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Regenerate Healing Outcomes in Unilateral Mandibular Distraction Osteogenesis Using Quantitative Histomorphometry

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Abstract

Background—The authors' goal was to ascertain regenerate bone-healing metrics using quantitative histomorphometry at a single consolidation period.

Methods—Rats underwent either mandibular distraction osteogenesis ($n=7$) or partially reduced fractures ($n=7$); their contralateral mandibles were used as controls ($n=11$). External fixators were secured and unilateral osteotomies performed, followed by either mandibular distraction osteogenesis (4 days' latency, then 0.3 mm every 12 hours for 8 days; 5.1 mm) or partially reduced fractures (fixed immediately postoperatively; 2.1 mm); both groups underwent 4 weeks of consolidation. After tissue processing, bone volume/tissue volume ratio, osteoid volume/tissue volume ratio, and osteocyte count per high-power field were analyzed by means of quantitative histomorphometry.

Results—Contralateral mandibles had statistically greater bone volume/tissue volume ratio and osteocyte count per high-power field compared with both mandibular distraction osteogenesis and partially reduced fractures by almost 50 percent, whereas osteoid volume/tissue volume ratio was statistically greater in both mandibular distraction osteogenesis specimens and partially reduced fractures compared with contralateral mandibles. No statistical difference in bone volume/tissue volume ratio, osteoid volume/tissue volume ratio, or osteocyte count per high-power field was found between mandibular distraction osteogenesis specimens and partially reduced fractures.

Conclusions—The authors' findings demonstrate significantly decreased bone quantity and maturity in mandibular distraction osteogenesis specimens and partially reduced fractures compared with contralateral mandibles using the clinically analogous protocols. If these results are extrapolated clinically, treatment strategies may require modification to ensure reliable, predictable, and improved outcomes.

The use of distraction osteogenesis in the craniofacial skeleton has been increasing steadily for a variety of reconstructive options^{1–7} since its original discovery over a century ago.⁸

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Nevertheless, since its initial application for lengthening the mandible in congenital hypoplasia,⁹ we have lacked discrete, quantitative metrics to evaluate the degree of success or failure of the technique. The same complications, including relapse, asymmetry, and open-bite deformity, remain unchanged today,¹⁰ as do our protocols. Despite the increasing use of this vigorous tool for regeneration of bony deficiencies in the craniofacial skeleton, the outcome measures that demonstrate optimal distraction osteogenesis remain unknown.

Establishing accurate and reproducible parameters with which to gauge regenerate healing during mandibular distraction osteogenesis should lead to advances in proper application of this technique and improved distraction protocols for enhanced clinical use. Experimental animal studies assessing regenerate healing in mandibular distraction osteogenesis using histologic analysis have often been subjective and qualitative, or “semiquantitative,”^{11–15} lacking the measurable precision required to reproducibly determine outcomes. In addition, previous tissue and cellular examination of mandibular distraction osteogenesis have focused on the consequences of multiple confounding variables such as rate, rhythm, and consolidation, and have eschewed approaches that provide adequate numbers using a single time point to enable valid statistical conclusions.^{16–22}

The purpose of this study was to objectively quantify bone healing in mandibular distraction osteogenesis compared with both a partially reduced fracture and the contralateral mandible, using a single, clinically accepted consolidation period.^{4,23–25} We used conventional destructive metrics, and established meticulous quantitative histomorphometric protocols, which could be correlated with our biomechanical outcome studies²⁶ and ultimately nondestructive imaging metrics for future studies. Our specific aim was to quantitatively measure the tissue and cellular constituents of an established region of interest, referred to as tissue volume, within the regenerate after unilateral mandibular distraction osteogenesis in comparison with the contralateral mandibles. A further specific aim of this study was to determine whether mandibular distraction osteogenesis has attenuated quantitative histomorphometric outcome metrics when compared with partially reduced fractures, another previously established gauge of consolidated bone in this animal model.²⁷

Our laboratory has developed a rat model of mandibular distraction osteogenesis that differentiates new bone formation attributable to distraction versus secondary bone formation from unaided fracture healing.^{27–29} This model has permitted isolation of the variables necessary to discern the significant differences between regenerate healing from mandibular distraction osteogenesis compared with callus healing from partially reduced fractures. Using quantitative histomorphometry to measure the ratio of bone volume to tissue volume, the ratio of osteoid volume to tissue volume (which includes all nonmineralized matrix), and detailed counts of osteocytes in a standardized 16× high-power field per region of interest, we hypothesized the following:

1. There would be a greater percentage of bone volume/tissue volume within contralateral mandibles compared with mandibular distraction osteogenesis specimens; furthermore, the bone volume/tissue volume in partially reduced fractures would be intermediate between contralateral mandibles and mandibular distraction osteogenesis specimens.

