occlusion occurred. To avoid this complication, a sectional removal acrylic bite appliance was made [Figure 26]. Further, to prevent relapse of the new segments of the regenerated bone (between the first and the second transport disk), an acrylic spacer was placed between the teeth [Figures 16 and 26].

It was significant that the abutment teeth between the areas of bone regenerate did not have any axial or nonaxial forces imposed upon them so that healing of the osteoid around these teeth would not be compromised.

Conclusions

In the present study, the production of curvilinear bone and soft tissue along a horizontal plane has been clearly demonstrated, as well as the quantity and the quality of the newly created bone and soft tissue. From a clinical perspective, the new alveolar bone achieved all the goals that were set out, namely the correct width and height to create a physiological vestibule and palatal vault shape. In addition, the depth to reestablish the shape of the hard palate as well as the integrity to place dental implants in the esthetic zone was also achieved. This clinical picture is well demonstrated in Figures 20 and 21. The anatomical landmarks mentioned above are not seen in the RFFF.

The method of CTDO as described has been shown to be a reliable method of maxillary reconstruction. The HU produced by CTDO was sufficient for dental implant placement after 3 months. Besides providing hermetic closure of the orosinonasal cavities, this method of CTDO also maximizes function and esthetics.

Declaration of patient consent

The authors certify that they have obtained all appropriate patient consent forms. In the form the patient(s) has/have given his/her/their consent for his/her/their images and other clinical information to be reported in the journal. The patients understand that their names and initials will not be published and due efforts will be made to conceal their identity, but anonymity cannot be guaranteed.

Financial support and sponsorship

The CTDO device was designed and developed by the authors and manufactured by a state-of-the-art industry in Cape Town, TiTaMED. Its design and manufacturing were financed entirely by the authors, by the Postgraduate Fund of the University of Cape Town (UCT), and by the ATTRI Orthopaedics (Pty) Ltd. UCT has also financed the application and maintenance of the patent with reference: US2014/0324046 A1 and PCT/1B2012/056664.

It is envisaged that the CTDO device would be commercially available and distributed by a South African company.

Conflicts of interest

There are no conflicts of interest.

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