Integrating Structural and Functional Patient Data with the ArtiSynth Platform: A Technical Report

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Abstract

The ability to map structural and functional patient data onto a computer model as a means to realize virtual surgical planning is a necessary prerequisite in achieving individualized medicine in the area of head and neck resection and reconstruction. For several years now, the creation of computerized tools for virtual medical intervention has been a high priority for many clinicians and engineers. This paper describes the methods used to import CT and jaw function data into the ArtiSynth model, a 3D biomechanical modeling toolkit that allows for dynamic simulation of anatomical structures. We will describe the process involved in the preparation of the image-based CT data, including the removal of artifacts and the registration of the jaws, as well as the importation of these data onto the ArtiSynth platform. Furthermore, we will outline the process used to estimate jaw muscle forces related to jaw function data captured via electrognathography and videofluoroscopy. A discussion of the challenges encountered and solutions created for importing both static and dynamic data will be offered.

Keywords: CT data, surgical simulation, functional outcome, dynamic modeling

1. Introduction

The structures of the head and neck form one of the most intricate and highly-interdependent systems of bone, muscle, nerve, vascular and connective tissues in the human body. These structures must function synergistically to successfully execute the highly-complicated physiological acts of speech, mastication and deglutition. Surgical alterations to the structures of the head and neck often impair this synergy and result in deficits in these functions. A clinical responsibility exists to inform patients of the potential outcome of surgical intervention, whether we believe that it will improve or cause a decrement in function. However, our ability to do so at the current time is limited in part by conflicting reports in the literature regarding functional outcomes in patients undergoing extensive surgical interventions of the head and neck, and, perhaps more so, by the extremely individual nature of patient treatment and related outcomes in this area.

In previous literature, a call was made for *functional outcome planning* to be a necessary component of surgical planning in the future.[1] As defined there, functional outcome planning is “the process of taking a patient’s pre-operative functional data and morphing it onto a fully-functional virtual structure such that a surgeon could plan and execute a surgical procedure on a virtual patient” (p. 62). Currently, computer planning software exists for *structural outcome planning*. Such software targets surgical interventions including the movement of bony segments of the jaws and dental implant installation. While these programs have revolutionized surgical planning for static portions of the head and neck, they cannot account for functional outcome related to perturbation of the associated soft tissues of the head and neck, such as the muscles of the jaw, tongue and pharynx. The ArtiSynth model represents a first step in the quest to understand functional outcomes in relation to perturbation of not only the bony structures, but also the soft tissues, of the head and neck region.

In this paper, we will describe our process of importing two sets of data – one patient and one control – into the ArtiSynth model. We will describe challenges and solutions for importing “messy” CT data. Further, we will describe the process of importing functional data related to jaw function into the ArtiSynth jaw model for the control, and estimating muscle forces related to those data.

2. Preparation of Digital Patient Data

Two sets of digital data were prepared for use with the ArtiSynth modeling platform – one from a normal control subject and one from a patient hemimandibulectomy case. The digital inputs consisted of conventional CT data and functional assessment data captured via electrognathography and videofluoroscopy. The CT scans were captured with 1mm slices for the control case while the patient case was captured with 1.3mm slices prior to surgery and 3mm slices post surgery. Digital manipulation of the CT scans was required for both sets of data before they could be imported into the ArtiSynth platform. For the control case the only digital manipulation required was separation of the upper and lower teeth before making digital models of the mandible and maxilla. This separation was completed manually slice by slice within Mimics Medical Imaging Software (Materialise, Leuven, Belgium). However, the patient case required significant digital manipulation of the CT data as described below.

2.1 Removing CT Scan Artifacts

The patient CT data file had significant scattering artifacts (shown in Figure 1) caused from prior dental bridgework. These artifacts made it impossible to separate the mandible from the maxilla and completely obscured the teeth in the digital model as shown in Figure 2 (left).

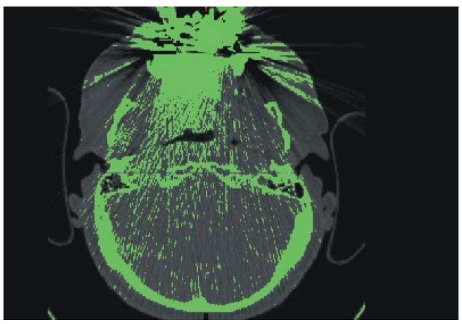

Figure 1. Patient with significant CT artifacts caused from prior dental bridgework.

Some of the scatter could be reduced by reviewing the CT scan slice by slice and editing the data file (Figure 2 (right)) in Mimics. During this process the user could interpolate between CT scan slices and estimate what the geometry in each slide would look like producing a "cleaned up" scan.