2. The percentage of osteoid volume/tissue volume would be greater in mandibular distraction osteogenesis specimens than in partially reduced fractures, and the least in contralateral mandibles.
3. The mature bone of the contralateral mandibles would have a greater osteocyte count per high-power field compared with mandibular distraction osteogenesis specimens, and the osteocyte count per high-power field in partially reduced fractures would be intermediate between contralateral mandibles and mandibular distraction osteogenesis.

The purpose of this study was to objectively quantify bone healing in mandibular distraction osteogenesis compared with both a partially reduced fracture and the contralateral mandible using a single consolidation period based on Ilizarov's original design.^{30,31} The overall goal in our series of experiments was to establish more objective, quantitative outcome measures with which to assess regenerate healing, to guide and improve our clinical judgment regarding the optimal management for our patients undergoing mandibular distraction osteogenesis.

PATIENTS AND METHODS

Animals were randomly assigned preoperatively into two surgical groups: mandibular distraction osteogenesis ($n=7$) or partially reduced fractures ($n=7$). Both groups underwent 28 days of consolidation postoperatively, excluding latency and distraction time. The contralateral mandibles ($n=11$) from the respective mandibular distraction osteogenesis and partially reduced fracture specimens were controls.

Male Sprague-Dawley rats weighing 400 g were housed in a pathogen-free, restricted-access facility with chow and water. All animal procedures were performed according to the National Institutes of Health *Guide for the Care and Use of Laboratory Animals* and approved by the University of Michigan Animal Care and Use Committee.³²

Having performed this mandibular distraction osteogenesis and partially reduced fracture procedure over the years,^{26–29,33–36} we briefly describe it as follows. Under sterile conditions, using general anesthesia, a midline incision was placed from the submentum to the neck crease, elevating skin flaps exposing the anterolateral mandible. Bone was predrilled to insert an 0–80 stainless steel threaded rod horizontally across the symphysis, perforating the skin and securing the ends, creating the anterior portion of our fixator. The inferior borders of the mandible were exposed bilaterally and then predrilled to insert bilateral 0–80 threaded stainless steel pins from buccal to lingual, anterior to the angle. The pin ends perforated the skin and then were secured with our custom titanium caps, creating the posterior aspect of the modified distractor. The right side was fixed rigidly, and the left side received a distraction screw.

A vertical osteotomy was created on the left hemimandible, posterior to the third molar, using a 10-mm micro-reciprocating blade (Stryker, Portage, Mich.) that extended from the inferior border superiorly to the sigmoid notch. The osteotomy edges were reduced and then resecured, and the incision was closed.

Mandibular distraction osteogenesis specimens were distracted after 4 days' latency on a 12-hour interval. A clockwise half-turn of the distraction screw corresponded to 0.3 mm of osteotomy separation, resulting in 5.1 mm of distraction over 8 days. The partially reduced fracture group underwent seven half-turns immediately postoperatively for a 2.1-mm fracture defect and then remained fixed throughout consolidation.

After the animals were euthanized, 24 specimens remained nondecalcified (molars removed with a burr) and underwent 48-hour alcohol dehydration and then infiltration with a 1:1 combination of 2-hydroxyethyl methacrylate and embedding medium. Using vacuum heating, the specimens were embedded over 14 days and then sectioned at 5 μ m using the Polycut (Leica Microsystems, Wetzlar, Germany) sledge microtome with a carbon-tungsten blade, mounted, and then stained with modified Villanueva-Gomori trichrome.

