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SOFT AND HARD TISSUES IN ESTHETIC IMPLANT DENTISTRY: A NOVEL 3D COMPUTER-AIDED APPROACH TO DIMENSIONAL CHANGES EVALUATION IN IMMEDIATE VS DELAYED IMPLANTATION TREATMENT.

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ABSTRACT

Aim of this work is to develop and to validate a structured methodology to investigate the three-dimensional variation that occurs around implants in dentistry.
Surgeons need to know in an objective way if what they are doing is correct and if it is the best for the patient.
In last decades implantology deeply changed the way to operate of dentists, giving to the patients new opportunities to replace missing teeth.
Implantology has known a very big spread all around the world and numbers of patients treated with success is growing year by year. To know exactly what happens around implants is a growing need for clinicians. A standardized method that can investigate in an objective way what soft and hard tissues do around implants doesn't exist yet. The solutions that researchers used in literature are various and difficult to compare each other.
This work after a general discussion that follows the evolution of implantology, wants to investigate some new instruments that could lend to the comparability of results among different studies and finally to give better answers to the clinical questions.
Using the method proposed in this work, soft-hard tissue variation are been evaluated from a new prospective that gave impressive results both qualitatively and quantitatively speaking.
The procedure is recommended as a new aid in the future studies.

Obiettivo del lavoro è di sviluppare e validare una metodologia strutturata per indagare la variazione tridimensionale che avviene intorno agli impianti endossei in odontoiatria.
I chirurghi hanno bisogno di sapere in modo oggettivo se quello che stanno facendo è corretto ed è la migliore terapia per il paziente.
Negli ultimi decenni l'implantologia ha profondamente cambiato il modo di operare dei dentisti, dando ai pazienti nuove opportunità per sostituire i denti mancanti.
Implantologia ha conosciuto una grande diffusione in tutto il mondo e il numero di pazienti trattati con successo sta crescendo di anno in anno. Sapere esattamente ciò che accade intorno agli impianti è una crescente necessità per i medici. Un metodo standardizzato che possa indagare in modo oggettivo come si modifichino i tessuti duri e molli intorno agli impianti non esiste ancora. Le soluzioni che i ricercatori hanno utilizzato in letteratura sono molteplici e difficili da confrontare tra loro.
Questo lavoro, dopo una discussione generale che segue l'evoluzione dell'implantologia, vuole approfondire l'uso di alcuni nuovi strumenti che possano portare alla comparabilità dei risultati tra i diversi studi e, infine, di dare risposte migliori alle domande cliniche che ancora non hanno risposta.
Utilizzando il metodo proposto in questo lavoro, è possibile valutare i tessuti peri-implantari da una nuova prospettiva che ha dato risultati impressionanti sia sul versante qualitativo sia su quello quantitativo.
La procedura è un ausilio raccomandato come nuovo aiuto nei futuri studi.

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INTRODUCTION

OVERVIEW

In the last decade, dentistry has experienced profound changes. They had a revolutionary impact on the dental compartment.
The present of the clinical practice is a chimaera of past and future that includes both traditional and innovative procedures. They intersect each other at different levels, with a very complex and chaotic context as result.
The new technological tools approached in dentistry through a big transfer of technology from the industrial compartment and allow the operators to work in an innovative way.
In dental clinics the bigger change is the introduction into routine clinical practice of CBCT (Cone beam computer tomography) that allow the clinician to investigate better the particular anatomical characteristics and eventually to plan the surgical procedure via computer. Thanks to computer aided techniques is now possible to create a Three-dimensional replica of the radiographic model and, even better, it is possible to plan and build templates that can be used later during surgery both simplifying the surgical procedure and giving the surgeon some predetermined landmarks.
Another innovative tool that was introduced in the clinical setting is the so called: Diagnocam (Kavo gmbh Germany) which works through an infrared laser beam that use the healthy tooth structure as a photoconductor: if the tooth is healthy, CCD sensor detects a large brightness teeth, if the tooth is demineralized, the chalky structure of the tooth spreads the brightness in all directions blocking so the light directed to the sensor, which detects a dark area. This tool allows the detection of proximal demineralization (proximal caries called Hidden Caries).
Another technologically advanced tool, the itraoral optical 3D scanner, is presented as a possible alternative to traditional impression taking in dentistry. For years Sirona Cerec system has been known as a pioneeristic trademark in the clinical field, but today many other manufacturers are investing in this technology also (e.g. Straunman, 3M, Zfx, etc etc).
In clinical dentistry the technological instruments that are definitely influencing more the professional's practice are prevalently diagnostic tools. Indeed the intraoral 3D optical

impression remains very expansive and for this reason it does not have a big spread in clinical practice yet.

Another big technological influence in dental clinical practice, is represented by the access for the dentists to new materials that was impossible to use before the industrial revolution in dentistry. Iintegral Zirconia crowns nowadays are a big reality that is widely spreading for the beauty and the strength shown by crowns made with CAD-CAM systems.

The prosthesis is an artisan medical device created thanks to a series of complex processing steps that, if not accurately controlled, can lead to a non-lasting restoration. In the realization of such devices, the production of the series has struggled so far to spread because of the uniqueness of the problems related to individual patients and to the very high quality requirements of quality in this field. For this reason the production was, and largely still is, directly hand crafted and requires big knowledge and skills to make a functionally restoration that is both durable and safe for the patient. On one hand traditional techniques allows to create custom objects based on the patient, but on the other hand they do not ensure uniformity of results in terms of quality, a series of critical variables in the process, cause by the lack of automation.

Directive 93/42/EEC on medical devices force the manufacturer of medical devices, the goal of creating a product complies with the essential health and safety for users. All appropriate actions have to be applied with the objective of the elimination, or at least a reduction, to acceptable levels of risk, of all critical variables to obtain at the end a "safe" prosthesis. To provide a product that fully fit the patient’s needs, it is compulsory to manage its production process, with the knowledge of materials involved and a series controlled processes that must respect the requirements set the normative. The spread of new processes and technologies in place of traditional techniques of dentures construction, make increasingly complex and difficult to assess the impact of the methodological choices, keeping the respect of the functional requirements, quality and safety of the implants themselves as a major priority. However all these novelties bring new possibilities of standardization and predictability of the result.

With this background, it is increasingly necessary to train clinicians that can interact between these two great realities: the clinic on one side and the industrial engineering on the other.

The integration of new tools for clinical and dental technology also opens the door to unexpected possibilities of storage or of the analysis of data: for example, thanks to the methods of reverse engineering is possible to create a database containing all the information of the three-dimensional plaster models of our patients and to store them in a small space.

These tools can then also be used as measuring instruments, opening the door to new methods of analysis, more realistic and reliable that can complement the traditional evaluation systems.

The analysis of the methods of assessment of biological phenomena used in the last 10 years shows that there is still much to do to be able to have the results that are repeatable and that are able to correctly describe the biological phenomenon that was investigated.

After assessing the pros and cons of each method, we have chosen what one to follow and consequently we developed a method more that was faster, more accurate and reliable than the one we used before and that gave us surprising results.

The analysis of the inclusion criteria for the selection of the patient and the operative protocol has been fundamental for the analysis and on the goodness of the results obtained and obtainable.

The proper use of new technologies can lead to upset the beliefs that have spread in dentistry without having the correct analytical basis.

This thesis is an attempt to unravel the complexity of the phenomena and their methods of analysis, bringing a little more to what already exists, it is done, and it is long established, because only a correct understanding and analysis of biological phenomena can lead to a planning protocols operating on evidence based medicine. The insertion of dental implants is currently a therapeutic solution commonly implemented to replace teeth that are no longer present in the jaws. The elements may be lacking due to advanced dental caries diseases, endodontic diseases, periodontal diseases that has not been properly treated, trauma or root fractures. Among the therapeutic solutions that can be undertaken to restore the lost element there is the execution of a bridge which includes the use of the adjacent teeth as pillars to support the prosthetic crown of the missing tooth. This practice, however, requires a certain sacrifice of tooth substance of pillars and cannot be the ideal solution in the case of young patients or patience that has healthy elements adjacent to the edentulous site. Another solution may be to make a Maryland bridge (bonded bridge) or a removable prosthesis. Both of these alternatives, however, are not considered definitive. The implant to replace the missing root element with the subsequent final restoration is a permanent therapeutic solution, fixed, that does not compromise adjacent elements. This procedure now has a long clinical experience and has proven over the years to follow up a high percentage of success. It is therefore considered a safe procedure and predictable when applied according to the protocols provided by scientific literature.

Given the scale of the phenomenon "implantology" as socio economic impact on the population, it is necessary that the phenomenon and its physiology is properly assessed for predictive ability on the same phenomenon given the high rate of evolution of surgical procedures and the materials themselves.

The phases of tests for the evaluation of the supposed improvements in implants, are limited to a few cases and follow up with a time-limited. This implies that the choices of companies that produce implants are most often "tested" on the patients themselves given the run-up speed of evolution the new implants they want to first hit the market trying to corner the market first. Given the breadth of techniques for the analysis of success in implantology we have analyzed the pros and cons of various methods to develop our own.

According to the standard protocol, once the avulsion of the element to be replaced, the implant must be postponed for a few months in order to allow healing of the site concerned. However in recent years have developed protocols that provide for the insertion of the implant in the extraction site immediately. The insertion of implants in such sites has the following advantages: it reduces the number of surgical procedures required, preserves the size of the alveolar ridge, reduces the time interval between the removal of the tooth and the final restoration (Schwartz-Arad & Chaushu 1997 Mayfield 1999), reduces the overall treatment time. Being a commonly accepted procedure is in any case a surgical practice that while presenting a high success rate is still lacking of radiological and clinical data in the long term.

Subsequently to the avulsion of teeth, insertion of implants and prosthetic ultimately, dimensional modifications occurs in hard and soft tissues of the sites involved. Such changes may be partly prevented and then clinicians can implements procedures to minimize the aesthetic effects but there are no studies in the literature that present a discussion of the overall three-dimensional variation. This aspect is particularly relevant in the anterior teeth or those sites where the aesthetic component plays a key role in considering the success or failure of therapy.

According to Botticelli, dimensional variation of bone tissue in sites rehabilitated with immediate post-extraction implants is achieved with resorption of the crest of 56% of the initial size in the vestibular portion and 30% in the palatal (Botticelli 2004).
According to Caneva in a study of dogs, conducted by applying a model with three-dimensional evaluation of tissues is a variation of 11.5 ± 1.7 in the vestibular and 4.6 ± 3.1 in the lingual after 4 months immediate post-extraction implant sites without filler and / or membrane (Caneva 2011).
The use of protocols that provide the inclusion of post-extraction implants has also been proposed to reduce these size variations, in this research we want to analyze the dimensional changes of the hard and soft tissues in humans.

ORGANIZATION OF THE DOCUMENT

This work represents the description step by step of the process that lent to the creation of the method.
The idea was to create an objective methodology that could to investigate what happens to the tissues volumes around implants.
All literature has been studied and applying my ideas to a real clinical protocol a new method steps by steps has been created.
This method showed us impressive results that are telling us that we are in the right way, for this reason in future this method will be implemented more and more because I believe that some traditional ways to investigate biologic phenomena in dentistry are going to be obsolete very soon.
The reader of this work will follow my way of thinking and step by step will appreciate the strength of the new method propose.
In the final part, a more technical section about reverse engineering has been treated to give the reader the correct terms that is right to use when we are treating that field, and a more complete view of the process, in spite if we are only clinicians.

CAPITOLO 1. HISTORY OF IMPLANTOLOGY

1.1 IMPLANT THERAPY IN THE ANCIENT AGE

There is archeological evidence that humans tried to replacing missing teeth with root form implants for thousands of years. Remains from ancient China (dating 4000 years ago) shows that people have carved bamboo pegs to tap them into the bone, in order to replace lost teeth. In addition to that, 2000 years old remains from ancient Egypt have similarly shaped pegs made of precious metals. Some Egyptian mummies were found to have transplanted human teeth, and in other instances, researchers found also teeth made of ivory.

One of the most remarkable archeological finds was made by Wilson Popenoe and his wife in 1931, at a site in Honduras dating back to 600 AD. The lower mandible of a young Mayan woman, with three missing incisors replaced by pieces of shell, shaped to resemble teeth. Bone growth around two of the implants, and the formation of calculus, indicates that they were functional as well as esthetic.

1.2 DISCOVERY OF OSSEOINTEGRATION

In the 1950s researchers was studying blood flow in vivo at Cambridge University in England. These workers devised a method of constructing a chamber of titanium which was then embedded into the soft tissue of the ears of rabbits. In 1952 the Swedish orthopedic surgeon, Per-Ingvar Brånemark, was interested in studying bone healing and regeneration. During his research time at Lund University he adopted the Cambridge designed "rabbit ear chamber" but he used these chambers not in ears but in the rabbit femur. Following the study, after the sacrifice of the studied rabbits, he tried to remove these expensive chambers from the rabbits and found that he was unable to do it. Brånemark observed that bone was able to grown into such close proximity with the titanium that it effectively adhered to the metal. Brånemark carried out further studies into this phenomenon, using both animal and human subjects, which all confirmed this unique property of titanium.

In 1978, the first Dental implant Consensus Conference was held, sponsored jointly by the National Institutes of Health and Harvard University. It was a landmark event, at which retrospective data on dental implants were collected and analyzed and criteria and standards for implant dentistry were established.

In 1982 in Toronto, Brånemark presented work that had begun 15 years earlier in Gothenburg. His discovery and application of osseointegration, or the biological fusion of bone to a foreign material, was unparalleled and such scientific documentation of implantology had never been gathered before. The Toronto conference brought widespread recognition to the Brånemark implant methods and materials and it resulted in being one of the most significant scientific breakthroughs in dentistry since the late 1970s.

FIGURE 1 RADIOGRAPH OF BRÅNEMARK'S INITIAL RABBIT SPECIMEN, SHOWING THE TITANIUM OPTIC CHAMBER FIXED TO THE RABBIT'S TIBIA AND FIBULA.

Brånemark's discovery of osseointegration revolutionized the realm of implant dentistry and brought it from being a shunned field into one that became recognized and incorporated into dental school curricula and training programs.

1.3 IMPLANTOLOGY BEFORE THE DISCOVER OF OSSEOINTEGRATION

Prior to the discovery of osseointegration, dental implant technology consisted of blade and transosteal implants. Blade implants, introduced in 1967, consisted of a metal blade that was placed within a bony incision that subsequently healed over the horizontally situated piece of metal but allowed a vertical segment to perforate the healed surface. Transosteal implants, the application of which was strictly limited to the mandible, consisted of a number of needles which were inserted into the inferior aspect of the mandible, some of which extended through and through into the oral cavity.

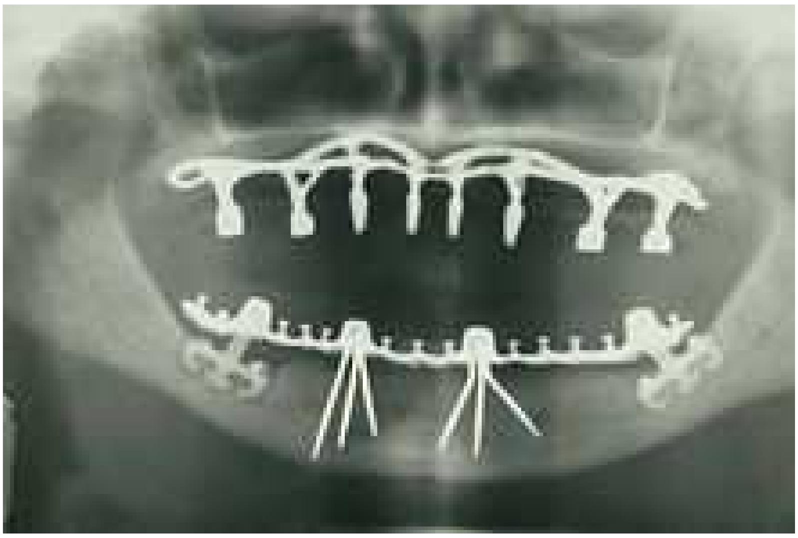


FIGURE 2 EXAMPLE OF BLADE IMPLANTS AND TRANSOSTEAL NEEDLES (SOURCE WIKIPEDIA)

FIGURE 3 ANOTHER EXAMPLE OF IMPLANTOLOGY BEFORE THE DISCOVER OF OSSEOINTEGRATION (THANKS TO DOCTOR STEFANO DANELLI DDS PARODONTAL SPECIALIST PRIVATE PRACTICE MANTOVA ITALY)

Both of these implant types relied on mechanical retention, because at the time doctors were not awared that metal could be fused into the bone. With the advent of osseointegration, however, root-form endosteal implants became the new standard in implant technology.

1.4 IMPLANTOLOGY IN MODERN TIMES

Brånemark developed and tested a type of dental implant utilizing pure titanium screws, which he termed fixtures.

Common types of implants

Since then implants have evolved into three basic types:

- Root form implants; the most common type of implant indicated for all uses. Within the root form type of implant, there are lot of variants, all made of titanium but with different shapes and surface textures. There is limited evidence showing that implants with relatively smooth surfaces are less prone to peri-implantitis than implants with rougher surfaces and no evidence showing that any particular type of dental implant has superior long-term success.
- Zygomatic implants; a long implant that can anchor to the cheek bone by passing through the maxillary sinus to retain a complete upper denture when bone is absent. While zygomatic implants offer a novel approach to severe bone loss in the upper jaw, it has not been shown to offer any advantage over bone grafting functionally although it may offer a less invasive option, depending on the size of the reconstruction required.
- Small diameter implants are implants of little diameter often in one piece construction (implant and abutment are made by the same piece of titanium because there isn't enough space to make a geometrical connection that can fix them together) sometimes are used for mobile prosthesis retention or orthodontic anchorage,

A typical implant consists of a titanium screw (resembling a tooth root) with a roughened or smooth surface. The majority of dental implants are made out of commercially pure titanium, which is available in four grades depending upon the amount of carbon, nitrogen, oxygen and iron contained. Cold work hardened CP4 (maximum impurity limits of N .05 percent, C .10 percent, H .015 percent, Fe .50 percent, and O .40 percent) is the most commonly used titanium for implants. Grade 5 titanium, Titanium 6AL-4V, (signifying the titanium alloy containing 6 percent aluminum and 4 percent vanadium alloy) is slightly harder than CP4 and used in the industry mostly for abutments. Most modern dental implants also have a textured surface (through etching, anodic oxidation or various-media blasting) to increase the surface area and osseointegration potential of the implant (Guo, Cecilia Yan et al. 2012).

If C.P. titanium or a titanium alloy has more than 85% titanium content it will form biocompatible titanium oxide surface layer or veneer that encloses the other metals preventing them from contacting the bone.

CAPITOLO 2. MEDICAL USES OF IMPLANTS

2.1 COMMON USES OF DENTAL IMPLANTS

Implantology is born to support dental prosthetics. Modern dental implants are able to stuck in the bone making use of osseointegration, the biologic process in which the bone grow tightly to the surface of titanium. The integration of implant and bone can support physical loads for decades without failure (Misch, Carl E 2007).

For individual tooth replacement, there are two possibilities: after the surgical operation and healing, the prosthetic crown can be secure to the implant through an implant abutment (that is first secured to the implant with an abutment screw) or directly screwed to the implant. The crown (the dental prosthesis) is then connected to the abutment with dental cement, a small screw, or fused with the abutment as one piece during fabrication (Brånemark, 1989). Dental implants, in the same way, can also be used to retain a multiple tooth dental prosthesis either in the form of a fixed bridge or removable denture. It is up to the clinician to evaluate the better solution.

An implant support bridge is a group of teeth (that can be made in different materials) secured to dental implants so the prosthetic cannot be removed by the patient (is called fixed prosthesis). Bridges typically connect to more than one implant and may also connect to teeth as anchor points but the clinician usually prioritize the connection of implants with other implants and teeth together, because implant and teeth have different mechanical properties (the implant do not have the periodontal ligament so the implant results in a rigid structure, while the tooth is a "dumped" structure). This choice is made to prevent long-term outcomes that could possibly be negative. Typically the amount of teeth is more than the anchor points with the teeth that are directly over the implants referred to as abutments and those between abutments referred to as pontics. Implant supported bridges attach to implant abutments in the same way as a single tooth implant replacement. A fixed bridge may replace as few as two teeth (also known as a fixed partial denture) and may extend to replace an entire arch of teeth (also known as a fixed full denture). In both cases, the prosthesis is said to be fixed because it cannot be removed by the denture wearer (Brånemark, 1989).

A removable implant supported denture (also an implant supported overdenture (Jokstad, Asbjorn, ed. 2009) is a type of dental prosthesis which is not permanently fixed in place. The dental prosthesis can be disconnected from the implant abutments with pressure in opposite direction of implants by the wearer. To enable this, the abutment is shaped as a small connector that can have different shapes: a button, ball, bar which can be connected to the analogous specific joints adapters in the underside of the dental prosthesis. Facial prosthetics, used to correct facial deformities (e.g. from cancer treatment or injuries) can utilize connections to implants placed in the facial bones (Sinn et al 2011). Depending on the situation the implant may be used to retain either a fixed or removable prosthetic that replaces part of the face. (Arcuri MR; et al 1995).)

In orthodontics small diameter dental implants are used always more and this method is spreading worldwide, it is called as Temporary Anchorage Devices (or TADs) and it can assist tooth movement by creating anchor points from which forces can be generated (Chen Y; et al 2009). If a clinician wants to move a tooth, a force must be applied to it in the direction of the desired movement. The force stimulates cells and will cause bone remodeling, removing bone in the direction of travel of the tooth and adding it to the space created backwards. In order to generate a force on a tooth, an anchor point is needed. Implants do not have a periodontal ligament, and bone remodeling will not be stimulated when tension is applied, for this reason they are ideal anchor points in orthodontics. Normally Implants that are designed for orthodontic movement are small in diameter and length and often do not fully osseointegrate, allowing easier removal after the orthodontic treatment than other implants (Lee, SL; et al 2007).

2.2 CLINICAL PLANNING AND TECHNIQUES USED TO PLAN IMPLANTS

2.2.1 GENERAL CONSIDERATIONS

When a clinician is planning for dental implants he has to focus on some aspects:

- The general health condition of the patient;
- The local health condition of the mucous membranes;
- The shape, size, and position of the bones of the jaws;
- Adjacent and opposing teeth (is necessary to check if there is enough space in occlusion and among teeth).

There are few health conditions that absolutely preclude placing implants although there are certain conditions that can increase the risk of failure:

- Patient with poor oral hygiene;
- Heavy smokers and diabetics are all at greater risk for a variant of gum disease that affects implants called peri-implantitis, increasing the chance of long-term failures;
- Long-term steroid use patients;
- Osteoporosis and other diseases that affect the bones can increase the risk of early failure of implants (Brånemark, et al 1989).

In the evaluation of the patient, in addition to considering the suitability of the implant-prosthetic rehabilitation, it is generally necessary to take account of valid contraindications for dental surgery.

Among these can be mentioned:

- Alterations chain blood coagulation therapies performed with anticoagulants;
- Disorders of wound healing or bone regeneration;
- Uncompensated diabetes mellitus;
- Metabolic diseases or systemic metabolic affecting tissue regeneration with particular impact on wound healing and bone regeneration;
- Abuse of alcohol and tobacco and drug use;
- Immunosuppressive therapies such as chemotherapy and radiotherapy;
- Infections and inflammations such as gingivitis and periodontitis;
- Poor oral hygiene;
- Inadequate motivation;
- Defects occlusion and / or of the joint as well as an insufficient occlusal space;
- Inadequate alveolar process.

It is contraindicated the insertion of implants and prosthetic implant in patients with poor general health, poor oral hygiene or inadequate, inability or lack of ability to control the general conditions, or who have previously undergone organ transplants.

Patients with psychos, or found to be abusing alcohol or drugs, with low motivation or insufficient cooperation must also be discarded. Patients with poor periodontal status must be pre-treated and re-evaluated during time before to start an implant therapy.

If there is a lack of bone at the implant site or the resulting bone is poor quality and the stability of the implant could be affected, is necessary to perform a tissue regeneration to gain a better tissue quality.

Other possible contraindications that the clinic must to evaluate:

- Bruxism,
- Allergy to titanium (extremely rare),
- Acute infectious diseases or chronic maxillary osteitis, sub-acute or chronic,
- Systemic diseases,
- Endocrine disorders,
- Diseases resulting in micro-vascular disorders,
- Pregnancy and breastfeeding,
- Previous radiation exposure,
- Hemophilia ,
- Granulocytopenia,
- Steroid use,
- Diabetes mellitus,
- Renal failure,
- Fibrous dysplasia.
- Anticoagulant therapy
- Anticonvulsant therapy
- Immunosuppressive therapy

Normal contraindications common to all oral surgery have also to be observed.

Patients with cardiovascular disease, hypertension, thyroid disease or parathyroid, malignant tumors found in the 5 years prior to the intervention, or nodular swellings must be discarded. Chemotherapies reduce or remove the ability of osseointegration; therefore patients undergoing such treatments should be carefully screened before working with prosthetic implant rehabilitations.

2.2.2 BISPHOSPHONATE DRUGS

The use of bone building drugs, like bisphosphonates and anti-RANKL drugs require special consideration with implants, because they have been associated with a disorder called Bisphosphonate-associated osteonecrosis of the jaw (BRONJ). The drugs change bone turnover blocking it, this can lend problems of inability to heal of the bone also when having minor oral surgery. At routine doses (for example, those used to treat routine osteoporosis) the effects of the drugs will be lasting for months or years but the risk appears to be very low. Because of this duality, uncertainty exists in the dental community about how to best manage the risk of BRONJ when placing implants. A 2009 position paper by the American Association of Oral and Maxillofacial Surgeons, discussed that the risk of BRONJ from low dose oral therapy (or slow release injectable) as between 0.01 and 0.06 percent for any procedure done on the jaws (implant, extraction, etc.). The risk is higher with intravenous therapy, procedures on the lower jaw, people with other medical issues, those on steroids, those on more potent bisphosphonates and people who have taken the drug for more than three years. The position paper recommends against placing implants in people who are taking high dose or high frequency intravenous therapy for cancer care. Otherwise, implants can generally be placed (Ruggiero et al 2009) and the use of bisphosphonates does not appear to have an impact on implant survival (Kumar M; et al. 2012).

