Asymmetric Maxillary Expansion After Surgically Assisted Rapid Palatal Expansion (SARPE)

2023 Orthodontic Faculty Development Fellowships (OFDFA)

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FollowUp Form

Award Information

In an attempt to make things a little easier for the reviewer who will read this report, please consider these two questions before this is sent for review:

- *Is this an example of your very best work, in that it provides sufficient explanation and justification, and is something otherwise worthy of publication? (We do publish the Final Report on our website, so this does need to be complete and polished.)*

- *Does this Final Report provide the level of detail, etc. that you would expect, if you were the reviewer?*

Title of Project*

Asymmetric Maxillary Expansion After Surgically Assisted Rapid Palatal Expansion (SARPE)

Award Type

Orthodontic Faculty Development Fellowship Award (OFDFA)

Period of AAOF Support

July 1, 2023 through June 30, 2024

Institution

The Trustees of the University of Pennsylvania

Names of principal advisor(s) / mentor(s), co-investigator(s) and consultant(s)

Mentors: Dr. Chun-Hsi Chung, Dr. Anh D. Le; Significant contributor: Dr. Steven Wang

Amount of Funding

$30,000.00

Abstract

(add specific directions for each type here)

Please see attached file.

Respond to the following questions:

Detailed results and inferences:*

If the work has been published, please attach a pdf of manuscript below by clicking "Upload a file".
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Use the text box below to describe in detail the results of your study. The intent is to share the knowledge you have generated with the AAOF and orthodontic community specifically and other who may benefit from your study. Table, Figures, Statistical Analysis, and interpretation of results should also be attached by clicking "Upload a file".

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There are two papers that are published, and one paper that is currently under revision with Angle Orthodontists. Please see the attached file as the combined file for all three manuscripts.

Were the original, specific aims of the proposal realized?*

Yes. by constructing a novel FEA model of SARPE, the current study demonstrated that a larger difference between the angulations of the left and right buccal osteotomies resulted in increased asymmetry in both transverse and vertical dimensions after expansion.

Were the results published?*

Yes

Have the results of this proposal been presented?*

Yes

To what extent have you used, or how do you intend to use, AAOF funding to further your career?*

The current AAOF OFDFA fund not only supported me to conduct the proposed research project as described above. it also allowed me to attend several training sessions to further advance my teaching and research skills.

Accounting: Were there any leftover funds?

$0.00

Published

Citations*

You indicated results have been published. Please list the cited reference/s for publication/s including titles, dates, author or co-authors, journal, issue and page numbers

The support of the current AAOF award is acknowledged in the following publications:

1. Lin, J.-H., Wu, G.-L., Chiu, C.-K., Wang, S., Chung, C.-H., Li, C. (corresponding author): Finite Element Analysis Model for Assessing Expansion Patterns from Surgically Assisted Rapid Palatal Expansion. J. Vis. Exp. (200): e65700, 2023.
2. Li, C., Zheng, Z., Pin, H., Jiang, W., Soo, C., Ting, K.: Neural EGFL-like 1, a craniosynostosis-related osteochondrogenic molecule, strikingly associates with neurodevelopmental pathologies. Cell Biosci, 13(1): 227, 2023.
3. Xu, J., Wang, S., Yu, W., Chung, C.-H., Le, A.D., Wolff, M.S., Li, C. (corresponding author): Orthodontic-Orthognathic Combined Case Management in Postgraduate Orthodontic and Oral Maxillofacial Surgery Programs. Journal of Dental Education, accepted on 10/29/2024.
4. Gershater, E., Griswold, O., Talsania, B.E., Zhang, Y., Chung, C.-H., Zheng, Z., Li, C. (co-corresponding author): Effects of Plasma Treatment on the Bonding Strength to Ceramic Surfaces in Orthodontics - A Comprehensive Review. Bioengineering 10(11): 1323; 2023.
5. Park, T., Shen, C., Chung, C.-H., Li, C. (corresponding author): Vertical Control in Molar Distalization by Clear Aligners: A Systematic Review and Meta-analysis. Journal of Clinical Medicine, 13(10): 2845, 2024.
6. Shen, C., Park, T., Chung, C.-H., Li, C. (corresponding author): Molar Distalization by Clear Aligners with Sequential Distalization Protocol: A Systematic Review and Meta-analysis. Journal of Functional Biomaterials, 15(6): 137, 2024.
7. Li, C., Azami, N., Campos, H., Chan, M., Doan Van, A., Tisot, P., Goolsby, S.: Dental Students' MBTI Personality Profile in the Past 50 Years: Systematic Review and Meta-Analysis. Journal of Dental Education, 7 2024 Jul 10. doi: 10.1002/jdd.13660. Online ahead of print.
8. Elabed, I., Zheng, Z., Zhang, Y., Chung, C.-H., Li, C. (corresponding author): The Mechanical and Clinical Properties of Customized Orthodontic Bracket Systems - A Comprehensive Review. Journal of functional Biomaterials, 15(10): 299, 2024.

Was AAOF support acknowledged?

If so, please describe:

yes

Presented

Please list titles, author or co-authors of these presentation/s, year and locations:*

Conference abstracts:

1. Xue, B., Wang. S., Li, C.: Management of SARPE Complications Using Digital-Workflow Based Vacuum-Formed Essix Palatal Stent: Case Reports. (Presented at the 2023 Penn Dental Medicine Advances in Clinical Care and Education (ACCE) Day, 2023).
2. Li. C., Lin, J.-H., Wang, S., Wu, G.-L., Chiu, C.-K., Boucher, N., Chung, C.-H.: Relationship Between Buccal Osteotomy Angulation And Asymmetric Expansion In SARPE. (Presented at the 2024 IADR/AADOCR/CADR General Session, New Orleans, LA, 2024).

3. Xue, B., Wang. S., Li, C.: Management of SARPE Complications Using Digital-Workflow Based Vacuum-Formed Essix Palatal Stent: Case Reports. (Presented as Table Clinic at the 2024 AAO annual Session, New Orleans, LA, 2024).

Invited presentation:
October 20th, 2023 "The Prevalence of Temporal Tendinitis and TMD" - Quarterly Combined TMJ Lecture Series, University of Pennsylvania School of Dental Medicine.
June 21st, 2024 "Relationship Between Buccal Osteotomy Angulation and Asymmetric Expansion in Surgically Assisted Rapid Palatal Expansion" - The 2024 Angle East Annual Scientific Orthodontic Meeting, Boston, MA.
July 10th, 2024 "Opportunities and Challenges in Bridging Orthodontic Education and Innovation – Optimized Teaching for Personalized Care" - Ohio State University College of Dentistry.

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Internal Review

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Finite Element Analysis Model for Assessing Expansion Patterns from Surgically Assisted Rapid Palatal Expansion

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Abstract

Surgically assisted rapid palatal expansion (SARPE) was introduced to release bony resistance to facilitate skeletal expansion in skeletally mature patients. However, asymmetric expansion between the left and right sides has been reported in 7.52% of all SARPE patients, of which 12.90% had to undergo a second surgery for correction. The etiologies leading to asymmetric expansion remain unclear. Finite element analysis has been used to evaluate the stress associated with SARPE in the maxillofacial structures. However, as a collision of the bone at the LeFort I osteotomy sites occurs only after a certain amount of expansion, most of the existing models do not truly represent the force distribution, given that the expansion amount of these existing models rarely exceeds 1 mm. Therefore, there is a need to create a novel finite element model of SARPE that could perform a clinically required amount of expander activation for further analysis of the expansion patterns of the hemimaxillae in all three dimensions. A three-dimensional (3D) skull model from cone beam computed tomography (CBCT) was imported into Mimics and converted into mathematical entities to segment the maxillary complex, maxillary first premolars, and maxillary first molars. These structures were transferred into Geomagic for surface smoothing and cancellous bone and periodontal ligament creation. The right half of the maxillary complex was then retained and mirrored to create a perfectly symmetrical model in SolidWorks. A Haas expander was constructed and banded to the maxillary first premolars and first molars. Finite element analysis of various combinations of buccal osteotomies at different angles with 1 mm clearance was performed in Ansys. A convergence test was conducted until the desired amount of expansion on both sides

(at least 6 mm in total) was achieved. This study lays the foundation for evaluating how buccal osteotomy angulation influences the expansion patterns of SARPE.

Introduction

Surgically assisted rapid palatal expansion (SARPE) is a commonly used technique for transversely expanding the maxillary bony structure and the dental arch in skeletally mature patients[1]. The surgery involves a LeFort I osteotomy, a mid-palatal corticotomy, and, optionally, the release of the pterygoid-maxillary fissure[2]. However, undesired expansion patterns from SARPE, such as uneven expansion between left and right hemimaxillae[3] and dentoalveolar process buccal tipping/rotation[4], have been reported, which could lead to failure of SARPE, and sometimes, even requiring additional surgeries for correction[5]. Previous studies have indicated that the variation in circum-maxillary osteotomies may play a significant role in post-SARPE expansion pattern[2,3], as the collisions between the bone blocks at the Le Fort I osteotomy sites can contribute to the uneven resisting force of lateral expansion of the hemimaxillae and to the rotation of the hemimaxillae with the alveolar edges below the cut moving inwards while the dentoalveolar process expands[3,4]. Therefore, there is a need to investigate the effects of different osteotomy directions, especially the buccal osteotomy, on post-SARPE expansion patterns.

Several finite element analysis (FEA) models have been set up to evaluate the force distribution during SARPE. However, the amount of expansion set in these models is limited to up to 1 mm, which is far below the required clinical amount[6,7,8,9,10,11,12]. Inadequate expansion in FEA models can lead to erroneous predictions of post-SARPE outcomes. More specifically, the collision between the bones at the osteotomy site, as reported by Chamberland

and Proffit[4], may not be demonstrated if the expander is not adequately turned, which may not reflect the true clinical reality. With the limited amount of expansion built in the previous models, the outcome evaluations of these models were focused on stress analysis. However, the stress analysis of FEA in dentistry is usually conducted under static loading with the mechanical properties of materials set as isotropic and linearly elastic, which further restricts the clinical relevance of the FEA studies[13].

Furthermore, most of these studies did not consider the thickness of the surgical instrument at the osteotomy site[6,7,8,10,11,12], often setting friction to zero at the cuts as part of the boundary conditions. However, this setting oversimplifies the contacts between the hard and soft tissues. It may significantly impact the distribution of force and the resulting expansion pattern of the hemimaxillae.

Nevertheless, no available literature has investigated the effect of osteotomy on post-SARPE asymmetry using finite element analysis (FEA) models. All the current studies employed models with symmetrical osteotomy patterns[6,7,8,9,10,11,12,14], which do not reflect the reality of clinical practice where the osteotomies may differ on each side of the skull. The lack of literature examining the effect of asymmetrical osteotomies on post-SARPE asymmetry represents a significant knowledge gap that must be addressed.

Therefore, the goal of this study is to develop a novel FEA model of SARPE that can truly mimic the clinical conditions,

including the expansion amount and osteotomy gap, and investigate the expansion patterns of the hemimaxillae in all three dimensions with various designs of the osteotomy. Such an approach would provide valuable insight into the mechanics underlying post-SARPE expansion patterns and serve as a useful tool for clinicians in the planning and execution of SARPE procedures.

Protocol

This study utilized a pre-existing, de-identified, pre-treatment CBCT image of a patient who had SARPE as part of the treatment plans. The study was conducted in accordance with the Declaration of Helsinki and approved by the Institutional Review Board (protocol #853608).

1. Sample acquisition and tooth segmentation

1. Acquire a human CBCT image of the head in a natural head position that includes the patient's maxillary complex, including the maxillary basal bone, maxillary alveolar bone, and maxillary dentition.

2. Import the CBCT Digital Imaging and Communications in Medicine (DICOM) files into Mimics software.

   1. Create **New Project (Ctrl + N)**, select all the DICOM images, and click **Next** and **Convert**.

   2. Define the direction of the model (A: anterior, P: posterior, T: top, B: bottom, L: left, R: right) and click **OK**.

3. Segment the file into maxillary complex, maxillary first premolars, and maxillary first molars.

   1. Click **Thresholding**, select an appropriate threshold to segment bones, and click **Apply**.

2. Create new masks and click **Edit Masks**, using **Draw** and **Erase** to segment the patient's maxillary complex, maxillary first premolars, and maxillary first molars.

4. Export the targets as stereolithography (STL) files.

   1. Right-click on masks and select **Calculate 3D** to generate 3D objects.

   2. Right-click on 3D objects, select **STL+**, choose the demanded objects, and press **Add** and **Finish** to create STL files.