All subsequent histology was performed using paraffin as follows: hemimandibles were fixed in 10% neutral buffered formalin for 72 hours and then transferred to 70% ethanol at 4°C. The specimens were cleared of all soft tissue and the teeth were ground, leaving the roots as landmarks, and transferred to a formic acid/sodium citrate decalcification solution (equal parts 40% formic acid and 6.25% sodium citrate), changed every 2 to 3 days, and stored at 4°C. The specimens were followed radiographically through decalcification and then landmarked with an 18-gauge needle at the third molar root. Specimens were vacuum processed (dehydration and paraffin infiltration) under a 48-hour program in the Hypercenter (Hypercenter XP, Shandon, Pittsburgh, Pa.), and then infiltrated once more for 2 hours in a vacuum bath (Leica Embedding Center, model EG1160; Leica Microsystems), followed by embedding in paraffin using paraffin containing dimethylsulfoxide (Paraplast Plus; Ted Pella, Inc., Redding, Calif.). Peel-away embedding molds (22×40 mm) were used and refrigerated overnight (4°C). Blocks were sectioned from buccal to lingual into 7- μ m sagittal sections and mounted on glass slides (Fisherbrand Superfrost Plus; Fisher Scientific, Pittsburgh, Pa.). Six to eight sections per slide, chosen approximately 50 to 100 μ m apart from each other, from a total of 70 to 100 sections per block, were stained. The prepared slides were deparaffinized in xylene and then dehydrated through graded alcohol. Specimens were then stained with Gomori's "one-step" trichrome and mounted.

The Gomori trichrome stains separated bone in turquoise and osteoid/nonmineralized matrix in red, providing for easy digital color analysis. Using a G4 Macintosh (Apple Inc., Cupertino, Calif.) with Nikon (Nikon, Tokyo, Japan) scanning software, the slides were scanned, cropped, and saved as TIFF files. Using Adobe Photoshop CS2 (Adobe Systems, Inc., San Jose, Calif.), the images were oriented with the anterior hemimandible on the right, cropped to 1596×1287 pixels, and then adjusted to final dimensions of 640×480 pixels. The file was loaded into the imaging analysis software program (Bioquant NOVA Osteo version 7; R&M Biometrics, Nashville, Tenn.) for region-of-interest placement and color thresholding. Using a sagittal microcomputed tomographic scan from a prior study³⁴ for orientation (Fig. 1, *above*), the appropriate region of interest template was loaded onto the TIFF file and then adjusted to fit the surgical gap or matched control area (Fig. 1, *below*).

Color thresholding was performed as follows: bone volume was obtained by manually selecting a few areas of turquoise bone within the region of interest (Fig. 2, *above*), which

the Bioquant program thresholded, and then osteoid volume was similarly obtained by selecting the red-stained regions within the region of interest (Fig. 2, *below*). Bioquant measured the region of interest area and then calculated the bone volume/tissue volume and osteoid volume/tissue volume ratios.

In addition, osteocytes were “point counted” as follows: region-of-interest templates for mandibular distraction osteogenesis specimens, partially reduced fractures, and contralateral mandible were superimposed onto the digital light microscopy image and then rotated so the bisected base was landmarked as 0 and 0 on an x and y grid and the apex coordinate as 0 and +9000. We divided the region of interests into superior, middle, and inferior subregion of interests, and then randomly selected three high-power fields per each subregion of interest using 16× magnification, for a total of nine high-power fields per region of interest. The high-power fields, measuring 295×366 μm, were stored as TIFF files and printed in color, and the osteocytes were counted inside each high-power field (Fig. 3).

All analysis was performed by at least three individual reviewers. SPSS for Windows, version 16.0 (SPSS, Inc., Chicago, Ill.) was used as follows: bone volume/tissue volume, osteoid volume/tissue volume, and osteocyte count per high-power field between mandibular distraction osteogenesis, partially reduced fractures, and contralateral mandible specimens were analyzed using one-way analysis of variance with post hoc Tukey-Kramer test. Results were accepted as statistically significant at a value of $p<0.05$.

RESULTS

The majority of partially reduced fracture slides revealed a pattern of woven bone, with a paucity of lamellar bone, in the region of interest. The osteotomy edges were imprecise but did allow the newly formed woven bone in the fracture region to be distinguished from the mature lamellar bone outside the region of interest (Fig. 4, *left*). Cartilage remnants were found in only one partially reduced fracture specimen. At higher magnification, red osteoid channels were scattered throughout the thick lattice of turquoise-stained bone (Fig. 4, *right*).

The mandibular distraction osteogenesis slides revealed turquoise woven bone bridges in a multi-directional, honeycomb pattern, separating canals of red osteoid (Fig. 5, *left*). Multiple osteoid canals streamed through random islands and bridges of turquoise bone, but we were unable to discern any directional healing pattern along the axis of distraction (Fig. 5, *right*). The contralateral mandibles revealed mature lamellar bone and minimal nonmineralized matrix, primarily surrounding the incisor root. Three specimens were excluded because of incisor root constituting the majority of the region of interest and less than four of nine high-power fields showing bone or osteocytes.