2.2.3 BIOMECHANICAL CONSIDERATIONS

The long-term success of implants depends in part, by the biting forces that they have to support. Implants haven’t periodontal ligament, so there is no sensation of pressure when biting and the forces created could be higher. To offset this, the location of implants must distribute forces evenly across the prosthetics they support. (Brånemark, et al.1992). Concentrated forces can lend to the fracture of the structure of the bridge, implant fracture, or a loss of bone that can occur in the adjacent zone to the implant (Pallaci, Patrick 1995). The ultimate location of implants is based on both biologic (bone type, vital structures, health) and mechanical factors. Implants placed in thicker, stronger bone like that found in the front part of the bottom jaw have lower failure rates than implants placed in lower density bone, such as the back part of the upper jaw. People who grind their teeth also increase the force on implants and increase the likelihood of failures (Brånemark et al.1989). The design of implants has to account for a lifetime of real-world use in a person's mouth.

Regulators and the dental implant industry have created a series of tests to determine the long-term mechanical reliability of implants in a person's mouth where the implant is struck repeatedly with increasing forces (similar in magnitude to biting) until it fails (Guidance for Industry and FDA Staff 2004 retrieved in 2013).

When a more exacting plan is needed beyond clinical judgment, the dentist can make an acrylic guide (called a stent) prior to surgery which guides optimal positioning of the implant (from a prosthetic point of view); but if the dentists will make a CT scan of the jaws of the patient the surgery can be planned on CAD/CAM software and the stent can then be made using rapid prototyping following computerized planning of a case from the CT scan. The use of CT scanning in complex cases also helps the surgeon to identify and avoid vital structures such as the inferior alveolar nerve and the sinus (Spector, L 2008) (Lindhe, Clinical Periodontology and Implant Dentistry 5th edition 2008).

2.3 PLACING THE IMPLANTS

Most implant systems have about five basic steps for placement of each implant:

1. Flaps: After a good anesthesia an incision is made straight over the crest of bone, splitting the thicker attached gingiva roughly in half so that the final implant will have a thick band of tissue around it. The edges of tissue, each referred to as a flap are pushed back to expose the bone. Flapless surgery is an alternate technique, where a small punch of tissue (the diameter of the implant) is removed for implant placement rather than rising flaps.
2. Pilot hole: After reflecting the flaps, and using a surgical guide or stent as necessary, pilot holes are placed with precision drills at highly regulated speed to prevent burning or pressure necrosis of the bone.
3. Final preparation of the bone: The pilot hole is expanded by using progressively wider drills. Care is taken not to damage the osteoblast or bone cells by overheating. A cooling saline or water spray and the very low speed help to keeps the temperature low.
4. Placement of the implant: The implant screw is placed and can be self-tapering otherwise the prepared site is tapered with an implant analog. It is then screwed into place with a torque controlled drill (McCracken et al. 2010) at a precise torque so as not to overload the surrounding bone (overloaded bone can die, a condition called osteonecrosis, which may lead to failure of the implant).

5. Tissue adaptation: The flap is adapted around the entire implant to provide a thick band of healthy tissue around the healing abutment that is immediately inserted during surgical procedure (this procedure is called “one stage”). In contrast, an implant can be "buried", where the top of the implant is sealed with a cover screw and the tissue is closed to completely cover it. A second procedure would then be required to uncover the implant at a later date (this procedure is called “two stages” because required a second re-entry surgical procedure called secondary surgery).

2.3.1 TIMING OF IMPLANTS AFTER EXTRACTION OF TEETH

There are different approaches to placement dental implants after tooth extraction (Esposito et al. 2010).

The approaches are:

- Immediate post-extraction implant placement.
- Delayed-immediate post-extraction implant placement (two weeks to three months after extraction).
- Delayed-late implantation (three months or more after tooth extraction).

There are also various options for when to attach teeth to dental implants (Esposito 2103) classified into:

- Immediate loading procedure.
- Early loading (one week to twelve weeks).
- Delayed loading (over three months)

2.3.2 HEALING TIME

After the surgical procedure, the body will need time to permit osseointegration and allow the permanent stability of the implant. Based on this biologic process, it was thought that loading an implant during the osseointegration period would result in movement that would prevent osseointegration, and thus increase implant failure rates. As a result, three to six months of integrating time (depending on various factors) was allowed before placing the teeth on implants (restoring them).

However, a more recent research suggests that the initial stability of the implant in bone is a more important determinant of success of implant integration, rather than a certain period of healing time. As a result, the time allowed to heal is typically based on the density of bone the implant is placed in and the number of implants splinted together, rather than a uniform amount of time. When implants can withstand high torque (35 N-cm) and are splinted to other implants, there are no meaningful differences in long-term implant survival or bone loss between implants loaded immediately, at three months, or at six months (Esposito et al. 2013). The corollary is that single implants, even in solid bone, require a period of no-load to minimize the risk of initial failure (Atieh et al. 2009).

2.3.3 ONE-STAGE, TWO-STAGE SURGERY

After an implant is placed, the internal components are covered with either a healing abutment, or a cover screw. A healing abutment passes through the mucosa, and the surrounding mucosa is adapted around it. A cover screw is flush with the surface of the dental implant, and is designed to be completely covered by mucosa. After an integration period, a second surgery is required to reflect the mucosa and place a healing abutment (Miloro 2004).

In the early stages of implant development (1970−1990), implant systems used a two-stage approach, believing that it improved the odds of initial implant survival. Subsequent researches suggest that no difference in implant survival existed between one-stage and two-stage surgeries, and the choice of whether or not to "bury" the implant in the first stage of surgery became a concern of soft tissue management (Esposito et al. 2009).

If we have a lack of gingiva around implants is up to the surgeon to decide if use a one or two stages technique to be able to reconstruct better the gingiva’s anatomy of the missing teeth because once the implant is osseointegrate the surgeon can move the gingiva up or down helped by the healing abutments.

2.3.4 IMMEDIATE PLACEMENT

An increasingly common strategy to preserve bone and reduce treatment times includes the placement of a dental implant into a recent extraction site. On the one hand, it shortens treatment time and can improve esthetics because the soft tissue envelope is preserved. On the other hand, implants may have a slightly higher rate of initial failure. Conclusions on this topic are difficult to draw, however, because few studies have compared immediate and delayed implants in a scientifically rigorous manner (Esposito et al. 2010).

2.4 RECOVERY

Recovery is the term used to indicate the steps taken to secure dental crowns on the implant fixture including placement of the abutment and crown.
The prosthetic phase begins when the implant is well integrated (or has a reasonable assurance that it will integrate) and an abutment is in place to bring it through the mucosa. Even in the event of early loading (less than 3 months), many practitioners will place temporary teeth until osseointegration is confirmed. The prosthetic phase of restoring an implant requires an equal amount of technical and surgical expertise, because of the biomechanical considerations, especially when multiple teeth are interested in the process. The dentist will work to restore the vertical dimension of occlusion, the esthetics of the smile, and the structural integrity of the teeth, in order to evenly distribute the forces of the implants (Brånemark et al. 1989).

2.4.1 PROSTHETIC PROCEDURES FOR SINGLE TEETH, BRIDGES AND FIXED DENTURES

The abutment is selected depending on its application. In many single crowns and fixed partial denture scenarios (bridgework), custom abutments are used. An impression with a transfer is made of the top of the implant including also the rest of dentition and gingiva. A dental lab then simultaneously fabricates an abutment and crown. The abutment is secured to the implant with a screw that passes through the abutment to secure it to an internal thread on the implant (lag-screw). It is important to consider also the possible variations that this choice can present, such as the case of the abutment and the implant body being one piece or when a stock (prefabricated) abutment is used. Custom abutments can be made by hand, as a cast metal piece or custom milled from metal or zirconia.

The platform that connects the implant and the abutment can be of various shapes: flat (buttress) or conical fit.

In conical fit abutments, the collar of the abutment sits inside the implant which allows a stronger junction between implant and abutment and a better seal against bacteria into the implant body. To improve the gingival seal around the abutment collar, a narrowed collar on the abutment is used, referred to as platform switching. The combination of conical fits and platform switching gives marginally better long term periodontal conditions compared to flat-top abutments (Atieh et al. 2010).

Regardless of the abutment material or technique, an impression of the abutment is then taken and a crown secured to the abutment with dental cement. Another variation on abutment/crown model happens when the crown and abutment are one piece and the lag-screw traverses both to secure the one-piece structure to the internal thread on the implant.

2.4.2 MAINTENANCE OF IMPLANTS AND PROSTHETICS

Implants are a very good prosthetic solution but they need to be cleaned (similar to natural teeth) with a dental tooth paste to remove any plaque. Often patients believe that it is not necessary to clean implants because they cannot have decays. This misconception could lead to serious consequences, since an implant that is not regularly brushed is destined to fail , due to periodontal tissue’s sensibility to plaque.

2.5 RISKS AND COMPLICATIONS: IMPLANT COMPLICATIONS

2.5.1 POSSIBLE ADVERSE EFFECTS OF IMPLANT THERAPY

After the surgery the patient can have some clinical manifestation (signs)like:

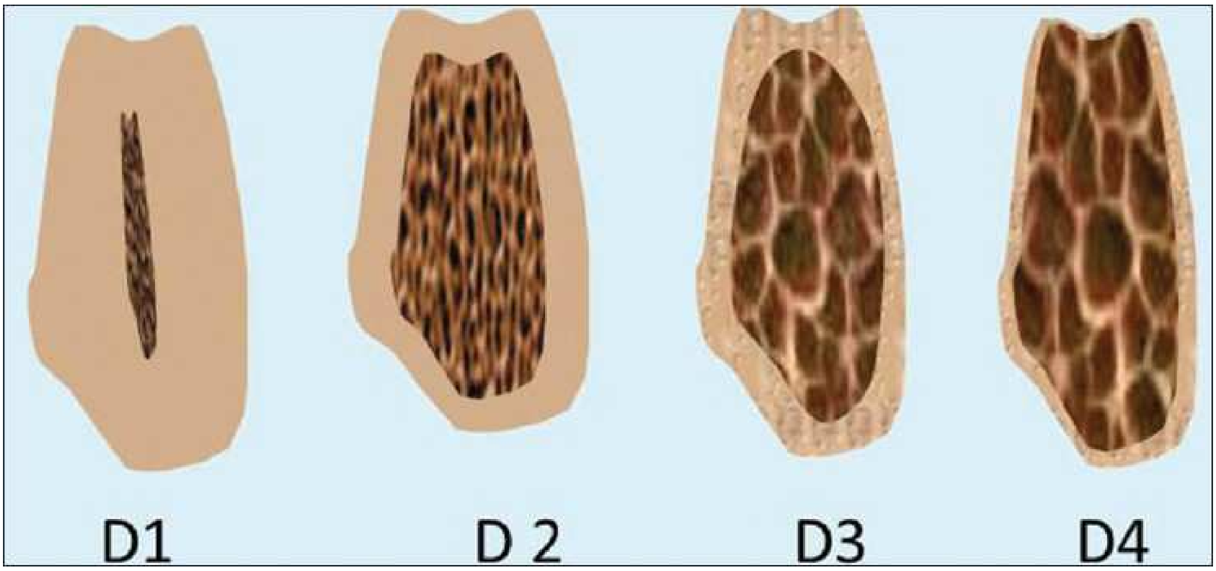
- Temporary local swelling,
- Edema,
- Bruising,
- Temporary limitations of sensitivity,
- Temporary limitations of masticatory,
- Micro hemorrhages postoperative in 12/24 hours.

The patient will tell us to have (symptoms):

- Pain;
- Pronunciation problems;
- Gingivitis;
- Permanent paresthesia;
- Dysesthesia;
- Local or systemic infections;
- Exfoliation;
- Oro-nasal fistulas;
- Perforation of the labial or lingual plate;
- Membrane of Schneider perforation;
- Aesthetic problems;
- Impairment of natural dentition.

With the study of preoperative Cone beam computer tomography (CBCT), is possible to identify the type of bone present in the area where you plan to insert the implant. The choice of surgical procedure cannot be separated from the type of bone present.

The bone is normally identifiable in four types depending on the density. The classification (according to Karl Misch) is the following:



D1	Dense cortical bone	Anterior mandible Posterior mandible
D2	Dense to porous cortical bone surrounding dense trabecular bone	Anterior mandible Posterior mandible Anterior maxilla
D3	Thin porous cortical bone surrounding fine trabecular bone	Anterior maxilla Posterior maxilla
D4	Fine trabecular bone	Posterior maxilla

FIGURE 4 MISCH CLASSIFICATION OF THE BONE

2.5.2 IMPLANT FAILURE

Osseointegration occurs between 8 and 24 weeks later the surgery. There is significant variation in the criteria used to determine implant success; the most commonly cited criteria at the implant level are the absence of pain, mobility, infection, gingival bleeding, radiographic transparency or peri-implant bone loss greater than 1.5 mm (Albrektsson 1986; Papaspyridakos, P. et al. 2011). Dental implant success is related to operator skill, quality and quantity of the bone available at the site, and the patient's oral hygiene, but the most important factor is primary implant stability (Javed, F et al. 2010).

Integration failure is rare in most cases, particularly if instructions given by the dentist or the oral surgeon are followed closely by the patient. Immediate loading implants may have a higher rate of failure, potentially due to being loaded immediately after trauma or extraction, but the difference with proper care and maintenance is well within statistical variance for this type of procedure. More often, osseointegration failure occurs when the patient is either too unhealthy to receive the implant or engages in behavior that contraindicates proper dental hygiene including smoking or drug use.

2.5.3 LONG TERM RISKS FOR IMPLANTS

The long-term complications that result from restoring teeth with implants relate, directly, to the risk factors of the patient and the technology involved. There are the risks associated with esthetics including a high smile line, poor gingival quality and missing papillae, difficulty in matching the form of natural teeth that may have unequal points of contact or uncommon shapes, bone that is missing, atrophied or otherwise shaped in an unsuitable manner, unrealistic expectations of the patient or poor oral hygiene. The risks can be related to biomechanical factors such as the case in which the geometry of the implants does not support the teeth in the same way the natural teeth used to do or when there are cantilevered extensions, fewer implants than roots or teeth that are longer than the implants that support them (a poor crown-to-root ratio).

Similarly, in a patient that grinds his teeth, which has little bone or if we use low diameter implants the biomechanical risk is increased. To conclude, there are also technological risks: the implants themselves can fail due to fracture or a loss of retention to the teeth they are intended to support (De Brandão 2013).

These theoretical risks, lead to everyday practice complications. Long-term failures are due to either loss of bone around the tooth and/or gingiva due to peri-implantitis or a mechanical failure of the implant. While large-scale, long-term studies are scarce, several systematic reviews estimate the long-term (five to ten years) survival of dental implants at 93–98 percent depending on their clinical use (Papaspyridakosn 2013; Berglundh 2002; Pjetursson 2012).

During initial development of implant retained teeth, all crowns were attached to the teeth with screws, but more recent progresses have allowed placement of crowns on the abutments with dental cement. This has created the potential for cement to escape from under the crown during cementation going apically in the gingiva creating a peri-implantitis.

Criteria for the success of the implant supported dental prosthetic varies from study to study, but can be broadly classified into failures due to the implant, soft tissues or prosthetic components or a lack of satisfaction on the part of the patient.

The most commonly cited criteria for success are function of at least five years in the absence of pain, mobility, radiographic lucency and peri-implant bone loss of greater than 1.5 mm on the implant, the lack of suppuration or bleeding in the soft tissues and occurrence of technical complications/prosthetic maintenance, adequate function, and esthetics in the prosthetic.

In addition to that, the patient should not feel any pain or paresthesia and he should be able to chew and eat, also granting the best possible degree satisfaction with the final esthetics (Papaspyridakos 2011).

The rates of complications vary by implant use and prosthetic type and are listed below (Goodacre 2003):

Single crown implants (5-year)

- Implant survival: 96.8 percent
- Peri-implantitis: 9.7 percent
- Implant fracture: 0.14 percent
- Screw or abutment loosening: 12.7 percent
- Abutment screw fracture: 0.35 percent

Fixed complete dentures

- Progressive vertical bone loss but still in function (Peri-implantitis): 8.5 percent
- Failure after the first year 5 percent at five years, 7 percent at ten years
- Incidence of veneer fracture at:
- 5-year: 13.5 to 30.6 percent,
- 10-year: 51.9 percent (32.3 to 75.5 percent with a confidence interval at 95 percent)
- 15-year: 66.6 percent (44.3 to 86.4 percent with a confidence interval at 95 percent)
- 10-year incidence of framework fracture: 6 percent (2.6 to 9.3 percent with a confidence interval at 95 percent)
- 10-year incidence of esthetic deficiency: 6.1 percent (2.4 to 9.7 percent with a confidence interval at 95 percent)
- prosthetic screw loosening: 5 percent over five years to 15 percent over ten years

- The most common complication being fracture or wear of the tooth structure, especially beyond ten years (Pjetursson 2012; Bozini 2011) with fixed dental prostheses made of metal-ceramic having significantly higher ten-year survival compared those made of gold-acrylic.

CAPITOLO 3. TRADITIONAL ASSESMENT TECNIQUE IN HARD-SOFT TISSUE CHANGES

The quantitative assessment of surgical changes in hard/soft tissue of the site of implant has always been a big concern in the science of implantology. This concern got worse with time and complexity of the surgery procedures, while the need of being able to obtain data from the clinical reference became critical.

Only to obtain a clear mindset of the methods used in the evaluation of variation in tissues, we can grossly divide them into four major classes:

- Clinical and photographic assessments
- Radiological assessments
- Computer Aided elaboration after reverse engineering on cast models with laser scanners, structured light scanners or photogrammetric scanners.
- VAS scores (patient and clinical operator) (Belser et al. Consensus Statement 2004)

These methods can be used both one at a time or combined to obtain more precise data and being sure that different methods lead to the similar conclusions.

Every method has some advantages and some issues, but the research is now moving to the 3D evaluation, as scientifically literature grows and makes clearer and clearer the potentiality and precision of the new Computer Aided Design techniques. In this chapter we are going to focus, in the single group of methods found in literature. We will list them one at a time, trying to show the characteristics and the issues related to every method.

The following list is essential to make the reader understand the complexity of the matter itself, and the heterogeneity in evaluating results.

We decided to start with clinical evaluation, since it is the first aspect in terms of historical hierarchy and simplicity.

3.1 CLINICAL AND PHOTOGRAFIC ASSESSMENTS

3.1.1 HISTORICAL EVALUATION: FUNCTIONALITY

The start of the science of implantology was developed rapidly after the discovery of osseointegration in the early ‘80s. The traditional way to assess the success in implantology was first described by Albrektsson in 1986 by his Albrektsson’s clinic criteria for success in implantology.

Definitions given:

- Absence of mobility
- Absence of painful symptoms or paresthesia
- Absence of peri-implant radiolucency
- Absence of progressive marginal bone loss (<0.2 mm per year after the first year in function)

3.1.2 THE GROWING AESTHETIC PROBLEM

Albrektsson was the first researcher that gave some criterias for clinical success in implantology. Nowadays they are still considered good functional criterias for success and also the base for modern implantology evaluation. There is, anyway, a total lack of interest about the aesthetic impact of the implant, and no evaluation for the health of the soft tissue contour. Changes in the volume and shape of soft tissue are critical in implant treatment of frontal teeth, also due to the high aesthetic impact on the smile of the patient. The soft tissue is still evaluated in different ways, and there is not yet an objective validated method for assessing the soft tissue esthetic results. The need for a solid, objective and reproducible assessment of the esthetics and hard/soft tissue conservation is growing since the start of the development of clinical use of implantation in frontal teeth.

This lead to the development of different clinical scores methods for the evaluation of esthetics of the prosthesis itself and, later on, of the mucosa around the extraction site. The scores are actually several.

An historical examination of most significant scores and parameters taken in consideration in scientifically literature will follow, trying to make it easier to approach and to understand the critical aspects of these evaluation assessments on the last ten years.

Several differences can be found in every work which tries to assess the aesthetics, and even if there is some kind of convergence to some parameters, every study evaluates them in a different way, making it difficult to compare the values from a study to another. This fact makes the above classification gross, because there is a continuum between merely clinical scores and those which integrate data from other sources such as radiological evaluation.

We are now going to propose a list of variables which have been conserved in the last ten years and that recur in most of the fundamental studies, as they are probably the most accepted indexes of success in clinical terms.

About the evaluation of soft tissues we can separate qualitative recordings (color/ texture) and quantitative ones (e.g. papilla reduction, vertical soft tissue deficiency). Evaluation of different parameters in this field requires different techniques to obtain data. Different approaches have been developed for the purpose. The simplest way of evaluation consists in analyzing a photograph with known magnification or the clinical situation directly on the patient. (Furhauser 2005; Belser 2009)Another option is to obtain linear values with the aid of graduated probes and compare the values to references (Cosyn 2009/2012, Chang 2012). Some quantitative approaches have been used on a fundamentally clinical evaluation to get more quantitative recordings to analyze (e.g. ultrasonic devices to assess the mucosa thickness Cardaropoli 2005). A study of some variables on clinical cast can also be found (Belser et al 2009).

In some studies there has been an attempt to quantify color and other fundamentally qualitative parameters of the soft tissue with the aid of proper machines (e.g. spectrophotometric evaluation in mucosa color (Zembic et al. 2009).

3.1.3 SOFT TISSUE CONTOUR

The most commonly evaluated recording is the modification (normally the lack) of soft tissue contour in the site adjacent to the implant, called in various ways (e.g. curvature of the facial mucosa, contour of the labial surface of the mucosa, mid-facial soft tissue level, mid-facial recession, and so on). This is probably associated with a lack of volume in all the peri-implant soft tissue. In fact it is also very frequent the evaluation of mucosa thickness with different methods (e.g. a caliper in Chang et al. 2012, using an endodontic file with a rubber stop in Zembic et al. 2009). These evaluations usually converge on a ranks system to insert the values in every particular score.

The contour of the soft tissue is assessed mostly on sight or with known magnification photographs, in different sites and with different grading scores, according to last ten years studies. The contour is valuated together with soft tissue vertical deficiency or as a separate parameter. In particular, Cosyn et al. (2009) in his study evaluates it as "mid-facial soft tissue level" also, measured with the aid of a periodontal probe, as the distance of the mid-facial soft tissue margin at the crown to a line connecting the mid-facial soft tissue margin of the two adjacent teeth. If the level at the crown was located apical to this line, a negative value was scored. If the level at the crown was located coronal to this line, a positive value was attached. This evolved in 2012 into "mid-facial recession": mid-facial mucosa level was measured using the same acrylic stent provided with a central direction groove and defined as the distance from the top of the groove to the zenith of the restoration measured to the nearest 0.5 mm using a manual probe.

The only convergence is a major concern to the vestibular side of the soft tissue, which is the most esthetically important.

3.1.4 INTERPROXIMAL PAPILLAE

Easy detectable index of the quality of the soft tissue around the implant site is adjacent papillae health. Mesial and distal papillae are taken into consideration in most studies and compared with the contralateral healthy tooth, but also with the neighboring tooth (Pink Esthetic Score PES of Furhauser 2005). This is probably due to the high esthetic impact of the contour of papillae around the implant site. This parameter is evaluated in various ways, and with different scoring system, but there is an obvious trend on the grading of the shape. Most of the scoring systems separate an absent papilla from a deficient one, from a normal one. There is anyway not perfect match between studies about thresholds in ranking characteristics and what a perfectly conserved papilla is.

3.1.5 COLOR EVALUATION

The evaluation of color of the soft tissue around the crown is based on the comparison with healthy tissue on contralateral healthy gingiva. It is often pulled through together with other aspects of the tissue. There is no point in a numerical evaluation in color in a clinical assessment method, because collected data will be inserted in a score which needs a ranks division of values. These ranks are mostly divided in: same color/slightly different/really different, with lesser differences between studies.

3.1.6 QUALITY AND TEXTURE OF SOFT TISSUES AROUND IMPLANTS

The evaluation of the quality and texture of the soft tissues around the surgical site is more fragmentary, mostly associated with other parameters, and there is no trend to analyze the same aspects. The quality of the tissue is often brought towards together with the color analysis (e.g. “soft tissue quality” distinguished as -adequate, pink and firm with a normal contour, -compromised, slightly red color and soft, spongy, or with uneven contour, -deficient red gingiva with a soft edematous and boggy or craterlike appearance (Juodzbalys 2008/2010), because an edematous site is quite always associated with inflammation and with vasodilation which leads to a red inflammatory color.

3.1.7 KERATINIZED MUCOSA WIDTH

The keratinized mucosa width is taken in consideration in several studies because a keratinized mucosa, due to its nature, is less prone to bleed and to be damaged in the act of chewing than a non-keratinized one, and therefore less prone to chronical inflammation around the implant site. This is usually measured with the aid of probes (e.g. the keratinized gingival width on the mid-buccal side of the socket: ‡2,1 to 2, and <1 mm were defined as adequate, compromised, and deficient, respectively) (Juodzbalys 2008).