2. Surface smoothing and creation of cancellous bone and periodontal ligament space

1. Import the STL files into Geomagic software.

   1. Click **File > Open**, select the STL files, then press **Open**.

   2. Choose **Millimeters** for the data in **Units** pop-up window and click **OK**.

2. Smooth the surface of the maxillary complex, maxillary first premolars, and maxillary first molars.

   1. Click **Polygons > Remove Spikes**, click and drag the smoothness level near **Low**, click **Apply**, and **OK**.

   2. Click **Polygons > Relax Polygons**, click and drag the smoothness level near **Min**, click **Apply**, and **OK**.

   3. Click **Polygons > Repair intersections**, choose **Relax/Clean** in the **Mode** window, click **Apply**, and **OK**.

3. Modify the surface of the model into a continuous and closed region.

   1. Click and drag the sharp surface, and press delete to create a hole.

2. Click **Polygons > Fill Holes**, use **Fill**, **Fill Partial, Create Bridges** in the **Fill Method** window to fill up the holes, click **Apply**, and **OK**.

4. Convert the 2D surface to a 3D solid model and export it as a computer-aided design (CAD) file.

   1. Click **Edit > Phase > Shape Phase**, select **Edit contours** to sketch the contours of the surface, then click **OK**.

   2. Click **Draw Patch Layout** and draw quadrilateral meshes to cover all the surfaces, then click **OK**.

   3. Click **Construct Grids**, define a proper **Resolution**, and click **OK** to generate a finer mesh.

   4. Click **Fit Surfaces**, click **Apply**, and **OK** to construct a 3D solid model.

   5. Click **File > Save as** to export the 3D model and save it in an IGES file (named Maxilla).

5. Create the cancellous bone by reducing the volume of the maxillary complex by 1 mm from the buccal alveolar surface. Create periodontal ligament space by expanding the contour of the roots by 0.2 mm.

   1. Click **Polygon Phase**, choose **Delete** in the **Contour Lines** window, select **Preserve** in the **Patch Layout** window, then press **OK** to convert the 3D solid model into a 2D surface.

   2. Click **Polygons > Offset**, enter -1 mm and 0.2 mm in the Distance panel for cancellous bone and periodontal ligament, then click **Apply** and **OK**.

   3. Click **Edit > Phase > Shape Phase**, select **Restore Patch Layout** and press **OK**.

   4. Click **Construct Grids**, define a proper **Resolution**, and click **OK** to generate a finer mesh.

5. Click **Fit Surfaces**, click **Apply**, and **OK** to construct a 3D solid model.

6. Click **File > Save as** to export the 3D model and save it in IGES files (named CB and PL).

3. Construct an anatomical symmetric maxilla model

1. Import the CAD files into SolidWorks.

   1. Click **File > Open**, select the Maxilla file, and press **Open** to import the CAD file.

   2. Click **File > Save** to save the file into the **Part** format.

2. Construct the cancellous bone below the palatal plane (PP).

   1. Click **Insert > Part**, select the CB file, and press **Open** to import the CAD file.

   2. Click **Insert > Reference Geometry > Plane**, choose three feature points on the palatal plane, and click **OK** to create a cutting plane.

   3. Click **Insert > Features > Split**, choose the palatal plane in **Trim Tools**, and click **Cut Part** to create a cutting preview.

   4. Tick the checkboxes in the **Resulting Bodies**, and click **OK** to separate the cancellous bone.

   5. Click the cancellous bone above the palatal plane, right click and press **Delete** in the **Body** section.

3. Construct the periodontal ligament of maxillary first premolars and maxillary first molars.

   1. Click **Insert > Part**, select the PL file, and press **Open** to import the CAD file.

   2. Click **Insert > Features > Intersect**, and choose Maxilla and PL in the **Selections** window.

3. Select **Create both** in the **Selections** window, choose the periodontal ligament part in the **Region List**, then click **OK** to generate the ligament.

4. Perform a midpalatal cutting plane from the anterior nasal spine (ANS) to posterior nasal spine (PNS) and retain the right half of the maxillary complex.

   1. Click **Insert > Reference Geometry > Plane**, choose three feature points on the midpalatal plane, and click **OK** to create a cutting plane.

   2. Click **Insert > Features > Split**, choose the palatal plane in **Trim Tools**, and click **Cut Part** to create a cutting preview.

   3. Tick the checkboxes in the **Resulting Bodies**, and click **OK** to separate the maxillary complex.

   4. Click the left half of the maxillary complex, right-click, and press **Delete** in the **Body** section.

5. Mirror the right half of the maxillary complex and create an identical left half.

   1. Click **Insert > Pattern/Mirror > Mirror**, and choose the midpalatal plane in **Mirror Face/Plane**.

   2. Choose all the right half maxillary complex in **Bodies to Mirror**, and click **OK** to generate the left half of the maxillary complex.

4. Create a Haas expander and band to the maxillary first premolars and first molars

1. Construct the premolar band and molar band.

   1. Click **Insert > Part**, select the PL file, and press **Open** to import the CAD file.

   2. Click **Insert > Features > Split**, choose the teeth in the PL file, and set a **Uniform Scaling** of 1.05. Click **OK** to generate bands with 0.5 mm in thickness.

3. Click **Insert > Reference Geometry > Plane**, choose three feature points on the occlusal plane, and click **OK** to create a reference plane.

4. Click **Insert > Reference Geometry > Plane**, choose the occlusal plane, and set an offset distance of 1.5 mm. Click **OK** to create the first cutting plane.

5. Click **Insert > Reference Geometry > Plane**, choose the occlusal plane, and set an offset distance of 4.0 mm. Click **OK** to create the second cutting plane.

6. Click **Insert > Features > Split**, and choose the first and second plane in **Trim Tools** and the teeth in **Target Bodies**. Click **Cut Bodies** to create a cutting preview.

7. Tick the checkboxes in the **Resulting Bodies**, and click **OK** to separate the teeth.

8. Click the band above the first plane and below the second plane, right-click, and press **Delete** in the **Body** section.

2. Construct the acrylic plate.

   1. Click **Insert > Reference Geometry > Plane**, choose three feature points on the hard palate plane, and click **OK** to create a sketch plane.

   2. Click **Insert > Sketch**, draw an acrylic plate refer to the Haas expander, and click **Exit Sketch**.

   3. Click **Insert > Boss/Base > Extrude**, choose the sketch of the acrylic plate, set 5 mm in **Depth**, and click **OK**.

   4. Click **Insert > Features > Flex**, and bend the acrylic plate to fit the anatomy of the palate.

5. Click **Insert > Features > Fillet/Round**, and fillet the sharp edges of the acrylic plate in a radius of 1 mm.

3. Construct the expander arms.

   1. Click **Insert > Reference Geometry > Plane**, choose three feature points on the band, and click **OK** to create a sketch plane (named P1).

   2. Click **Insert > Sketch**, draw a circle 2 mm in diameter, and click **Exit Sketch** (named C1).

   3. Click **Insert > Reference Geometry > Plane**, choose three feature points on the acrylic plate, and click **OK** to create a sketch plane (named P2).

   4. Click **Insert > Sketch**, draw a circle 2 mm in diameter, and click **Exit Sketch** (named C2).

   5. Click **Insert > Reference Geometry > Plane**, choose the P2 plane, and set an offset distance of 6 mm. Click **OK** to a sketch plane.

   6. Click **Insert > Sketch**, draw a circle 2 mm in diameter, and click **Exit Sketch** (named C3).

   7. Click **Insert > Boss/Base > Loft**, and choose the C1, C2, and C3 sketch in the **Profiles** window.

   8. Select the band and the acrylic plate in the **Feature Scope** window, tick **Merge Result** in the **Options** window , and click **OK**.

5. Design the osteotomy

1. Create a 1 mm thick plane, equivalent to the diameter of a bur usually used by the surgeon, from the corner of the piriform aperture (Alar) towards the infra zygomatic crest (IZC) at various degrees from the horizontal plane.

   1. Click **Insert > Reference Geometry > Plane**, choose three feature points on the osteotomy plane

(0°, 10°, 20°, or 30° to the horizontal plane), and click **OK** to create the plane (named O1).

2. Click **Insert > Reference Geometry > Plane**, choose the osteotomy plane, and set an offset distance of 1.0 mm. Click **OK** to create an inferior cutting plane (named O2).

3. Click **Insert > Features > Split**, choose the O1 and O2 plane in **Trim Tools**, and click **Cut Part** to create a cutting preview.

4. Tick the checkboxes in the **Resulting Bodies**, and click **OK** to separate the maxillary complex.

5. Click the body between O1 and O2 planes, right-click, and press **Delete** in the **Body** section.

2. Export models with different buccal osteotomy angles in Parasolid Model Part File (X_T) for analysis.

   1. Click **File > Save as**, and choose **Parasolid (x_t)** in the **File Type** list.

   2. Click **Save** to export the models for finite element analysis software.

6. Finite element analysis

1. Import and set the material parameters of the maxillary complex model into Ansys software.

   1. Click and drag the **Static Structural** in **Toolbox** to create an analysis workspace.

   2. Double click the **Engineering Data**, and set Young's modulus and Poisson's ratio of all the materials in **Properties**. The material properties of different structures[12,15,16] are listed in **Table 1**.

   3. Double-click **Geometry**, click **File > Import External Geometry File**, then click **Generate** to import the maxillary complex model.

4. Click **Create > Boolean**, and generate the cortical bone and periodontal ligament by Boolean with the cancellous bone and teeth.

2. Set up the finite element analysis model.

   1. Double-click the **Model**, and click **Geometry** to select the material properties for each part.

   2. Right-click **Mesh** and click **Generate Mesh** to build the elements on the model.

   3. Click **Connections**, and assign the soft/small part in **Contact Bodies** and the stiff/large part in **Target Bodies**.

   4. Assign the contact type and friction coefficient in **Definition**. The connection properties of different parts[17] are listed in **Table 2**.

   5. Right-click **Connections**, click **Insert > Spring** to connect the upper and lower parts of the osteotomy plane. Set the springs as 1 mm long with spring constant k = 60 N/mm and place one spring at each grid node.

3. Set a clinically acceptable force along the x-axis (perpendicular to the midline) on the acrylic plate on various combinations of osteotomies.

   1. Right-click **Static Structural**, click **Insert > Fixed Support** and set the structure on the palatal plane immovable.

   2. Right-click **Static Structural**, click **Insert > Force** and set a 150 N force to apply on the acrylic plate with a direction away from the medial line.

   3. Right-click **Solution**, and click **Insert > Deformation > Total** to monitor the deformation of the expansion.

4. Conduct a convergence test until expansions on both sides are achieved.

   1. Click **Solve** on the toolbars, and wait until the **Force Convergence** level reaches the **Force Criterion**.

   2. Click **Total Deformation** to display the expansion results.

5. Measure the displacements of the anatomic landmarks in all three dimensions as the results of expansion. Suggest the following landmarks to be used to evaluate the expansion pattern:
   Mesioincisal line angle of the maxillary central incisor (U1).
   Buccal cusp tip of the maxillary first premolar (U4).
   Mesiobuccal cusp tip of the maxillary first molar (U6).
   Lateroinferior corner of the piriform aperture (Alar).
   Infra-zygomatic crest (IZC).
   Midpoint of the expander.

Representative Results

The demonstration model utilized the CBCT image of a 47-year-old female with maxillary deficiency. In the generated model, the anatomic structure of the nasal cavity, the maxillary sinus, and the periodontal ligament space for the expander anchored teeth (first premolar and first molar) are preserved (**Figure 1**).

To simulate the surgical procedure accurately, the nasal septum, lateral walls of the nasal cavity, and pterygomaxillary fissure were separated from the maxillary body in all simulations. Furthermore, a plane, representing the buccal osteotomy during surgery, was created at a thickness of 1 mm. The plane started from the corner of the piriform aperture

(Alar) and extended posteriorly to the pterygomaxillary fissure (PMF) (**Figure 2A-D**).

A preliminary test was performed on the model with symmetric zero-degree cuts on both left and right sides (**Figure 2E**), which showed that 150 N of force resulted in more than 8 mm of expansion at the expander (**Figure 2F**), exceeding the amount of expansion seen in most literature. This result was deemed appropriate since it falls within the range of expansion most often needed for SARPE patients. In addition, a variety of angles can be built in the osteotomy to mimic different clinical conditions (**Figure 3**).

