Digitalization of virtual articulator: methods, discrepancy to real articulators, comparing of each methods.

Master’s Thesis

Supervisor
Assist. Rimantas Ožiūnas

Kaunas, 2017
Digitalization of virtual articulator: methods, discrepancy to real articulators, comparing of each methods.

Master’s Thesis

The thesis was done
by student .................................................

Supervisor ...............................................

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Kaunas, 2017
# EVALUATION TABLE OF THE MASTER'S THESIS
## OF THE TYPE OF SYSTEMIC REVIEW OF SCIENTIFIC LITERATURE

**Evaluation:** ........................................................................................................................................................................

**Reviewer:** ........................................................................................................................................................................

(Scientific degree, name and surname)

**Reviewing date:** ........................................

<table>
<thead>
<tr>
<th>No.</th>
<th>MT parts</th>
<th>MT evaluation aspects</th>
<th>Compliance with MT requirements and evaluation</th>
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<tbody>
<tr>
<td>1</td>
<td>Summary (0.5 point)</td>
<td>Is summary informative and in compliance with the thesis content and requirements?</td>
<td>0.3 Yes, 0.1 Partially, 0.0 No</td>
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<tr>
<td>2</td>
<td></td>
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<td>3</td>
<td>Introduction, aim and tasks (1 point)</td>
<td>Are the novelty, relevance and significance of the work justified in the introduction of the thesis?</td>
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<td>4</td>
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<td>7</td>
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<td>8</td>
<td>Selection criteria of the studies, search methods and strategy (3.4 points)</td>
<td>Are all the information sources (databases with dates of coverage, contact with study authors to identify additional studies) described and is the last search day indicated?</td>
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<td>Is the electronic search strategy described in such a way that it could be repeated (year of search, the last search day; keywords and their combinations; number of found and selected articles according to the combinations of keywords)?</td>
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<td>Is the data extraction method from the articles (types of investigations, participants, interventions, analysed factors, indexes) described?</td>
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<td><strong>13</strong></td>
<td>Are the methods, which were used to evaluate the risk of bias of individual studies and how this information is to be used in data synthesis, described?</td>
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<td>Were the principal summary measures (risk ratio, difference in means) stated?</td>
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<td>Is the number of studies screened: included upon assessment for eligibility and excluded upon giving the reasons in each stage of exclusion presented?</td>
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<td>Are the characteristics of studies presented in the included articles, according to which the data were extracted (e.g., study size, follow-up period, type of respondents) presented?</td>
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<td><strong>17</strong></td>
<td>Are the evaluations of beneficial or harmful outcomes for each study presented? (a) simple summary data for each intervention group; b) effect estimates and confidence intervals</td>
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<td>Are the extracted and systemized data from studies presented in the tables according to individual tasks?</td>
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<td><strong>19</strong></td>
<td>Are the main findings summarized and is their relevance indicated?</td>
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<td>Are the limitations of the performed systemic review discussed?</td>
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<td><strong>21</strong></td>
<td>Does author present the interpretation of the results?</td>
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<td><strong>22</strong></td>
<td>Do the conclusions reflect the topic, aim and tasks of the Master’s thesis?</td>
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<td><strong>23</strong></td>
<td>Are the conclusions based on the analysed material?</td>
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<td>Are the conclusions clear and laconic?</td>
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<td>0.1</td>
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<td>Is the references list formed according to the requirements?</td>
<td>0.4</td>
<td>0.2</td>
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<tr>
<td><strong>26</strong></td>
<td>Are the links of the references to the text correct? Are the literature sources cited correctly and precisely?</td>
<td>0.2</td>
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<td><strong>27</strong></td>
<td>Is the scientific level of references suitable for Master’s thesis?</td>
<td>0.2</td>
<td>0.1</td>
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<td><strong>28</strong></td>
<td>Do the cited sources not older than 10 years old form at least 70% of sources, and the not older than 5 years – at least 40%?</td>
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</tbody>
</table>

**Additional sections, which may increase the collected number of points**

<p>| <strong>29</strong> | Annexes | Do the presented annexes help to understand the analysed topic? | +0.2 | +0.1 | 0 |
| <strong>30</strong> | Practical recommendations | Are the practical recommendations suggested and are they related to the received results? | +0.4 | +0.2 | 0 |</p>
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<td>Were additional methods of data analysis and their results used and described (sensitivity analyses, meta-regression)?</td>
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<td>32</td>
<td>Was meta-analysis applied? Are the selected statistical methods indicated? Are the results of each meta-analysis presented?</td>
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</table>