We found no significant difference in the percentage of bone volume/tissue volume in the mandibular distraction osteogenesis specimens (36.27 ± 9 percent) when compared with the partially reduced fractures specimens (34.11 ± 8 percent). As expected, contralateral mandibles had a significantly ($p<0.05$) greater bone volume/tissue volume ratio (53.22 ± 9 percent), revealing a 47 percent comparatively larger amount of bone volume than either surgical group (Fig. 6).

Similarly, there was no statistical difference of osteoid volume/tissue volume ratio in the mandibular distraction osteogenesis specimens (34.38 ± 6 percent), when compared with partially reduced fracture specimens (30.19 ± 10 percent). The percentage osteoid volume/tissue volume ratio in contralateral mandibles (15.20 ± 5 percent), as expected, was significantly lower than the osteoid volume/tissue volume ratio in the mandibular distraction osteogenesis and partially reduced fractures specimens ($p < 0.05$), demonstrating at least 40 percent less immature bone in contralateral mandibles than either surgical group (Fig. 7).

At $16\times$ magnification, we readily distinguished the flattened maroon osteoblasts at the periphery of the red osteoid islands, abutting the bridges of bone within the region of interest. The mature, spindle-shaped osteocytes were easily visualized within their spacious lacunae surrounded by waves of blue woven bone in both partially reduced fractures (Fig. 8, *above*) and mandibular distraction osteogenesis specimens (Fig. 8, *below*). At this high magnification, it was difficult to appreciate gross architectural variations between mandibular distraction osteogenesis and partially reduced fracture specimens.

We found that the osteocyte count per high-power field in the mandibular distraction osteogenesis group (27.42 ± 10) was not statistically different from that of the partially reduced fracture group (30.2 ± 9). In contrast, the contralateral mandible specimens had a statistically greater osteocyte count per high-power field (52.2 ± 16) than the mandibular distraction osteogenesis and partially reduced fracture groups, demonstrating a 40 percent increase in mature bone cells in contralateral mandibles, compared with both surgical groups (Fig. 9).

DISCUSSION

Mandibular distraction osteogenesis as a reconstructive option for congenital mandibular deficiencies is now being performed in craniofacial centers throughout the world.^{25,37–39} The haste to apply this new technique has resulted in clinical protocols that are predicated on empiric evidence and trial and error. Despite the increasing use of this powerful tool throughout the craniofacial skeleton,^{40–44} the outcome measures that demonstrate optimal distraction osteogenesis are unknown. Our goal was to establish quantifiable metrics to evaluate the degree of healing regenerate based on current clinical protocols. Our ultimate purpose was to quantitate histologic measures of bone healing that may be extrapolated for eventual clinical use to best determine functional healing.

Using our unique rodent model of mandibular distraction osteogenesis, we have previously demonstrated significantly decreased mechanical metrics within the regenerate.⁴⁵ Specifically, breaking load, yield, and stiffness were significantly lower in mandibular distraction osteogenesis specimens than in the contralateral mandibles. Mechanical testing, however, does not examine the anatomical changes that occur at the tissue and cellular levels. Quantitative histomorphometry serves as the standard with which to objectively measure the effects of distraction and fracture healing on tissue and cellular composition. Using reproducible quantitative histomorphometric methods, we have delineated quantifiable differences between mandibular distraction osteogenesis specimens and partially reduced fractures when compared with contralateral mandibles. The analysis was

performed at a solitary consolidation point that mimicked the clinical protocol most commonly used today.^{4,23,25,30,31,46}

Gross histologic findings concurred with other studies, revealing an abundance of newly formed bridges of woven bone as the predominant type found in mandibular distraction osteogenesis,^{16,47,48} and noted a conspicuous absence of trabecular bone in the mandible. The significance of woven bone, rather than lamellar bone, suggests that we have young, immature osseous tissue, in its earliest stages of remodeling.^{23,49} Cartilage was found in less than 1 percent of specimens, suggesting that our rate, rhythm, and consolidation did result in successful intramembranous ossification, supporting the reliability of our procedure.

In addition to the bone immaturity, we also demonstrated statistically greater bone volume in contralateral mandibles when compared with both mandibular distraction osteogenesis and partially reduced fracture specimens. Interestingly, similar to the clinical situation, plain radiography at the end of consolidation displayed evidence of bony union with opacification of the regenerate. Despite radio-graphic findings, our quantitative histomorphometric results document a convincing reduction of bone volume that exists in mandibular distraction osteogenesis and partially reduced fractures when compared with contralateral mandibles. Our experimental model suggests that such a protocol overestimates the quality of consolidation and union, and fails to demonstrate the actual regenerate immaturity or paucity of bone volume in mandibular distraction osteogenesis specimens when compared with contralateral mandibles.