Unlike most finite element studies that focused on von Mises stress and its relationship to material fracture or yield, the current model was conducted to help clinicians foresee the amount and pattern of expansion post-SARPE. Therefore, the left and right hemi-maxillae change could be directly visualized by the color map (representing the amount of total movement in 3D) and the superimposition of before- (grey) and after-expansion (color) maxilla models (**Figure 2E**). In addition, the displacement of the anatomic landmarks (as mentioned in step 6.5.) in all three dimensions were the target outcome to be further analyzed (**Figure 2F**).
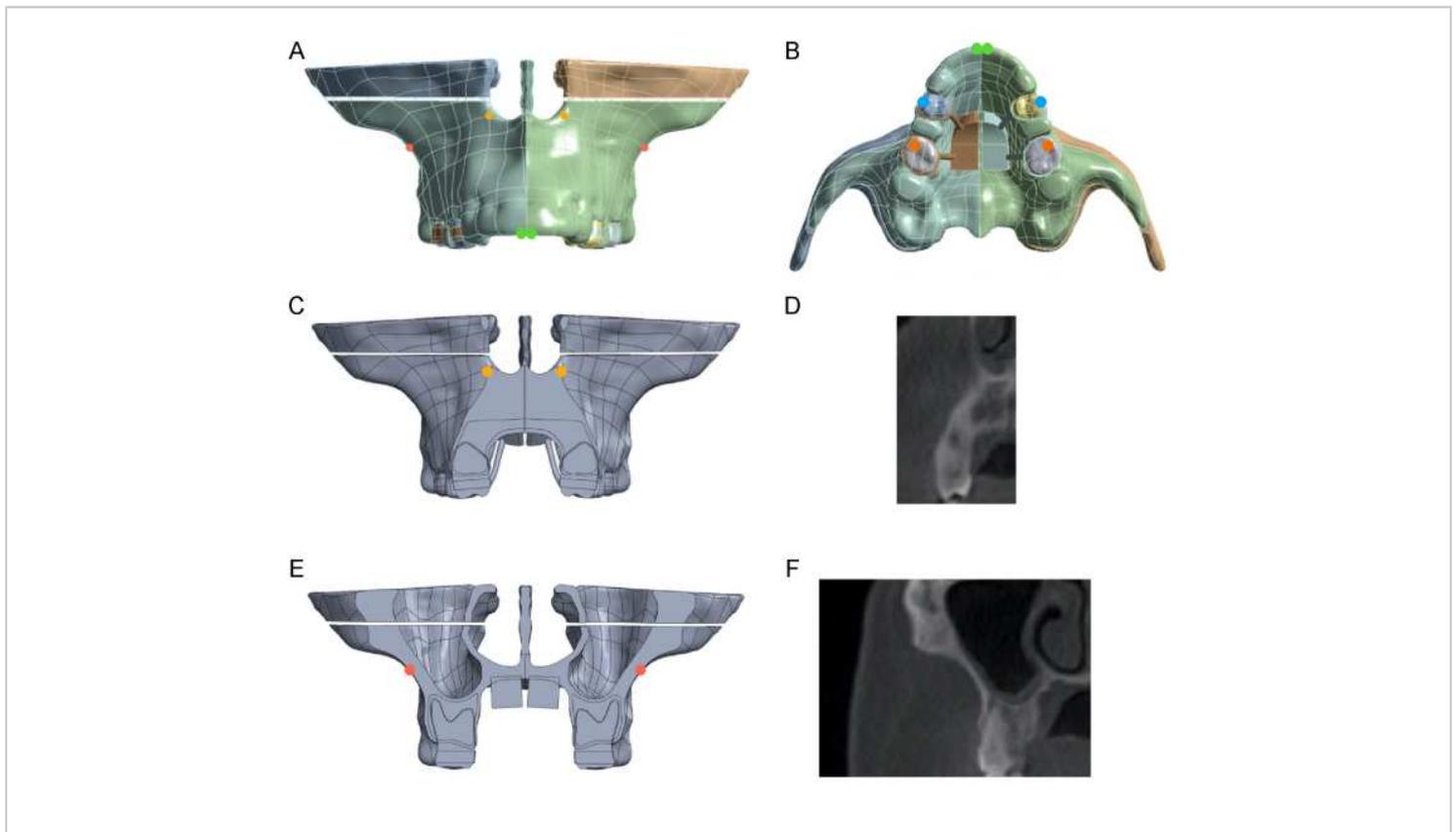

Figure 1: The constructed model preserving the anatomic structure. (**A**,**B**) The frontal (**A**) and the occlusal (**B**) views of the constructed model. (**C**,**D**) The coronal section of the constructed model at the level of maxillary first premolar (**C**), which represent the anatomic structure observed in the CBCT at the same coronal slide (**D**).(**E**,**F**) The coronal section of the constructed model at the level of maxillary first molar (**E**), which represent the anatomic structure observed in the CBCT at

the same coronal slide (**F**). Please note the preservation of the nasal cavity, the maxillary sinus, and the periodontal ligament space for the expander anchoring teeth (first premolar and first molar) in the constructed model. Please click here to view a larger version of this figure.
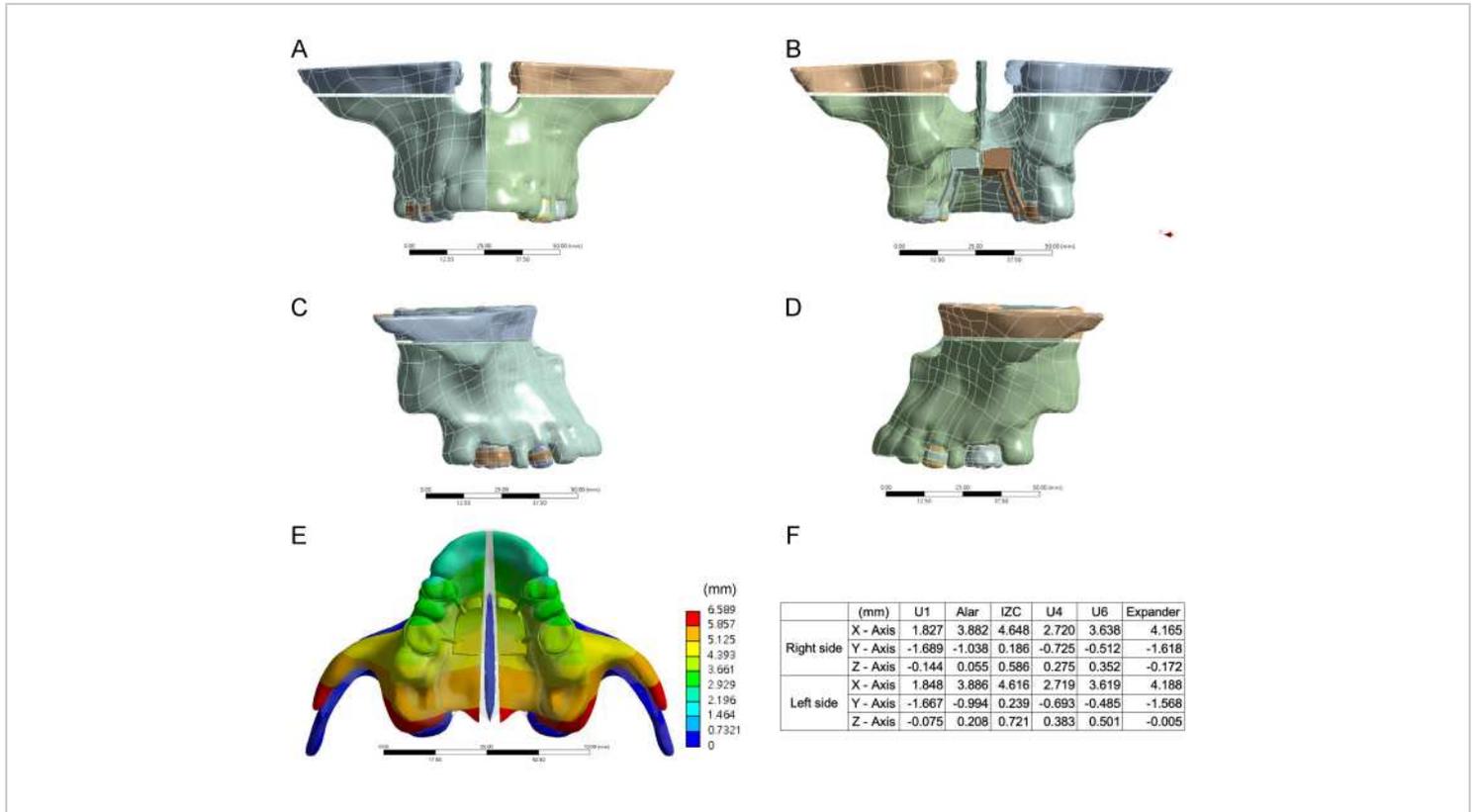

(mm)		U1	Alar	IZC	U4	U6	Expander
Right side	X - Axis	1.827	3.882	4.648	2.720	3.638	4.165
	Y - Axis	-1.689	-1.038	0.186	-0.725	-0.512	-1.618
	Z - Axis	-0.144	0.055	0.586	0.275	0.352	-0.172
Left side	X - Axis	1.848	3.886	4.616	2.719	3.619	4.188
	Y - Axis	-1.667	-0.994	0.239	-0.693	-0.485	-1.568
	Z - Axis	-0.075	0.208	0.721	0.383	0.501	-0.005

Figure 2: Simulation of maxillary expansion with symmetric zero-degree LeFort I osteotomy cuts on both sides. (**A-D**) The frontal (**A**), posterior (**B**), right (**C**), and left (**D**) views of the constructed model with zero-degree LeFort I osteotomy cuts on both sides. (**E**) The expansion observed in the occlusal view of the model after the application of 150 N force. The color map demonstrates the total amount of displacement (in millimeter) in 3D. In addition, the superimposition of before- (grey) and after-expansion (color) maxilla models could be performed. (**F**) The displacement of the anatomic landmarks (as mentioned in step 6.5. and shown in **Figure 1**) in all three dimensions could be generated. X-axis: horizontal dimension; a positive value means lateral movement, and a negative value means medial movement. Y-axis: sagittal dimension; a positive value means anterior movement and a negative value means posterior movement. Z-axis: vertical dimension; a positive value means inferior movement and a negative value means superior movement. Please click here to view a larger version of this figure.

Figure 3: Osteotomies in different angles on the current model. Please click here to view a larger version of this figure.

Structure	Young's modulus (MPa)	Poisson's ratio
Cortical bone	1.37×10^4	0.3
Cancellous bone	1.37×10^3	0.3
Premolars and molars	2.60×10^4	0.3
Periodontal ligament	5.00×10^1	0.49
Stainless steel (expander)	2.10×10^5	0.35

Table 1: The material parameters for each structure.

Type	Contact/Target
Bonded	(1) Cancellous bone/Cortical bone
	(2) Molar and Premolar/Expander
	(3) Periodontal ligament/Molar and Premolar
Frictional (coefficient of friction [μ] = 0.2)	(1) Cortical/Upper cortical
	(2) Cortical bone/Molar and Premolar
Frictional (coefficient of friction [μ] = 0.1)	(1) Cortical/Nasal septum
	(2) Periodontal ligament/Cortical bone
	(3) Periodontal ligament/Cancellous bone
Rough	(1) Cortical bone/Expander
	(2) Cancellous bone/Expander

Table 2: The connection types of each structure.

Discussion

The direction of the buccal osteotomy in SARPE can be either a horizontal cut from the nasal aperture before stepping down at the maxillary buttress area or a ramped cut from the piriform rim towards the buttress corresponding to the maxillary first molar, as described by Betts[2]. Either way, the osteotomy extends well below the zygomatic process of the maxilla. However, most current FEA studies on SARPE use a horizontal cut extending posteriorly at the same level as the piriform rim[6,7,12,14]. This deviates from what is usually performed clinically and changes the conditions in FEA, such as the center of mass of the hemimaxillae and the direction and contact area of the osteotomy. Since the expansion force does not always travel through the center of mass, rotation is bound to happen to the hemimaxillae during FEA. However, in the clinical scenario, collision at the osteotomy line can occur, and the resulting center of rotation can subsequently change. Therefore, to yield a clinically applicable result, it is imperative

that the osteotomy in FEA mimics the surgery pattern that is performed in real life. The model introduced in the current study allows researchers to build the osteotomy at different angles (**Figure 3**) to truly represent what is done clinically.

The critical difference between this study and previous literature is that instead of allowing the two surfaces of the osteotomy to contact at zero friction, the current model introduced a modification by including thickness to the osteotomy plane, which is commonly overlooked in current literature[6,7,8,10,11,12]. Prior research has disregarded the gap formed by a piezoelectric saw or a surgical bur during osteotomy, a critical oversight as it affects the freedom of the hemimaxillae as well as the pivoting or rotating of the hemimaxillae in the event of a bony collision. Additionally, it fails to account for the potential resistance or cushioning effects that may arise from the formation of bone callus or osteoid tissue during initial heal[18]. The design introduced in the current study addresses this issue by introducing a 1 mm

thickness gap between the skull and hemimaxillae to reflect the width of the surgical bur used in the authors' institute. To further simulate forces from the wound-healing tissue, springs (1 mm long, spring constant $k = 60$ N/mm) were implemented to link and suspend the hemimaxillae at the grid nodes, as well as to simulate soft tissue resistance at the osteotomy gap, thereby applying compression and tension during expansion. This approach offers significant advantages in generating a clinically relevant FEA model. It is worth noting that the thickness of the gap should be adjusted based on the surgical instruments used when future research groups plan to adopt this model for data analysis. The design of the springs will also need to be adjusted accordingly.