**General requirements, non-compliance with which reduce the number of points**

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<th>&lt;15 pages (-5 points)</th>
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<td>Is the thesis volume sufficient (excluding annexes)?</td>
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<td>Is the thesis volume increased artificially?</td>
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<td>Does the thesis structure satisfy the requirements of Master’s thesis?</td>
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<td>36</td>
<td>Is the thesis written in correct language, scientifically, logically and laconically?</td>
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<td>Are there any grammatical, style or computer literacy-related mistakes?</td>
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<td>38</td>
<td>Is text consistent, integral, and are the volumes of its structural parts balanced?</td>
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<td>39</td>
<td>Amount of plagiarism in the thesis.</td>
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<td>&gt;20% (not evaluated)</td>
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<td>40</td>
<td>Is the content (names of sections and sub-sections and enumeration of pages) in compliance with the thesis structure and aims?</td>
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<td>-0.5 points</td>
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<td>41</td>
<td>Are the names of the thesis parts in compliance with the text? Are the titles of sections and sub-sections distinguished logically and correctly?</td>
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<td>Are there explanations of the key terms and abbreviations (if needed)?</td>
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<td>43</td>
<td>Is the quality of the thesis typography (quality of printing, visual aids, binding) good?</td>
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*In total (maximum 10 points):*

*Remark: the amount of collected points may exceed 10 points.*
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Abstract
Objectives: The purpose of the present study is to know the method of digitalization from conventional articulator to virtual articulator.

Material and Methods: In this literature review literatures has been searched using Pubmed and other sources, the search keywords: virtual articulator, intraoral scanning, and indirect scanning.

Study: the virtual articulator, scanned cast, relation between articulator and jaw, motion simulation are required for building the virtual articulator system

Conclusions: there are many ways to build a virtual articulator. Each step has various methods, the environment of dentist and dental technician should be consider when setting up virtual articulator

Keywords: virtual articulator, intraoral scanning, extraoral scanning (die scanning, indirect, oral scanning), accuracy, face-bow

Introduction

Articulator enable technicians to carry out a study of occlusal relations between dental arches and to detect harmful occlusal interferences on models before more sophisticated occlusal equilibration procedures are performed on the patient (1). Nowadays, around 90% of technical dental work is using the wax-up technique to generate the cast framework and then, the design work finishes with the hand ceramic phase (2). Mechanical articulators are necessary for this environment, technician are checking jaw movement and relationship between upper and low jaw and using it as the holder for fabrication. But now dental environment are changing, as the computer system develops, the use of mechanical articulator decreases and the empty space of the conventional articulators are occupied by virtual articulator.

With developing digital impression and dental CAM/CAM system, today’s dentistry has become dentistry of single visit. Patient can be putted the crown on teeth in single appointment. But even the latest CAD/CAM system has its own limitations. Main disadvantage of the system is limited accuracy of the occlusal surface. This is because it acts as simple mechanical articulator and cannot take into consideration the functional movements of the mandible. So the occlusal surface of new tooth has to be trimmed manually after in patient’s mouth, at the cost of valuable chair side time, and if we are not considering the
mandibular movements and placing the restoration as it is, we are creating problems for the patient’s TMJ. So for accurate occlusal surface construction there is need to use kinematic method i.e. virtual articulator along with CAD/CAM system.(3)

(figure1) dental laboratory process
adapted from [Design of a Virtual Articulator for the Simulation and Analysis of Mandibular Movements in Dental CAD/CAM E. Solaberrieta, O. Etxaniz, R. Minguez, J. Muniozguren, A. Arias]

The virtual articulator is based on virtual reality and will reduce the limitation of the mechanical articulator by simulating real patient’s jaw such as static and dynamic occlusion and also jaw relation. [4]

So to follow this change, knowing how to transfer from conventional articulator to digital articulator is required. This thesis will study how to make digital articulator from patient mouth and conventional cast, even method to record the path of mandible jaw movement.