The results of quantitative histomorphometry with regard to osteoid provide an essential and reliable metric of immature bone with no mineralization. Considered in concert with the bone volume/tissue volume results, the osteoid volume/tissue volume ratio gives a more comprehensive picture of overall regenerate healing quality in mandibular distraction osteogenesis. Even in contralateral mandibles, there is some nonmineralized matrix and new osteoid production as part of remodeling homeostasis. However, our mandibular distraction osteogenesis specimens had 125 percent greater osteoid volume when compared with contralateral mandibles. This increased osteoid volume/tissue volume ratio in mandibular distraction osteogenesis corroborates our aforementioned findings of immature bone within the regenerate and quantifiable evidence of incomplete healing and reduced functional bone quality.

Our final quantitative metric of bone healing is cellular number, specifically, osteocyte count. Osteocytes are the gatekeepers of bone formation and remodeling.^{50,51} Osteocytes are able to translate mechanical shear strain into biochemical signals that can communicate with other cells to affect remodeling.^{51–53} In response to mechanical forces, osteocytes activate genes, production of growth factors, and synthesis of matrix.⁵⁴ In addition, they stimulate osteoblastogenesis from mesenchymal cells⁵⁵ and enhance their own viability when exposed to intermittent, compressive mechanical loading.⁵⁶ Osteocytes were an integral part of our quantitative outcome analysis of mandibular distraction osteogenesis because these factors would relate to their involvement with the enhanced up-regulation of osteogenesis from the mechanical forces of distraction.^{57,58} We found that the number of osteocytes was significantly deficient in mandibular distraction osteogenesis specimens compared with

contralateral mandibles, which again provides a corroborative metric supporting the contention of a deficiency of mature bone in the regenerate.

We used a partially displaced fracture model of the mandible to act as a surgical control for the mandibular distraction osteogenesis specimens. This partially reduced fracture group would isolate the variable of mechanical tension on the healing callus from simple fracture repair. Although we hypothesized that mandibular distraction osteogenesis specimens would have less mature bone than partially reduced fractures because of the expanded callus volume and theoretical tendency for the stretching process to maintain regenerate plasticity, this did not occur. In fact, we negated our hypothesis. Indeed, although mandibular distraction osteogenesis does fill a fivefold larger gap when compared with partially reduced fractures, we found no statistical difference in bone volume/tissue volume ratio, osteoid volume/tissue volume ratio, or osteocyte count per high-power field. Our results suggest that the powerful osteogenic potential of mandibular distraction osteogenesis allows it to overcome the fivefold greater bone deficit compared with partially reduced fractures in its relatively unperturbed state of healing.

When combined with our previous biomechanical metrics of structural integrity, our quantitative histomorphometric results offer compelling objective evidence of the diminished bone volume and immature state of bone healing at the consolidation periods we are currently using in our patients. Our findings call into question the adequacy of bone healing in mandibular distraction osteogenesis and the efficacy of relying on unproven and antiquated protocols, subjective assessments, and plain radiography to assess bone-healing quality.⁵⁹ These histologic findings have consequential biomechanical correlates of decreased functional integrity.

These metrics may now be used as a core group of outcome measures to gauge efforts advancing the application of mandibular distraction osteogenesis. Potential measures to maximize and accelerate regenerate bone healing include retaining the distractor through a longer consolidation period,⁶⁰ increasing the distraction frequency, or even cycling the distraction in tension and compression, further augmenting the micromechanical forces.^{61,62} In fact, a human study of vertical mandibular distraction osteogenesis in the edentulous mandible for osseointegrated implants, using similar quantitative histomorphometric methods, found that at least 3.5 to 4 times the distraction period was minimally required to obtain sufficient bone volume before approaching premandibular distraction osteogenesis bone volumes.⁶³ Other options may include supplementing the regenerate with a variety of growth factors through carrier gels and/or scaffolds,^{64–66} hyperbaric oxygen treatments,⁶⁷ parathyroid hormone treatment,^{68–70} and even manipulation of cellular mechanisms that can enhance osseous regeneration through up-regulation of mechano-transduction pathways.^{28,29,36}

This study established quantitative histomorphometric outcome measures with which to evaluate the overall quality of bone healing in mandibular distraction osteogenesis using the prevailing clinical consolidation protocols popularized by Ilizarov. Our findings demonstrate decreased bone maturity and quantity, questioning the adequacy and functional integrity of regenerate bone healing in mandibular distraction osteogenesis, thus challenging our

reliance on long-standing venerable protocols and plain radiography to ascertain adequate bone healing. If our findings can be extrapolated to the clinical arena, treatment strategies may require modification to ensure consistent, predictable, and reliable outcomes.