Lastly, almost all available FEA studies on SARPE suffer from insufficient activation at the expander. SARPE is almost always performed on patients requiring at least 5 mm of maxillary expansion[2]. The expansion pattern, which can be affected by collision at the osteotomy site, is dependent on the amount of activation at the expander. The expansion of 1 mm in most FEA studies[6,8,9,11,12], which results in only 0.5 mm of transverse displacement on each side, is insufficient to represent the effects of larger activation amounts clinically. To overcome this limitation, a preliminary test was conducted to determine a force that would adequately expand the hemimaxillae in a symmetric model, with the resulting force falling in the range of clinical force levels from rapid maxillary expanders[19], which further proved the clinical relevance of this model. This force was then used for activation in all subsequent subsets, providing great insights into the clinical expansion of the maxilla during SARPE.

There exist inherent limitations in this study that need to be acknowledged. The primary limitation is the absence of resistance from surrounding soft tissue. These included resistance from the pharyngeal area, the stretched palate, and pressure from the cheek and the lip. Resistance at the posterior soft tissue should not be disregarded. Clinically, a fan-shaped expansion pattern is typically seen, even in patients who underwent pterygomaxillary fissure release, indicating strong posterior soft tissue resistance[20]. However, considering soft tissue resistance in a finite element analysis is difficult since the resistance changes as the tissues are deformed during active expansion[21]. Another limitation was the lack of a jackscrew in the expander. The rigid metal bar in the jackscrew bounds the two hemimaxillae into one unit, which could decrease the freedom in rotation of the hemimaxillae. Last but not least, our design may not be indicated in some special cases, such as patients with cleft palate or other craniofacial deformities that cause significant maxillary asymmetry or any systemic diseases that may affect Young's modulus of the patient's bone.

Nevertheless, the methods presented in this study introduced several modifications, including improvements in the angulation of the buccal osteotomy, the gap at the osteotomy site, which reflects the thickness of the surgical instrument, and the amount of activation at the expander, which could produce a set of more clinically relevant FEA models that closely resemble the surgical procedures of SARPE.

Disclosures

The authors declare no conflict of interest.

Acknowledgments

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1 **Relationship Between Buccal Osteotomy Angulation and Asymmetric Expansion in Surgically**

2 **Assisted Rapid Palatal Expansion: A Finite Element Analysis**

3 **ABSTRACT**

4 **Objective:** Asymmetric expansion is one of the significant complications in surgically assisted rapid

5 palatal expansion (SARPE) which could lead to a second surgery for correction. Previous studies indicated

6 that the variation in circum-maxillary osteotomies may play a significant role in post-SARPE expansion

7 patterns. This study aimed to investigate the effects of buccal osteotomy angulation on SARPE expansion

8 patterns.

9 **Materials and Methods:** The FEA model of the maxilla with Haas expander was constructed from the

10 CBCT image using Mimics, Geomagic, and solidWorks software. 1 mm thick buccal osteotomies were

11 created with different combinations of 0º, 10º, 20º, and 30º from the horizontal plane to simulate the

12 discrepancy in bilateral osteotomy angulation. Springs were placed at the buccal osteotomy gaps to mimic

13 the strain of bone callus. After applying 150 Newton of expansion force at the level of the expander

14 jackscrew in each FEA scenario, the expansion pattern of the hemimaxillae was evaluated in Ansys

15 software.

16 **Results:** Scenarios with 20° (0°-20°; 10°-30°) and 30° (0°-30°) differences resulted in significant

17 transverse asymmetric expansion. Among the groups with 10° difference, 0°-10° resulted in a relatively

18 parallel expansion, while 10°-20° and 20°-30° experienced a V-shaped expansion with more anterior

19 widening.

20 **Conclusion:** A larger difference between the angulations of the left and right buccal osteotomies resulted

21 in increased asymmetry in both transverse and vertical dimensions after expansion.

22

23 **Keywords:** finite element analysis, orthognathic surgery, complications, osteotomy

24

INTRODUCTION

Currently, surgically assisted rapid palatal expansion (SARPE) is a standard procedure to skeletally correct significant maxillary transverse deficiencies in adult patients to achieve stable skeletal expansion.[1] It is worth noting that although SARPE is broadly used worldwide, variations in its surgical techniques occur.[2] These include differences in the angulation of the buccal osteotomy, the design of the buccal osteotomy with a step at zygomatic buttress, the resection of small bony wedges from lateral sinus wall, the involvement of pterygomaxillary disjunction, and the involvement of nasal septum release.[3-6] These variations in surgical techniques may lead to varying expansion outcomes of SARPE. For instance, Betts[7] proposed a horizontal buccal osteotomy technique that included a step-down at the zygomatic process to prevent the downward movement of the hemimaxillae which may occur in a ramped cut. Although there is a lack of evidence as to which technique is superior, literature has shown downward and forward movements of the maxilla after SARPE despite large variations among patients,[8] which may stem from variation in the buccal osteotomy designs.

Transverse asymmetric expansion between left and right sides is one of the significant complications in SARPE. Drobyshev et al.[9] reported 27 out of 665 patients experiencing asymmetry in expansion, in which 3 of them had to go through a secondary surgery. Huizinga et al.[10] even observed asymmetric expansion of more than 3 mm in 55% of their cases. Since a significant amount of unwanted asymmetric expansion could largely impact treatment progress and outcomes, including leading to additional surgeries or increased complexities in the second surgical phase,[11] a thorough investigation into this matter would undoubtedly aid clinicians during surgical planning and treatment. A recent systematic review revealed that variation in the surgical techniques of SARPE may be a contributing factor to asymmetric expansion, with a higher rate of asymmetric expansion occurring in cases without lateral nasal wall release, without

47 nasal septum release, or with pterygomaxillary fissure release.[12] However, none of the studies that reported

48 asymmetric expansion described their design in buccal osteotomies in detail.[12] Given that buccal

49 osteotomy is performed separately on either side of the maxilla, it can be difficult for the surgeon to

50 maintain symmetry in the direction or angulation of the cuts. Since buccal osteotomy is an indispensable

51 component of the SARPE procedure, there is a need to understand its contribution to the overall results of

52 maxillary expansion.

53   For ethical concerns, a computer-based model is favored over *in vivo* trials when evaluating and

54 comparing the effects of different surgical procedures on the expansion patterns of SARPE.[13] A novel

55 FEA model of SARPE was constructed recently which closely simulated the clinical condition of bony

56 callus formation at the osteotomy site and could be used to evaluate the expansion patterns of SARPE

57 after the activation of expansion force.[14] In this study, simulations of various combinations of buccal

58 osteotomies were set up in the novel FEA model and the expansion outcomes were studied to investigate

59 their impact on asymmetric expansion.

60

61 **MATERIALS AND METHODS**

62 **FEA Model Setup**

63   The FEA model was constructed step-by-step as described previously.[14] In brief, a 3D skull model

64 from the pre-SARPE CBCT of a 47-year-old female subject was imported into Mimics software

65 (Materialise NV; version 16.0, Leuven, Belgium) for the segmentation of the maxillary complex,

66 maxillary first premolars, and maxillary molars. The stereolithography (STL) files exported from Mimics

67 software were then imported into Geomagic Studio (3D systems; version 10, Rock Hill, SC, USA) for

68 surface smoothing and creation of cancellous bone and periodontal ligament space. The constructed 3D

69 solid model in the format of a computer-aided design (CAD) file was then imported into Solidwork

70 (Dassault Systèmes; version 2018, Vélizy-Villacoublay, France). In the Solidwork software, the right half

71 of the maxillary complex was retained and mirrored to create an identical left half, resulting in a perfectly

72 symmetrical model of the maxilla that eliminated any anatomic asymmetry that could potentially affect

73 the expansion outcome. In addition, a Haas expander was designed and banded to the maxillary first

74 premolars and first molars. To construct the buccal osteotomy, a 1 mm thick plane, equivalent to the

75 diameter of a surgical bur, was created from the corner of the piriform aperture (Alar) toward the infra-

76 zygomatic crest (IZC). Based on the suggestions from Betts *et al.*,[7] four different degrees of buccal

77 osteotomy, 0°, 10°, 20°, and 30°, were created. To simulate asymmetric cuts, the four osteotomies were

78 put into six combinations on a skeletally symmetric skull model: 0°-10°, 10°-20°, 20°-30° 0°-20°, 10°-

79 30°, and 0°-30°. Models with different buccal osteotomy angles were imported into Ansys (Ansys; version

80 2019, Canonsburg, PA, USA) in Parasolid Model Part File for finite element analysis.

81 The material parameters were set in Ansys as follows: cortical bone (Young's modulus = 1.37×10^4

82 MPa, Poisson's ratio = 0.3), cancellous bone (Young's modulus = 1.37×10^3 MPa, Poisson's ratio = 0.3),

83 premolars and molars (Young's modulus = 2.60×10^4 MPa, Poisson's ratio = 0.3), periodontal ligament

84 (Young's modulus = 5.00×10^1 MPa, Poisson's ratio = 0.49), and expander (stainless steel, Young's

85 modulus = 2.10×10^5 MPa, Poisson's ratio = 0.35). The connection properties between different parts

86 were defined as follows: Bonded connections were established between the cancellous bone and cortical

87 bone, between the tooth and expander, and between the periodontal ligament and tooth. Frictional

88 connections ($\mu = 0.2$) were set between the maxillary cortical bone and skull cortical bone, and between

89 cortical bone and tooth. Frictional connections ($\mu = 0.1$) were applied between the cortical bone and nasal

90 septum, between the periodontal ligament and cortical bone, and between the periodontal ligament and

91 cancellous bone. Lastly, rough connections were established between the cortical bone and expander, as

92 well as between the cancellous bone and expander.

93   To connect the hemimaxilla blocks to the skull at the 1 mm-thick osteotomy gap, springs (1mm long,

94   spring constant $k = 60$ N/mm) were implemented to link and suspend the hemimaxillae at the grid nodes

95   to simulate the tissue resistance provided by bony callus. Lastly, an expansion force of 150 Newton (N)

96   was set along the x-axis (perpendicular to the midline) on the jackscrew, and the displacements in all three

97   dimensions of the anatomic landmarks were measured as the results of expansion as described

98   previously.[14]

Evaluation Criteria of the FEA Model - Asymmetry Ratio

100   Given the variation in the osteotomy angulation and resulting resistance levels, the total activation at

101   the expander differs even under a same predetermined activation force of 150 N. Consequently, it was

102   impossible to compare the severity of asymmetry among groups based on the difference in displacement

103   of their left and right landmarks. Instead, a new metric called the "asymmetry ratio" was developed, which

104   was calculated by dividing the difference in left-right displacement at a certain landmark by the total

105   amount of activation at the expander. This approach allowed the quantification and comparison of

106   asymmetry levels across the different groups.

$$\text{Asymmetry Ratio} \quad = \quad \frac{\text{The absolute difference between the left and right sides}}{\text{Total activation at the expander}}$$

107   Asymmetric expansion of 3 mm transversely was regarded as "clinically significant" as reported by

108   Huizinga *et al.*.[10] A threshold for clinically significant asymmetry ratio was determined by dividing 3 mm

109   by 8 mm, which corresponded to the typical minimum amount of expander activation required in SARPE

110   patients.[1] The results yielded a 37.5% transverse asymmetry ratio, which was used as an evaluation

111   criterion for this study.

Evaluation Criteria of the FEA Model - Expansion Pattern

113   Another evaluation criterion applied in this study was the expansion pattern produced after activation.

114   An unfavorable expansion pattern from the occlusal view, when both hemimaxillae rotate in the same

115   direction, could produce a yaw of the upper jaw and result in asymmetry (**Figure 1**). On the other hand,

116   unfavorable expansion from the frontal view with both hemimaxillae rotating in the same direction could

117   produce an occlusal cant (**Figure 1**). Therefore, groups experiencing these movements were deemed to

118   have unfavorable post-surgical outcomes.

119

120   **RESULTS**

121   **The Asymmetry Ratio of Each FEA Scenario**

122   The asymmetry ratios in the transverse, sagittal, and vertical dimensions of each FEA scenario were

123   presented in **Table 1**. As shown in **Table 1**, 0°-20°, 0°-30°, and 10°-30° scenarios all showed a transverse

124   asymmetry ratio above 37.5% at different anatomic locations, with 0°-30° scenario showing the highest

125   transverse asymmetry ratio. On the other hand, 0°-10°, 10°-20°, and 20°-30° scenarios had relatively low

126   transverse asymmetry ratios.

127   **The Expansion Pattern of Each FEA Scenario**

128   **Figure 2** and **Figure 3** show the rotation pattern of the hemimaxillae from the occlusal and frontal

129   views, respectively. The combinations of 0°-20°, 0°-30°, and 10°-30° were all regarded as having

130   unfavorable rotation in both transverse and vertical dimensions.

