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UNIFORMED SERVICES UNIVERSITY OF THE HEALTH SCIENCES
POSTGRADUATE DENTAL COLLEGE
NAVAL POSTGRADUATE DENTAL SCHOOL
8955 WOOD ROAD
BETHESDA, MARYLAND 20889

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Name of Candidate: Nickoli Dubyk
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Nicholas J. Hamlin
ASSOCIATE DEAN, NAVAL POSTGRADUATE DENTAL SCHOOL
Committee Chairperson

HAWKINS.JAMES.MARK.1292526985 Digitally signed by HAWKINS.JAMES.MARK.1292526985 Date: 2022.06.06 07:17:23 -04'00' 6/6/22

James M. Hawkins
CHAIRMAN, OROFACIAL PAIN DEPARTMENT, NAVAL POSTGRADUATE DENTAL SCHOOL
Committee Member

IMAMURA.GLEN.MASAO.1088288510 Digitally signed by IMAMURA.GLEN.MASAO.1088288510 Date: 2022.06.03 14:25:50 -04'00' 6/3/22

Glen M. Imamura
RESEARCH DEPARTMENT, NAVAL POSTGRADUATE DENTAL SCHOOL
Committee Member

CBCT EVALUATION OF THE TMJ PRE AND POST-ORTHOGNATHIC SURGERY

by

Nickoli Dubyk
Lieutenant Colonel, Dental Corps
United States Army

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ABSTRACT

CBCT Evaluation of the TMJ Pre and Post-Orthognathic Surgery

Nickoli Dubyk, DMD, 2022

Thesis directed by: LCDR James Hawkins
Program Director, Orofacial Pain Department
Naval Postgraduate Dental School

Introduction: When post-orthognathic surgical condylar remodeling exceeds a patient's physiological ability to adapt, it may lead to surgical relapse and/or be associated with temporomandibular joint disorders (TMD) [1 2 3]. **Purpose**: This retrospective analysis will evaluate if resorptive changes within the temporomandibular joint (TMJ) are detectable with cone-beam computed tomography (CBCT) following orthognathic surgery (OGS). **Methods**: CBCT provides 3D imaging of hard tissues and can reveal morphologic changes of the condyle and the glenoid fossa as a result of bone remodeling when scans are compared over time. Geometric morphometric analysis of superimposed landmark based wireframes generated from CBCT scans will allow for the generation of deformation grids and heat maps to visualize shape differences and changes. Once segmented, inter-surface distance calculations will be measured between the superimposed 3D mesh models for quantitative and qualitative statistical analysis. **Results**: To date, no results have been collected.

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LIST OF ABBREVIATONS

2D	Two-Dimensional
3D	Three-Dimensional
CBCT	Cone Beam Computed Tomography
CPD	Condylar Positioning Device
CT	Computed Tomography
NIDCR	National Institute of Dental and Craniofacial Research
NIH	National Institutes of Health
OGS	Orthognathic Surgery
SSO	Sagittal Split Osteotomy
TMD	Temporomandibular Joint Disorders
TMJ	Temporomandibular Joint
UCSF	University of California San Francisco
UNLV	University of Nevada Las Vegas
VOI	Volume of Interest

CHAPTER 1: Introduction

Patients may present to dental facilities with existing skeletal maxillo-mandibular discrepancies in the sagittal, transverse and/or vertical planes, with or without the coexistence of skeletal asymmetries. Adolescents desiring therapy to correct skeletal disharmonies that exceed their remaining growth capacity or adults where facial growth has completely ceased, will require orthognathic surgery (OGS). Non-surgical camouflage of the discrepancy via orthodontics or prosthodontics can be an option in less severe cases.[4,5] Patients with developmental abnormalities of the jaws and facial bones usually present with a malocclusion. In addition to its adverse effect on chewing, malocclusions may also affect speech, facial esthetics and an individual's overall health.