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Fig.1.

(Above) Sagittal image of mandibular distraction osteogenesis specimen from a microcomputed to mographic scan, oriented with the posterior aspect/condyle on the left, showing region-of-interest placement over the regenerate using anatomical and surgical landmarks. All histologic sections were oriented similarly. (Below) Region-of-interest template placed on a 7-µm sagittal mandibular distraction osteogenesis stained paraffin section analogous to region-of-interest template calibrated from previous microcomputed to mographic scan and placed using the same methodology to ensure uniform placement between independent reviewers.

Fig. 2.
(Above) Mandibular distraction osteogenesis paraffin section uploaded as a TIFF file on a computer used for color thresholding. Turquoise-stained bone within the bright green framed region of interest was manually thresholded using Bio-quant software and now appears fuchsia. (Below) The same mandibular distraction osteogenesis paraffin section as TIFF file on computer showing osteoid/nonmineralized matrix that stains red/pink is now presenting as red with yellow borders within the region of interest, after it was color thresholded using Bioquant software for the osteoid volume/tissue volume calculation.

Fig. 3.

Point counting osteocytes required 16 $\times$ magnification and division of the region of interest into high-power fields of 295 $\times$ 366 μ m. This image is a high-power field from a mandibular distraction osteogenesis specimen. At 16 $\times$ magnification in both mandibular distraction osteogenesis specimens and partially reduced fractures, we readily distinguished the flattened osteoblasts at the periphery of the osteoid islands, abutting the bridges of bone within the region of interest. The mature, spindle-shaped osteocytes were easily visualized within their spacious lacunae surrounded by waves of blue woven bone.

Fig. 4.

(Left) Seven-micron paraffin section of a partially reduced fracture shows indiscrete osteotomy edges and still shows the separation of newly formed turquoise woven bone in the fracture region from the mature lamellar bone outside the region of interest. (Right) Seven-micron paraffin section of a partially reduced fracture at 4× magnification reveals osteoblasts at the periphery of the mineralized bone, and osteoid islands (red) scattered throughout the thick lattice of turquoise-stained bone.

Fig. 5.

(*Left*) Seven-micron mandibular distraction osteogenesis (*DO*) paraffin section at 1.6× magnification shows islands of pink/red osteoid scattered within the turquoise lattice of newly formed woven bone. (*Right*) Seven-micron mandibular distraction osteogenesis paraffin section at 4× magnification delineates the red osteoid canals with osteoblasts flowing randomly through the turquoise bridges of woven bone. No apparent axial or centripetal vector of osteoid production or mineralization can be discerned.

Fig. 6.

Graph comparing mandibular distraction osteogenesis specimens, partially reduced fractures, and contralateral mandibles along the x axis by their percentage of bone volume/tissue volume (TV) on the y axis. The bone volume/tissue volume ratio for contralateral mandibles was statistically greater ($*p<0.05$) than the bone volume/tissue volume ratio for both surgical groups, yet there was no statistical difference in the bone volume/tissue volume ratio between the mandibular distraction osteogenesis and partially reduced fractures groups.

Fig. 7.

This graph reveals no statistical difference in the percentage of osteoid volume/tissue volume (TV) ratio between the mandibular distraction osteogenesis and partially reduced fracture groups. However, the percentage of osteoid volume/tissue volume was statistically less in the contralateral mandible group ($*p < 0.05$) compared with either surgical group.

Fig. 8.

(Above) A random high-power field from a partially reduced fracture specimen at 16× magnification displays spindle-shaped osteocytes within their lacunae, surrounded by a sea of turquoise/blue woven bone bridge and the adjacent osteoid. (Below) A randomly selected high-power field from a mandibular distraction osteogenesis specimen at 16× magnification reveals a pattern of osteocytes within turquoise/blue woven bone bridge and adjacent red osteoid similar to that of the high-power field from the partially reduced fracture specimen.

Fig. 9.

Graph illustrating that no statistically significant difference in osteocyte count per high-power field (HPF) was found between the mandibular distraction osteogenesis and partially reduced fracture groups. However, the contralateral mandible group had a significantly greater osteocyte count per high-power field ($*p < 0.05$) when compared with both surgical groups.