131   From the occlusal view, the combination of 0°-10° resulted in a V-shaped expansion with more

132   posterior expansion; the combinations of 10°-20° and 20°-30° experienced a V-shaped expansion with

133   more anterior widening, with the 20°-30° combination having a more divergent V-shaped expansion.

134   Vertically, all 0°-10°, 10°-20°, and 20°-30° scenarios showed V-shaped expansion with more expansion

135   at the dental level than at the skeletal level. The 20°-30° scenario had the most prominent buccal tipping

136   of the hemimaxillary blocks.

137

DISCUSSION

The potential influence of buccal osteotomy on the expansion pattern of SARPE was first proposed by Betts *et al.*[7] as early as 1995. However, the hypothesis cannot be tested clinically due to ethical concerns. FEA is used for modeling complex structures and biomechanical analyses[15] and its usage in dentistry has been expanding rapidly due to advantages such as the repeatability of experiments and freedom in study parameters. The FEA model used in the current study is novel in design since it evaluates the expansion pattern, providing direct visualization of treatment outcomes that benefits clinicians. Moreover, the design of the 1 mm osteotomy gap filled with springs to simulate the stretching of bony callus in both lateral and rotational movements of the hemimaxillary blocks closely mimicked the clinical condition. The model was validated when a force of 150N, within the range of regular RPE,[16] was applied to a bilateral 0-degree osteotomy model, resulting in an 8 mm expansion.[14] As a result, the current FEA model is superior in that it resembles actual clinical scenarios. As shown in **Figures 2-3**, when the same amount of force was applied in different osteotomy scenarios, different amounts of expansion were achieved with the side with a steeper osteotomy showing less expansion.

When observing from the frontal view of the FEA (**Figure 3**), more buccal tipping of the hemimaxillary blocks was noted with steeper buccal osteotomy angles. This was inconsistent with Bett's theory that the hemimaxillary block would slide outward and downward along the osteotomy surface.[7] However, the findings in the current study were consistent with clinical studies by Chamberland and Proffit, which evaluated posteroanterior cephalometric X-rays, and by Chung and Goldman, who assessed dental models.[1,17] Both studies found that significant buccal tipping of the hemimaxillary blocks could occur in SARPE. In addition, while steeper osteotomy angles were correlated with greater buccal tipping of the hemimaxillary blocks – an issue prone to post-treatment relapse - this study also showed that limited

160 expansion can be achieved with steeper osteotomy. This may also explain why no correlation was found

161 between the amount of expander activation and the degree of relapse.[1]

162   From the asymmetry ratio and the rotation pattern results in the finite element analysis, it was clearly

163 demonstrated that groups with a 20° and 30° difference had a higher degree of asymmetric expansion

164 (**Table 1, Figures 2-3**). This was probably due to the increased difference in resistance between the left

165 and right halves at the osteotomy site where bony collision occurred. The difference in the angulation of

166 the cuts meant that the surface area, contact angle, and friction were different. Therefore, it was expected

167 that groups with a larger left and right difference would show more asymmetrical expansion.

168   The current FEA results further showed that within the 10° difference groups, relatively more

169 expansion could be achieved posteriorly in the 0°-10° and 10°-20° scenarios, while the 20°-30° group

170 resulted in a significantly anterior-posterior V-shaped expansion (**Figure 2**) with the smaller angulation

171 side having more expansion.

172   There are certain limitations in the current study that need to be taken into consideration. Firstly, soft

173 tissue resistance increases when it is stretched,[18] rendering it difficult to simulate in FEA. Therefore, it is

174 disregarded in most FEA studies, including the current one, leading to an underestimation of resistance,

175 especially around the posterior maxilla region, in an FEA environment. The presence of strong resistance

176 from the posterior soft and hard tissue probably means that an inverted V-shaped expansion (the posterior

177 being expanded more than the anterior) from the occlusal view may not happen clinically. However, it is

178 worth noting that Chung and Goldman reported that, after SARPE and before orthodontic tooth movement,

179 the expander abutment teeth exhibited rotations ranging from mesiolingual to mesiobuccal (17.2º

180 mesiolingual to 16.5º mesiobuccal rotation for first premolars, 15.8º mesiolingual to 6.5º mesiobuccal

181 rotation for first molars).[17] These data indicated that both anterior-out and posterior-out rotations could

182 occur on the hemimaxillary blocks in SARPE. Secondly, the current FEA model was set up with a Haas

183   expander on a symmetric maxilla to eliminate the possibility of anatomic influence.[14] It is worth noting

184   that the patient's anatomy, the orientation of the expander, and the types of expanders are also factors that

185   could lead to different expansion patterns,[12,19] which could lead to the discrepancy between the current

186   FEA outcome and the amount of asymmetric expansion for each patient.

187

188   **CONCLUSIONS**

189   • An increase in the buccal osteotomy angle from the frontal view induced an antero-posteriorly V-

190   shaped expansion and buccal tipping of the hemimaxillary blocks.

191   • A large discrepancy between the angles of the left and right buccal osteotomies resulted in increased

192   asymmetry in both the transverse and vertical dimensions after expansion.

193

200

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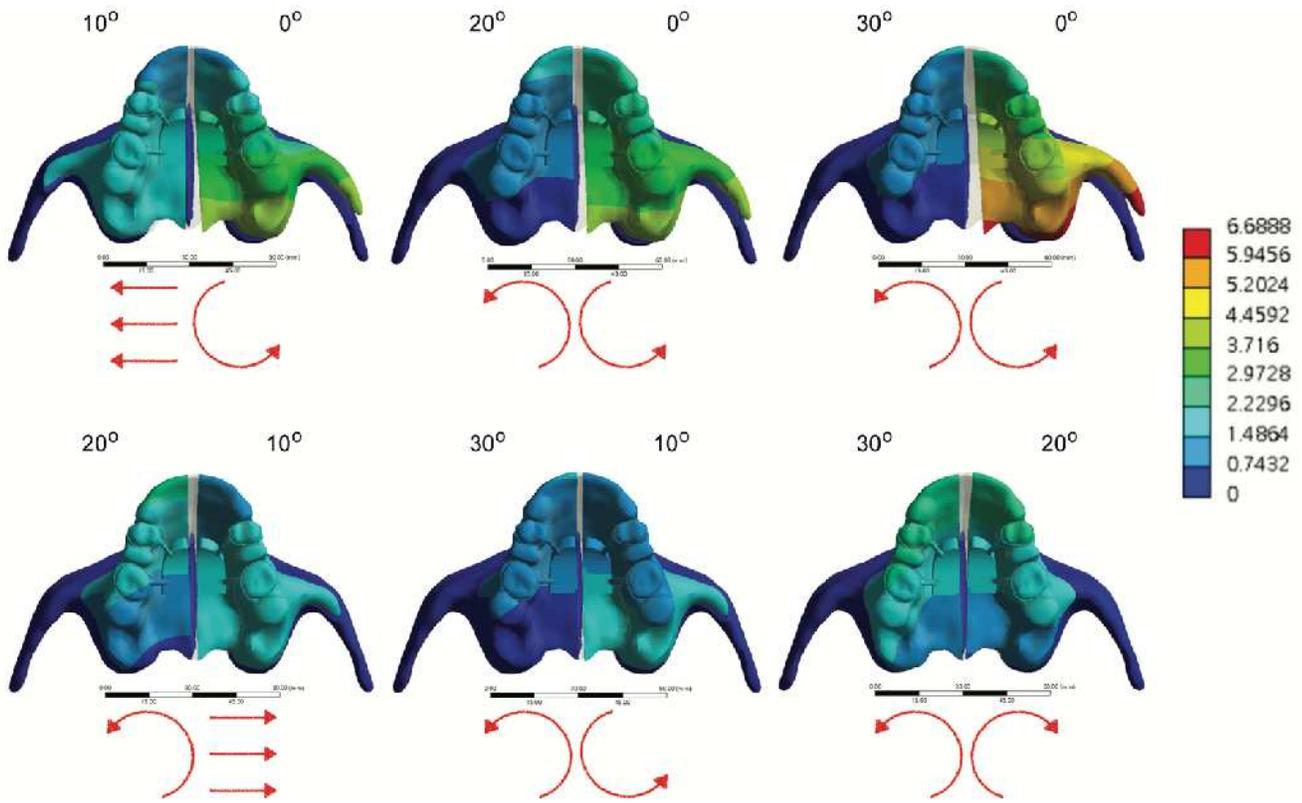251 Dental Expansion? *J Oral Maxillofac Surg.* Oct 2017;75(10):2211-2222.
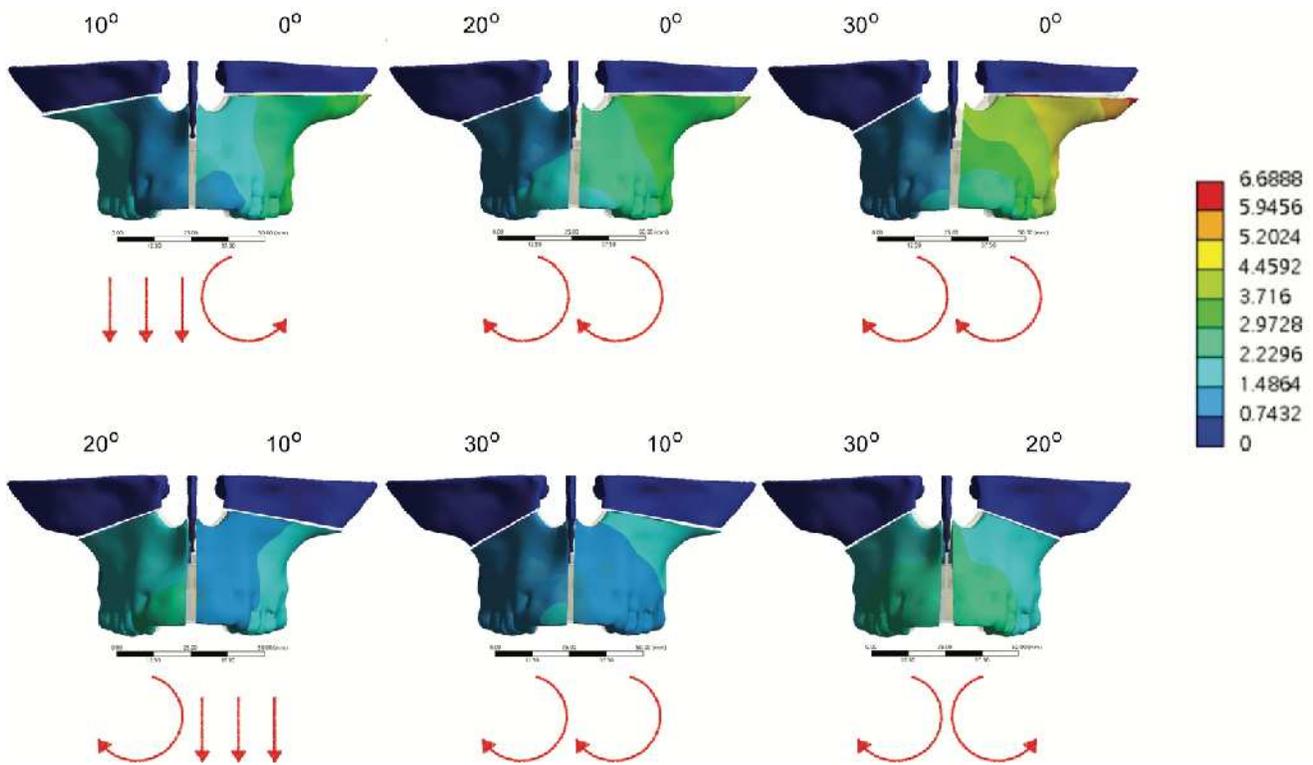252

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FIGURE LEGENDS

Figure 1. Demonstration of unfavorable and favorable expansion patterns from the occlusal and frontal views. The black dotted lines show the midsagittal plane. The red arrows show the rotation directions of the hemimaxillae. On the occlusal view, rotation of both the left and right hemimaxillae toward the same direction creates a yaw movement to the maxilla that is considered unfavorable; On the other hand, rotation of both left and right hemimaxillae toward opposite directions creates a more favorable fan-shaped expansion. On the frontal view, rotation of both the left and right hemimaxillae toward the same direction creates a roll movement that is considered unfavorable. Meanwhile, rotation of both left and right hemimaxillae to the opposite directions creates a more favorable expansion.

Figure 2. Transverse expansion pattern of the six combinations of buccal osteotomy on the FEA models from the occlusal view.

Figure 3. Expansion pattern in the vertical dimension of the six combinations of buccal osteotomy on the FEA models from the frontal view.