SELECTION CRITERIA OF THE STUDIES. SEARCH METHODS AND STRATEGY
--protocol of systemic review
Selected protocol ( Year, language, publication condition etc.)
The article are selected by the protocol, written in 10 years (2006~2016), in English and published
But also there are some user guide books for expressing the method and specification.
-- Information sources
A search was conducted on one database— pubmed
The user guides ware searched in company’s website. (medit, Planmeca PlanScan, straumann)
--electronic strategy of the search for data in such a way
The articles are searched in 2016, 2017. Last searching was end of January 2017.
The search terms those were used during the primary stage were as follows: virtual
articulator, intraoral scanning, extraoral scanning (die scanning, indirectoral scanning), accuracy, face-bow and their combinations,
Total 29 articles are found,

Inclusion criteria for the selection were:
- Methods of digitalization were useful nowadays.
- Methods of digitalization of articulator were explained.
- The name of software and hardware was written in a article
- Comparing at least 5 intraoral scanners.
- Comparing between intra and extra oral scanning

Exclusion criteria for the selection were:
- Just concept of virtual articulator.
- Comparing accuracy of CAD/CAM

Exception - user guide book.
By the criteria, 10 articles were selected.
Articles for systemic review

<table>
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<tr>
<th>Authors and year</th>
<th>Type of study</th>
<th>what study</th>
<th>Qualitative analysis</th>
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<td>E. Solaberrieta/2010</td>
<td>Original research</td>
<td>indirect method and design of virtual articulator</td>
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<td>Joo Hyun Kwon/2016</td>
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Selection process of data from the articles
Data was independently extracted from reports in form of variables according the aim and themes of present review as listed on words. The principle and method are extracted from articles for the study and the accuracies of intraoral and extraoral scanner are extracted for comparison.
All information from articles is used step by step from scanning until motion analyzer by the sequence of digitalization.

For evaluations about the risk of systemic mistakes of individual researches, the articles published were used and compared with user guide of product and the video about virtual articulator was watched.

1. Classification of the digital articulator
There are two types of digital articulators. One is Completely adjustable articulators, another is Mathematically simulated articulator.
Completely adjustable articulators (motion analyzer), it was designed by Kordass and Gaertner from the Greifswald University in Germany. (29) It records /reproduces exact movement paths of the mandible using an electronic jaw registration system called Jaw Motion Analyser (JMA).
Jaw Motion Analyser is device for tracking the jaw of patient. It is consists of facebow with receiver sensors, lower jaw and pointer sensor, occlusal adapter and software Eg: JMAnalyser.
Mathematically simulated articulator (motion parameter) which is designed by Szentpétery from the Martin-Luther University of Halle (28)

It is based on a mathematical simulation of the articulator movements. It is a fully adjustable three dimensional virtual articulator capable of reproducing the movements of a mechanical articulator. Eg: Stratos 200, Szentpetery’s virtual articulator(5)

![schematic diagram of virtual articulator](figure2)

(figure 2) schematic diagram of virtual articulator

2. 3D scanning of data

3D scanning is to take 3 Dimension shape of object with hardware device. In dentistry usually intraoral scanner and Desktop 3D scanners are used for scanning casts or patient’s teeth.

**3D Dental Intra Oral Scanner** create 3d image by active triangulation technique and Confocal laser scanning microscopy principle(30), laser dot or line is projected to an object from devices like hand held device and a sensor calculates the distance of object surface (or charge-coupled device or position sensitive device are used too).

![intraoral scanner iter](figure 3) intraoral scanner itero
The development of Intra oral scanner starts with the design of intra oral scanner hardware which is using the non-contact optical technologies based on confocal microscopy laser scanning principle. When the scanner is ready, the software will capture multiple 2D image data. Then the captured image will be changed to 3D image of the oral cavity on the display screen. And software will reconstruct the 3D image for being accuracy and color display from captured oral cavity image and also needless image which is taken during scanning can be deleted by the software. (30)

Desktop 3D scanners (laboratory scanner) are designed for 3D scanning small to medium size objects.

There are two main types of desktop 3D scanners:
- Closed-frame desktop 3D scanners: this scanner is box shape. The scanner camera is inside box which is connected to a computer and user put the object want to scan in the box. The environment such as where light it is and the location of object is can be controlled. Ideal Closed – frame desktop 3D scanners usage is jewelry or dentistry where a high scanning resolution is needed.
- Open-frame desktop 3D scanners: this 3D scanner is more flexible in terms of scanning area than desktop 3D scanner but usually it should be in a room with constant and not so bright lighting. In many case desktop 3D scanners are composed by a light projector or cameras mounted on a tripod for stability and accuracy.