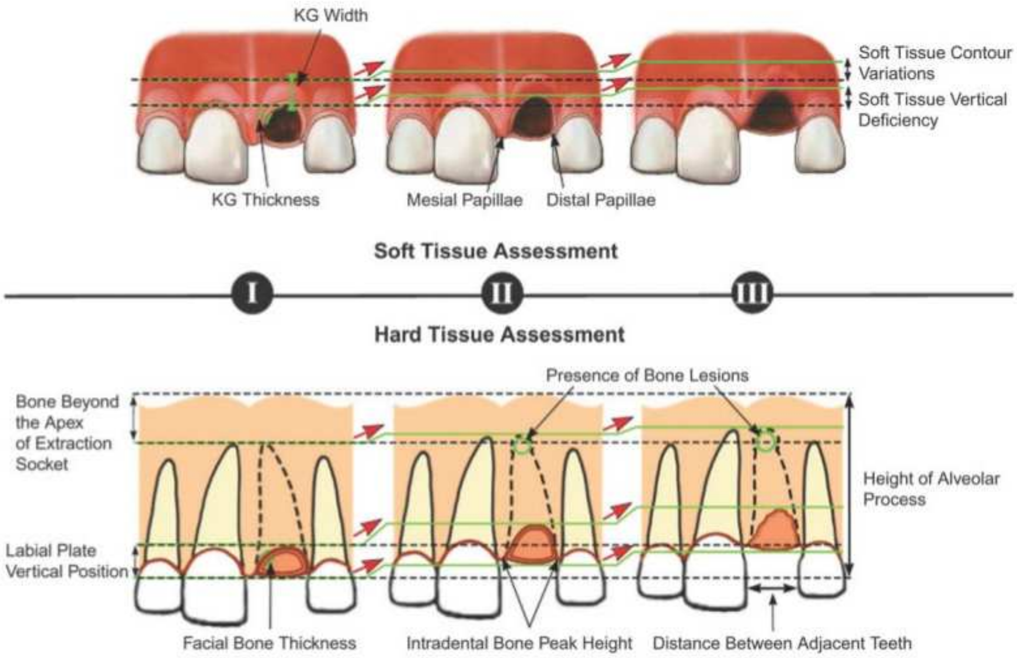


FIGURE 5 HARD AND SOFT TISSUE ASSESSMENT FOLLOWING JUODZBALYS ET AL. 2008

3.1.8 SOFT TISSUE CONDITIONS AND ORAL HYGIENE STATUS

In the studies based on probing for clinical evaluation there is also the presence of two factors which are ignored in other studies, to evaluate the quality of the soft tissue, which are probing depth, measured to the nearest 0.5 mm at four sites (mesial, mid-facial, distal, and palatal) using a manual probe (Cosyn 2012) and bleeding on probing. In bleeding on probing a dichotomous score was given (0 = no bleeding; 1 = bleeding) at four sites (mesial, mid-facial, distal, and palatal). (Cosyn 2012)

These two factors are indicators of a healthy soft tissue which could be taken in consideration for better evaluation of healthiness in soft tissue.

Plaque score is an interesting parameter which determines in a simple and clear way if the prosthesis is easy to keep clean; it was assessed to detect the presence/absence of plaque. It was evaluated at four sites (mesial, mid-facial, distal, and palatal) (Cosyn 2012).

3.1.9 PROSTHESIS EVALUATION

The crown is also taken in consideration in clinical evaluation methods. It is compared with the adjacent teeth for different parameters.

The main parameter is the dimension and shape of the crown, put in comparison with the contralateral healthy teeth. Normally this parameter is ranked to use the measurement in the scoring system. This is almost always present, from Meijer et al. (

2005) on. Belser et al. (2009) identify other parameters such as volume/outline of the crown, but of lesser interest.

The position of the crown and alignment is considered in as early as 2005 by Meijer et al. and considered than in 2010 by Juodzbalys et al.

Surface appearance is a parameter used from more than ten years ago (e.g. Meijer 2005). The surface texture has a deep impact on the esthetical aspect of the crown and on the plaque forming on it. In 2010 Juodzbalys et al. add to this parameter “roughness and ridges” to evaluate the surface of the crown, considering it adequate/compromised/deficient.

An aspect considered more and more with time is the color and transparency of the crown which is evaluated clinically, live or on photographs, always comparing with contralateral/adjacent teeth (Meijer et al. 2005, Belser et al. 2009, Juodzbalys et al. 2010)

Crown width/length ratio is another parameter used by Juodzbalys in 2010 to clinically assess the robustness of the crown.

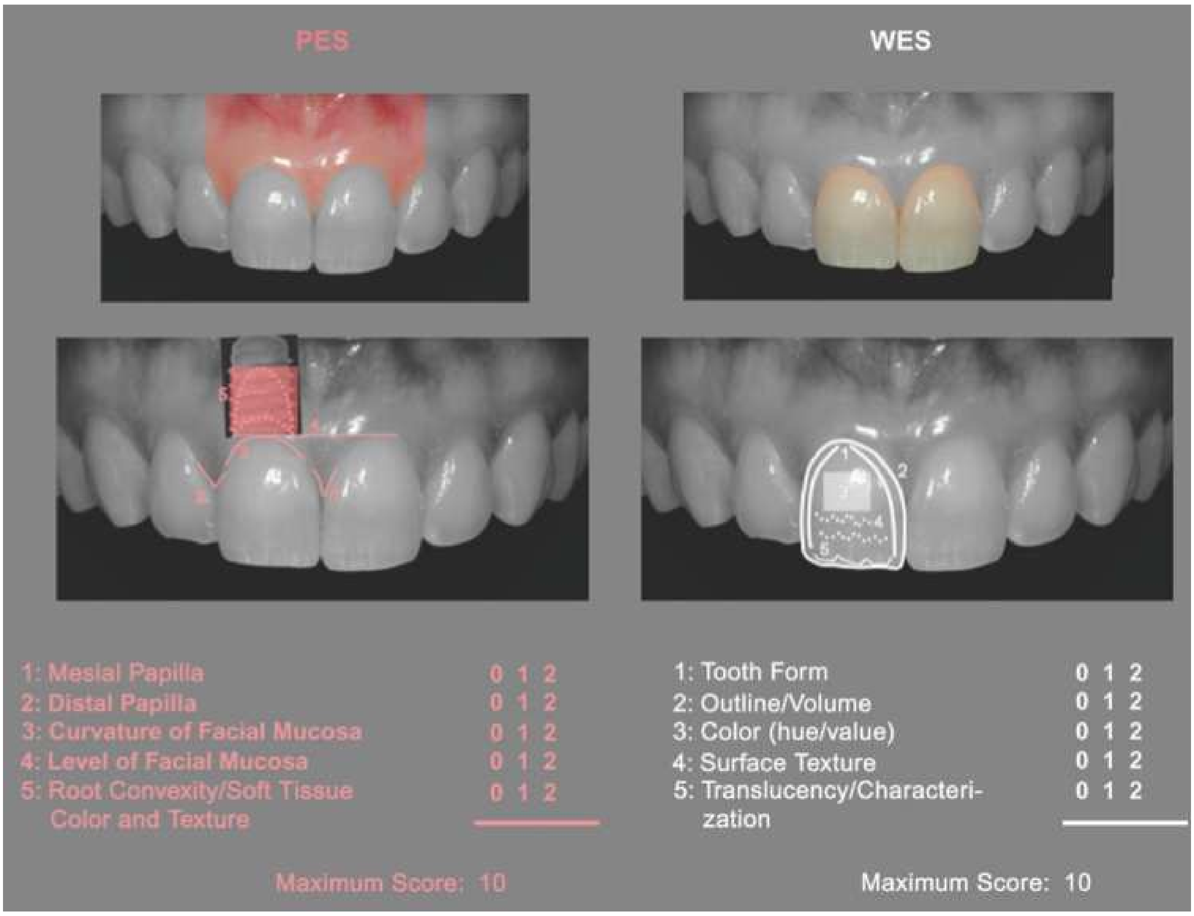


FIGURE 6 EXAMPLE OF CLINICAL SCORES PES WES MADE ON PICTURES (IMAGE TAKEN FROM BELSER ARTICLE 2009)

3.1.10 BONE LOSS EVALUATION WITH RE-ENTRY SURGICAL PROCEDURE

Re-entry surgical procedure means that a second surgical procedure was performed after the extraction to evaluate what happened to the alveolar bone. The reference was an acrylic stent used like reference or some titanium pins and a periodontal probe or an endodontic file (see Figure 7 and Figure 8) was used to measure the difference from the referral point of the stent and the bone

Human re-entry studies showed horizontal bone loss of 29–63% and vertical bone-loss of 11–22% after 6 months following tooth extraction. These studies demonstrated rapid reductions in the first 3–6 months that was followed by gradual reductions in dimensions thereafter. (Tan 2011)

FIGURE 7 EXAMPLE OF PERIODONTAL PROBE AND ITS USE TO MEASURE DISTANCE AMONG TEETH

FIGURE 8 ENDODONTIC FILES WITH A RUBBER STOP

3.2 RADIOLOGICAL EXAMINATION

In this paragraph we are going to show some methods of mainly radiological methods of assessment. The radiological methods are used to evaluate the hard tissue behavior and adjustment to surgery procedure, and to establish the clinical success of the implant. Therefore radiological evaluation is a strong complement to clinic assessments.

Importance of radiological procedures is also testified from Albrektsson’s criteria. It clearly states the importance of absence of peri-implant radiolucency as a criterion of clinical success of the implant.

There is no perfect concurrence in the times of evaluation of hard tissues between different studies, but usually it is possible to differentiate three Phases:

- Pre intervention imaging;
- Imaging at time 0;
- Imaging at a third time (from several weeks to several months) repeated or not.

The radiological technique utilized varies greatly from a study to another; we go from standardized parallel long-cone to CBCTs (cone beam computer tomography). Then the results are difficult to compare, because the output of these techniques can be two-dimensional or three-dimensional and on different planes.

The primary concern in radiological evaluation, especially to find linear values, is to find good reference points. Reference points mustn't have bias or more than one interpretation. It has to be easy to detect them in a univocal way and they must be present before and after the surgical procedure. They also must have a clinical meaning and primary clinical implications. Such referral points are in continuous evolution.

As examples, we will now show some good referral points found in the work of Araujo et al (2014):

- The apical extension of the alveolar ridge, identified by a line (a-line) crossing the apex of the socket, which was perpendicular to a bisector (BIS) that divided the image of the socket into a buccal and a palatal portion.
- The coronal extension of the alveolar ridge, identified by a line that connected the buccal and palatal crests (BC-PC line).
- From these referral points, Araujo and colleagues (2014) could then determine some parameters with easiness, such as the height of the buccal and palatal bone walls. That was determined by measuring in perpendicular direction the vertical distance between the a-line and BC and PC they also measured the profile of the alveolar process (ridge), including the peripheral portion of the graft, and the area measured (area mm2) with the use of a cursor (Figure 9).

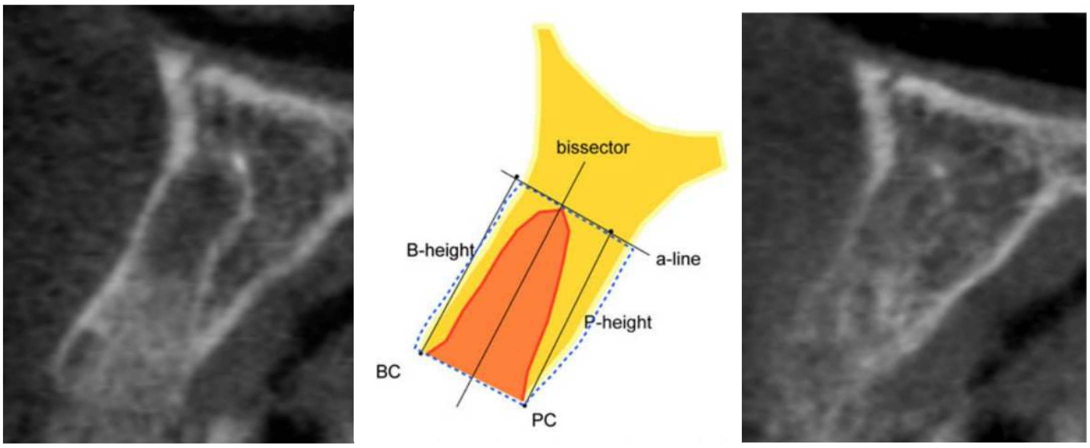


FIGURE 9 ON THE LEFT THERE IS A CORONAL SECTION OF CBCT JUST AFTER EXTRACTION AND ON THE RIGHT THE SAME IMAGE AFTER HEALING TIME; IN THE CENTER THERE IS THE SCHEMATIC REPRESENTATION OF THE MEASURE METHOD EXPLAINED ON TEXT (IMAGE TOOK FROM THE ARTICLE OF ARAUJO 2014)

Like in this case, most studies set their own references in a proper way, according to the evaluation method. We are now going to show some examples of radiologically determined linear parameters and briefly their clinical meanings.

A good example of radiological parameter clinically considered fundamental is the available bone beyond the apex of extraction socket (Juodzbalys 2008), meant as the distance between the socket apex and the nasal sinus floor. This dimension is fundamental to determine implant stability. The height of the alveolar process and the available remaining bone can be estimated from the orthopantomography, taking into consideration the x-ray magnification. The evaluation is usually linear and based on computers programs to superimpose in two dimensions the radiograms.

Another example is the implant apico-coronal position; long-cone paralleling technique was used to determine the mesial and distal interproximal bone height. The evaluation was performed in a linear fashion from the cement-enamel junction (CEJ) of the adjacent teeth to the mesial and distal alveolar bone crest using standardized computerized dental-imaging software. The implant apico-coronal position was recorded in the same way to measure the dental-implant shoulder position (Juodzbalys 2010)

In three dimensional radiological evaluations such as CBCTs the assessment of the modification in volume and shape is more precise but far more difficult to handle. The amount of data is massive and it is frequent to have a great loss of information to make the data to compare clear and concise. For this reason it is normal to find three-dimensional data converted in two-dimensional evaluations, with a great loss of information, but granting an easier concept to understand. We can include in this sub-category some literature way of simplifying data like in the work of Chappuis et al. 2013. In this study the evaluation of hard tissues was caught with two consecutive CBCTs with 8 weeks interval between them. A surface mesh model was subsequently generated and superimposed on the baseline model with alignment guaranteed by anatomical landmarks (Figure 10). The distance between the two surface meshes was then presented as color-coded figures to identify zones of facial bone resorption. Baseline facial bone thickness was measured at distances of 1, 3, and 5 mm from the most coronal point of the bone crest (as previously stated by Araujo and Lindhe, 2005). The analysis was performed in central (c) and proximal sites (a) oriented at a 45° degree angle, with the tooth axis as a reference (Figure 11). A horizontal reference line was then traced connecting the facial and palatal crest for standardized measurements (Fickl 2008). The point-to-point distance between the 2 surface meshes with the respective angle to the reference line was obtained for each sample, and the vertical and horizontal bone losses were calculated accordingly (Figure 12).

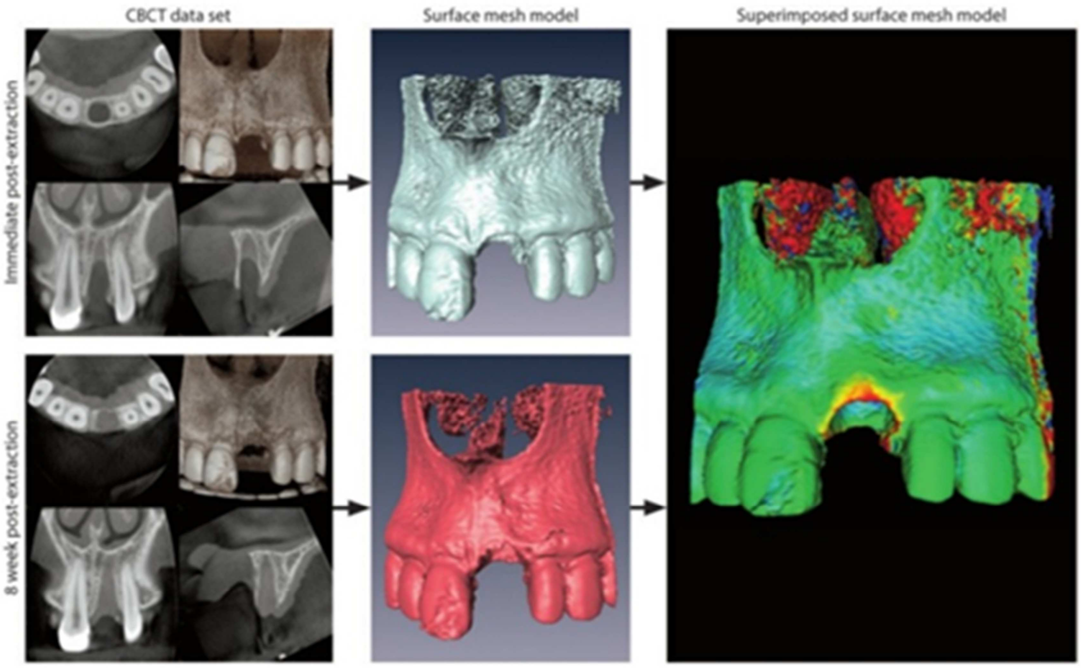


FIGURE 10 SUPERIMPOSION OF 3D MODELS FROM CBCT AND COLOR CODE VOLUME DIFFERENCE (IMAGE TAKEN FROM THE ARTICLE OF CHAPPUIS 2013)

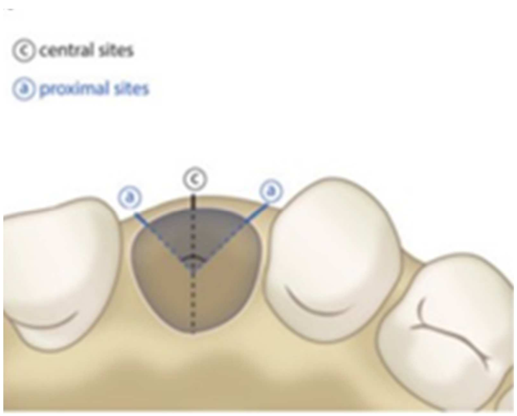


FIGURE 11 POINT TO POINT DISTANCE FOLLOWING CHIAPPUIS 2013

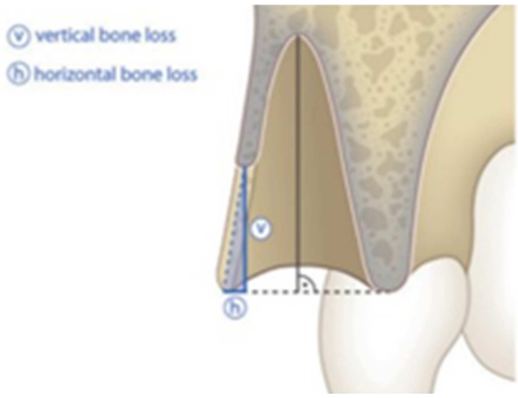


FIGURE 12 HORIZONTAL AND VERTICAL BONE LOSS FOLLOWING CHAPPUIS (2013)

The problem of these elaborations is that at the end only a bi-dimensional measure is taken and a lot of informations are lost.

The referral anatomical landmarks are very difficult to standardize so we got also this problem among the first and the second measure (not sure to have same referrals).

3.3 COMPUTER AIDED ELABORATION AFTER REVERSE ENGINEERING ON CAST MODELS WITH LASER SCANNERS, STRUCTURED LIGHT SCANNERS OR PHOTOGRAMMETRIC SCANNERS

This methodology probably is the most innovative from the last decade because with this systematic there is a try to obtain data from a simple traditional impression or with an intraoral 3D scanning.

This system is very little invasive for the patience (impressions are normally given to study the clinical case and to make prosthesis. This result in not being an addiction to normal practice, but it is show a better use of what dentists already do) and very good if the aim is to study the hard-soft tissue changes.

The use of 3D laboratory scanners has great repeatability and precision (Lehmann 2012) and are considered very good instruments to perform measurements.

The steps of this method are:

- Impression taking (in literature is done with different materials: alginate, polivinilsilossane and polyether);
- casting plaster models (this phase is typically made in dental laboratory);
- 3D scanning and creating a virtual model (called “mesh”);
- Evaluation with Computer aided instruments (normally Computer Aided Design software CAD or reverse engineering software).

I studied the articles made by Fickl 2008, Fickl 2009, Thoma 2010, Vanhoutte 2013, Schneider 2014 in which all passed from a traditional impression and after each one used different system to digitalize the model: Fickl and Thoma used the Sirona Cerec 3 intraoral camera, Vanhoutte use a 3Shape laboratory scanner and Schneider used an I-metric laboratory scanner too.

What varies most are the methods used for the successive analysis of 3D models that can be done with different systems:

- 2D Sections and with some landmarks some linear measure are taken;
- Area measure of the gingiva;
- Volume/area ratio that gives a linear measure that represents the medium distance among meshes.

The problem is that when other authors arrived to have the 3D models on the computer aligned together they don’t know what to do. A standardized procedure doesn’t exist, forcing professionals to find their own personal approach to measurements.

3.4 VAS: VISIVE ANALOGUE SCALE EVALUATION

This is a very simple way to obtain data of satisfaction of the implant therapy: using a simple scale from 0 to 10 the patient has to say, watching this scale, where the level of his satisfaction is between 0 (that is completely not satisfy) and 10 (completely satisfy). This procedure can be done both with patients and with clinician.

CAPITOLO 4. PLANNING OF A RANDOMIZED CLINICAL TRIAL TO OBTAIN DATA FOR THE ELABORATION OF THE NEW METHOD OF ANALYSIS

We have seen how many methods are been use in last years; it is necessary to identify a method that includes all these objectives:

- To Standardize
- To simplify
- To reduce human errors
- To increase the speed of elaboration of data

The phenomenon is very complex and there are so many variables to evaluate. I do not want to take care the aesthetic problems only. At the contrary, I think that clinicians need a method that could involve a simple and not invasive procedure and that can give them an objective analysis on volumes. Dentists need to understand if what they are doing is correct or if there is, for example, a different material or surgical technique that can lend to reach better results.
At the moment it is not possible to find such a method described in any document of scientific literature.

4.1 DESIGN OF THE STUDY

A randomized clinical trial with the collaboration of the odontostomatological clinic of Padua was planned. The aim of this study is to understand if an immediate implantation can preserve much more soft-hard tissue than a delayed one.
Sweden & Martina Company was the partner that gave for free to the clinic the materials:

- Premium Khono trasmucosal Implants (so called Premium Khono TG) of two diametres 3.8 and 4.2 (the choice was a surgeon choice depending from the width of alveolar process) and variable lengths (depending from the height of alveolar bone also this was a choice that had to be taken from the surgeon);

- Impressions materials: Sky putty and Sky light polivinilsilossane (two different viscosities to be able to perform a two stage impression).

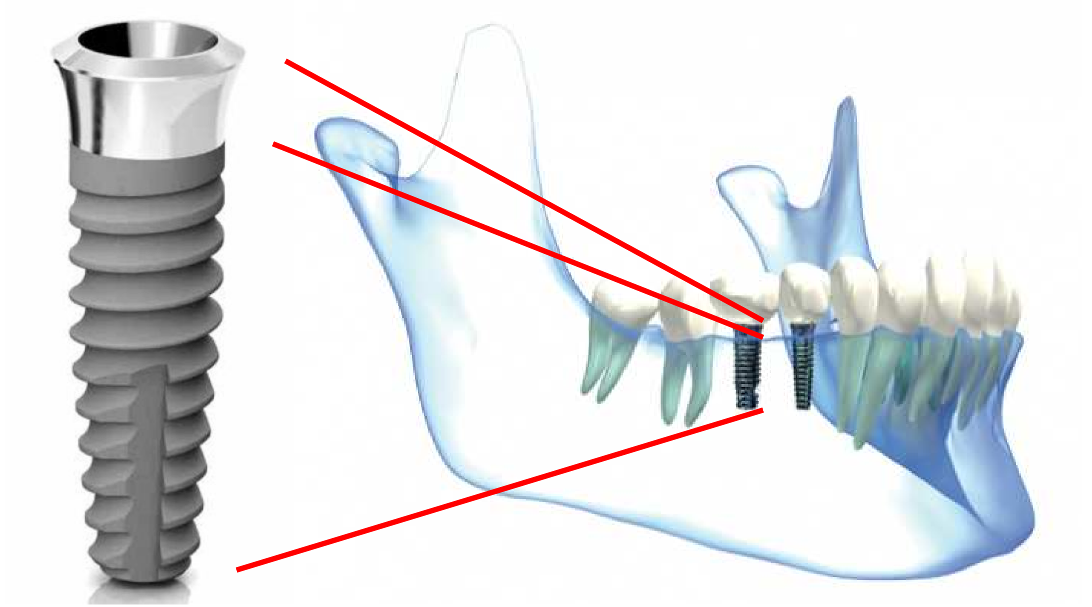


FIGURE 13 A SWEDEN & MARTINA PREMIUM KHONO TG IMPLANT WITH TREATED PART IN THE BONE AND THE SMOOTH COLLAR THAT HAVE A TRANSMUCOSAL POSITION

The aim of this study is to understand what happens to the alveolar bone in this two different clinical procedures, we know that alveolar bone maintains his tropism only if is functionally loaded, so the question is: can an immediate implant after extraction be a solution that can help in maintaining a bigger amount of alveolar bone and soft tissues than delayed implantation?

This question is still without answer yet, we need to wait till the study reaches its conclusion.

The patient was randomized casually to the test or control group.

To evaluate the volume changes the impression technique was chosen with successive 3D analysis on casts model. Some traditional measurements have been taken also with probes and photos.

All surgical procedures and impressions have been gathered by the same operators, Doctor Marco Caneva (DDS; ARDEC, Ariminum Odontologica, Rimini, Italy) and Doctor

Isacco Szathvary (DDS; PhD student at the department of industrial engineering university of Padua).