TABLE LEGENDS

Table 1. Asymmetry ratio for all six FEA scenarios. U6: Mesiobuccal cusp tip of the maxillary first molar; U4: Buccal cusp tip of the maxillary first premolar; IZC: Infra-zygomatic crest; Alar: Lateroinferior corner of the piriform aperture; U1: Mesioincisal line angle of the maxillary central incisor; Exp: Anterior-posterior midpoint of the medial border of the expander. In the transverse dimension: a positive value means the left side moves more laterally than the right side, negative value means the right side moves more laterally than the left side. In the sagittal dimension: a positive value means the left side moves more anteriorly than the right side, negative value means the right side moves more anteriorly than the left side. In the vertical dimension: a positive value means the left side moves more inferiorly than the right side, negative value means the right side moves more inferiorly than the left side.

Left	Right	Dimension	U6 (%)	U4 (%)	IZC (%)	Alar (%)	U1 (%)	Exp (%)
0°	10°	Transverse	29.75	10.39	32.99	11.90	-9.92	26.39
		Sagittal	4.00	-0.80	23.57	-8.60	-21.19	-20.04
		Vertical	0.05	-0.35	-2.14	0.40	0.94	1.86
0°	20°	Transverse	47.74	29.23	60.52	41.87	11.11	51.44
		Sagittal	10.34	5.98	23.57	-6.20	-13.69	-15.29
		Vertical	1.77	-1.64	6.03	-2.20	-7.65	-2.69
0°	30°	Transverse	54.85	32.15	78.61	57.14	11.07	65.22
		Sagittal	1.42	-4.15	19.52	-17.50	-28.13	-29.18
		Vertical	1.21	-3.39	10.52	-5.65	-14.65	-9.31
10°	20°	Transverse	4.58	-11.62	10.52	-8.55	-31.23	3.80
		Sagittal	28.67	24.59	31.71	-0.24	2.89	-0.79
		Vertical	-4.69	-13.78	-3.70	-9.52	-16.98	-5.91
10°	30°	Transverse	19.81	-0.13	39.22	22.17	-19.27	29.30
		Sagittal	12.16	7.49	19.42	-9.69	-14.24	-18.01
		Vertical	-1.66	-8.05	4.94	-9.57	-20.42	-11.34
20°	30°	Transverse	16.57	22.33	14.57	20.07	27.35	17.04
		Sagittal	-9.78	-8.11	-10.30	-2.04	-2.22	-0.39
		Vertical	6.79	8.61	5.58	7.80	10.52	4.02

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ORIGINAL ARTICLE

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Orthodontic–orthognathic combined case management in postgraduate orthodontic and oral maxillofacial surgery programs

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Abstract

Objectives: With the development of three-dimensional (3D) image, the 3D virtual surgical planning (VSP) system has been broadly used in the treatment planning of orthodontic–orthognathic cases. This study aimed to understand the current education status regarding the use of orthodontic–orthognathic surgical planning tools in the postgraduate orthodontic and oral and maxillofacial surgery (OMFS) programs in North America.

Methods: An electronic multiple-choice survey was sent via email with 2-week and 1-month follow-ups, requesting anonymous participation of program directors/department chairs from all postgraduate orthodontic and OMFS programs in North America. Responses were collected directly on Qualtrics for analysis.

Results: The response rate was 25.68% for orthodontic and 34.34% for OMFS programs. Two-dimensional traditional surgical planning (TSP) at initial treatment planning and 3D VSP right before surgery were most commonly utilized in both specialty programs. All responded postgraduate OMFS programs utilized VSP, yet 26.32% of responded orthodontic programs did not utilize VSP. For the surgical outcomes, fewer orthodontic programs were highly satisfied than OMFS programs. More orthodontic programs warranted secondary surgery at a higher rate due to the unsatisfied outcome. Additionally, the orthodontic programs that did not use VSP showed higher unsatisfied surgical outcomes than the programs that used VSP. Moreover, there were discrepancies between orthodontic and OMFS programs regarding the perceived level of collaboration of each other on the surgical planning for the patients.

Conclusion: There were discrepancies between orthodontic and OMFS programs regarding the utilization of VSP, treatment outcomes satisfaction, and perceived level of collaboration on surgical planning for the patients.

1 | INTRODUCTION

Patients who suffer from genetic growth imbalances beyond the orthodontic–orthopedic range of correction, facial trauma causing growth alterations, orthodontic retreatment problems that grow outside the range of conventional orthodontic correction, and sleep apnea disorders that require orthognathic procedures to completely resolve, require advanced management from orthodontists and oral maxillofacial (OMFS) surgeons through refined techniques of orthodontic–orthognathic combined therapy.[1] There are four phases of a combined orthodontic–orthognathic treatment: initial evaluation, presurgical orthodontics, surgical correction, and postsurgical orthodontics. The tight collaboration between the orthodontist and the OMFS surgeon is critical at each of these phases to secure successful treatment outcomes.[2] Thus, education on the initial diagnosis, treatment planning, treatment outcome evaluation, and proper interprofessional communication is an essential part of the postgraduate training of both specialties.

Historically, the treatment planning phase is performed using traditional surgical planning (TSP). TSP utilizes two-dimensional (2D) lateral cephalograms and cephalometric analysis and includes the use of facebow transfers, occlusal bite registrations, model analysis, and model surgery.[2] TSP has proven to be an acceptable method for orthognathic surgical planning; however, it requires a great amount of time commitment.[2] In addition, TSP can provide precision when planning for sagittal and vertical surgical movements of the jaws but oftentimes falls short regarding movements from the frontal view, leading to some asymmetry. Indeed, facial asymmetry was the leading chief complaint from the patients who asked for reoperation,[3] which might be due to the limitation of 2D TSP.

The emergence of cone-beam computed tomography has enabled three-dimensional (3D) virtual surgical planning (VSP). Recent meta-analyses and systematic reviews have shown that while VSP and TSP are similar in surgical accuracy for hard tissue in the sagittal and vertical dimensions, VSP shows clinically significantly greater precision for soft tissue prediction and leads to a more symmetrical frontal view. More importantly, VSP requires significantly shorter planning time and allows unlimited treatment planning tests,[4–6] which greatly accelerate clinical care and allow for better visualization of predicted treatment outcomes for patients.

As VSP gained popularity among oral and maxillofacial surgeons, one concern needs to be raised: the surgeon-based publications on VSP for treating combined orthodontic–orthognathic cases failed to include orthodontists' involvement[7] compared with decades ago in the TSP era that the close communication between orthodontists and surgeons was emphasized.[2,8] Consequently, what were shown as exemplary VSPs in such publications[9] might not deemed acceptable from an orthodontist's perspective, which demonstrates the miscommunication between these two specialties. This misperception may have some negative impact on the patients' care delivery and even on the training for the residents of these two specialties. Therefore, a study that closely examines the collaboration between postgraduate orthodontic and OMFS departments, especially in educational institutes, when treating combined orthodontic–orthognathic patients, is needed.

2 | METHODS

An electronic survey was developed using Qualtrics online software (Provo, UT, USA; account license purchased by the University of Pennsylvania). As the sole purpose of this survey was to collect program information, approval from the University of Pennsylvania Institutional Review Board (IRB) was exempted after consultation with the University IRB. The IRB exemption status was stated in the survey invitation to notify all the invited participants as follows: "The current project is exempted from the University of Pennsylvania Institutional Review Board approval. This exemption may or may not be sufficient at your local institution. Should you have any questions or concerns, please feel free to reach out to us."

Fourteen multiple-choice questions were included in the survey. The survey was validated through pilot feedback from three full-time orthodontic faculty members and two full-time OMFS faculty members. Questions were carefully embedded to only permit applicable follow-up questions based on previous responses. Responses either required only one answer choice to be selected or specified the participant to select all of the following that apply. Some questions allowed participants to enter additional comments under the answer choice "other."

The survey link was sent via email requesting the anonymous participation of program directors/department

chairs of 74 postgraduate orthodontic programs (program list obtained on the American Association of Orthodontists website: https://www2.aaoinfo.org/programs-for-residents-and-educators/accredited-orthodontic-programs/) and 99 postgraduate OMFS programs (program list obtained on the American Association of Oral and Maxillofacial Surgeons website: https://www.aaoms.org/docs/education_research/edu_training/aaomresidency_omsprogram.pdf). Emails were sent directly from Qualtrics with the intent of collecting and analyzing all data on one centralized platform. Qualtrics online software also enabled us to track participation to avoid multiple responses and follow up only with program directors/department chairs who had not yet responded. After the initial distribution, two follow-up emails were sent 2 weeks and 1 month after the initial email to each program director/department chair who had not responded. Any bounced emails were attempted to be redirected to the proper recipient. The survey link was deactivated 2 months after the second reminder email was sent out. The survey response collection ended on December 31, 2023. All emails and surveys were sent in English. All survey responses were collected directly on the Qualtrics platform for analysis and review.

Data were transferred to the GraphPad Prism (version 8.2.1; San Diego, CA, USA) for further analysis, visualization, and figure generation.

3 | RESULTS

3.1 | TSP versus VSP usage

Nineteen postgraduate orthodontic programs and 34 postgraduate OMFS programs responded to the survey, with response rates of 25.56% and 34.34%, respectively.

2D TSP at initial treatment planning (ortho: 63.16%, 12 responses; OMFS: 38.24%, 13 responses) and 3D VSP right before orthognathic surgery (ortho: 78.95%, 15 responses; OMFS: 97.06%, 33 responses) were most utilized (Figure 1A).

When asked specifically about the 3D VSP usage in the program, 100% (34 responses) of postgraduate OMFS programs and 73.68% (14 responses) of postgraduate orthodontic programs utilized 3D VSP. 82.35% (28 responses) of the postgraduate OMFS programs and 52.63% (10 responses) of the postgraduate orthodontic programs utilized the commercial 3D VSP exclusively (Figure 1B). None of the postgraduate OMFS programs and only 5.26% (one response) of the postgraduate orthodontic program exclusively utilized in-house 3D VSP (Figure 1B).

3.2 | VSP usage: types of surgery

Compared with utilizing commercial 3D VSP for one-jaw surgeries (for sagittal correction: 64.71%, 22 responses; for vertical correction: 67.65%, 23 responses; for transverse correction: 76.47%, 26 responses), postgraduate OMFS programs were more inclined to utilize commercial 3D VSP for bi-jaw surgeries (94.12%, 32 responses), surgeries for patients with large facial asymmetry (94.12%, 32 responses), and surgeries for patients with craniofacial anomalies (91.18%, 31 responses) (Figure 2A). Similar trends in usage were not observed in the postgraduate orthodontic programs where commercial 3D VSP was utilized more uniformly for the listed surgeries (Figure 2A).
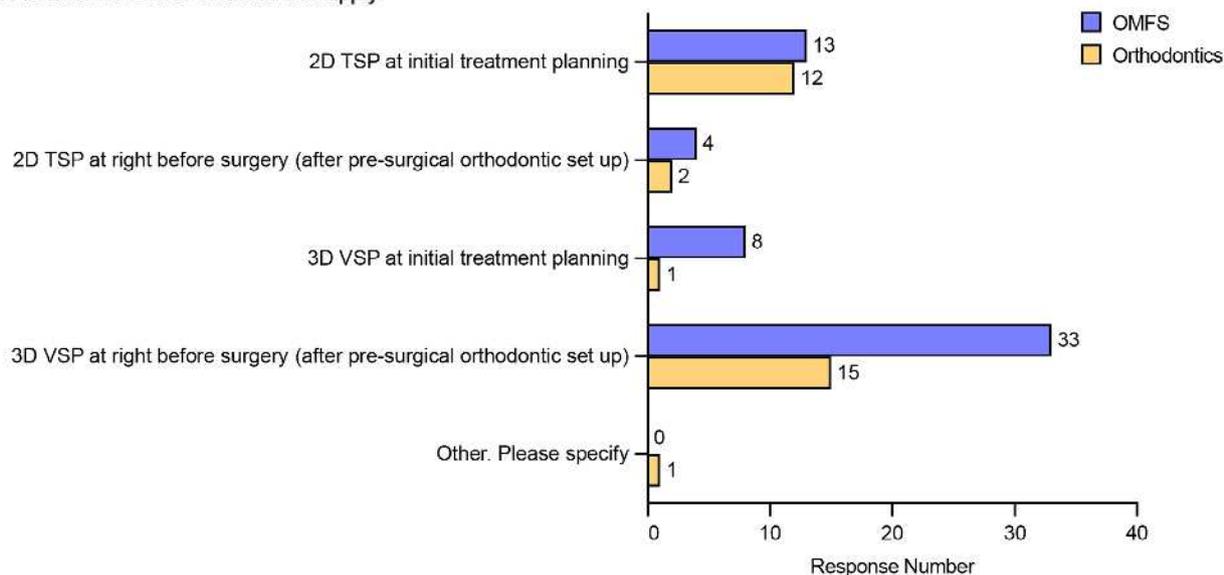
When in-house 3D VSP was utilized, postgraduate OMFS programs and postgraduate orthodontic programs used it indistinctively for all listed surgery options (Figure 2B).