OGS is usually conducted in combination with orthodontics. Surgery is performed under general anesthesia with a desired outcome to correctly reposition the jaws to improve the patient's occlusion and to restore normal facial appearance. Corrective OGS's include mono- or bimaxillary osteotomy accompanied by orthodontic treatment. OGS's can also be used to address obstructive sleep apnea and facial trauma resulting from combat injuries. Skeletal discrepancies involving the midface are corrected using LeFort osteotomies The LeFort I osteotomy is the most common osteotomy in OGS and enables three dimensional (3D) correction along the horizontal, vertical and transverse planes. This procedure can result in protrusion or advancement, a setback and impaction, a correction of occlusal cant, as well as rotation of the maxilla in the sagittal plane to correct an open-bite.[6] A sagittal split osteotomy (SSO) is the most common surgical technique used to correct mandibular horizontal discrepancies.[7,8] The SSO described by Trauner and later modified by DalPont involves splitting the mandible

along the sagittal plane and repositioning the proximal segment.[9,10] SSOs enable advancement or setback of the mandible to improve the occlusion and soft tissue profile.

Numerous methods have been developed to guide and assist practitioners in properly positioning the condyle within the fossa during surgery. These include manual positioning; fabrication of condylar positioning devices (CPDs); and image guided repositioning used in conjunction with ultrasound. While there is debate in the literature as to the need for CPDs, many authors favor the simpler and inexpensive manual repositioning technique.[11]

Stability of the repositioned segments is a concern for surgeons and patients, as segment instability during healing may contribute to surgical relapse. OGS's have the potential to initiate changes within the temporomandibular joint (TMJ), especially if less than ideal positioning of the condyle-glenoid fossa relationship occur post-surgically.[1,4] This may occur for various reasons including an over rotation of the proximal segment during a setback procedure; a malpositioning of the condyle within the fossa during rigid fixation; paralysis of the masticatory muscles due to anesthesia or edema -any of which can lead to a change in the condylar position.[4,11] If post-surgical condylar remodeling exceeds a patient's physiological ability to adapt, it may lead to surgical relapse and/or be associated with temporomandibular disorders (TMDs).[2,3,12] To minimize risk of pathologic remodeling authors have debated the desired post-surgical position of the mandibular condyle within the articular fossa, although it is generally accepted that the pre-surgical position is the desired post-surgical position.[1,13]

Cone-beam computed tomography (CBCT) provides 3D imaging of hard tissues. Due to its decreased radiation dose and lower cost, when compared to computed

tomography (CT), it has been extensively used in dentistry.[6,14] CBCT linear measurements have been shown to be accurate and provide a reliable method for evaluating the position of the condyle in three planes within the glenoid fossa.[15] CBCTs can also reveal morphologic changes of the condyle and the glenoid fossa as a result of bone remodeling when images/scans are compared over time.

Geometric morphometric analysis is a statistical method to measure shape change of 3D objects by comparing landmark coordinates between the samples. Superimposition of landmark based wireframes allow for the generation of deformation grids and heat maps used to visualize shape differences and changes. Accurate statistical evaluation requires the identification and use of unambiguous, homologues landmarks to make the comparisons.[16] In the study of facial growth and development, many well-known landmarks have been identified and used to compare two-dimensional (2D) cephalometric images. Additional landmarks have been developed and validated for comparison of 3D CBCT images.[17] Historically, statistical analysis of smooth curves and surfaces has been a challenge due to the relative absence of unambiguous, landmarks within the volume of interest (VOI). Recent technological advancements allow the use of semilandmarks or sliding landmarks to be used as a statistical means of establishing landmarks perpendicular to a curve lacking a well-defined anatomical landmark.[16] This technique allows for greater accuracy when measuring potential changes to the condyle and glenoid fossa.

The aim of this study is to evaluate if resorptive changes within the TMJ are detectable with CBCT following OGS. The investigators will also identify landmarks within the glenoid fossa to aid in point based registration comparisons within the glenoid

fossa VOI for accurate shape and form analysis. It is hypothesized there will be no difference in condylar and glenoid fossa remodeling between OGS cohort groups.

MILITARY RELEVANCE

Within the active military population, there are service members with dento-facial deformities who could benefit from OGS to improve masticatory function, esthetics or to correct facial trauma following wounds sustained in battle. Additionally, the ability to predict potential OSG complications in all populations would allow surgeons to better inform patients about complications following surgery and potentially reduce surgical morbidity for patients identified at higher risk for surgical relapse or TMDs.

CHAPTER 2: Materials and Methods

STUDY DESIGN

This study will be a retrospective analysis of CBCTs of patients who underwent a mandibular advancement or a setback OGS with or without a Le Fort I osteotomy for skeletal Class II or Class III malocclusion corrections. All surgeries were performed at University of California San Francisco (UCSF), University of Nevada, Las Vegas (UNLV) or National Institutes of Health (NIH) between 2004-2019. The de-identified CBCTs belong to Dr. Janice Lee at the National Institute of Dental and Craniofacial Research (NIDCR). Patients ages ranged from 12-53 years. All were healthy, with no diagnoses of facial trauma, syndromes or degenerative joint disease and no history of facial trauma.