Nowadays more than 25 patience was treated but for different reasons lot of them became drop out of this study because they didn't came back to the recall or because other dental problems occurs and the mouth was hardly modified making the matching from the first impression to the second one impossible.

The study is still in progress, so I selected 10 patients, all coming from the same group (immediate implantation). I studied the patients to create a 3D method that can answer to the objective expressed in precedence.

Study design:

- Not loaded trans-mucosal implants of the same model for all sites (different length and 3.8 or 4.2 mm diameter);
- The implant will be located to the mesial-distal alveolar ridge crest level;
- Impression: polivinilsilossane material with individual tray always performed by the same operator.
- Measure the gap buccal and lingual / palatal via caliber;
- No fillers-grafts, no membranes (Covani 2004; Botticelli 2004; Botticelli 2008; Sanz 2010);
- If 14 e 24 elements (e.g. Premolars) have two roots, the implant will be placed in the palatal root or in the in inter-radicular septum;
- Temporary crown not mucous-compressive.

FIGURE 14 EXAMPLE OF CONNECTION BETWEEN FIXTURE AND CROWN ON PREMIUM KHONO TG: ABUTMENT FOR CEMENTED CROWN (ON THE LEFT) OR BALANCE BASE PILLAR FOR OVERDENTURES (ON THE RIGHT) AND HIS SCREWED RETENTION SYSTEM

4.2 SELECTION OF THE PATIENTS

Patients were selected following extremely rigid criteria.

Inclusion criteria:

- Single maxillary incisors, maxillary canines and premolars, mandibular canines and premolars requiring mandibular implant-prosthetic rehabilitation
- Presence of the adjacent teeth to the extraction site
- Age greater than or equal to 18 years
- Final restoration cemented or screwed (fixed prosthodontics)
- Tolerance to the normal surgical procedures (ASA 1)
- Consensus to the participation to the study

Exclusion criteria:

- Infected extractive sites;
- Patients with extraction sites where there is an impaired vestibular cortical bone (due to the anatomy or an artifact defect made during extraction);

- Sites with alveolar compromise;
- Patients for whom implant therapy is contraindicated;
- Uncontrolled diabetes;
- Bone disorders (Paget's disease, osteoporotic patients on bisphosphonate therapy, multiple myeloma, bone metastatic tumor localization);
- History of radiotherapy in head and neck;
- Need for systemic corticosteroid therapy or other therapies that could compromise the health postoperative;
- Inability to return at follow-up, or inability to complete the study procedures, in accordance with the rules of the investigators;
- Patients who are pregnant and / or breastfeeding;

The selection of the patients represents a very important phase that need not to be underestimated. To have a good data output to perform a three-dimensional evaluation some important points need to be respected very strictly:

- Presence of adjacent teeth aside the interested area (we have seen that if there isn't one tooth near the studied area there will be a bigger volume loss, this is due to the continuous bone remodeling where the tooth was extracted);
- The teeth that are chosen need to be similar in size: inferior incisors are too little and molars are very big (so possible groups to compare are: molars with other molars and premolars, canine and upper incisors together, inferior incisors with inferior incisors);

4.3 SURGICAL PROCEDURE

For the patient that was selected, after the surgical procedure of extraction, a randomization occurred to decide if that patience was delayed or immediate implantation.

If the patient was selected for an immediate implantation, the surgical operation was performed immediately after the extraction. If it was chosen for a delayed treatment it required 3 months of healing were required before the implantation was performed.

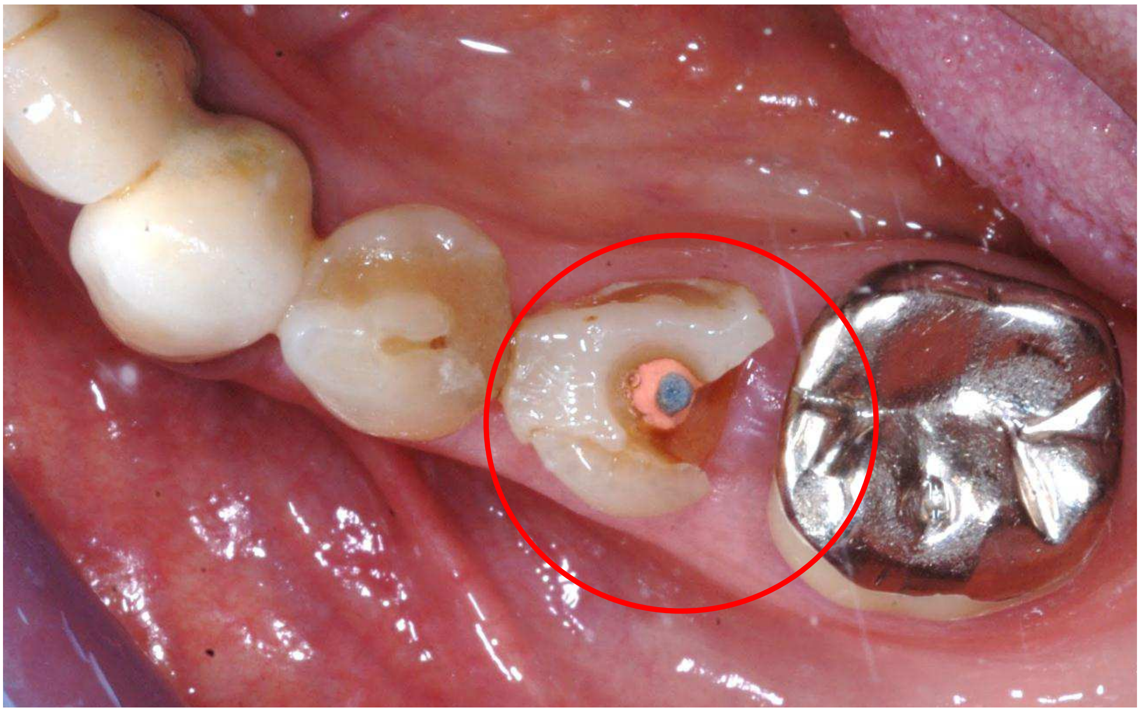


Figure 15 Occlusal view of 45 element that has a vertical fracture and needs to be extracted

Figure 16 Vestibolar view of 45 element

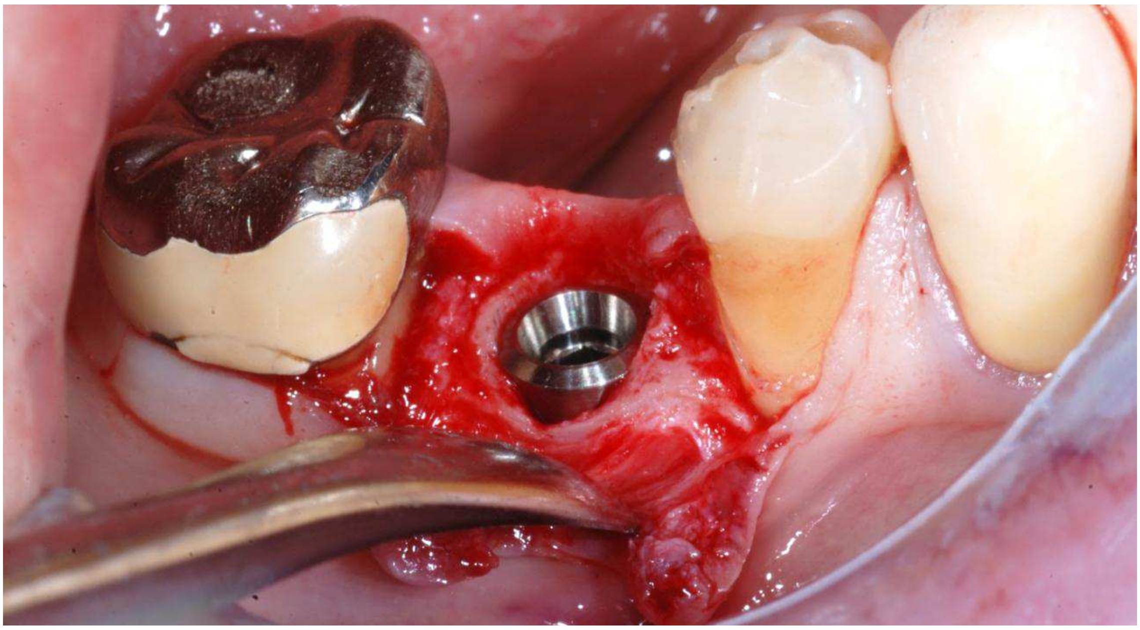


FIGURE 17 VESTIBULAR VIEW OF THE IMMEDIATE IMPLANTATION (OUTSIDE OF THE BONE THERE IS ONLY THE SMOOTH NECK OF IMPLANT)

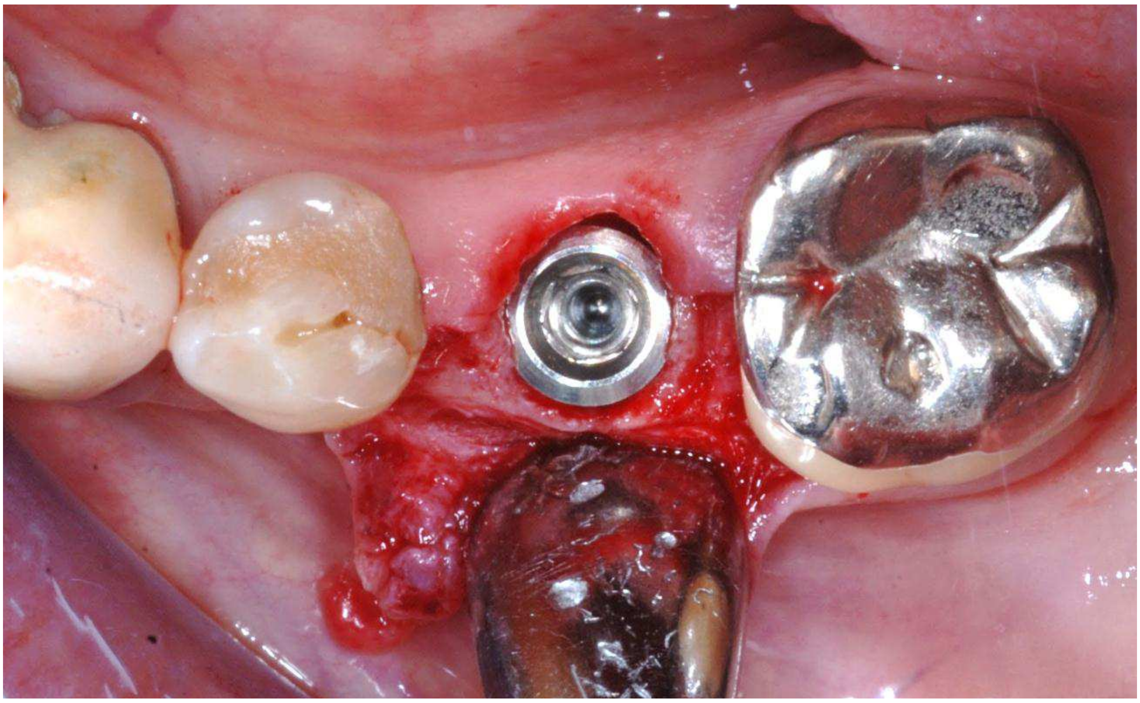


FIGURE 18 OCCLUSAL VIEW OF THE INSERTED IMPLANT IN 45 POSITION

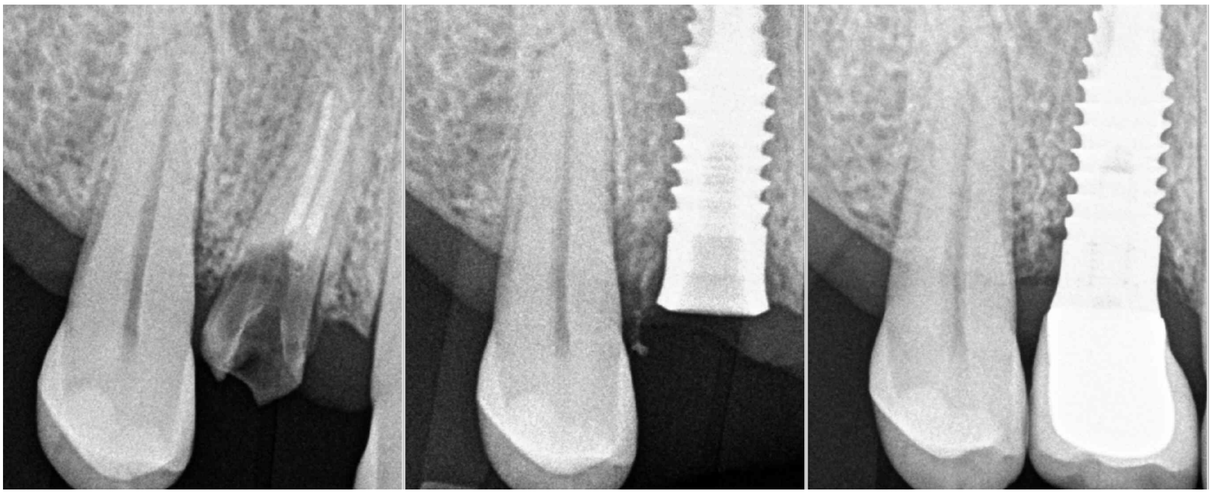


FIGURE 19 EXAMPLE OF RADIOGRAPHY OF THE CLINICAL STEPS FROM THE START TO THE CROWN IN FUNCTION

If the treatment was involving a first upper premolar (14-24 elements) the implant should be placed centered or if there isn't enough bone in the septum the implant will have to be put in the palatal root place.

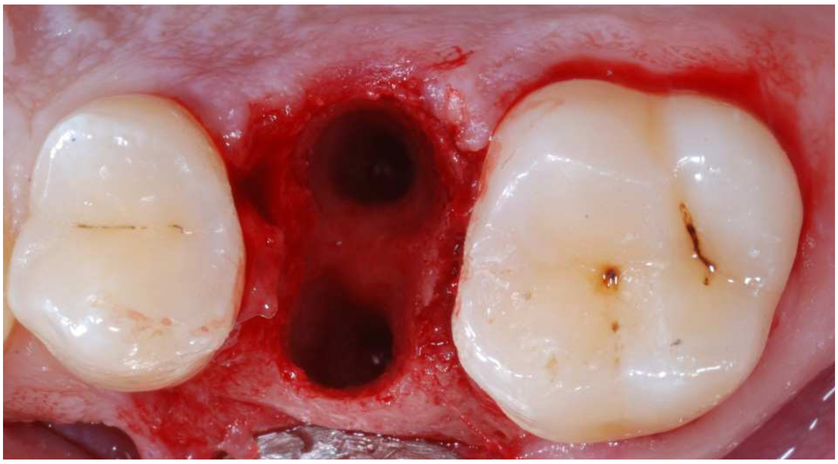


FIGURE 20 EXAMPLE OF FIRST UPPER PREMOLAR ALVEOLUS WITH TWO ROOTS PLACES

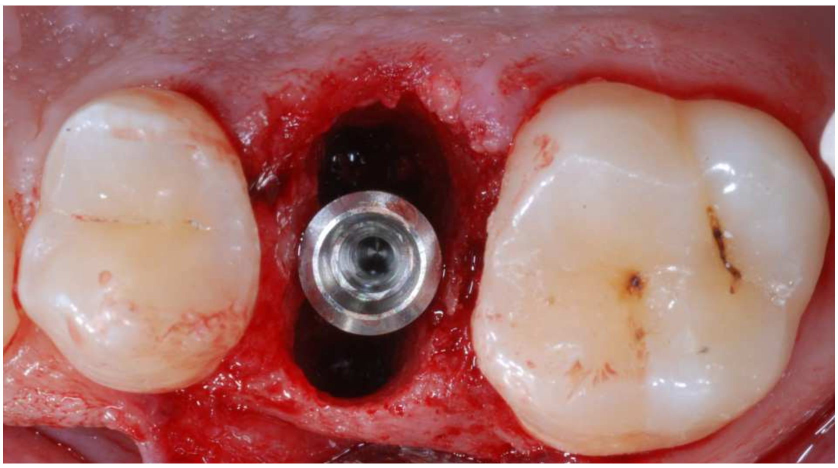


FIGURE 21 IMPLANT CENTERED IN THE MIDDLE OF THE SEPTUM BONE

4.4 IMPRESSION TECHNIQUE

The impression in this technique plays a key role: during this phase the operator should not make any error or he risks that it can affect the accuracy of the next measurements.

During this phase, the operator must pay absolute attention.

From our tests, we opted for a bi-phase impression technique using a polivinilsilossane.

This method gave us better results on vestibular and palatal/lingual areas than mono-phase impression technique did.

First impression was made with a high viscosity polivinilsilossane (Sweden & Martina Sky-putty), the impression was then run down to give at least 1 mm of space to the light viscosity material with whom was taken the second phase of impression (Sweden & Martina Sky-light).

FIGURE 22 FIRST IMPRESSION MADE WITH SWEDEN & MARTINA SKY-PUTTY (IMAGE COURTESY DOCT.

FIGURE 23 THE FIRST IMPRESSION WAS RUN DOWN PROGRESSIVELY TO GIVE SPACE FOR THE LIGHT VISCOSITY MATERIAL

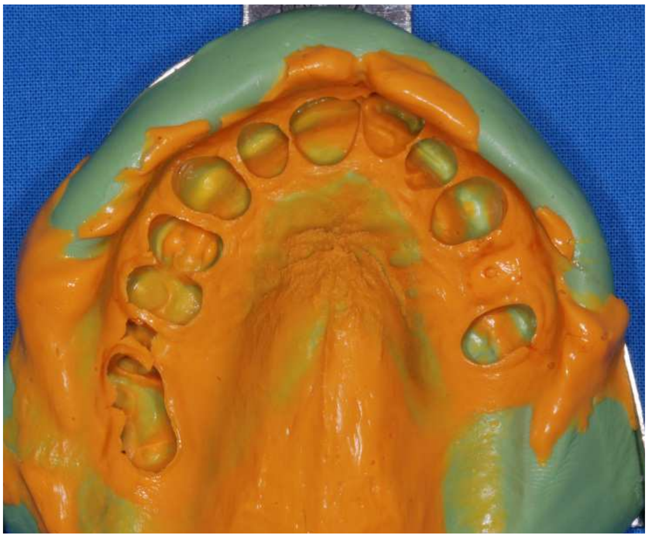


FIGURE 24 THE SECOND PHASE OF IMPRESSION TAKEN WITH LIGHT VISCOSITY POLIVINILSILOSSANE OF SWEDEN & MARTINA CALLED SKY-LIGHT

Special attention should be paid to the deformations of the impression that may occur for excessive speed during the impression, it is useful to remind the operator that the positioning in the patient's mouth have to be very slow and once is reached the proper position must be maintained stable not to deform the impression material during the plastic phase of the polymerization.

Once removed the spoon from the mouth, is necessary to check and make sure that the impression material is penetrated properly in buccal vestibule and there are no lack of material in areas of interest.

The teeth must be perfectly reproduced because, even if they are not of primary interest, they are critical for the superimposing of the two models together in the next phase, during virtual processing and elaboration.

It is important that the upper lip is not pinched between the tray and the teeth position losing the vestibular information from the cast model and close attention must to be put for the position of the tongue while the impression tray is lowered.

The impressions are performed in conditions of absence of bleeding and in conditions of absence of gingivitis, both of these conditions may alter the footprint creating volumetric changes that are artifacts and not present in reality.

To make an accurate impression is necessary to execute them before any clinical procedure.

Anesthesia itself could to alter the volume of the soft tissues altering the procedure.

Probably this is the most important phase of all three-dimensional evaluation and it have to follow these steps:

- Impression performed always by the same operators;
- The use of dual impression technique is recommended, the mono-phase impression is a very good technique when we are interested on the representation of teeth, but when we are interested on soft tissue with this technique we had problems because there is an increasing of defects probably due to the fast movement of light materials on heavies ones during the impression making. A by-phase impression technique reduce this problems giving a better representation of soft tissues;
- When the impression reach the position is important to keep a static position with no-load on it or an elastic deformation can occur.

CAPITOLO 5. LABORATORY PROCEDURES

5.1 PLASTER CAST AND CREATION OF SOLID MODEL

During this phase, which usually is performed in a dental laboratory, it is very important that the models are cast with plaster mixed in the correct ratio with water under vacuum, to avoid the formation of air bubbles.

Is not necessary a specific gypsum, just a third class gypsum any. The important thing is that the gypsum used by the dental laboratory is the right one to be scanned by the same laboratory with an optical scanner 3D (laser or structured light). In our research we used Lascod third class gypsum (Lascod SINGLETYPO 3 yellow LASCOD Spa Florence Italy) and Dentalwings laser scanner (Dental Wings Inc. Montreal Canada) to make the reverse engineering of the cast models.

Normally the optical scanners that are in dental laboratories are calibrated on plaster normally used in the laboratory itself. It would be better that the plaster models are scanned without the need to be further matted with a scan spray that can adversely affect the precision of the model. Detailed instructions shall be provided to the dental laboratory to properly preserve vestibular and palatal/lingual areas: the laboratory normally pays very little attention to palatal / vestibular areas because there aren’t any interests during normal prosthetic procedures that are not applied to these areas.

During squaring procedures of the plaster models, the dental mechanic must preserve palatal and vestibular zones, and the clinician has to tell the laboratory this thing or probably the problem of the alteration of vestibular or palatal zones can occur for an error.

5.2 3D SCANNING OF THE PLASTER MODEL

The model thus prepared must be read by an optical scanner or laser structured light. The file must be exported in STL format (Standard Triangulation Language) and prior to export is necessary to check that there are no missing parts (big holes), if the mesh should not to be complete is necessary to perform additional scans until all parts that interest to us are visible in the monitor.

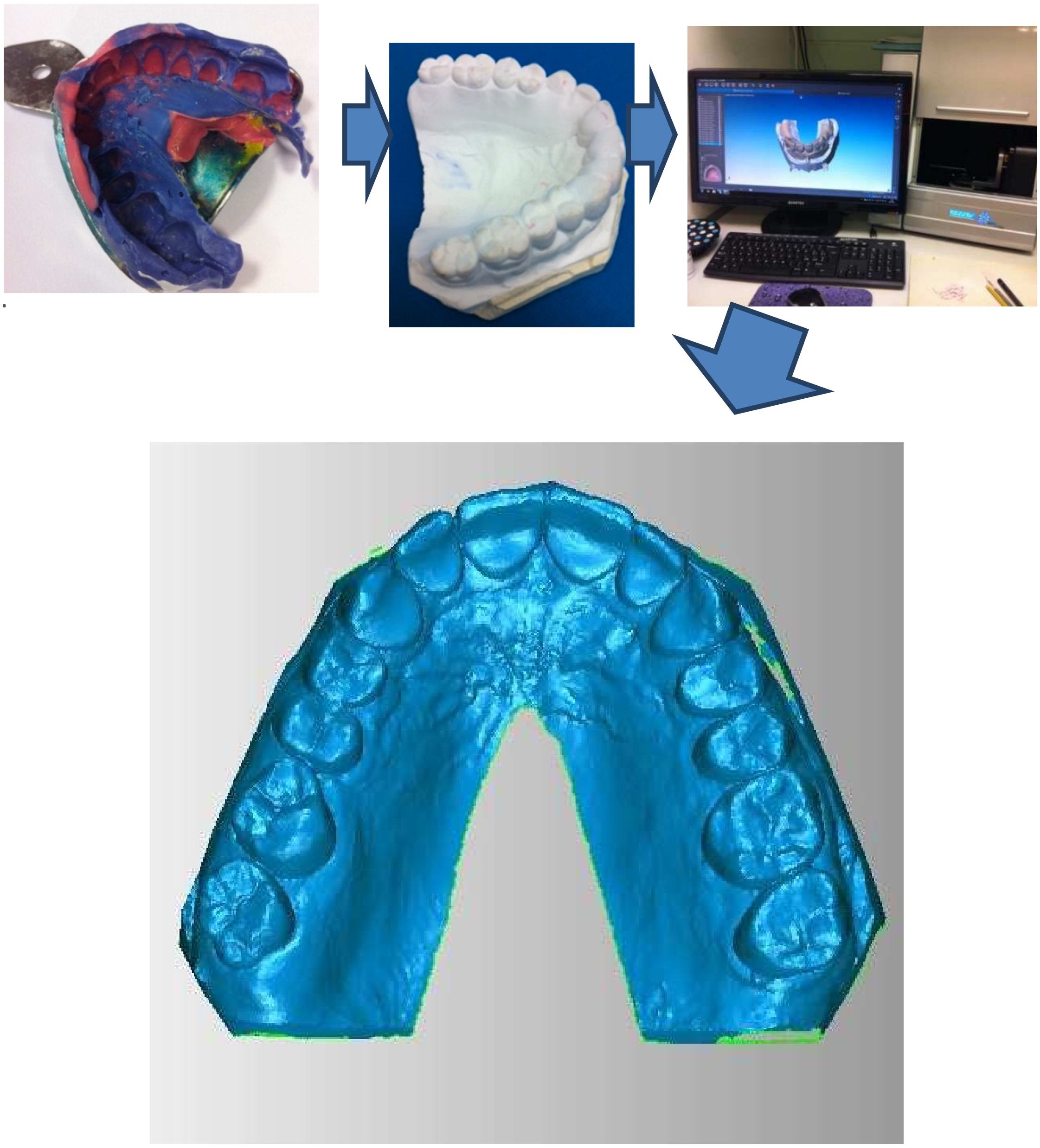


FIGURE 25 THE LABORATORY FLOW: FROM IMPRESSION TO PLASTER CAST MODEL TO VIRTUAL 3D MESH

6.1 3D MESH ELABORATION

The mesh in .STL format has been imported in a software called Geomagic (Geomagic Gmbh).