3.3 | Clinician's involvement in the surgical planning

A significant discrepancy between the postgraduate orthodontic and OMFS programs was observed with respect to the perceived levels of collaboration of the faculty and residents during surgical planning. The majority of the postgraduate OMFS program directors/department chairs (87.50%, 28 responses) believed their OMFS faculty members were involved all the time during 2D TSP or 3D VSP setup, while the rest of the OMFS program directors/department chairs (12.50%, four responses) believed their faculty members were involved extensively. On the other hand, only 50.00% of the postgraduate orthodontic program directors/department chairs believed the OMFS faculty members were involved all the time during 2D TSP or 3D VSP setup. Furthermore, 11.11% of the postgraduate orthodontic program directors/department chairs believed that OMFS faculty members were not involved at all during this step (Figure 3A).

Similar trends were observed regarding the perceived level of involvement of the OMFS residents. Among the postgraduate OMFS program directors/department chairs, 59.38% (19 responses) believed the OMFS residents were involved all the time, and 31.25% (10 responses) believed they were involved extensively during the 2D TSP or 3D VSP setup. On the other hand, a mere 22.22% (four responses) of the postgraduate orthodontic program directors/department chairs believed the OMFS residents were involved all the time, with another 38.89%
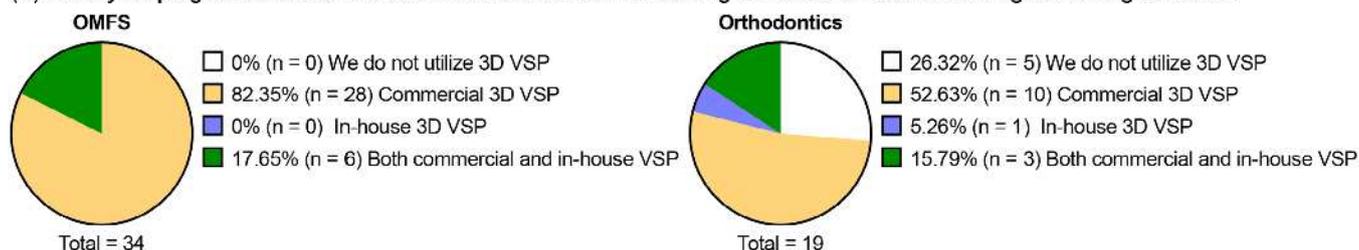
FIGURE 1 The usage of 3D VSP in oral maxillofacial surgery (OMFS) and orthodontic postgraduate programs. (A) Responses to question "For combined orthodontic-orthognathic surgical treatments, which of the following tools does your program utilize and at what stage of treatment? Please select all that apply." (B) Responses to the question "Does your program utilize commercial or in-house 3D VSP for treating combined orthodontic-orthognathic surgical cases?".

(seven responses) believed they were involved extensively. While none of the postgraduate OMFS program directors/department chairs thought their OMFS residents were not involved at all during the 2D TPS or 3D VSP setup, 11.11% (two responses) of the postgraduate orthodontic program directors/department chairs perceived the OMFS residents were not involved at all during this step of the orthodontic–orthognathic treatment (Figure 3B).

Regarding orthodontic faculty's involvement during the 2D TSP or 3D VSP setup process, more than half (53.13%, 17 responses) of the postgraduate OMFS program directors/department chairs believed the orthodontic faculty members had minimal involvement and 12.5% (four responses) believed the orthodontic faculty were not involved at all. The responses from the postgraduate orthodontic program directors/department chairs were evenly split between involved all the time, extensive involvement, and some involvement, each comprises 27.78% (five responses) of the responses (Figure 3C).

The discrepancy between the responses from postgraduate orthodontic and OMFS program directors/department chairs was perhaps the largest regarding orthodontic residents' involvement during 2D TSP or 3D VSP setup. The responses from the postgraduate OMFS program directors/department chairs were split between minimal involvement and not involved at all, with each option selected by 34.38% of the OMFS respondents. On the other, the responses from the postgraduate orthodontic program directors/department chairs were split between involved all the time and involved extensively, with each option being selected by 33.33% of the orthodontic respondents (Figure 3D).

3.4 | Differences of opinion during the surgical planning phase

When there was a conflict between the oral and maxillofacial surgeon and the orthodontist regarding the

(A) What type(s) of cases does your program utilize commercial 3D VSP? Please select all that apply.

(B) What type(s) of cases does your program utilize in-house 3D VSP? Please select all that apply.
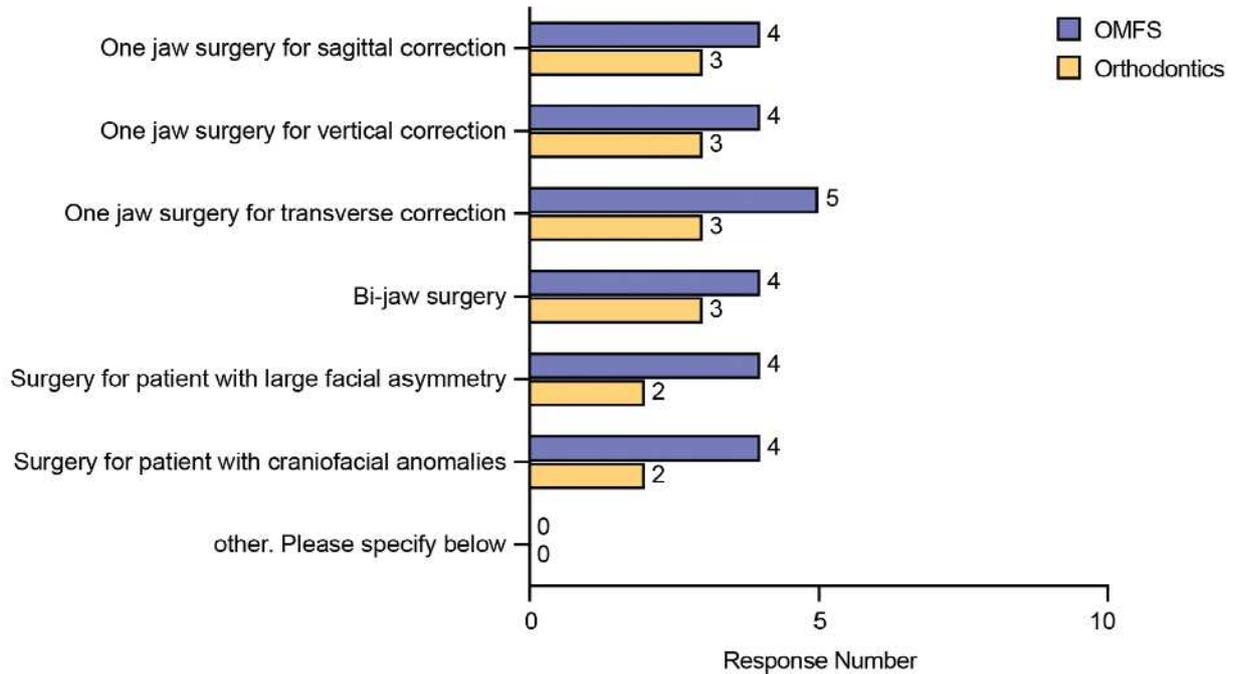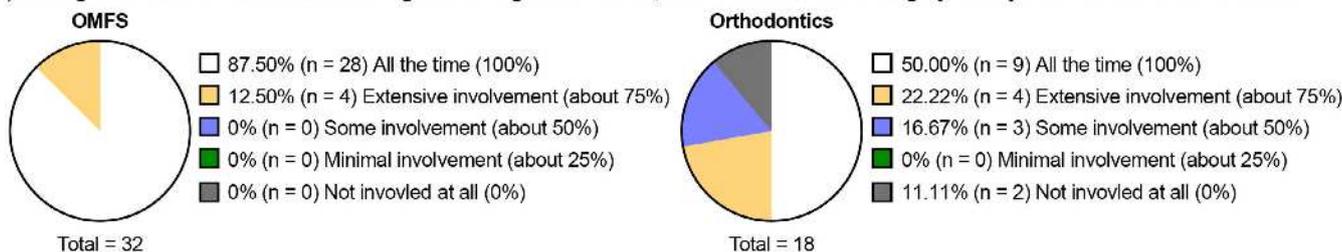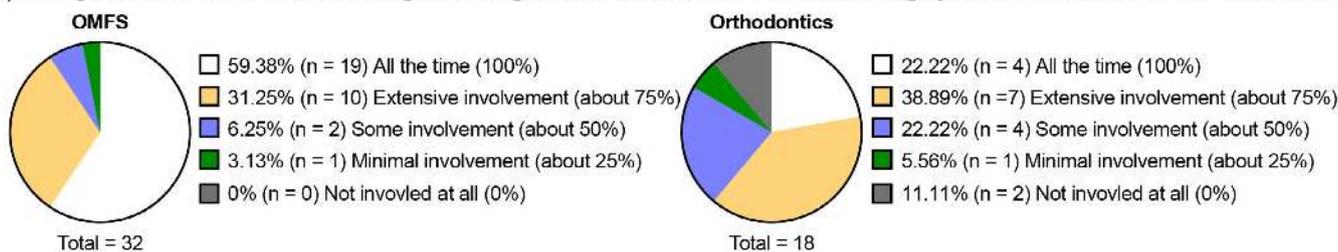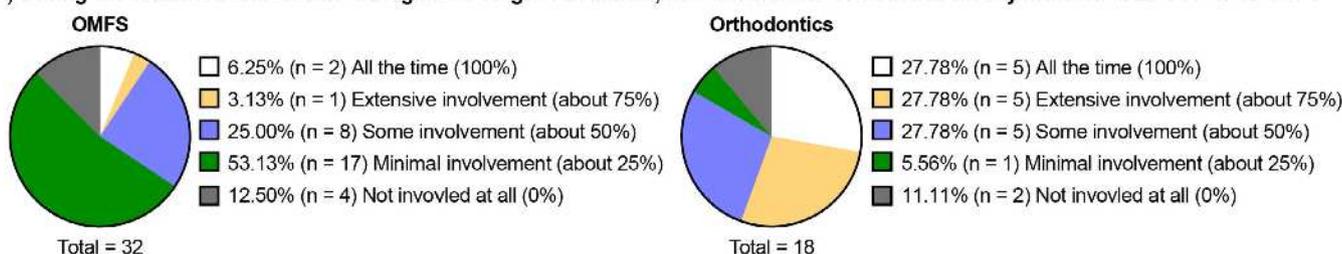
FIGURE 2 Types of surgery planned with 3D VSP. (A) Responses to the question "What type(s) of cases does your program utilize commercial 3D VSP? Please select all that apply." (B) Responses to the question "What type(s) of cases does your program utilize in-house 3D VSP? Please select all that apply."

(A) During the combined orthodontic-orthognathic surgical treatment, how much is the oral surgery faculty involved in 2D TSP or 3D VSP?

OMFS
- 87.50% (n = 28) All the time (100%)
- 12.50% (n = 4) Extensive involvement (about 75%)
- 0% (n = 0) Some involvement (about 50%)
- 0% (n = 0) Minimal involvement (about 25%)
- 0% (n = 0) Not invovled at all (0%)

Total = 32

Orthodontics
- 50.00% (n = 9) All the time (100%)
- 22.22% (n = 4) Extensive involvement (about 75%)
- 16.67% (n = 3) Some involvement (about 50%)
- 0% (n = 0) Minimal involvement (about 25%)
- 11.11% (n = 2) Not invovled at all (0%)

Total = 18

(B) During the combined orthodontic-orthognathic surgical treatment, how much is the oral surgery resident involved in 2D TSP or 3D VSP?

OMFS
- 59.38% (n = 19) All the time (100%)
- 31.25% (n = 10) Extensive involvement (about 75%)
- 6.25% (n = 2) Some involvement (about 50%)
- 3.13% (n = 1) Minimal involvement (about 25%)
- 0% (n = 0) Not invovled at all (0%)

Total = 32

Orthodontics
- 22.22% (n = 4) All the time (100%)
- 38.89% (n =7) Extensive involvement (about 75%)
- 22.22% (n = 4) Some involvement (about 50%)
- 5.56% (n = 1) Minimal involvement (about 25%)
- 11.11% (n = 2) Not invovled at all (0%)

Total = 18

(C) During the combined orthodontic-orthognathic surgical treatment, how much is the Orthodontic faculty involved in 2D TSP or 3D VSP?