De-identified pre- and post-operative full skull CBCT scans (N=60) will be used to assess condylar and glenoid fossa morphology. All patients underwent pre- and post-surgical orthodontic treatment. Maxillary surgeries were performed using the Le Fort I osteotomy. Mandibular treatments consisted of bilateral sagittal split osteotomies. The repositioned osseous segments were oriented using a prefabricated CPD. Subjects were grouped by skeletal type malocclusions and the types of surgery performed. Group 1 subjects were diagnosed as skeletal class II and received a mandibular advancement with a SSO (n=20). Group 2 subjects received a Le Fort I to correct a skeletal class III deformity (n=20). Group 3 subjects were diagnosed as skeletal class III and received a Le Fort I and maxillary setback (n=20).

CBCT IMAGES

A CB MercuRay system (Hitachi Medical Corporation, Tokyo, Japan) using a 0.377 mm voxel size was used to capture full skull CBCTs at UCSF and UNLV. A Planmeca Promax 3D Max system (Planmeca, Helsinki, Finland) using a 0.400 mm voxel size was used at NIDCR. The scans were captured within an average of 5.3 months (0-21 months range) prior to surgery and 5.5 months (1-25 months range) after surgery. All scans were acquired at natural head position.

ANALYSIS

To compare the pre-op and post-op morphology of the condyles and glenoid fossae, the areas of interest will initially be segmented from the full volume CBCT using the open source ITK-Snap 3.8.0 software (www.itksnap.org).[18,19] VOIs will be identified on CBCTs, and samples will be segmented into separate left and right condyles and right and left glenoid fossa followed by a voxel based registration for scan superimposition. A semi-automated, dynamic, 3D region-growing technique will be used to achieve segmentation based on voxel intensity thresholds and region growing techniques. The VOIs for condyle segmentation will be manually selected to include areas not likely to be effected by OGS such as the ramus of the proximal part of the osteotomized mandible and the mandibular notch. VOIs of the glenoid fossa will extend anteriorly to include the zygomaticotemporal suture and posteriorly to include the pterygotympanic fissure.

Once segmented, 3D surface meshes will be uniformly cropped with 3D Slicer 4.11.2 software (www.3dslicer.com) and exported.[20] Inter-surface distance calculations will be measured between the superimposed 3D mesh models for quantitative and qualitative statistical analysis using Geomorph 2.0 operating in the *R* statistical

computing environment (*R* version 4.0). Semi-landmarks will be added, in order to quantify the potential shape and form changes on the entire surface of the condyles and fossa despite the relative absence of unambiguous, anatomical landmarks along smooth curves and surfaces.[21-24]

A 3D heat map depicting the remodeling of the condylar head and glenoid fossa of the pre-op and post-op time points will be generated with the use of 3D MeshMetric 1.4.3 software (http://www.nitric.org/projects/meshmetric3d).[25] This method is superior for shape and form evaluation compared to a simple volumetric analysis, as a volume could theoretically remain unchanged if a loss in one dimension is compensated by an increase in another.[26]

CHAPTER 3: Results

No data has been analyzed at this point.

CHAPTER 4: Discussion

A recent article published in the Journal of Stomatology, Oral and Maxillofacial Surgery reported on a skeletal class III population using a similar method, segmenting 3D models with itkSNAP and using qualitative and quantitative to evaluate for condylar changes post bimaxillary OGS. They found that while post-surgical changes were detectable with these methods, hard tissue changes were <2mm which is thought to be less than clinically significant with regards to surgical stability or development of TMD symptoms.[27]

This study will be a prospective analysis of CBCT scans with an average follow up of 5.5 months. Some of the patients were followed beyond 2 years which will allow for initial investigation into how long morphological adaptation occurs in some individuals. Motta et al. observed changes at 1 year post-surgery in a skeletal class II population who received a mandibular advancement.[28] If significant differences exist between subgroups, surgeons will be able to better predict what surgical displacements are more stable over time.