The utility called "mesh doctor" was used to clean the mesh from defects like small holes and tunnels, non-manifold edges, spikes, self-intersections, highly creased edges and small components.

I often had the problem that there were some parts of the scanning support in the exported mesh. This big components must be cleaned by the operator, because the software is not capable of dividing the parts involved in the model and those who are not.

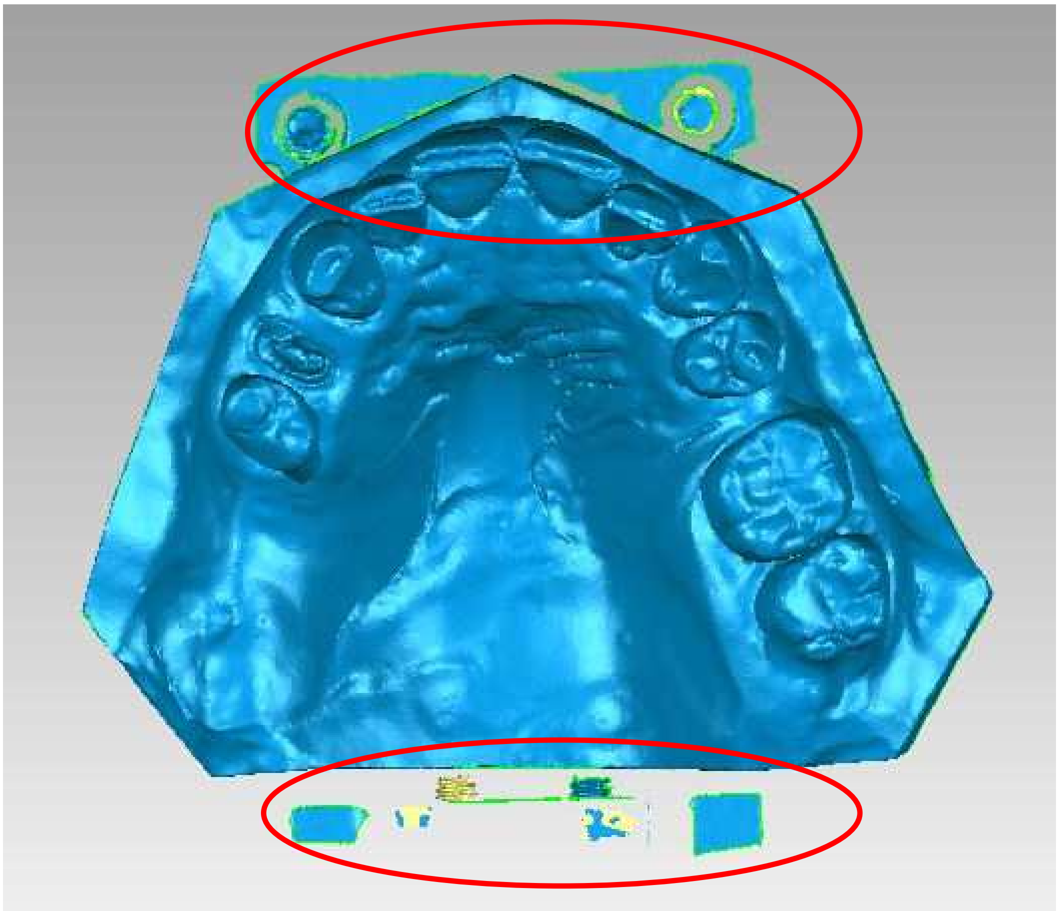


FIGURE 26 EXAMPLE OF RAW MESH (HOW COMES OUT FROM SCANNER SOFTWARE) THAT NEED TO BE CLEANED BY HAND (THE SCAN OF SUPPORTS IS IN THE RED CIRCLES)

When the mesh is clean from defects must be transformed in a solid, this will allow us to use some Boolean operator in the successive procedures.
In Geomagic software exists a tool that allows you to create bridges between two parts of the mesh. With this tool, is possible to create bridges that define smaller areas that are then easier to be close with the hole closing tool.

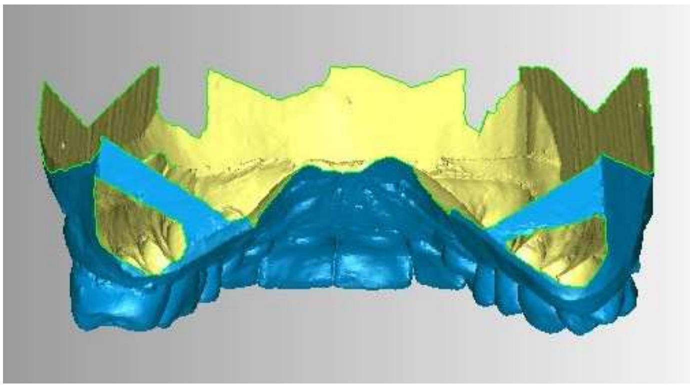


FIGURE 27 EXAMPLE OF BRIDGES CREATED DISTALLY TO CLOSE THE SURFACE

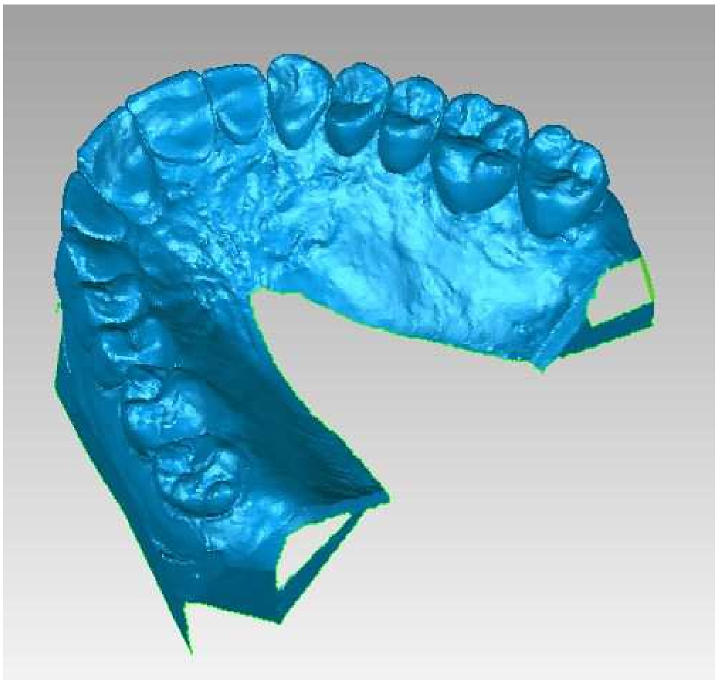


FIGURE 28 PROSPECTIC VIEW OF THE MESH BEFORE HOLE CLOSING TOOL

By performing these bridges on the mesh will allow the software to have a margin of error lower in the generation of surfaces missing: the holes so defined must be closed with the tool to close the holes in tangent with the curvature of the surrounding mesh.

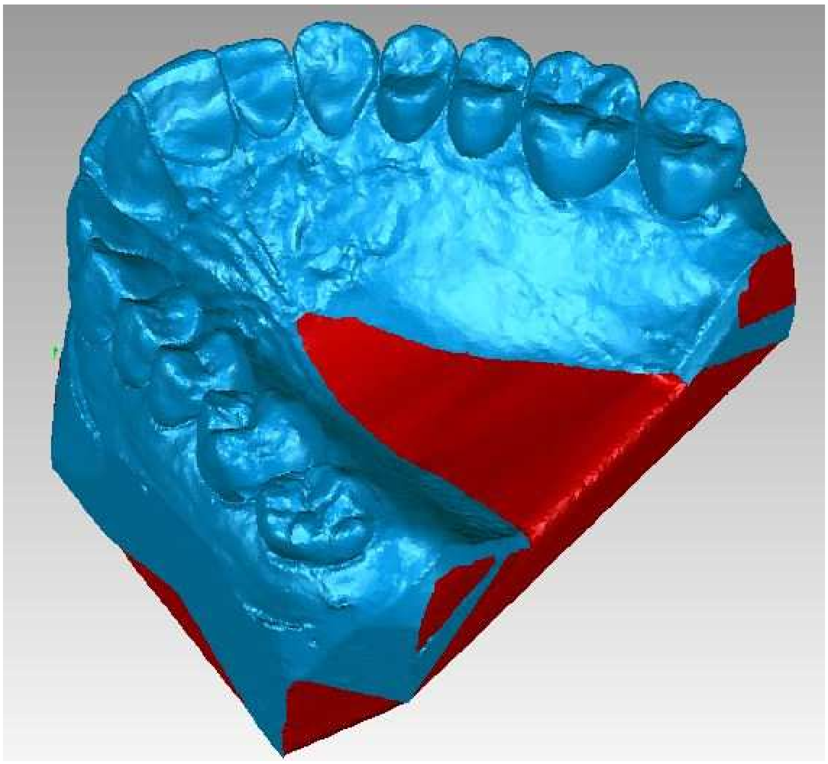


FIGURE 29 IN RED IS VISIBLE THE PART OF THE MESH THAT HAS BEEN CLOSED BY THE HOLE CLOSING TOOL

6.2 3D SUPERIMPOSION

When for the same clinical case are present both models (first impression model like reference and second impression model like test) we can proceed in the alignment procedure of the mesh.

Following Vanhoutte et al. 2014 the superimposition value have to be less than 0,1 mm.

In order to get a superimposing medium value better than 0.1 mm is necessary to be very careful during the selection process of superimposing area on the first model to align correctly the two meshes:

- Select only the teeth that haven't changed between the first and the second impression (check the patient's medical record and see if in the meantime were performed fillings or other prosthetic work to the rest of the teeth), If changes are located in a little area is easy just don't use them for alignment, but if the treatments are more extensive then the case need to be considered a "drop out" and the patient will be removed from the study;

- Clear from the selection the interproximal areas between the teeth: in these areas both the impression material and the optical technique of scanning during the phase of reverse engineering are insufficiently precise, then these areas must not be used for the alignment;
- The tooth used as a test of the study must be deselected because often the tooth is present both on the first impression (in several clinical cases the cause of the treatment was a vertical fracture of the tooth) that on the second impression as prosthetic crown;
- All areas where are visible in the dental impression some defects (or in the plaster model) should be cleared from selection, for example, bubbles of the impression, bubbles during casting, deformations etc. must be recognized by the operator and deselect them during alignment phase.

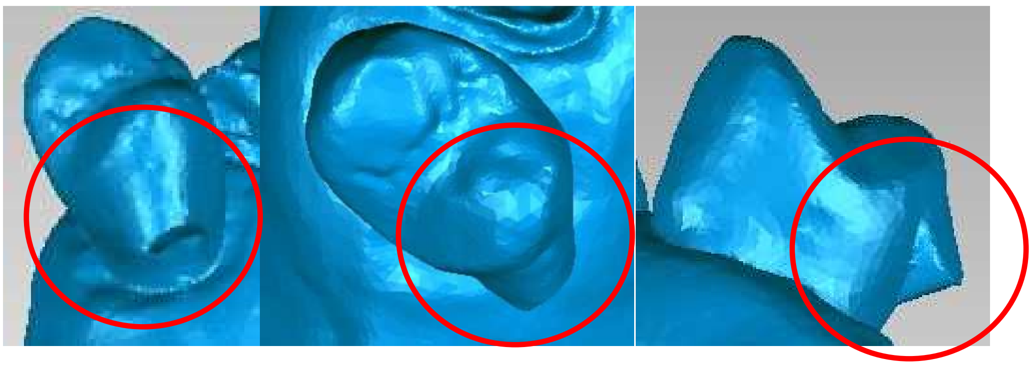


Figure 30 Example of deformation of impression

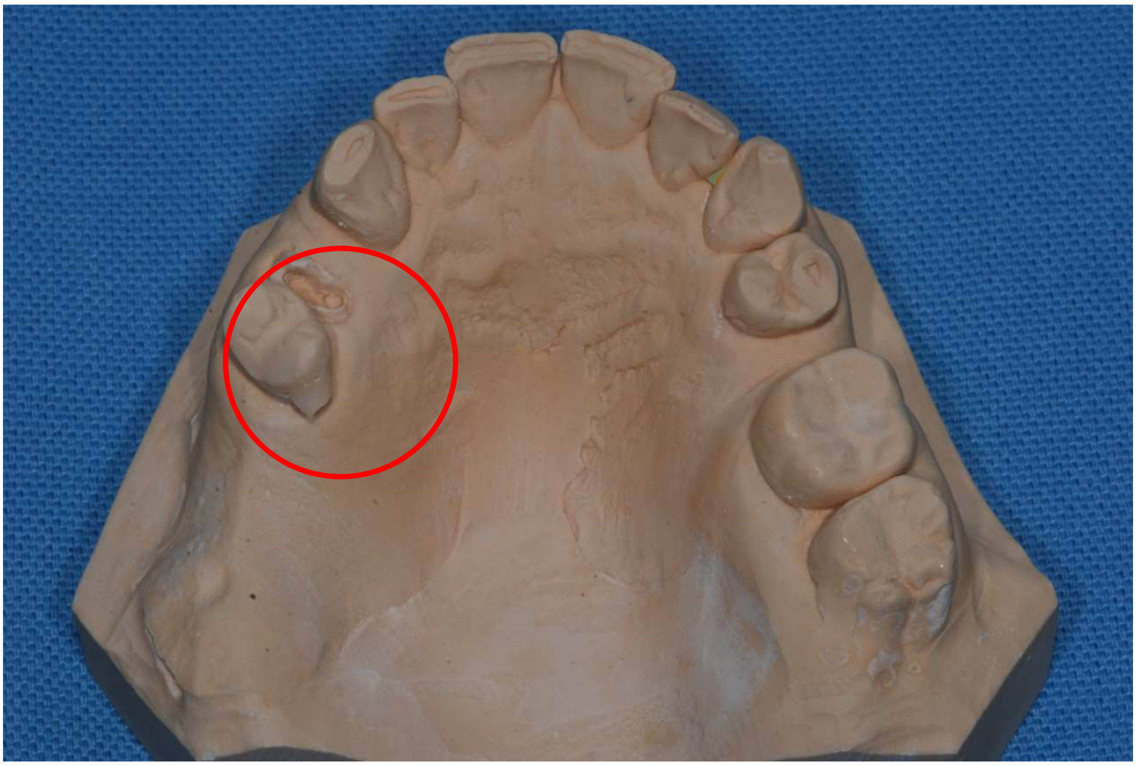


Figure 31 in the red circle there is the tooth before scanning showed in Figure 30

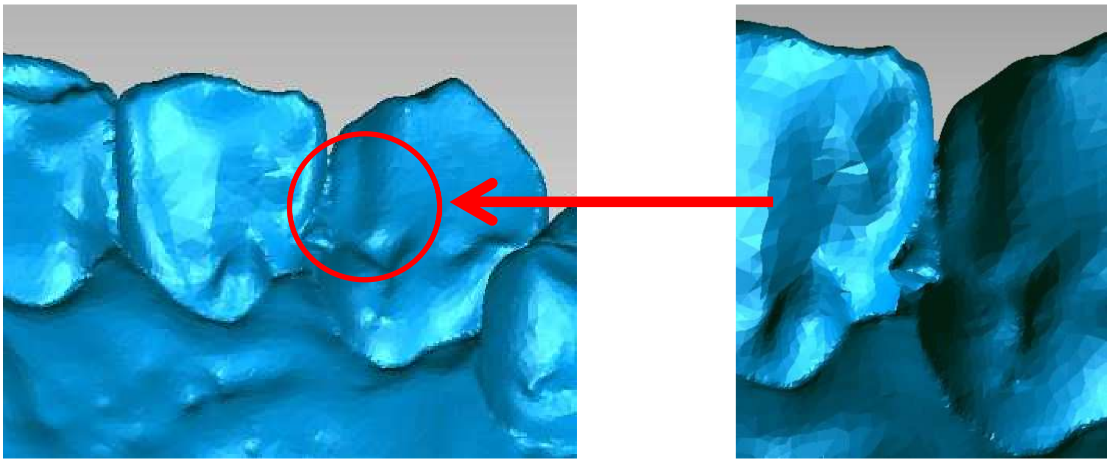


Figure 32 Example of artifact in the interproximal area and it's magnification

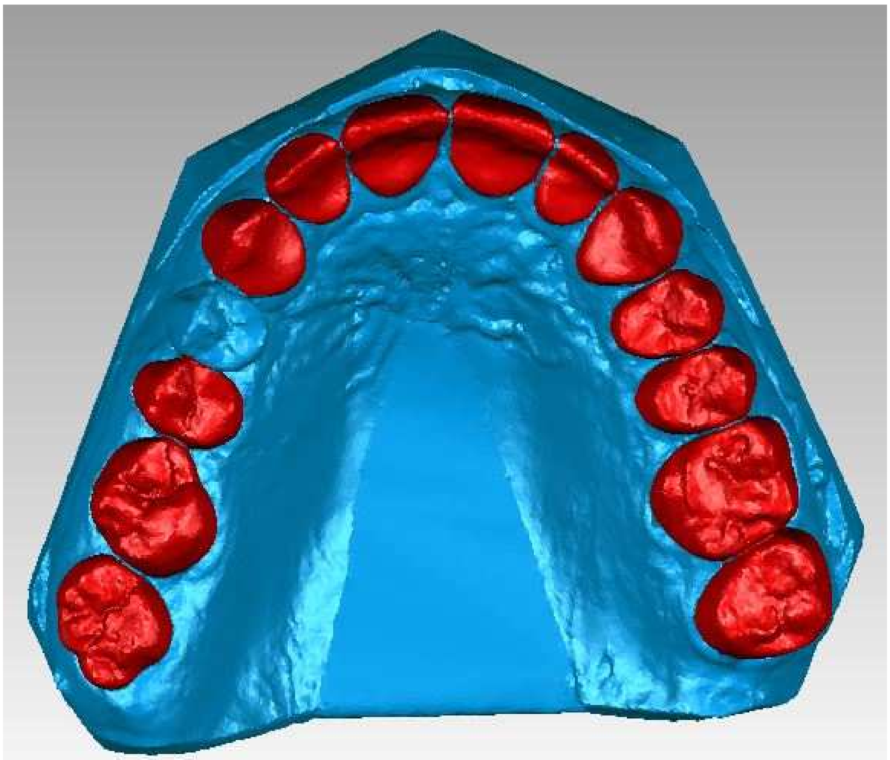


FIGURE 33 IN THIS CLINICAL CASE THE TEST TOOTH IS THE **14** ELEMENT THAT IS NOT SELECTED AND DO NOT HAVE TO BE USED DURING THE SUPERIMPOSITION PROCEDURES

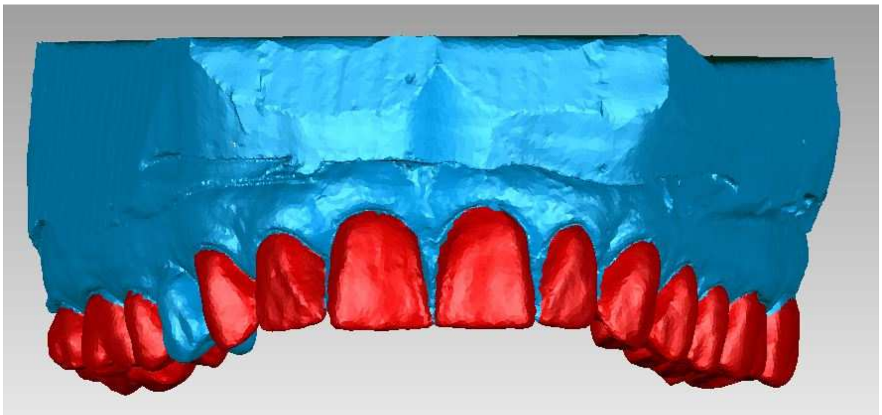


FIGURE 34 FROM THE FRONTAL VIEW IS VISIBLE HOW INTERPROXIMAL AREAS WAS NOT SELECTED TO ALLOW A BETTER REGISTRATION AMONG MESHES

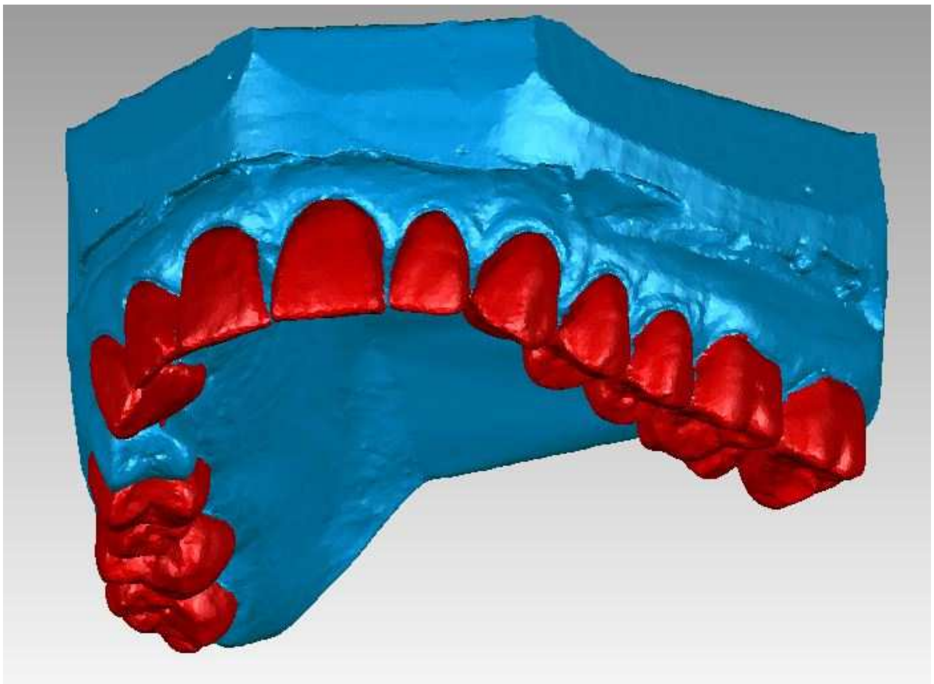


FIGURE 35 ISOMETRIC VIEW OF THE SAME MODEL

The alignment was done in Geomagic software selecting the first mesh as REFERENCE and second mesh as TEST by clicking the right mouse button on the model manager at the left side.

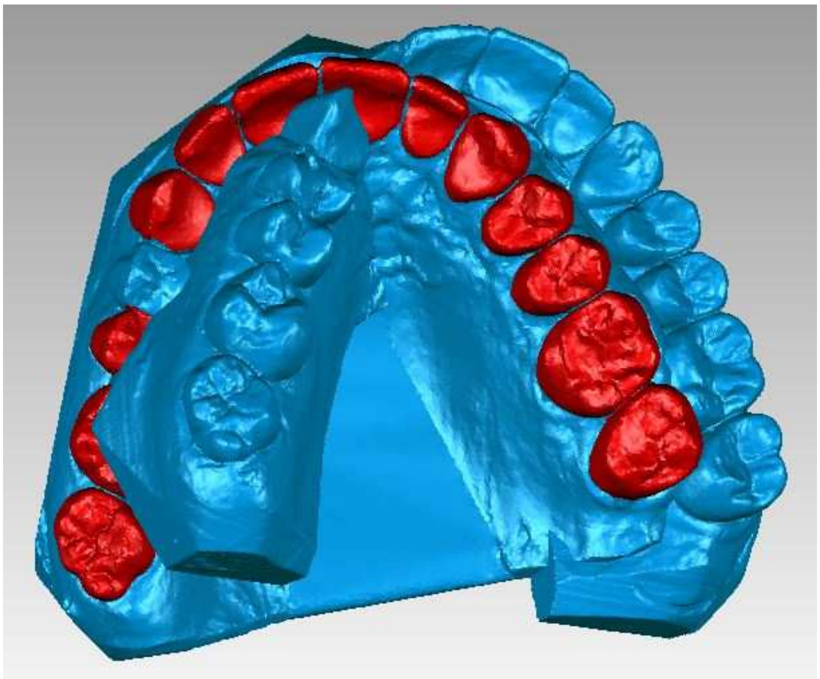


FIGURE 36 THE TWO MESHES TOGETHER BEFORE REGISTRATION

When reference and test are set, both meshes need to be selected pressing ctrl + left mouse button and then on the Alignment menu the manual registration is the button to press.

I used a 3 point alignment at first for positioning the two meshes close together in a good position to make after a global registration of all selected points.

The global registration need to be performed three times, normally at the third time, I reached the best superimposition value at all, repeating more and more won't make it better than three times do.