OMFS
- 6.25% (n = 2) All the time (100%)
- 3.13% (n = 1) Extensive involvement (about 75%)
- 25.00% (n = 8) Some involvement (about 50%)
- 53.13% (n = 17) Minimal involvement (about 25%)
- 12.50% (n = 4) Not invovled at all (0%)

Total = 32

Orthodontics
- 27.78% (n = 5) All the time (100%)
- 27.78% (n = 5) Extensive involvement (about 75%)
- 27.78% (n = 5) Some involvement (about 50%)
- 5.56% (n = 1) Minimal involvement (about 25%)
- 11.11% (n = 2) Not invovled at all (0%)

Total = 18

(D) During the combined orthodontic-orthognathic surgical treatment, how much is the orthodontic resident involved in 2D TSP or 3D VSP?

OMFS
- 9.38% (n = 3) All the time (100%)
- 3.13% (n = 1) Extensive involvement (about 75%)
- 18.75% (n = 6) Some involvement (about 50%)
- 34.38% (n = 11) Minimal involvement (about 25%)
- 34.38% (n = 11) Not invovled at all (0%)

Total = 32

Orthodontics
- 33.33% (n = 6) All the time (100%)
- 33.33% (n = 6) Extensive involvement (about 75%)
- 11.11% (n = 2) Some involvement (about 50%)
- 16.67% (n = 3) Minimal involvement (about 25%)
- 5.56% (n = 1) Not invovled at all (0%)

Total = 18

FIGURE 3 Clinician's involvement in the surgical planning. (A) Responses to the question "During the combined orthodontic-orthognathic surgical treatment, how much is the oral surgery faculty involved in 2D TSP or 3D VSP?" (B) Responses to the question "During the combined orthodontic-orthognathic surgical treatment, how much is the oral surgery resident involved in 2D TSP or 3D VSP?" (C) Responses to the question "During the combined orthodontic-orthognathic surgical treatment, how much is the orthodontic faculty involved in 2D TSP or 3D VSP?" (D) Responses to the question "During the combined orthodontic-orthognathic surgical treatment, how much is the orthodontic resident involved in 2D TSP or 3D VSP?"

need for extraction for the presurgical decompensation, 81.25% (26 responses) of the OMFS respondents and 94.44% (17 responses) of the orthodontic respondents believed the orthodontist should make the final decision (Figure 4A).
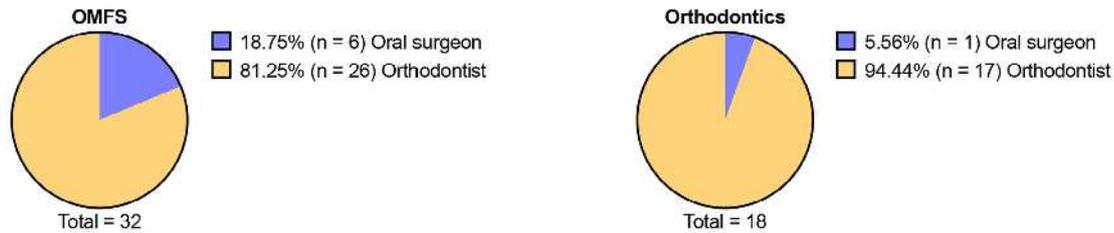
When there was a conflict between the oral and maxillofacial surgeon, the orthodontist, and the engineer from the VSP company regarding the surgical plan or specific surgical movements, 96.88% (31 respondents) of the OMFS respondents and 77.78% (14 responses) of the orthodontic

respondents believed the oral and maxillofacial surgeon should make the final decision (Figure 4B).

3.5 | Differences of opinion regarding the overall treatment outcome

One hundred percent of the OMFS respondents were either highly satisfied or satisfied (highly satisfied: 68.75%, 22 responses; satisfied: 31.25%, 10 responses) with the

FIGURE 4 Differences of opinion during the surgical planning phase. (A) Responses to the question "In case of a conflict between the oral surgeon and the orthodontist regarding the need for extraction for pre-surgical decompensation, who makes the final decision?" (B) Responses to the question "In case of a conflict regarding the surgical plan/specific surgical movements among the oral surgeon, the orthodontist, and the engineer from the VSP company, who makes the final decision?"
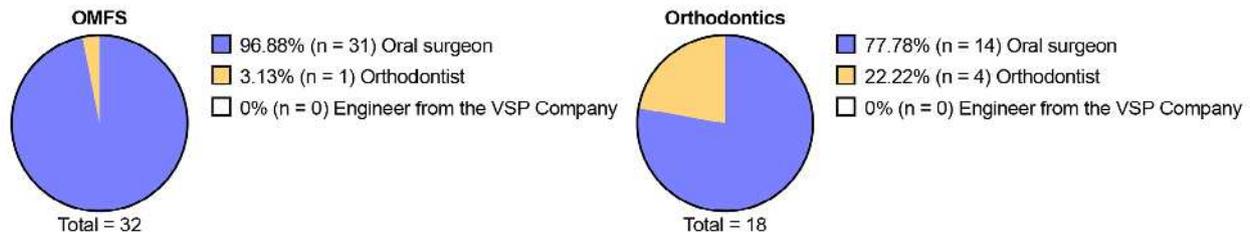
overall treatment outcome of the combined orthodontic–orthognathic surgery cases in their programs. In contrast, only 76.47% of the orthodontic respondents were either highly satisfied or satisfied (Figure 5A).

When the responses were further categorized into programs that utilized commercial VSP only, in-house VSP only, both commercial and in-house VSP, and no VSP, it showed that a lower rate of highly satisfied was in the orthodontic programs that did not utilize VSP (Figure 5A). In-house VSP potentially increased the satisfaction rate in both orthodontic and OMFS programs (Figure 5A).

Regarding the types of surgery that caused dissatisfaction in both specialists, surgeries for patients with large facial asymmetry (OMFS: 11 responses; ortho: eight responses) and for patients with craniofacial anomalies (OMFS: 10 responses; ortho: five responses) comprised the greatest number of dis-satisfying cases for both the OMFS and orthodontic respondents. Additionally, bi-jaw surgery was also considered as one of the most dis-satisfying surgical types by the orthodontic respondents (four responses), but not for OMFS respondents (Figure 5B).

3.6 | Need for the second surgery

In terms of the need for a second surgery due to dissatisfying results from the first surgery, 71.88% ($n = 23$)

of the OMFS respondents and 72.22% ($n = 13$) of the orthodontic respondents thought 1%–5% of their orthognathic patients needed a second surgery. However, while none of the OMFS respondents thought more than 10% of their orthognathic patients needed a second surgery, 11.11% ($n = 2$) of the orthodontic respondents thought about 10%–25% of their orthognathic patients needed a second surgery (Figure 6).

Furthermore, for the orthodontic programs, the programs that did not utilize VSP showed a higher rate of second surgery compared with the programs that utilized VSP (Figure 6). The usage of in-house VSP potentially reduced the rate of second surgery in OMFS programs (Figure 6).

4 | DISCUSSION

Since the introduction of 3D VSP as a new technology, the specialty of oral and maxillofacial surgery has been heavily impacted.[7] Although there existed a slow pick-up rate for the use of VSP, a high adoption rate of 98.7%–100% was presented between 2019 and 2021.[10] In fact, our current survey showed that 100% of the responded postgraduate OMFS programs in North America utilize 3D VSP when treating orthodontic–orthognathic surgical combined cases, in the form of either commercial or in-house 3D VSP.
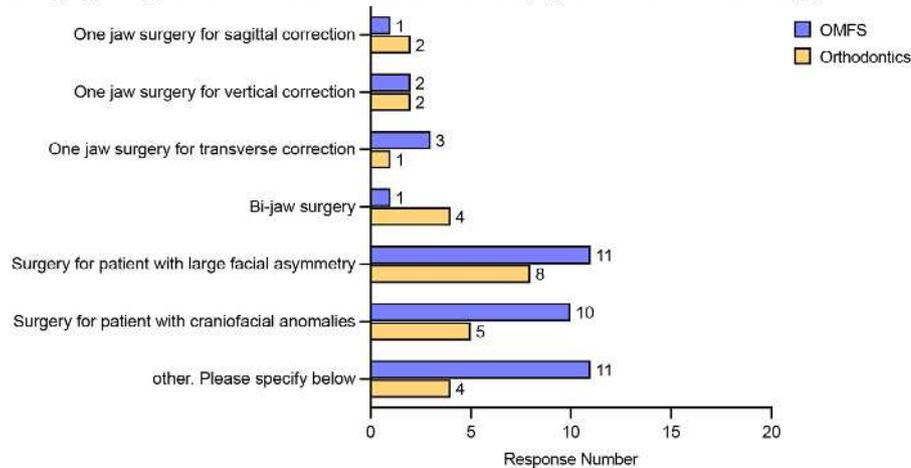
FIGURE 5 Differences of opinion regarding the overall treatment outcome. (A) Responses to the question "How satisfied are you with the overall treatment outcome of the combined orthodontic-orthognathic surgery cases in your program?" (B) Responses to the question "Which types(s) of surgical cases result in the most amount of dis-satisfying cases? Please select all that apply."

In contrast, orthodontists, another specialty that is heavily involved in the management of orthodontic–orthognathic surgical combined cases, do not adapt well to this new technology, with 26.32% of the responded programs not utilizing 3D VSP. Such differences in 3D VSP adaption may lead to discrepancies in communications during clinical patient care. In fact, our study showed that the program directors/department chairs from two specialties reported different satisfying rates of surgical outcomes and different rates of second surgery due to dis-satisfying

What is the percentage of patients in your program that needs a second orthognathic surgery due to outcome dissatisfaction of the first orthognathic surgery?

FIGURE 6 Responses to the question "What is the percentage of patients in your program that need a second orthognathic surgery due to outcome dissatisfaction of the first orthognathic surgery?"

treatment outcomes. And higher dissatisfying rate was reported by the orthodontic programs that do not utilize 3D VSP. By comparing orthodontic residents' performance when treatment planning for combined orthognathic-orthodontic cases using TSP and VSP, Sytek et al.[11] reported that while there were no significant differences in diagnosis, the use of VSP facilitated the creation of more thorough and complex surgical movements. Thus, proper training in 3D VSP usage in orthodontic programs is also critical.

However, our current survey also showed that 3D VSP is more commonly utilized at the stage right before surgery (after presurgical orthodontic setup) instead of at initial treatment planning. This might be due to the fact that although most VSP show occlusal interferences,[12] most, if not all, VSP do not integrate digital dental movement setup, making it less useful for surgical treatment planning before presurgical orthodontic setup. Developing software that integrates both dental movement and skeletal movement will likely encourage the use of VSP at the initial treatment planning and better communication among orthodontists, oral surgeons, and patients.

It has also been shown that although VSP does not necessarily decrease surgery time in the operating room, utilizing VSP in orthognathic surgery, indeed, significantly decreases planning time when compared with using TSP,[5] which could even allow same-day and surgeon-direct planning.[6] However, with the broad usage of commercial VSP which relies on the engineers from the companies doing initial surgical setups, it seems to lead to a loss of the close collaboration between the orthodontist and the oral surgeon during the surgical planning session. Our current survey showed that there were significant discrepancies in the perceived levels of involvement. In general, regarding the perceived orthodontist's involvement in orthodontic–orthognathic surgical combined cases, the oral surgeon's rating was significantly lower than the orthodontist's rating. A similar conclusion can be made regarding the perceived oral surgeon's involvement in such cases. The orthodontist's rating was significantly lower than the oral surgeon's rating. These results reflect the fact that there was a lack of collaboration and communication between these two specialties during the treatment of orthodontic–orthognathic surgical combined cases. It is worth noting that direct collaboration between the two specialists is critical to the long-term stability of the postoperative outcomes.[13] Thus, it is imperative to have close communication between the orthodontist and the oral and maxillofacial surgeon when setting up the VSP,[13] and this should draw attention from the educators of both specialties.

Last but not least, as the use of the VSP can accurately detect occlusal cant as well as asymmetry,[12] it is reasonable to assume there will be a decrease in unsatisfactory rate in the treatment of facial asymmetry cases. In fact, a meta-analysis and systematic review concluded that compared with TSP, VSP resulted in a more symmetrical frontal view.[4] However, our current survey showed that facial asymmetry cases still comprised most of the unsatisfactory cases, from both the orthodontist's and the oral and maxillofacial surgeon's perspective. This might be due to the fact that the ratio of soft tissue adap-tion to hard tissue change is still unclear, and the 3D VSP could not perform precision soft tissue prediction.[14,15] Further studies are warranted to improve the soft tissue change prediction in orthodontic–orthognathic combined treatment.

5 | CONCLUSION

Our survey demonstrated that there exists a discrepancy between the postgraduate orthodontic and OMFS programs regarding the usage of 3D VSP, the perceived level of collaboration, and the overall satisfaction of the treatment outcome, in managing the orthodontic–orthognathic combined cases. Attention from the educators of both specialties is warranted to improve our postgraduate education in this aspect, which in turn, will improve clinical interdisciplinary care.

CONFLICT OF INTEREST STATEMENT

The authors declare that they have no conflict of interests.

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