For taking the object with various position desktop 3D scanners have turntable. During the 3D scanning process, the turntable rotates while 3D scanner remains in fixed position, it possible to scanning all surface of the object from all angles. The rotation of turntable is automatically operated by 3D scanner software.
These desktop 3D scanners typically use the structured light or triangulation 3D scanning technologies. They are used for medical applications (dental, hearing aid), reverse engineering, entertainment, jewelry or prototyping applications usually.

Prices of desktop 3D scanners is ranged from about hundreds euros for entry level machines to tens of thousands euros for advanced professional-grade 3D scanners. (11)

Data which is from **Hand-held laser scanners and Desktop 3D scanners** is collected in a computer and recorded as data points within three-dimensional space, with processing this can be converted into a triangulated mesh and then a computer-aided design model (10)

2.1 Scanning of articulator. (Optional)

There is lots of virtual articulator software (Zfx CAD Software, CEREC Articulation, Medit 5-axis CAD/CAM system) and usually 3D scanner for dentistry is connected to the software. But 3D scanners for industry don’t have articulator system their own; In this case dentist and dental technician have to build virtual articulator by CAD/CAM software.

2.1.1 Solid Edge and CATIA.

Different mechanical articulators are selected first to be modeled through CAD systems (Solid Edge and CATIA). The design process will then be carried out using measuring. Tools and reverse engineering tools those are available at the PDL. The tools used are: Handyscan REVscan

(Figure 7) procedure of making virtual articulator by CAD/CAM system.

Redraw from Design of a Virtual Articulator for the Simulation and Analysis of Mandibular Movements in Dental CAD/CAM
3D scanner, the scanner is scanning articulators and change it into digital files by the software (VXscan), and Reverse engineering and computer-aided inspection software (Geomagic Studio and Qualify), Rapidform XOR, ATOS I rev.2 GOM 3D scanner, in this stage you can correct the debris and empty space due to lack of accuracy. After the virtual articulator is constructed, all the measurements are verified and checked. If any problem exists, that needs to be rectified and redesigned. (6)

2.1.2 Scanning program has the digital articulators own.
In this case, to digitalize the articulator to computer is unnecessary; just choose your conventional articulators in program. But some programs have only few kinds of articulator, so dentist or dental technician should check that there are own articulator in program. In the Medit 5-axis CAD/CAM system, it has Artex, Sam, Kavo articulator s in the software. But some other articulator is possible to download from company’s website. (7)

2.2. DIGITAL CAST.
Cast is a replica of prepared teeth and other parts of dental arch by pouring dental plaster or acrylic into impressions (imprints, or molds) of the teeth, and allowing it to harden. It can be Diagnostic cast (less precise, used for evaluation of state of occlusion, positions of teeth, defects, and treatment planning), Working cast used for fabrications of patterns of prostheses (should be precise, no error, usually made by super gypsum). Virtual cast also have same goal as conventional cast, it represent patient teeth and jaw digitally.

After making digital articulator, digital cast is required for being proper system of the articulator. For that, scanning jaw and teeth are essential. In conventional articulator, stone cast which is made by impression, pouring and trimming is used, and which is representing patient’s jaw, and dentist and dental technician work with the cast but in CAD/CAM system digital cast is required, so scanning from conventional to virtual is needed.

Scanning of a tooth or tooth surface or restoration or complete denture models or centric relation, 3D Laser scanner is used. This scanner projects a vertical laser beam to the surface of the object. A digital camera equipped with a charge coupled device (CCD) registers the beam reflected from the object and transmits the digital signals to an electronic processing system. The processed image data are stored as digital matrix brightness values, ready for use by the scanner software–
The scanning can be done in 2 ways:

- Indirect digitising - done outside on the patient’s master cast obtained after making final impression.
- Direct digitising - done directly from the patient’s mouth using an intraoral scanner. (8)

### 2.2.1 Indirect digitising

It is known as die scanning, requires conventional cast which is made by impression, pouring and trimming to begin the CAD/CAM system. This method is usually used in dental laboratory (9)

But nowadays just impression can be used to scan for making digital cast. Software automatically changes the negative shape to positive shape. Even dual arch tray can be scanned. (7).

Usually **Desktop 3D scanners** is used for indirect die scanning.