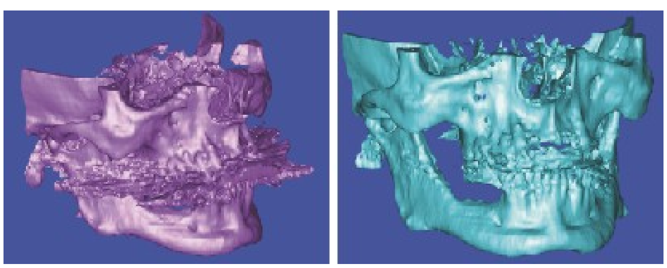

Figure 2. Original patient digital model (left) compared to edited model to reduce scatter (right).

2.2 Use of Dental Impressions to Recover Teeth Data

While scatter could be reduced in the CT scans as shown above in Figure 2, it was not possible to clean up the file to the point where data on tooth geometry and occlusion could be obtained. To determine the teeth geometry and occlusion, dental casts that had been obtained as part of the patient's clinical treatment were put into occlusion on a standard dental articulator as shown in Figure 3 (left).

Figure 3. Dental casts placed in occlusion (left) casts digitally reproduced with a touch-probe scanner (right).

The casts were then scanned with a Pix30 3D touch probe scanner (Roland DG Corporation, Irvine, CA, USA) in occlusion to create digital models of the teeth (Figure 3 (right)).

2.3 Aligning Digital Teeth/Occlusion Models with Mandible/Maxilla

The computerized occlusion teeth models were then aligned with the mandible and maxilla in FreeForm (SensAble Technologies, Woburn, Massachusetts, USA) and the merged models were then imported back into Mimics to check accuracy of placement within the CT data (Figure 4).

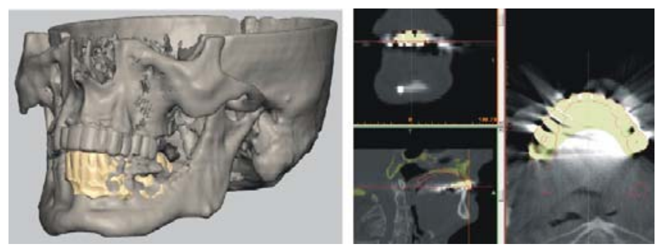

Figure 4. Teeth in occlusion aligned with mandible/maxilla (left) with accuracy verified with original CT data (right).

3. Constructing an ArtiSynth Model from Digital Patient Data

The following details the process used to import the patient digital models into the ArtiSynth platform.

3.1 Converting STL Files to OBJ Files for ArtiSynth

Importing the digital models into ArtiSynth required converting the digital data from their native STL format to OBJ format. This was accomplished with the use of FreeForm. However, the created OBJ data files were too large in size (had too much detail) causing a Java memory stack error when running simulations. To reduce the size of the OBJ files FreeForm had the option of making a rough shape OBJ with less detail producing a smaller data file. One complication in this process was that thin bones/regions were not reproduced as shown in Figure 5 (right).

Figure 5. Fine detail skull file (left) compared to a smaller "rough shape" file (right).

Thin areas were manually filled in within Mimics to produce the completed model.

3.2 Aligning Patient Data Files with Existing ArtiSynth Files

Before importing patient skull geometries into ArtiSynth, an existing ArtiSynth OBJ mandible/maxilla file was opened with Rhinoceros (McNeel North America, Seattle, Washington, USA). Utilizing Rhino, the digital model could be aligned to the existing ArtiSynth one and then saved as an OBJ. This effectively provided a saving template locating the digital model in 3D space to import into ArtiSynth. This allowed the digital model to be imported into an appropriate position within a previously developed ArtiSynth project with existing muscle structures.[2] When imported, due to prior alignment of the OBJ file the new patient model had the desired muscles in positions which took minimal effort moving to the desired insertion points. This process was significantly more efficient than starting a completely new ArtiSynth project and creating entirely new muscle structures.

3.3 Modeling the Temporomandibular Joint

As in previously developed ArtiSynth models the temporomandibular joint was modeled with rigid planar constraints restricting the translation of the condyles to a planar surface.[2]

4. Estimating Muscle Forces

While muscles were visible on CT data, due to the volume of many of the muscles, identifying a single insertion point from these data was very difficult and required an approximation. The following muscles were included in the ArtiSynth model at their approximate anatomical locations: anterior, middle and posterior temporalis, deep and superficial masseter, superior and inferior lateral pterygoid, medial pterygoid, anterior digastric, anterior and posterior mylohyoid, geniohyoid. The following sections outline the processes for inputting the control subject data into ArtiSynth.

4.1 Measured Jaw Function

Currently at iRSM, jaw motion is tracked using electrognathography (EGN) as part of patients' functional assessment pre and post surgery. Patients perform range of motion tasks including maximum jaw opening and maximum lateral movement as well as chewing tasks with the EGN system. While the EGN measurements provide some idea of jaw motion, the measurements only occur at one point at the front of the mandible. The EGN data provide translation of one point on the mandible, however, data on this single point does not provide enough information to define the 3-D translation/rotation of the entire mandible. To reconstruct jaw motion during the functional tasks, modified barium swallow (MBS) videofluoroscopic data provided the required additional information on the rotation of the mandible along with the condyle movement during the opening/chewing tasks. By combining the modified barium data with the EGN data it was possible to reconstruct the motion of the mandible during the opening/chewing tasks. An example of this reconstructed mandible position during a chewing cycle is shown in Figure 6. While it was possible to reconstruct the approximate 3D mandible motion using a combination of MBS and EGN data, this method was quite time consuming and may not be practical for routine clinical use.