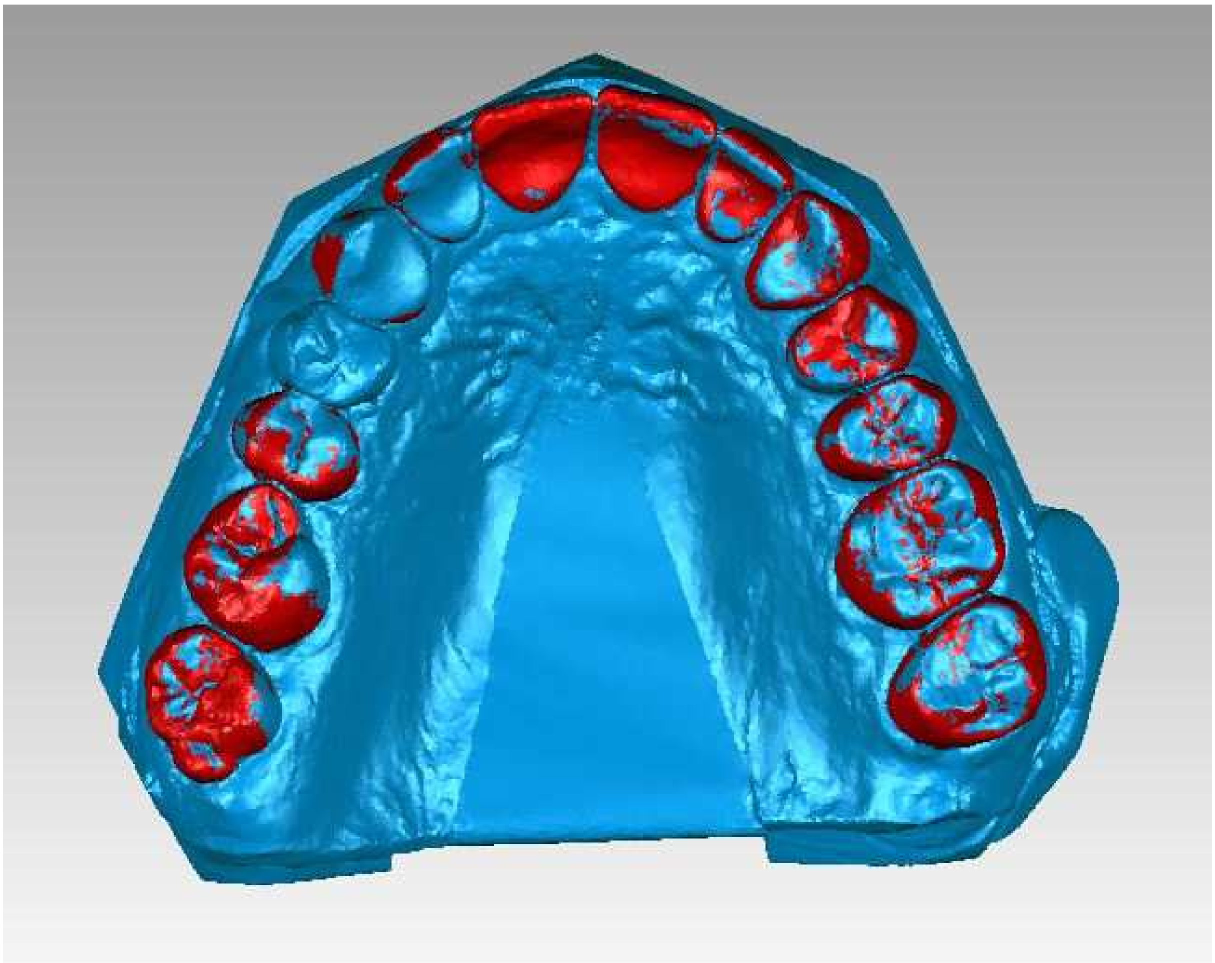


FIGURE 37 THE TWO MESHES SUPERIMPOSED AFTER REGISTRATION

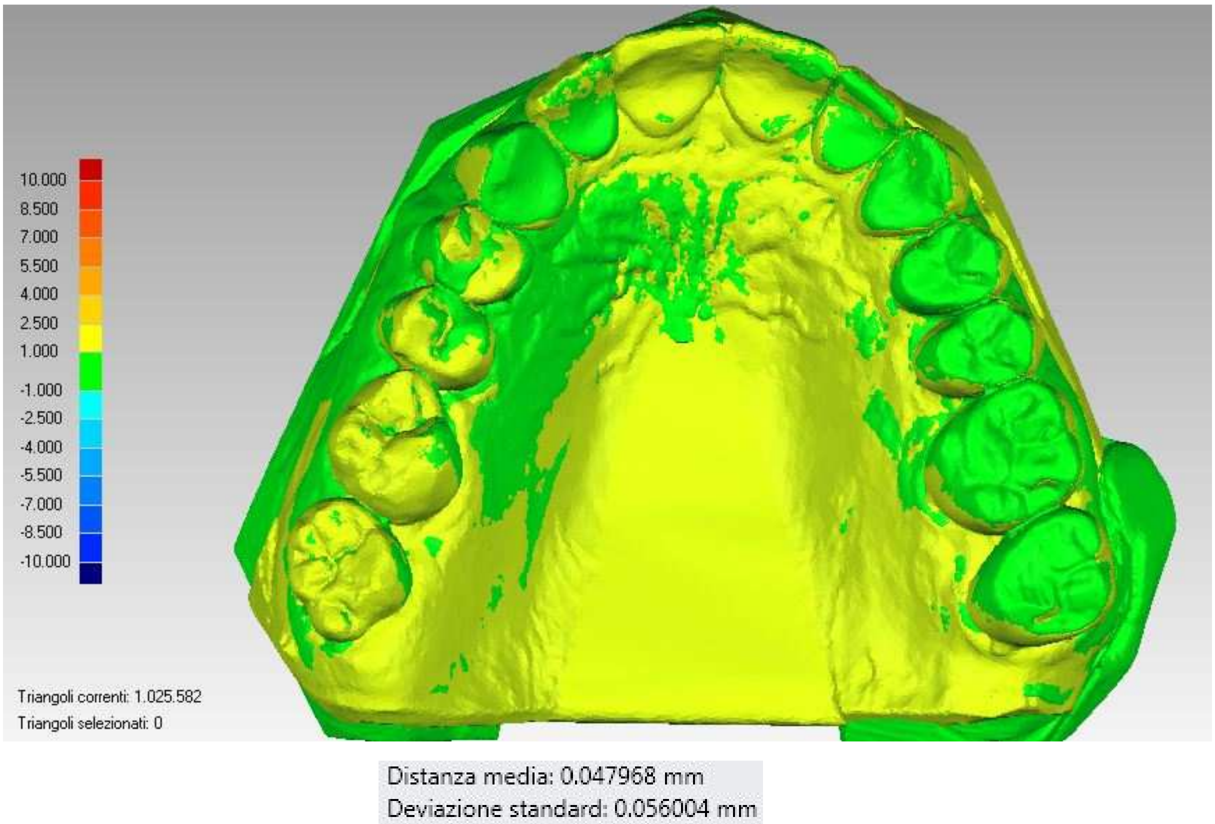


FIGURE 38 EXAMPLE OF VERY GOOD ALIGNMENT THE MEAN VALUE IS 0.048 MM

If the value is not good as needed (<0.1 mm) we have to make a step backward and to check if we selected something wrong in the superimposition area.

If all precedent points have been followed in a correct way, this means that probably the impression has a tridimensional deformation that can depend from a compression during transport, or incorrect storage or the impression was not kept stable during the plastic phase inside of the mouth and it deformed permanently.

In this last case we have to check if is the first or the second impression that is deformed and if is the second the solution is to re-call the patience and make it again, if was the first we have to discard this clinical case from the analysis.

In

Table 1 is possible to see the medium value where the program found a convergence on the average distance of points:

TABLE 1 SUPERIMPOSION MEDIUM VALUE IN OUR 10 CASES

Patient code	Convergence Average Distance [mm]
2	0,071
4	0,080
6	0,087
12	0,064
13	0,075
18	0,091
19	0,048
23	0,092
25	0,047
26	0,063

CAPITOLO 7. 2D ANALYSIS

The two mesh aligned are imported into Rhinoceros Software, it was decided to use this software for the bi-dimensional analysis because it is very versatile.

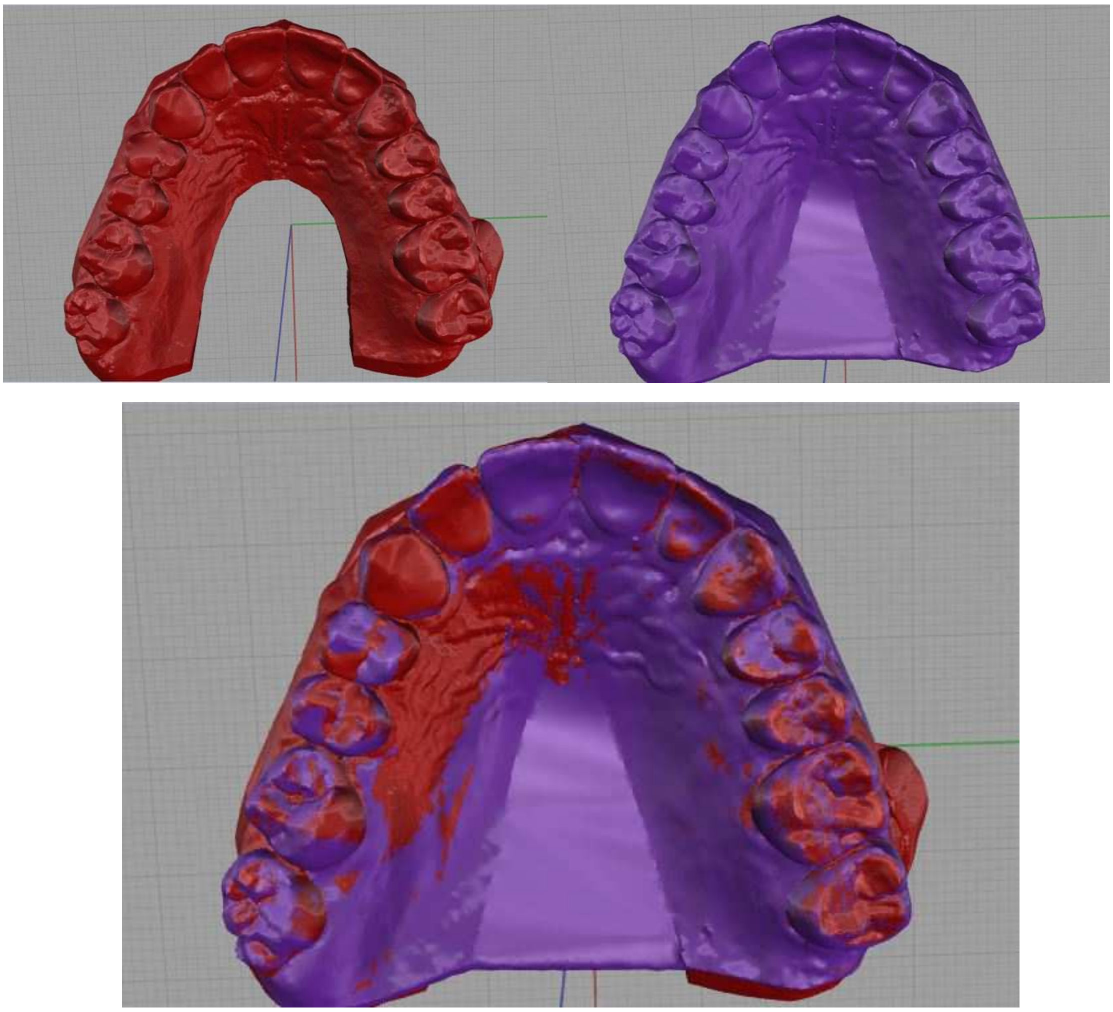


FIGURE 39 TOP LEFT WE HAVE THE FIRST MESH, TOP RIGHT THE SECOND MESH AND IN CENTER THE TWO MESHES ALIGNED TOGETHER

Despite Rhinoceros has a limited capacity of tri-dimensional analysis as a native software, it has an excellent versatility in the programming by Rhino-python scripts with which you can create macros that can automate a part of the process.

The ability to automate is a goal of primary importance for us because it increases the repeatability of the measurement allowing better results with a higher comparability with the work done by other research teams and this answer to the necessity of standardization that is one of our goals.

The bi-dimensional analysis was performed (according with Vanhoutte et al. 2014) using like referral plane the occlusion plane. From this plane, a perpendicular plane in lingual/palatal-vestibular direction was created and the two meshes superimposed were cut. They cut the model with the vertical planes in the center of interested area, 3 mm mesially and 3 mm distally; the measure was taken with the intersection of horizontal planes that was created parallel to the occlusion plane at level -3, -5 and -7 from the gingival line in the center of the test tooth.

The save values like Vanhoutte et al. was used to measure the models of a Swedish study in which we had about 30 cases to analyze and we observed that the horizontal plane at level -7 was too down, was not on keratinized gingiva so was susceptible of high variability also during the impression time.

Only keratinized mucosa is suitable to perform the measure, the free gingiva is too variable on impression depending from the compression strength during the impression making.

For this reason to study a lower level of -5 mm is wrong because keratinized gingiva is about 5 mm wide from teeth.

I asked myself… what happen in the first 3 mm of gingiva? Why we have to measure starting from -3?

So the Grid that was used to section the meshes at the end was so made:

- Vertically: 7 vertical planes (+3; +2; +1; 0; -1; -2; -3) from mesial (+3) to distal direction (-3);
- Horizontally: 6 horizontal planes (0; -1; -2; -3; -4; -5) from most coronal (0) to the most apical (-5).

A total of 42 points for horizontal variation for each side was tested: 42 at the buccal side and 42 at the lingual/palatal side.

The vertical variation was measured in 7 points at the buccal side and 7 point at the palatal-lingual side.

To perform the bi-dimensional analysis 3 rhino python scripts was generated at the department to make more fast and accurate the measures.

7.1 RHINO-PYTHON SCRIPTS

Three Rhino-python scripts was generated to perform the bi-dimensional analysis:

- Referral plane: the occlusal plane;
- Slicer: from the referral plane a series of cuts sectioned the two meshes;
- Distance: from cut-section to a measure in mm.

7.1.1 REFERRAL PLANE

The first script permits to generate a plane from the occlusal surfaces of teeth.
After running the script, the software asks you to select the points of the occlusal surface, to prevent a human error of the selection of some vertexes that aren't a part of the surface on the script was added a selection option that allows the operator only the selection of the vertexes of the mesh in the direction of the view of that moment (Rhino itself normally permit the selection also of points under the surface).
I choose to select one point for each tooth, so normally is about 12-14 points per mesh.

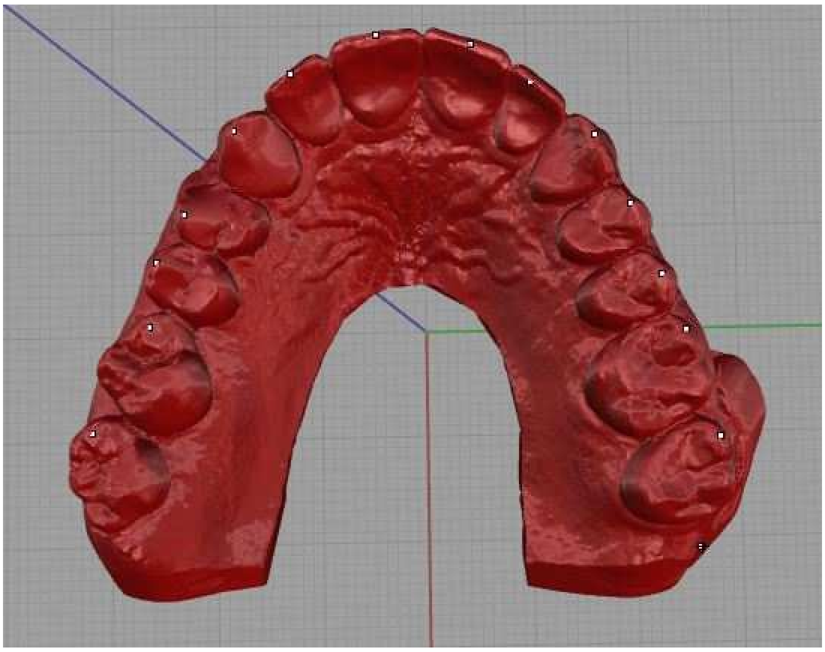


FIGURE 40 SELECTION OF POINTS THAT WILL GENERATE THE OCCLUSAL PLANE

When the points are selected (if you take a wrong point the script allows you to deselect with ctrl-left button mouse) right-click with the mouse or enter and the script generate a plane that is the medium plane that intersect all these points.

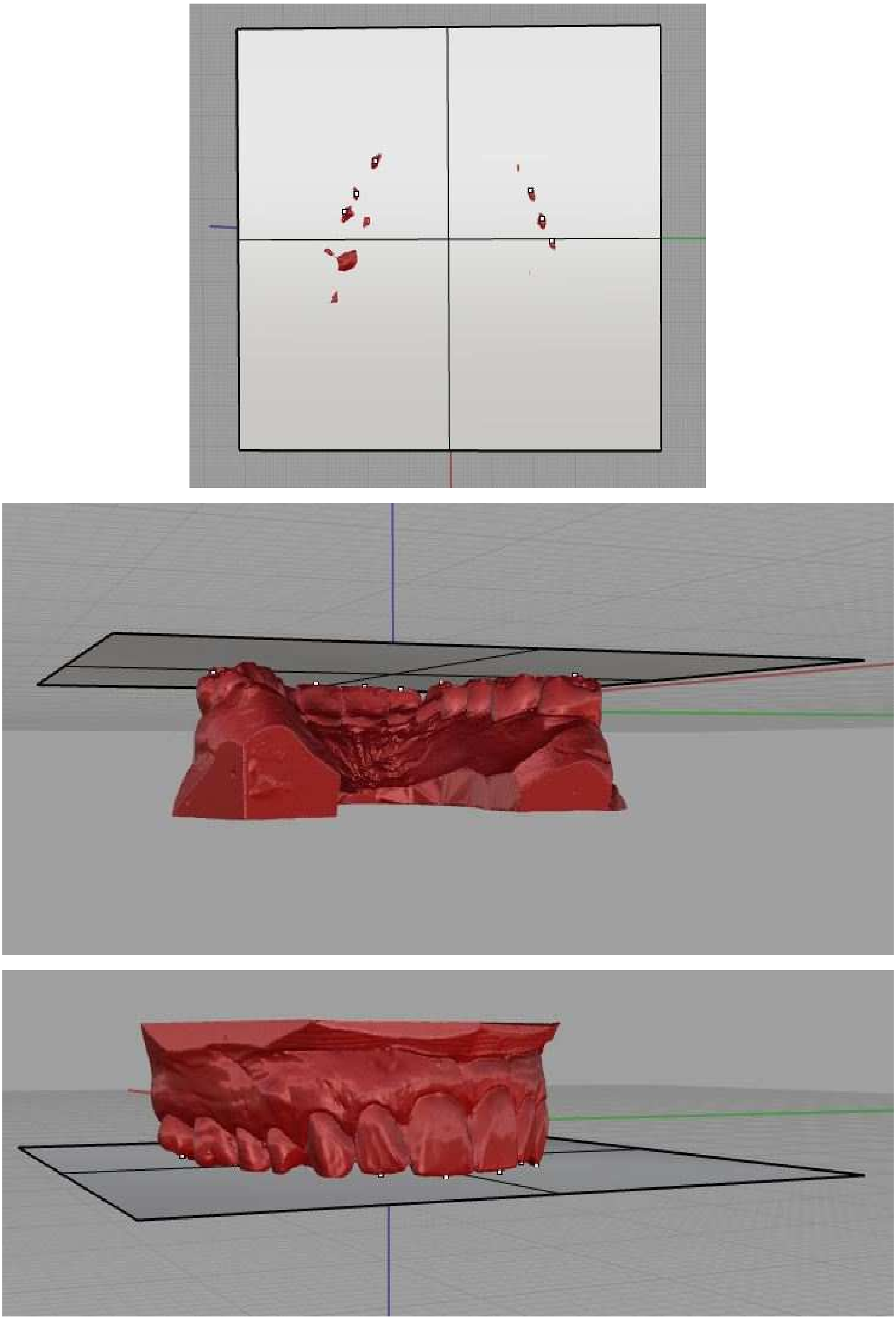


FIGURE 41 DIFFERENT VIEWS OF THE OCCLUSAL PLANE

7.1.2 SLICER

This second script after running asks you to select the first mesh and the second mesh, when it's done it asks you to select two points that defines the lingual/palatal- buccal direction for the vertical planes.
I choose two points that was located immediately apically of the clinical crown of the tooth in a centered position mesio-distally.

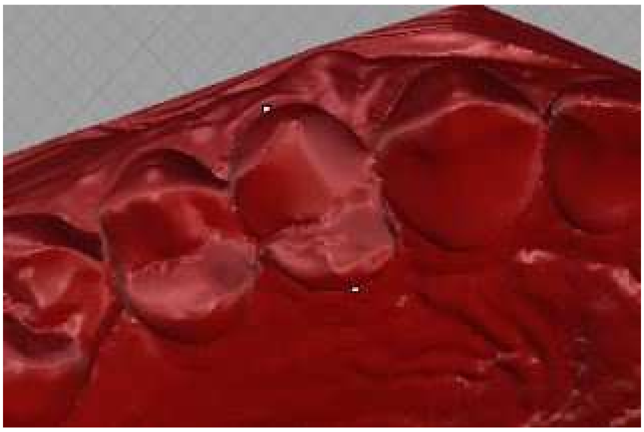


FIGURE 42 THE TWO POINTS THAT IDENTIFY THE VESTIBULAR-PALATAL DIRECTION

When the two points of the direction are selected, right-click or enter and the script generate the 7 vertical planes, the 6 horizontal ones and create on separate layers all the sections (verticals and horizontals) and at the intersections generates points.

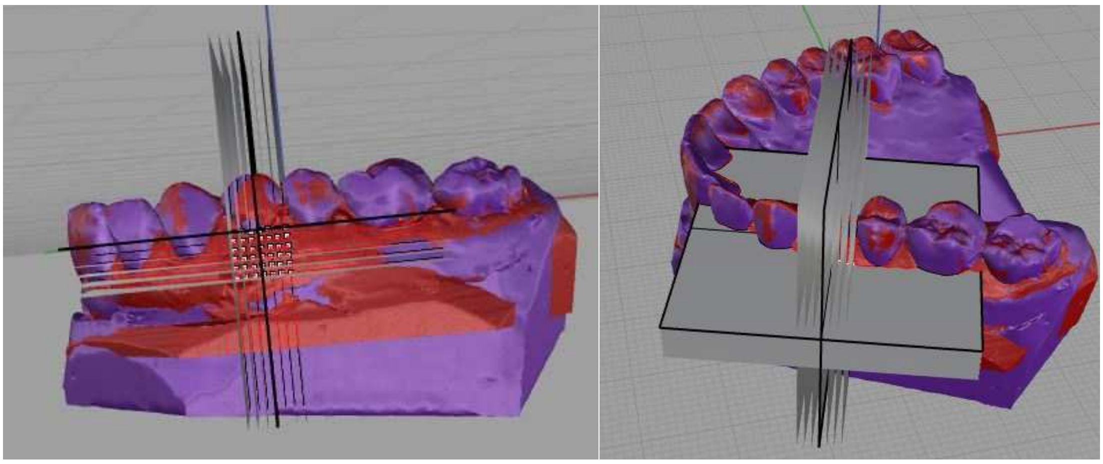


FIGURE 43 THE CUTTING PLANES GENERATED WITH THE RHINO-PYTHON SCRIPT

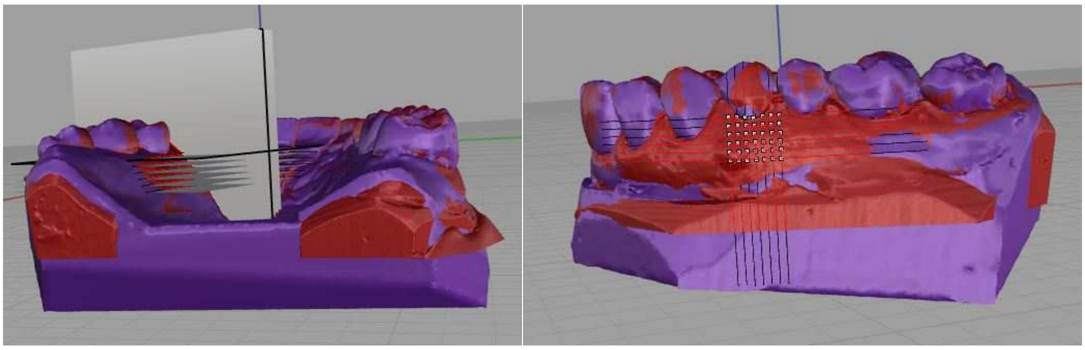


FIGURE 44 ANOTHER VIEW OF THE CUTTING PLANES AND THE POINTS THAT REMAINS ON THE SURFACE AFTER HIDING THE PLANES

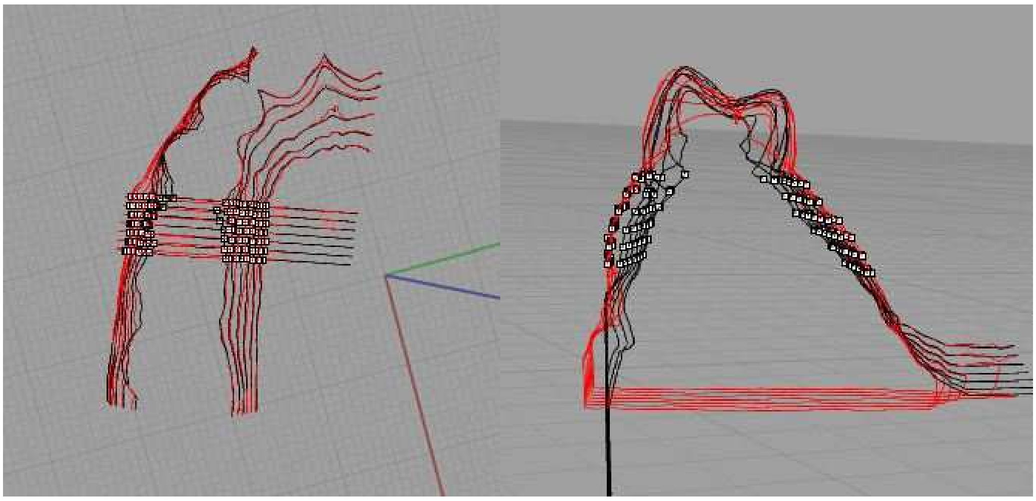


FIGURE 45 THE RESULTING LINES AND POINTS AFTER HIDING THE MESHES AND PLANES

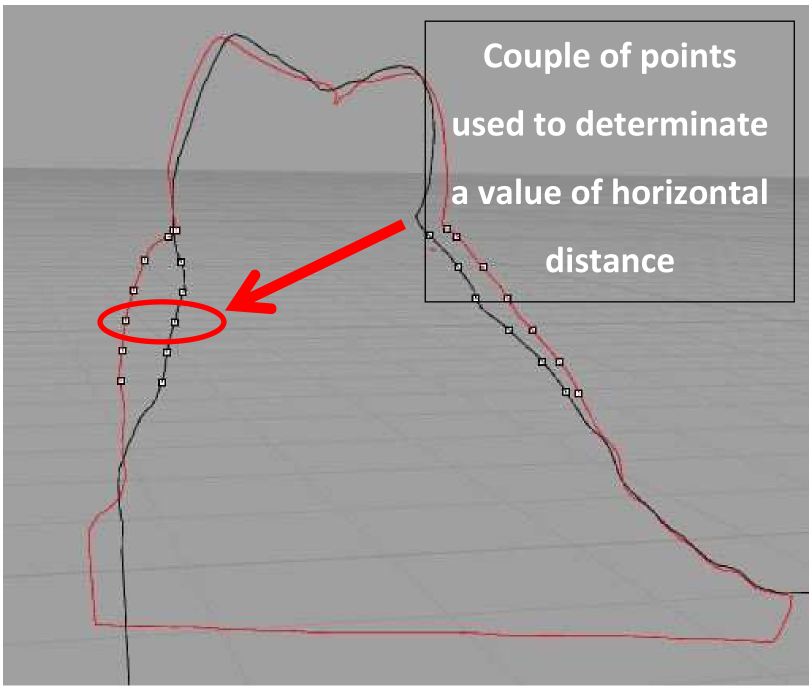


FIGURE 46 EXAMPLE ON HOW TO MEASURE THE DISTANCES ON MESHES

7.1.3 DISTANCE

This script guide the operator in the selection of the points and after selecting in the sequence that the script asks to the operator a text file with the name of the mesh file is generate.