When changes exceeds a patient's physiological ability to adapt undesired outcomes may occur. A large retrospective study of 500 consecutive patients who received bimaxillary OGS investigated the relationship between OGS and TMD. While some patients reported improvement of TMD symptoms (pain, TMJ clicking, crepitus) a small percentage of patients developed new TMD symptoms. Risk factors identified contributing to post-operative of TMD symptoms were large skeletal class II deformities, pre-operative crepitus and pre-operative clicking.[29]

Predicting which patients may develop TMD symptoms has been a challenge due to the lack of randomized control trials and the large heterogeneity in individual patient variables and measured outcomes.[29] Future studies should involve large populations of cohorts divided by skeletal class as well as patients receiving OGS to correct facial asymmetries. Quantitative and qualitative analysis of morphological changes occurring within the TMJ should be evaluated to identify if hard tissue remodeling occur on articulating surfaces.

CHAPTER 5: Conclusions

By comparing different groups of skeletal classes and different orthognathic surgeries (Le Fort I vs SSO vs bimaxillary) we hope to see if there are particular characteristic differences in these populations which might lead to geometric morphological changes which may contribute to OGS instability or TMDs.

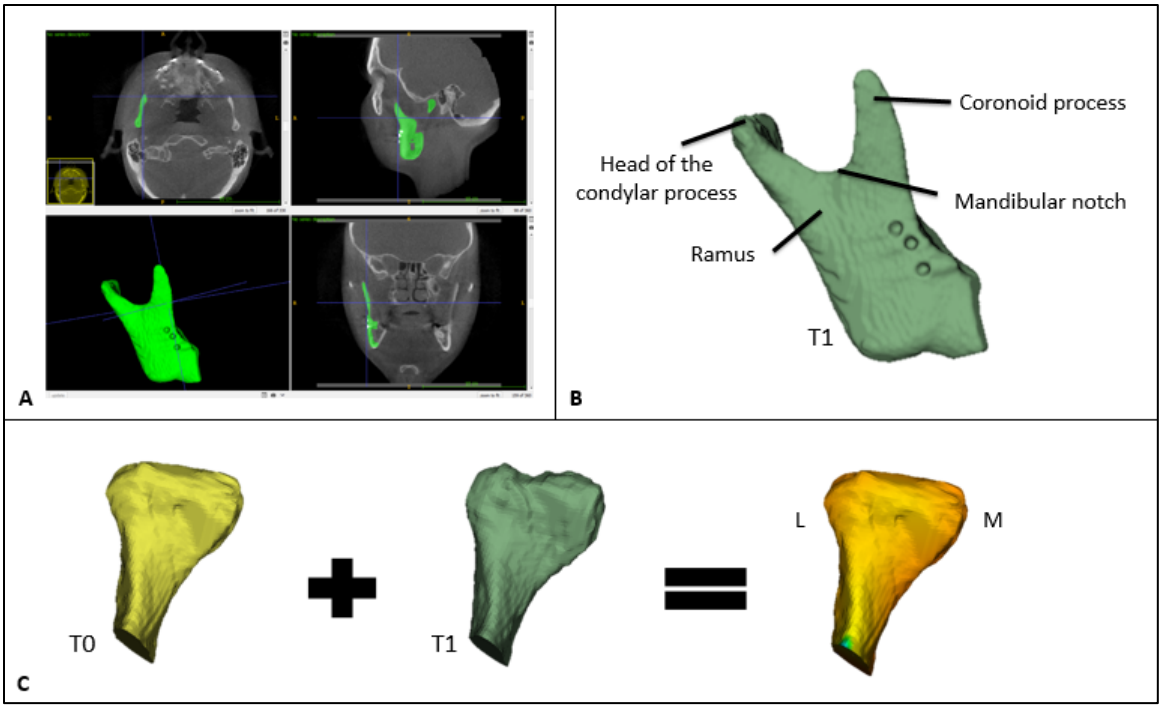

Figure 1. Digital workflow comparing morphological changes of the condylar process of the mandible following orthognathic surgery. (A) Sample, open-access, CBCT data, post sagittal split osteotomy (T1) visualized in itk-SNAP 3.8.0. A volume of interest is segmented using a semi-automated, dynamic, 3D region-growing technique based on voxel intensity thresholds. (B) 3D surface mesh export of the right posterior mandible. (C) Pre and post-surgical right condyles uniformly cropped using 3D Slicer 4.11.2 and wire frames superimposed with 3D MeshMetric 1.4.3 to visualize morphological changes. Sample data freely available at https://slicer.org.

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