First, machine should be connected to computer and software which is given from the company is installed. Check how to use scanner by seeing catalog. Put on cast or impression on the plate

Select the type of model to be scanned [Stone Model] or [Impression]. Set the scan method for the upper and lower jaw., Then scan the cast or impression. Then automatically machine will take 3dimesion image by moving cast (7)

However, Conventional impression techniques using tray and impression material cannot eliminate the error of expansion, shrinkage and distortion of impression or gypsum material. (10)

### 2.2.2 Direct digitizing (intraoral scanning)

All of the various chair side intraoral digital scanning devices are based on optical principles such as blue light-emitting diodes, blue laser technology, multiple single images that are stitched together, and continuous acquisition (streaming) of optical images (15).
Intraoral scanner can be divided according to the compatibility, applying powder such as titanium dioxide or magnesium oxide, ability to evaluate emergence profile and use articulator on software, working principle, light source, operative process and output file format. (Table 1) The powder is used to enhance scanner’s recognition rate and shorten scan time by reducing reflection on the tooth surface with various materials. (13) A specific scan order was employed to avoid any contamination of the reference model due to the necessary application of a reflective powder, which is needed for the 3M True Definition Scanner. (15) So remove all the debris and apply the application as titanium dioxide or magnesium oxide on the all the teeth of jaw (if intraoral scanner needs application). And insert intraoral scanner gently into patient mouth and scan according to software instructions.

In itero and E4D groups, abutment scan was finished first then other remained teeth are scanned.

Zfx intrascan and Trios, occlusal sweep has to be scanned and followed by buccal and lingual sweeps in case of maxillary jaw, in mandible scanning buccal and lingual sweeps were changed. When scanning with Fastscan, posterior parts on both side and anterior parts were scanned separately and made it one piece afterwards. (12)

Position the scanner along the mesial-distal relation of skull and articulator
axis with the tip of the scanner pointing towards the distal. The axis follows the curve of the arch. Rest the tip of the scanner gently on the teeth during scanning. This will give you the correct focal depth for the scans. (16) After scanning, you can check the virtual cast by computer for re-checking error of the cast and empty space. If there is something wrong take scan again wrong part.

3. Correct position CAST and articulator.

Articulator represents anatomy of jaw. Casts are patient’s jaw, hinge is TMJ. Therefore the relation of between articulator and cast is should be same as patient’s jaw. In the conventional procedure, the facebow was used for taking the information of relation. The Bonwill triangle and height above the occlusal plane or the Balkwill angle is used for determining the position of the condyles accordingly (32)

![Figure 9](image)

**Figure 9**  A: bonwill triangle B: balkwill angle

h, height of Bonwill triangle. B, Balkwill angle. pi, middle incisal edge point. pm, distobuccal cusp tip of the second molar. P2, center of condyle. (Adapted from Cephalometric study of tooth position in young Afro-Caucasian Brazilian individuals with normal occlusion Eduardo Jacomino FrancoI; Arnaldo PinzanII; Guilherme JansonIII; José Fernando Castanha HenriquesIV; Célia Regina Maio Pinzan-VercelinoV)

The bonwill triangle is connection between right, left condyle head and lower incisors. The balkwill angle is the angle formed by the imaginary plane of the occlusal plane and bonwill triangle. (33)

Method to correct position can be divided into 2 groups

- With conventional articulator and cast.
Without conventional articulator and cast.

### 3.1 With conventional articulator and cast.

Digitalization from conventional articulator to virtual articulator is easier than making from nothing. Because of the relationship between TMJ and jaw is already inherent in conventional articulator.

First of all, centric relation is needed for mounting lower jaw, so take it from the patient by occlusal wax plate. And 2 arms of face bow should place in external auditory meatus and make tighten by thumbscrew, and firm nasion relator at the Frankfort horizontal plane or Camper plane and tighten the thumbscrew. Then, bite folk is connected with face bow but released by thumbscrew. Put silicon on the bite folk then insert into patient mouth and push it to the upper jaw, then tighten the bite folk by thumbscrew. Now bite folk copy the relationship between upper jaw and TMJ. By this bite folk, dentists or dental technicians transfer the relationship on the conventional articulator. Equip the bite folk on the articulator, make the articulator to be upside down, and the cast is putted on silicon registration from the patient on bite folk and mounted at that position. And again make the articulator to be upside down, complete mounting lower jaw.

After making conventional articulator, 3D scanner will scan the relationship. But there are 2 methods to get the relationship between TMJ and jaw.