After running the script, it asks to the operator to select the point of the first mesh and after of the second mesh for each measure(An example is visible in Figure 46).

The measurements follow the sequence in Table 2:

TABLE 2 SEQUENCE OF POINTS TO SELECT FOR THE DISTANCE OF RHINO-PYTHON SCRIPT

1	Buccal	Vertical Plane +3	Horizontal plane 0
2	Buccal	Vertical Plane +3	Horizontal plane -1
3	Buccal	Vertical Plane +3	Horizontal plane -2
4	Buccal	Vertical Plane +3	Horizontal plane -3
5	Buccal	Vertical Plane +3	Horizontal plane -4
6	Buccal	Vertical Plane +3	Horizontal plane -5
7	Buccal	Vertical Plane +2	Horizontal plane 0
8	Buccal	Vertical Plane +2	Horizontal plane -1
9	Buccal	Vertical Plane +2	Horizontal plane -2
10	Buccal	Vertical Plane +2	Horizontal plane -3
11	Buccal	Vertical Plane +2	Horizontal plane -4
12	Buccal	Vertical Plane +2	Horizontal plane -5
13	Buccal	Vertical Plane +1	Horizontal plane 0
14	Buccal	Vertical Plane +1	Horizontal plane -1
15	Buccal	Vertical Plane +1	Horizontal plane -2
16	Buccal	Vertical Plane +1	Horizontal plane -3
17	Buccal	Vertical Plane +1	Horizontal plane -4
18	Buccal	Vertical Plane +1	Horizontal plane -5
19	Buccal	Vertical Plane 0	Horizontal plane 0
20	Buccal	Vertical Plane 0	Horizontal plane -1
21	Buccal	Vertical Plane 0	Horizontal plane -2
22	Buccal	Vertical Plane 0	Horizontal plane -3
23	Buccal	Vertical Plane 0	Horizontal plane -4
24	Buccal	Vertical Plane 0	Horizontal plane -5
25	Buccal	Vertical Plane -1	Horizontal plane 0
26	Buccal	Vertical Plane -1	Horizontal plane -1
27	Buccal	Vertical Plane -1	Horizontal plane -2
28	Buccal	Vertical Plane -1	Horizontal plane -3
29	Buccal	Vertical Plane -1	Horizontal plane -4

30	Buccal	Vertical Plane -1	Horizontal plane -5
31	Buccal	Vertical Plane -2	Horizontal plane 0
32	Buccal	Vertical Plane -2	Horizontal plane -1
33	Buccal	Vertical Plane -2	Horizontal plane -2
34	Buccal	Vertical Plane -2	Horizontal plane -3
35	Buccal	Vertical Plane -2	Horizontal plane -4
36	Buccal	Vertical Plane -2	Horizontal plane -5
37	Buccal	Vertical Plane -3	Horizontal plane 0
38	Buccal	Vertical Plane -3	Horizontal plane -1
39	Buccal	Vertical Plane -3	Horizontal plane -2
40	Buccal	Vertical Plane -3	Horizontal plane -3
41	Buccal	Vertical Plane -3	Horizontal plane -4
42	Buccal	Vertical Plane -3	Horizontal plane -5
43	Palatal/Lingual	Vertical Plane +3	Horizontal plane 0
44	Palatal/Lingual	Vertical Plane +3	Horizontal plane -1
45	Palatal/Lingual	Vertical Plane +3	Horizontal plane -2
46	Palatal/Lingual	Vertical Plane +3	Horizontal plane -3
47	Palatal/Lingual	Vertical Plane +3	Horizontal plane -4
48	Palatal/Lingual	Vertical Plane +3	Horizontal plane -5
49	Palatal/Lingual	Vertical Plane +2	Horizontal plane 0
50	Palatal/Lingual	Vertical Plane +2	Horizontal plane -1
51	Palatal/Lingual	Vertical Plane +2	Horizontal plane -2
52	Palatal/Lingual	Vertical Plane +2	Horizontal plane -3
53	Palatal/Lingual	Vertical Plane +2	Horizontal plane -4
54	Palatal/Lingual	Vertical Plane +2	Horizontal plane -5
55	Palatal/Lingual	Vertical Plane +1	Horizontal plane 0
56	Palatal/Lingual	Vertical Plane +1	Horizontal plane -1
57	Palatal/Lingual	Vertical Plane +1	Horizontal plane -2
58	Palatal/Lingual	Vertical Plane +1	Horizontal plane -3
59	Palatal/Lingual	Vertical Plane +1	Horizontal plane -4
60	Palatal/Lingual	Vertical Plane +1	Horizontal plane -5
61	Palatal/Lingual	Vertical Plane 0	Horizontal plane 0
62	Palatal/Lingual	Vertical Plane 0	Horizontal plane -1
63	Palatal/Lingual	Vertical Plane 0	Horizontal plane -2
64	Palatal/Lingual	Vertical Plane 0	Horizontal plane -3
65	Palatal/Lingual	Vertical Plane 0	Horizontal plane -4
66	Palatal/Lingual	Vertical Plane 0	Horizontal plane -5
67	Palatal/Lingual	Vertical Plane -1	Horizontal plane 0
68	Palatal/Lingual	Vertical Plane -1	Horizontal plane -1
69	Palatal/Lingual	Vertical Plane -1	Horizontal plane -2
70	Palatal/Lingual	Vertical Plane -1	Horizontal plane -3
71	Palatal/Lingual	Vertical Plane -1	Horizontal plane -4
72	Palatal/Lingual	Vertical Plane -1	Horizontal plane -5
73	Palatal/Lingual	Vertical Plane -2	Horizontal plane 0
74	Palatal/Lingual	Vertical Plane -2	Horizontal plane -1
75	Palatal/Lingual	Vertical Plane -2	Horizontal plane -2
76	Palatal/Lingual	Vertical Plane -2	Horizontal plane -3

77	Palatal/Lingual	Vertical Plane -2	Horizontal plane -4
78	Palatal/Lingual	Vertical Plane -2	Horizontal plane -5
79	Palatal/Lingual	Vertical Plane -3	Horizontal plane 0
80	Palatal/Lingual	Vertical Plane -3	Horizontal plane -1
81	Palatal/Lingual	Vertical Plane -3	Horizontal plane -2
82	Palatal/Lingual	Vertical Plane -3	Horizontal plane -3
83	Palatal/Lingual	Vertical Plane -3	Horizontal plane -4
84	Palatal/Lingual	Vertical Plane -3	Horizontal plane -5

If there isn't a point that we have to select, it is enough to right click and script will add "none" to the text file in correspondence to that point, so will consider null that value.

The width of the alveolar crest was also measured before (on the first mesh) and after (on the second mesh), in this way the absolute distances in mm was converted in percentages following other results of literature.

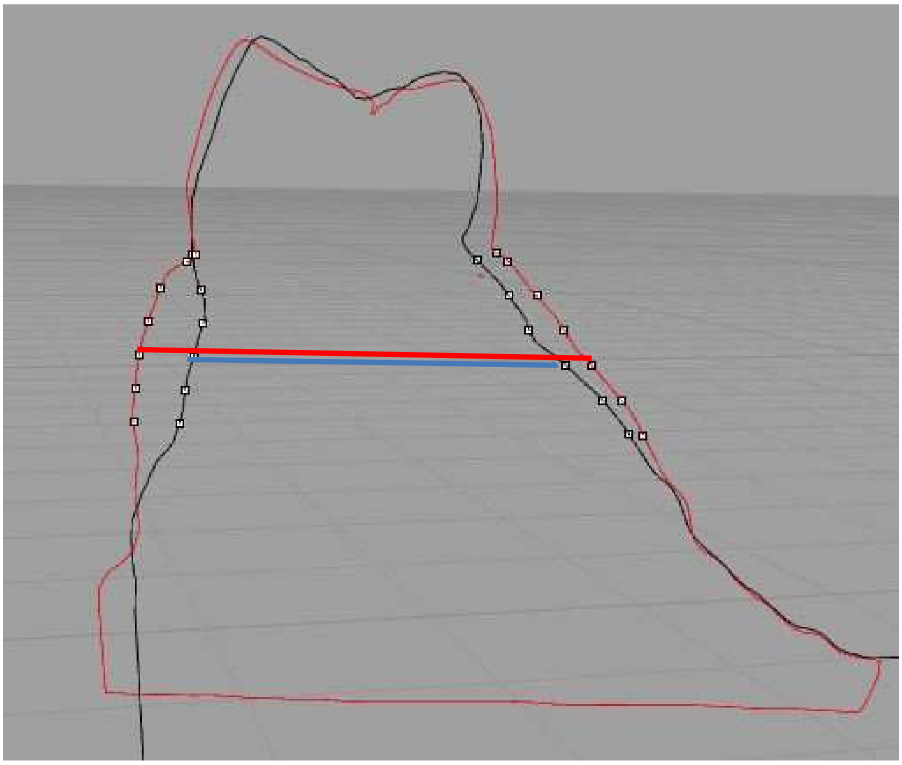


FIGURE 47 THE RED LINE REPRESENT THE ALVEOLAR CREST BEFORE ON FIRST IMPRESSION AND THE BLU ONE THE ALVEOLAR CREST AFTER 1 YEAR

For what concerns the vertical variation evaluation, it has not been possible to make it automatic, for the extremely high variability of the area.
So for this measurement was used straight a Rhinoceros tool activated from the menu:

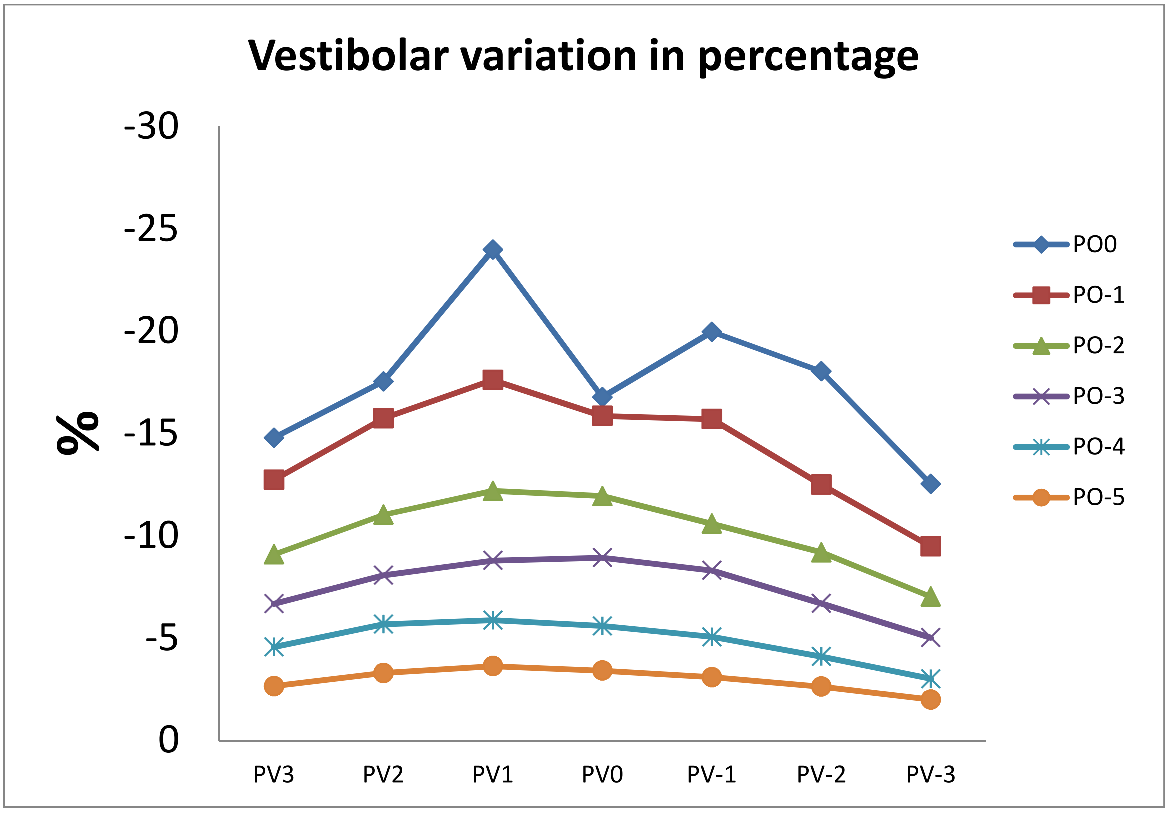
Analyze → Distance and the higher point of gingiva on first and second mesh was selected by hand, both at the buccal side and at the palatal/lingual side.
In this case is the ΔZ the referral value because the C plane is set on the occlusal plane by the "occlusal plane script" and a total of 14 measures were taken for each clinical case.

7.2 RESULTS

More than 20 patients have been treated at this point of our research, but we encountered big problems of drop out from the study while it was still in progress due to the patients that did not come back after our recall, making impossible to take the second impression or because other dentistry treatments occurred and altered the dentition, not allowing the matching of the two impressions.
So, we planned to have 15 patience immediate implantation and 15 delayed implantation, but today we have only 10 patients immediate implantation and 8 delayed. The others are stilling in the middle of the study.
Only the 10 immediate implantation cases are been studied and analyzed.
In the following table is possible to recognize the medium value for each vestibular point, each number is the media of 10 immediate implantation clinical cases.
It is possible to see in the picture how looks like the grid in the vestibular area and in the graph we see the variation in percentage of the alveolar crest.

Table 3 This table represent the medium vestibular value of the ten patients in each point of our cutting grid

Vestibular/Buccal variation in percentage							
	PV3	PV2	PV1	PV0	PV-1	PV-2	PV-3
PO0	-14,780	-17,534	-23,972	-16,766	-19,962	-18,031	-12,526
PO-1	-12,727	-15,726	-17,608	-15,854	-15,701	-12,494	-9,473
PO-2	-9,085	-11,019	-12,185	-11,937	-10,585	-9,183	-7,020
PO-3	-6,675	-8,070	-8,787	-8,926	-8,302	-6,693	-5,018
PO-4	-4,561	-5,671	-5,871	-5,588	-5,058	-4,094	-3,011
PO-5	-2,647	-3,290	-3,621	-3,408	-3,087	-2,622	-1,990



Graph 1 This graph represent the medium horizontal variation at the vestibular side of the ten patients in each point of the grid, each horizontal layer is represented by a line and the intersection with vertical plane is represented with a point

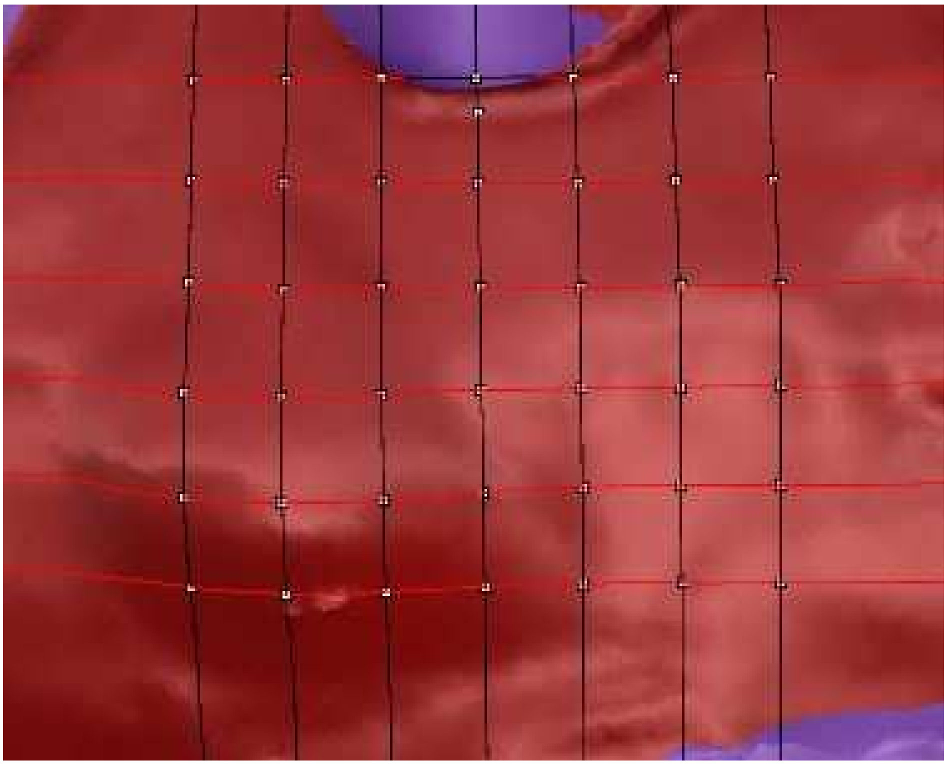
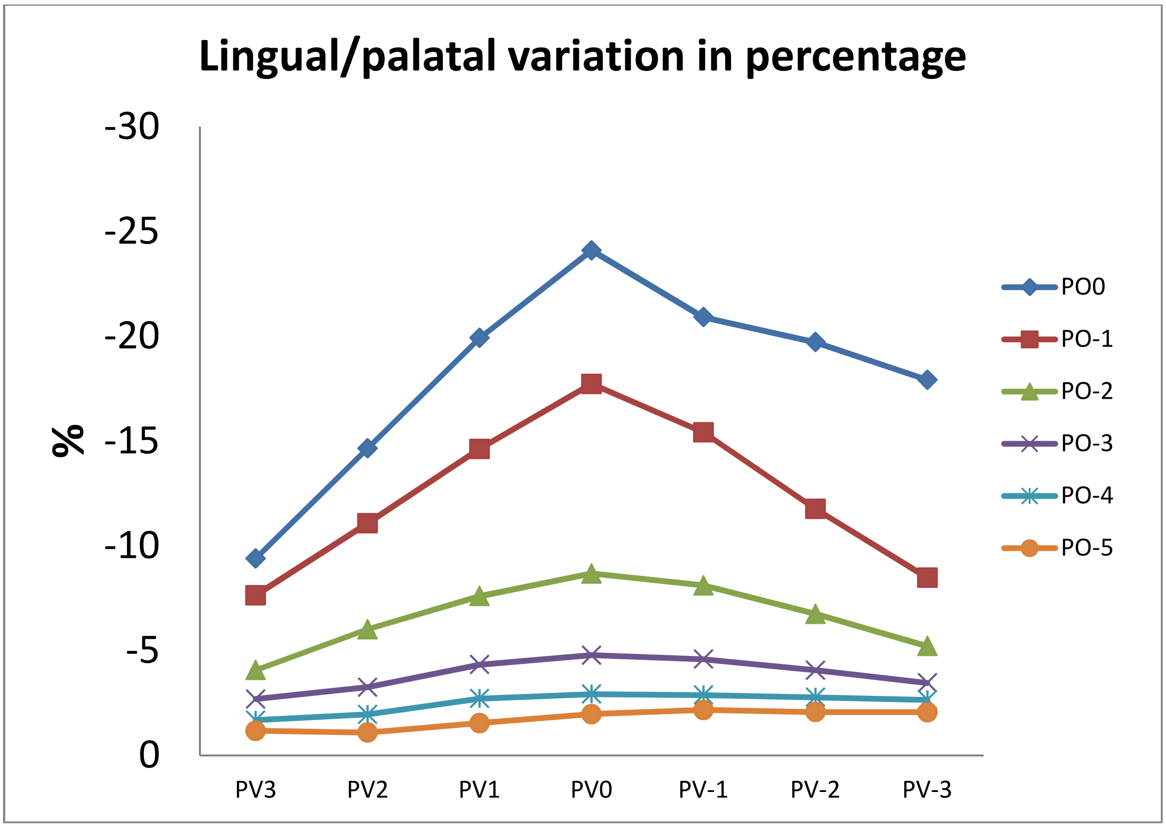


FIGURE 48 THIS PICTURE SHOWS THE VESTIBULAR POSITION OF THE CUTTING GRID

The same was done for the palatal/lingual side:

TABLE 4 THIS TABLE REPRESENT THE MEDIUM LINGUAL/PALATAL VALUE OF THE TEN PATIENTS IN EACH POINT OF OUR CUTTING GRID

Lingual/palatal variation in percentage							
	PV3	PV2	PV1	PV0	PV-1	PV-2	PV-3
PO0	-9,395	-14,651	-19,919	-24,096	-20,916	-19,724	-17,915
PO-1	-7,642	-11,078	-14,627	-17,729	-15,418	-11,769	-8,480
PO-2	-4,073	-6,017	-7,602	-8,682	-8,115	-6,756	-5,220
PO-3	-2,689	-3,257	-4,334	-4,780	-4,589	-4,062	-3,457
PO-4	-1,682	-1,952	-2,708	-2,928	-2,878	-2,771	-2,650
PO-5	-1,179	-1,094	-1,542	-1,970	-2,171	-2,067	-2,058

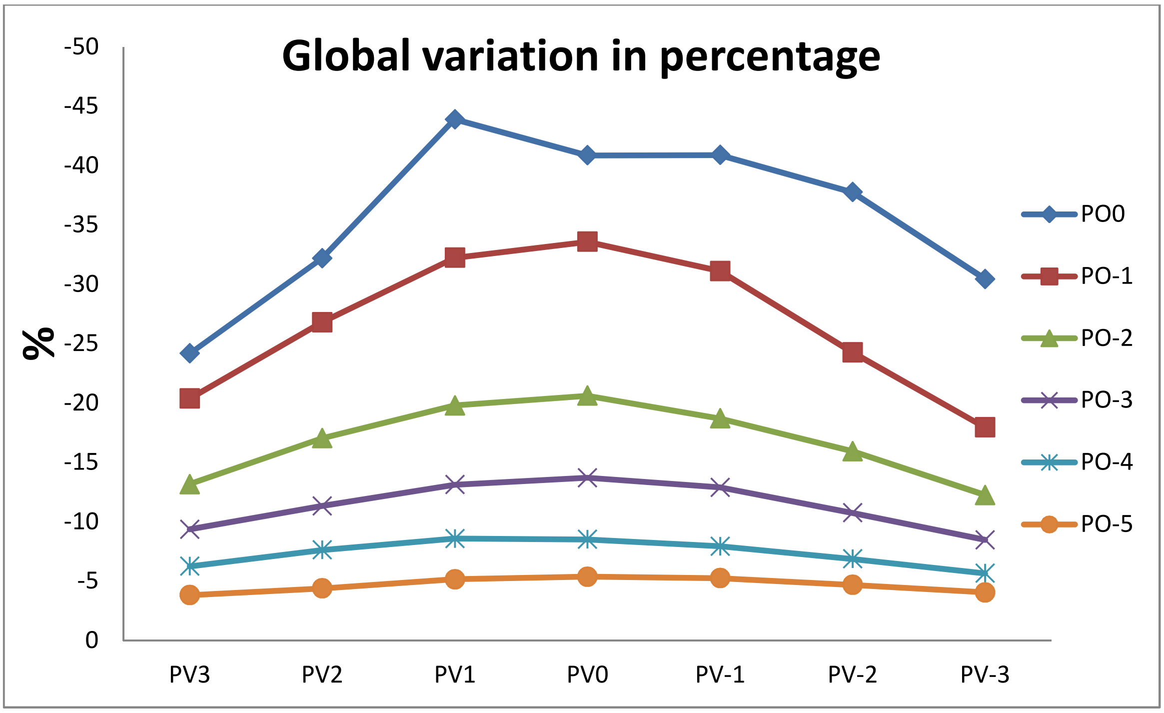


GRAPH 2 THIS GRAPH REPRESENT THE MEDIUM HORIZONTAL VARIATION AT THE LINGUAL/PALATAL SIDE OF THE TEN PATIENTS IN EACH POINT OF THE GRID, EACH HORIZONTAL LAYER IS REPRESENTED BY A LINE AND THE INTERSECTION WITH VERTICAL PLANE IS REPRESENTED WITH A POINT