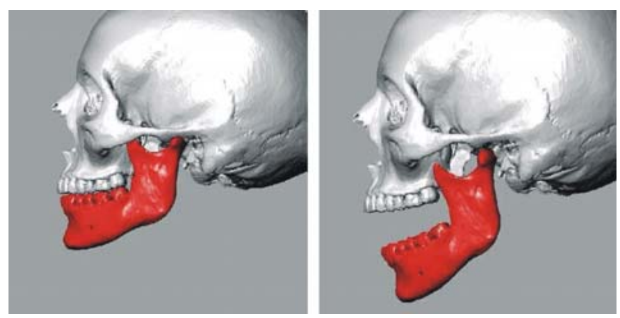

Figure 6. Estimated mandible position from EGN and modified barium data during a chewing cycle.

Approximation of the muscle activation timing of right and left masseter and digastric muscles during the range of motion tasks were measured with surface electromyography (sEMG).

4.2 Comparing Simulated Motion to Measured Motion

Timings for the muscles were set in ArtiSynth based on the sEMG data. For the model, muscles were classified as either opening (anterior digastric, anterior and posterior mylohyoid, geniohyoid) or closing (anterior, middle and posterior temporalis, deep and superficial masseter, medial pterygoid). The opening and closing muscles that had no sEMG data were assumed to have the same approximate activation timings as the measured masseter (closing) and digastric (opening) muscles. A plot of these timings and the amplitudes of activation (based as a percentage of total muscle activation) is shown in Figure 7.

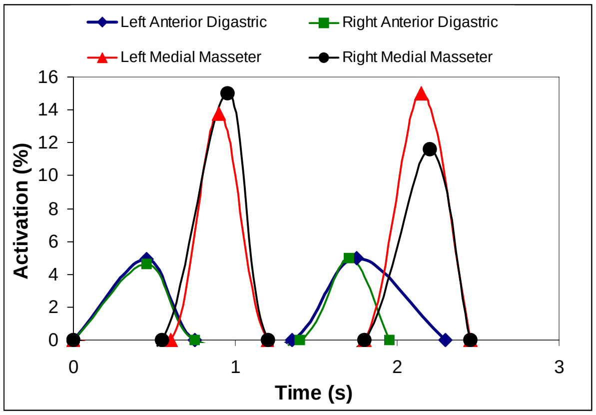

Figure 7. Muscle activations used in ArtiSynth.

The amplitude of the activations for each muscle were first approximated based on previous muscle activations for a previously developed ArtiSynth project.[2] A marker was placed at the front of the mandible on the ArtiSynth model and estimated marker displacements were directly compared to the measured EGN data. The predicted mandible position during a chewing cycle from the ArtiSynth model is shown in Figure 8.

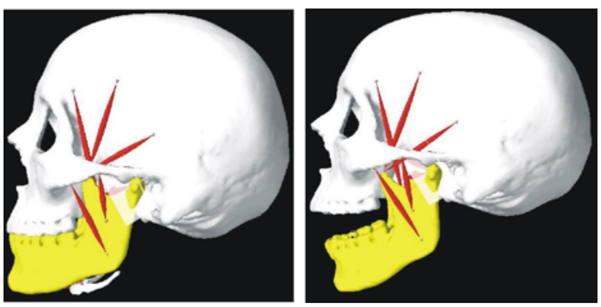

Figure 8. Predicted mandible position from ArtiSynth model during a chewing cycle.

The vertical and anterior-posterior displacements of the front of the mandible during a chewing cycle are similar between the ArtiSynth model and the measured EGN displacements. However, further testing is required to verify these results and to quantify the differences between the ArtiSynth model and the EGN measurements.

5. Future Considerations

5.1 Development of a CT Scanning Protocol

To ensure patients have a common jaw alignment/position during scanning, it would be helpful to develop a consistent CT scanning protocol. Additionally, to ensure the mandible and maxilla are separated during scanning patients could have a bite guard of known dimensions built so that teeth are separated by a known amount during scanning.

5.2 Estimating Effects of Hemimandibulectomy Surgery on Jaw Function

While the control case data were placed into the ArtiSynth platform and jaw function was compared to measured results, this process needs to be completed for the patient hemimandibulectomy case. Once this is complete, it may be possible to estimate the effects that the hemimandibulectomy surgery has on jaw function for specific patients.

6. Final Words

This study demonstrates that it may be possible to one day integrate a patient's pre-operative functional data (i.e., multi-dimensional time-varying image-based data captured during functional tasks, overlaid with other facets of function) onto a virtual platform, such as the ArtiSynth model. Interaction with this model could then allow a surgeon to plan and execute a surgical procedure that will result in a known functional outcome.

References

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