- Scanning whole articulator (articulator and cast)
- Scanning face bow

(Figure 10) procedure of conventional articulator adapted from A VIRTUAL DENTAL PROSTHESES DESIGN METHOD USING A VIRTUAL ARTICULATOR. E. Solaberrieta, A. Arias, L. Barrenetxea, O. Etxaniz, R. Minguez and J. Muniozguren.

### 3.1.1 3D scanner for dentistry. (medit korea, CS ULTRA, dwos, DWOS_Virtual_Articulator)

DENTISTY 3D SCANNER can scan the jaw position easily, just put the conventional cast on the specific mechanical articulator which is already installed as virtual articulator in the software, and put articulator with cast on the scanner plate, and set the option of software
(articulator scan and brand of articulator) and scanning. Scanner automatically scans whole articulator, cast and change it to 3d image, which will be criteria of the position of jaw with articulator. (7, 17)

(Figure 11) scanning articulator with casts

3.1.2 Scanning face bow (ATOS I v.2; GOM mbH, Braunschweig, Germany)

Conventional face bow is used for taking the jaw relationship, the relationship is taken from patient, and reference point are attached on cast and bite folk (figure5)

(Figure 12) procedure of scanning face bow adapted from Capture (A VIRTUAL DENTAL PROSTHESES DESIGN METHOD USING A VIRTUAL ARTICULATOR E. Solaberrieta, A. Arias, I. Barrenetxea, O. Etxaniz, R. Minguez and J. Muniozguren)

And scan this bite folk and cast with reference point are scanned, then this reference point will be criteria for locating the virtual jaw in good position between virtual cast and virtual articulator. After setting position of the jaw, the bite of maximum intercuspidation is scanned too. 3D file of bite will is exported to the Reverse Engineering software (rapidform, geomagic), this software will delete useless and wrong image. Then the reference elements are generated in order to locate the models in the CAD system (SolidEdge and CATIA). As the reference elements the virtual lower jaw will be mounted in CR virtually. (18)
3.2. **without conventional articulator and cast.**

One of the most problems of the intraoral scanning is the transfer of digitized casts onto the virtual articulator. For Previous methods to find the relationship between jaw and TMJ, dentist and dental technician must do the all procedure of conventional articulator (impression, pouring cast, face bow, and mounting). (20)(21) So previous virtual articulator system take more time than conventional articulator. However, virtual facebow will take the relationship directly from a patient. It reduces the time of the procedure.

### 3.2.1 Virtual facebow

Virtual cast which is already taken by extraoral (ATOS I v.2; GOM mbH, Braunschweig, Germany) and intraoral dental scanners (Lava COS; 3M ESPE, St Paul, Minn) is required for consisting the virtual articulator. Then, 3 reference points are attached on patient’s head, 2 are on temporomandibular joints and 3rd one is on infraorbital point. Fixed part of the pointer is equipped on the patient’s head and fixed by tighten belt. (22)

(Figure 13) **procedure of virtual facebow** adapted from Direct transfer of the position of digitized casts to a virtual articulator; Eneko Solaberrieta

Scanning with optical scanner (ATOS I v.2; GOM mbH) the pointer part placed on 3 reference points (1infraorbital, 2 TMJ) to obtain the relationship between fixed part of head and the pointers (each devices have the their own reference point for determining the position of the device), And this information is transferred to scanner’s software (Each scans, fixed part and pointer part should be taken together.) And then determine 3 most prominent cusp of upper jaw by pushing the articulating paper on the metal facebow fork to upper jaw. pointer’s tip locate on the a prominent point and pointer is scanned. Do this 2 times more for 3 cusps. (22)

Transfer the 6 position of pointer (3 intraoral, 2 TMJ, 1 infraorbital) are transferred into
scanner’s software (GOM professional software) coincidentally(22)

(Figure 14) computer procedure of virtual facebow adapted from Direct transfer of the position of digitized casts to a virtual articulator; Eneko Solaberrieta

By using reverse engineering software (Rapidform CAD, v2006; INUS Technology, Inc, Seoul, Korea).
Align the digital pointer which had scanned to correct position. There 6 pointer is located on patient’s TMJ, infraobtital, 3prominent cusps. This image is transferred to virtual articulator software for indicating the position of the upper jaw between virtual articulator and virtual cast.
By taking 3 surfaces (left, right, frontal) of the patient’s jaw in centric relationship, mandibular virtual cast will be located in correct position. (22)

(Figure15) computer procedure of virtual facebow adapted from Direct transfer of the position of digitized casts to a virtual articulator; Eneko Solaberrieta

4. Simulation of jaw motion.
The purpose of virtual articulator is to simulate jaw motion for contributing to design the virtual crown and other prosthetics. During simulation of CR, protrusion, laterotrusion, dental technician can reduce the error of design and make comfortable crown for patient. There are 2 type of articulator,
Mathematically simulated articulator and completely adjustable articulators each articulator has difference method to simulate the jaw motion.

4.1 Mathematically simulated articulator

It acts like conventional articulator. This articulator needs the information taken from the conventional articulator or jaw motion analyzer (bennet angle, condyle angle, protusion, retrusion, laterotrusion). With the information articulator automatically simulate the motion of lower jaw like a mechanical articulator. However, curved bennet movement can be simulated by mathematically simulated articulator. (1)

4.2 Completely adjustable articulators

Completely adjustable articulators (motion analyzer), it was designed by Kordass and Gaertner from the Greifswald University in Germany. (29) It records/reproduces exact movement paths of the mandible using an electronic jaw registration system called Jaw Motion Analyser (JMA).

4.2.1 Jaw Motion Analyser

Jaw Motion Analyser records exact jaw motion of patient, special device called ‘Jaw Motion Analyser’ (JMAnalyser+: zebris Medical GmbH, Germany) is required. It is consisted of basic unit, Head bow, Lower jaw Sensor, and sensor pen, bite fork.(23)

This device has the sensory components. Receiver and transmitter are mounted in geometrically defined position. Head bow has 8 Ultrasonic microphones transmitters which make continuously pulse, device calculate the location of lower jaw part of device by transit time of pulse between transmitter and receiver microphone by triangulation method.(4)

First of all, the device should be connected to computer and the software from company need to be installed. After all of device and software is installed, dentist sets a bite folk (it should...
be fixed in lower jaw). And locate the head bow on patient’s head and nose supporter on nose. By a sensor pen, patient’s TMJ and infraorbital are pointed as follows the instruction of software. Lower jaw sensor is connected to bite fork. It is end of setting.

Device is used for tracking the patient’s movement such as protrusion, retrusion, laterotrusion. And this motion will be expressed in numbers. The number can be adapted to full adjustable articulator (Artex AR (Girrbach/Amann) • KaVo PROTAR 7 • SAM • Stratos 300 (Ivoclar)). And also exact movement of jaw can exported to CAD systems via XML-files.

(Figure 18) software of jaw motion analyser

However, this system also has disadvantages. First of all, it need special device (mandibular motion-tracking system) and there is no universal digital format for saving the jaw motion digital date therefore it is hard to use in some virtual articulator software.(23) in this case the number which is taken is used to simulate jaw motion in virtual articulator.

5. Integration of data

Virtual articulator data file should be transferred to CAD software for fabrication of prosthesis. Virtual articulator which is combined with indirect scanning also needs to send it to CAD system. Usually scanning software is connected to CAD software, so articulator model, cast, relation of jaw and TMJ, movement of articulator are automatically transferred to CAD in this case.

In case of intraoral scanning, virtual cast is transferred to CAD system which already have virtual articulator, then relation of TMJ and jaw are adapted by virtual facebow or criteria from scanning conventional facebow.
6. DISCUSSION.

Virtual articulator is useful for dental prostheses, including crowns, crown lays, veneers, inlays and onlays, fixed bridges, dental implant restorations, dentures and orthodontic appliances. The usage of the virtual articulator will be increased as developing CAD/CAM system

**Advantage of virtual procedure**
- Virtual articulator is kept in digital format so no need storage place
- Immediate transmission to technician
- A measurement of virtual casts is easy, accurate, and automatic.
- Virtual cast can be magnified and hence pointing on anatomic points easily.
- It can be stored original malocclusion in digital format.
- There is no dust from plaster, alginate and so on.
- Patient can get prosthesis in one visit.
Disadvantage of virtual procedure
-during indirect scanning, the plaster dental casts should be pure (no error)
-mixed dentition is hard to recognize and measure.
-high cost of system

Comparing indirect scanning and direct scanning

Indirect scanning is more familiar than intraoral scanning, and easy to introduce to laboratory because there is no big gaps between conventional procedure and virtual procedure. However, during impression patient can get damage physically and chemically and the cast can be distorted by humidity and temperature (37).

Direct scanning, patient feel comfortable because of absence of impression, Easy repeatability and other advantage of direct scanning like Real time representation, Material savings, Virtual follow-up, Real color representation. For these reason, many dental clinic is going to introduce intraoral system.

6.1 CBCT

Cone Beam Computed Tomography reconstruct 2D x-ray image to 3D image by using a rotating gantry (24). In many case, the average value has been used in virtual articulator, therefore to get exact patient’s movement of jaw was hard. However, CBCT articulator uses patient’s jaw and hence there is any skeptical opinion that facebow transfer does not offer clinically significant advantages compared to an average mounting (31). The movement of mandible jaw becomes being more accuracy, realistic with patient’s skull.

By using CBCT, patient’s jaw and skull is scanned and reconstruct to 3D image and segmented into maxilla and mandible by image processing software (OnDemand3D, Cybermed, Korea), and the virtual cast already taken by intraoral scanner or Desktop 3D scanners are combined with virtual skull taken by CBCT virtually because CBCT scanning have poor accuracy to occlusal surface. After that, the reference points for tracking jaw motion are attacked to patient anterior teeth. Scan the point in the oral cavity with maximum intercuspation by using a structured-light 3D scanner (Rexcan CS2, Medit, Korea). And then jaw motion is recorded by the 3D scanner. (25)
7. Accuracy.

The accuracy of cast is one of the most important requisites for getting good quality of crown and other prosthesis.

Accuracy is a combination of trueness and precision. Trueness refers to the closeness of a measured value to a standard or known value and precision refers to the closeness of two or more measurements to each other. If you measure a certain object 3 times, and get 30 mm each time, it means the measurement is very precise. But if the known value of the object is 10 mm, that means your measurement doesn’t have trueness. So for accuracy measurement both trueness and precision are required.

Accuracy of intraoral scanner can be differ by Necessity of coating (Coating is more accuracy than non-coating method) and by scanning technology (Active triangulation have more accuracy than confocal microscopy, and optical coherence tomography have lower than others). (14)

**Between Intraoral scanner**

As the protocol 2 articles are selected. Numbers mean deviation, so small deviation is more accuracy.
However, the deviation can be changed by size of object and laboratory situation, so the accuracy should be calculated within an article. I calculate average of all value, and then I divided into 2 groups high and low (if the value is higher than overall, mean low accuracy, if the value is lower than overall mean, it is high accuracy. The high accuracy need both high trueness and high precision. Both are low that means low accuracy. And one is low and other is high that means middle accuracy.

High accuracy group-fastscan, iTero, Trios, truedefinition, CS3500,
Low accuracy group- E4D dentist, Zfx Intrascal, ominicam, PlanScan.

And as the method of scanning,

**Intraoral vs. indirect oral scanner**
As articles, extra oral scanner showed the higher accuracy than intraoral scanner except old version scanner in vitro study (34)(35)(36). However, in vivo situation the gap of accuracy between extra and intra scanner are reduced because in vivo extraoral scanners are used in combination with conventional silicone materials and subsequent working casts made of plaster. Ender et al. said the error that occurs during the manufacturing process. As the article, deviation of extraoral without impression has a precision of 1.6 ±0.6 µm and a trueness of 5.3 ±1.1 µm but with impression the error of trueness was 20.4 ± 2.2 µm and the error of precision was 12.5 ± 2.5µm in plaster working cast, it means deviation was occurred during impression and casting, but still extraoral scanner has more accuracy than intraoral (36).
8. Conclusion

The virtual articulator is going to be one of important stop of CAD/CAM system. By simulating of jaw motion, the error of restoration can be reduced for prevention of patient’s TMJ problems.

The compositions of the virtual articulator are virtual articulator, virtual cast, and the relationship of jaw and simulating of motion. Each step has various methods.

In making virtual articulator, users can build virtual articulator by scanning and software (soild edge, CATIA) or don’t have to make if scanner program have their own virtual articulator.

Virtual cast can be scanned by intraoral scanner directly or Desktop 3D scanners indirectly. After scanning cast, taking relationship is required by virtual facebow or scanning articulator or convention facebow or CBCT.

During building up the crown and other restorations, the problems have to be found by simulating the virtual articulator.
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