The sum of vestibular and Palatal/lingual variation give us the value of global variation of the alveolar crest:

TABLE 5 THIS TABLE REPRESENT THE MEDIUM VALUE OF THE GLOBAL VARIATION OF THE TEN PATIENTS IN EACH POINT OF OUR CUTTING GRID

Global variation in percentage							
	PV3	PV2	PV1	PV0	PV-1	PV-2	PV-3
PO0	-24,175	-32,186	-43,891	-40,862	-40,878	-37,755	-30,441
PO-1	-20,369	-26,805	-32,235	-33,583	-31,119	-24,263	-17,953
PO-2	-13,158	-17,035	-19,787	-20,619	-18,700	-15,939	-12,240
PO-3	-9,364	-11,326	-13,120	-13,706	-12,892	-10,755	-8,475
PO-4	-6,243	-7,623	-8,579	-8,515	-7,935	-6,865	-5,661
PO-5	-3,826	-4,383	-5,163	-5,379	-5,258	-4,689	-4,048



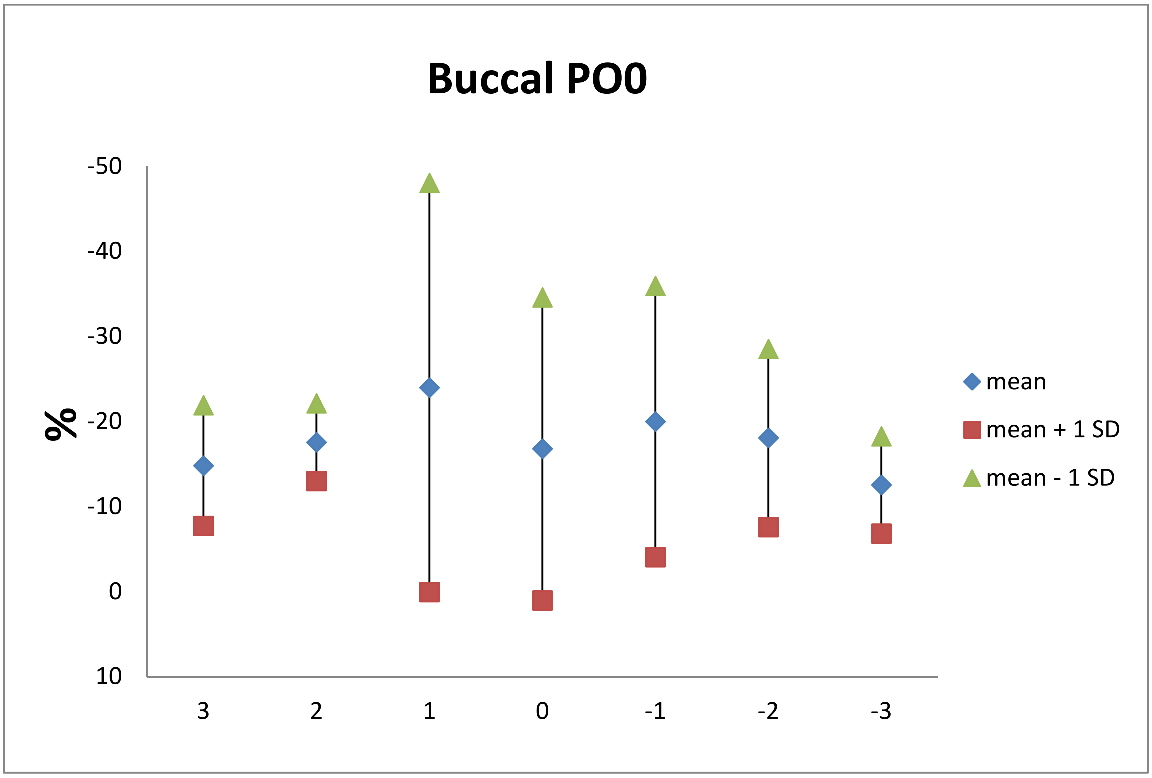
GRAPH 3 THIS GRAPH REPRESENT THE MEDIUM HORIZONTAL VARIATION AT THE LINGUAL/PALATAL SIDE OF THE TEN PATIENTS IN EACH POINT OF THE GRID, EACH HORIZONTAL LAYER IS REPRESENTED BY A LINE AND THE INTERSECTION WITH VERTICAL PLANE IS REPRESENTED WITH A POINT

Immediately watching these graphs is visible how big the difference of variation among different layers of our investigation is.

This is the global evaluation, but we also need to investigate how much variability there is inside every group, so a more detailed analysis was performed: For each horizontal plane a graph showing the medium and +1 and -1 Standard Deviation was made for both buccal and palatal/lingual side.

TABLE 6 HORIZONTAL PLANE 0 REPRESENTED AT THE BUCCAL SIDE BY THE MEDIA AND +1 AND -1 STANDARD DEVIATION

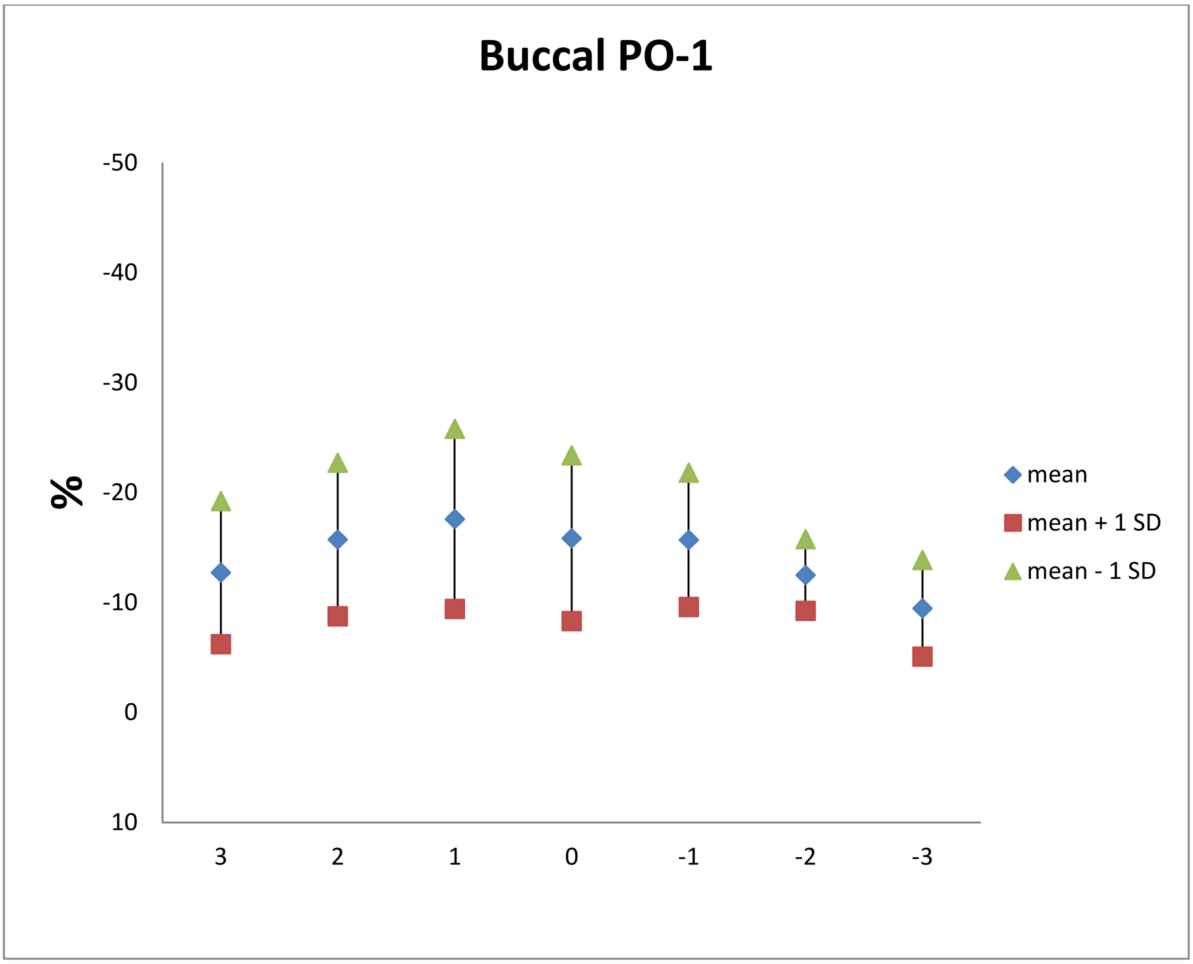
Buccal PO0			
	mean	mean + 1 SD	mean - 1 SD
3	-14,78	-7,69	-21,87
2	-17,53	-12,96	-22,11
1	-23,97	0,07	-48,02
0	-16,77	1,05	-34,58
-1	-19,96	-4,01	-35,91
-2	-18,03	-7,54	-28,52
-3	-12,53	-6,81	-18,24



GRAPH 4 HORIZONTAL PLANE 0 WITH +1 AND -1 STANDARD DEVIATIONS AT THE BUCCAL SIDE

TABLE 7 HORIZONTAL PLANE -1 REPRESENTED AT THE BUCCAL SIDE BY THE MEDIA AND +1 AND -1 STANDARD DEVIATION

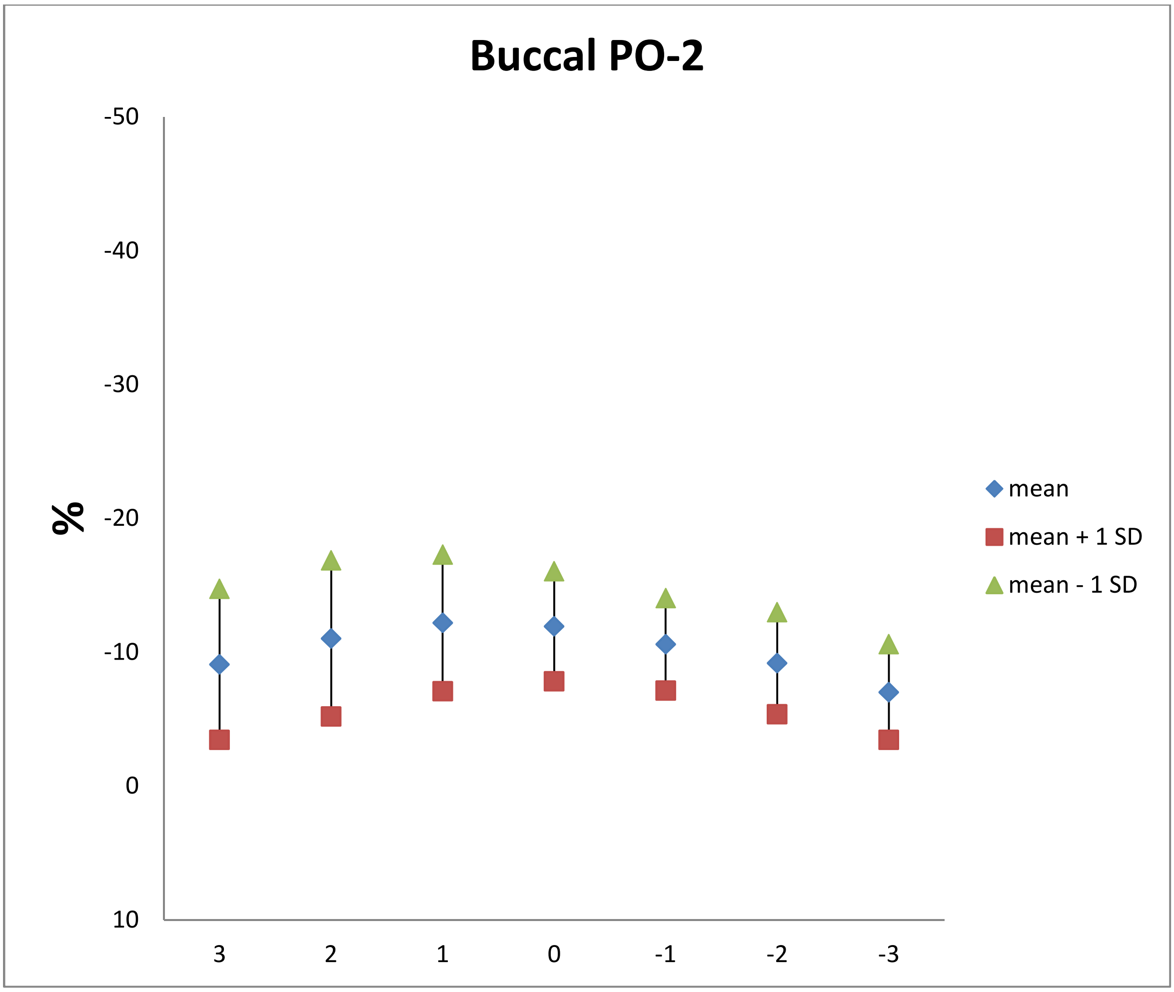
Buccal PO-1			
	mean	mean + 1 SD	mean - 1 SD
3	-12,73	-6,22	-19,23
2	-15,73	-8,74	-22,71
1	-17,61	-9,42	-25,80
0	-15,85	-8,31	-23,40
-1	-15,70	-9,60	-21,80
-2	-12,49	-9,24	-15,75
-3	-9,47	-5,08	-13,86



GRAPH 5 HORIZONTAL PLANE -1 WITH +1 AND -1 STANDARD DEVIATIONS AT THE BUCCAL SIDE

TABLE 8 HORIZONTAL PLANE -2 REPRESENTED AT THE BUCCAL SIDE BY THE MEDIA AND +1 AND -1 STANDARD DEVIATION

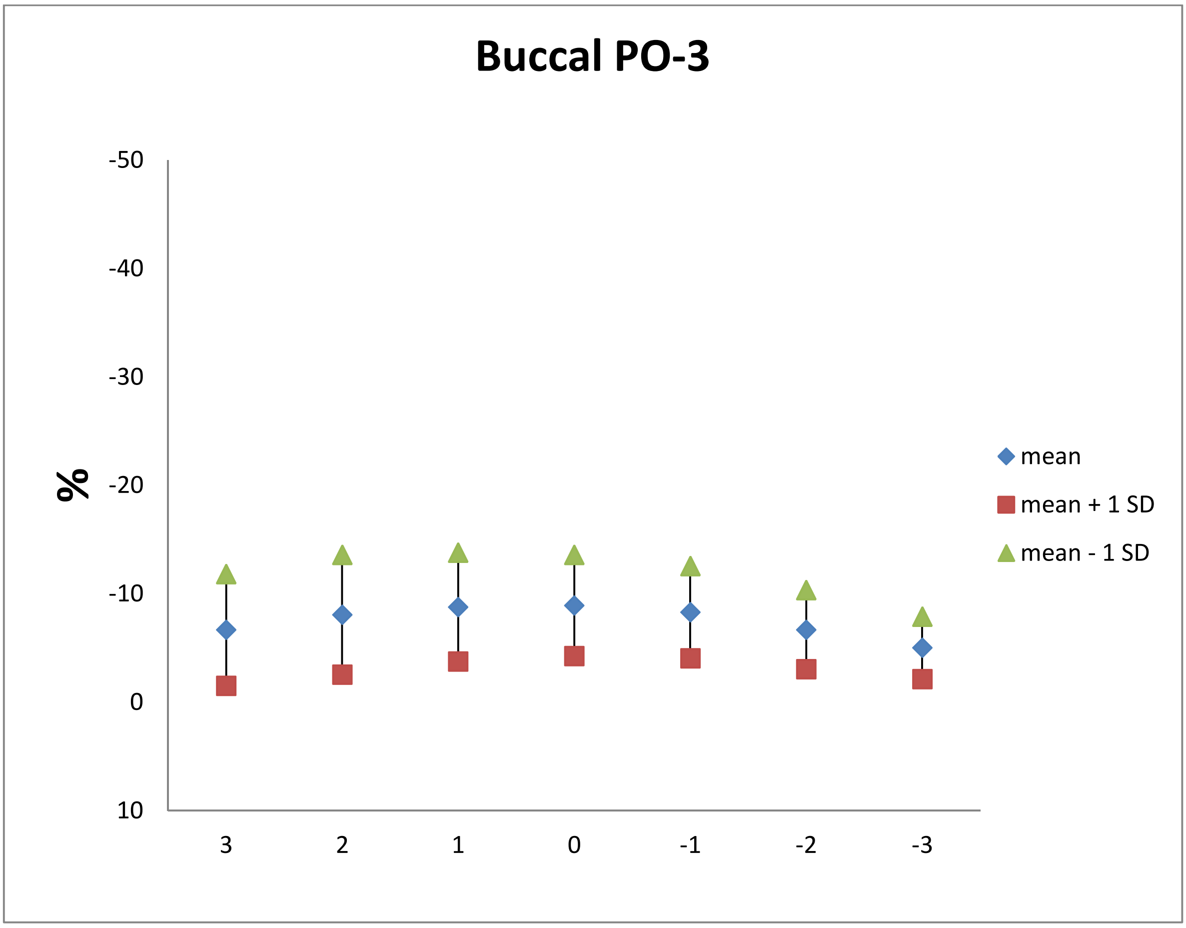
Buccal PO-2			
	mean	mean + 1 SD	mean - 1 SD
3	-9,08	-3,45	-14,72
2	-11,02	-5,19	-16,85
1	-12,19	-7,07	-17,30
0	-11,94	-7,83	-16,04
-1	-10,59	-7,14	-14,03
-2	-9,18	-5,37	-13,00
-3	-7,02	-3,44	-10,60



GRAPH 6 HORIZONTAL PLANE -2 WITH +1 AND -1 STANDARD DEVIATIONS AT THE BUCCAL SIDE

Table 9 Horizontal plane -3 represented at the buccal side by the media and +1 and -1 standard deviation

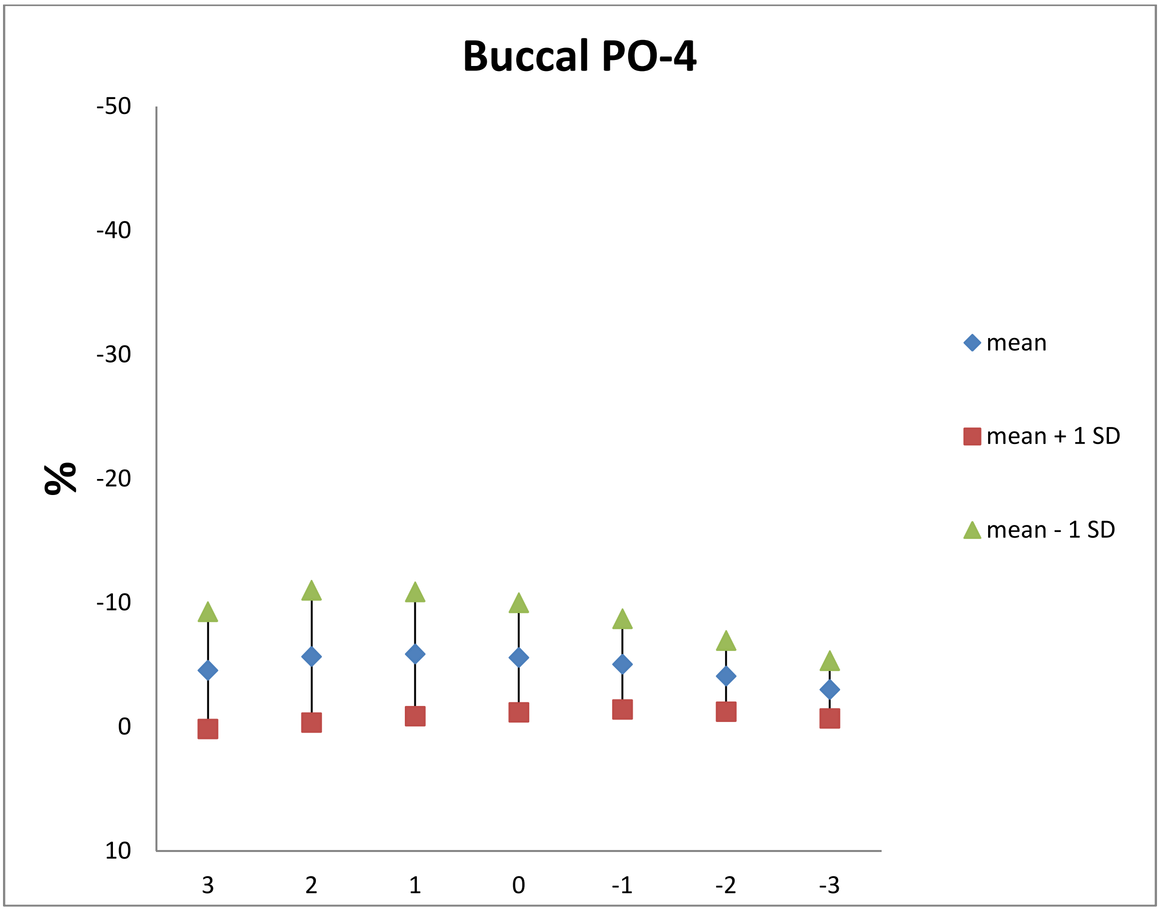
Buccal PO-3			
	mean	mean + 1 SD	mean - 1 SD
3	-6,68	-1,52	-11,83
2	-8,07	-2,55	-13,59
1	-8,79	-3,76	-13,81
0	-8,93	-4,25	-13,60
-1	-8,30	-4,05	-12,56
-2	-6,69	-3,04	-10,34
-3	-5,02	-2,13	-7,91



Graph 7 Horizontal plane -3 with +1 and -1 standard deviations at the buccal side

TABLE 10 HORIZONTAL PLANE -4 REPRESENTED AT THE BUCCAL SIDE BY THE MEDIA AND +1 AND -1 STANDARD DEVIATION

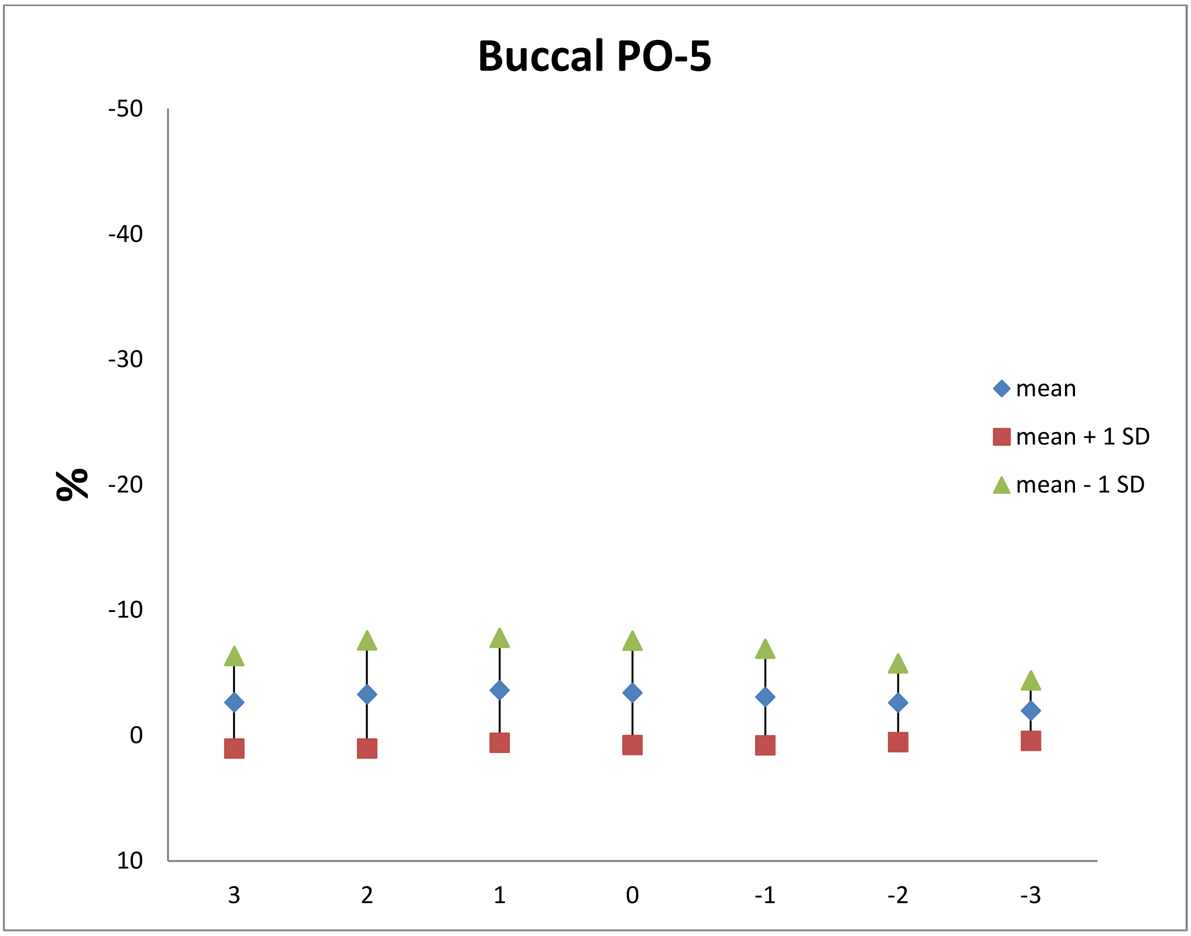
Buccal PO-4			
	mean	mean + 1 SD	mean - 1 SD
3	-4,56	0,15	-9,27
2	-5,67	-0,35	-10,99
1	-5,87	-0,86	-10,88
0	-5,59	-1,17	-10,01
-1	-5,06	-1,40	-8,72
-2	-4,09	-1,23	-6,96
-3	-3,01	-0,69	-5,34



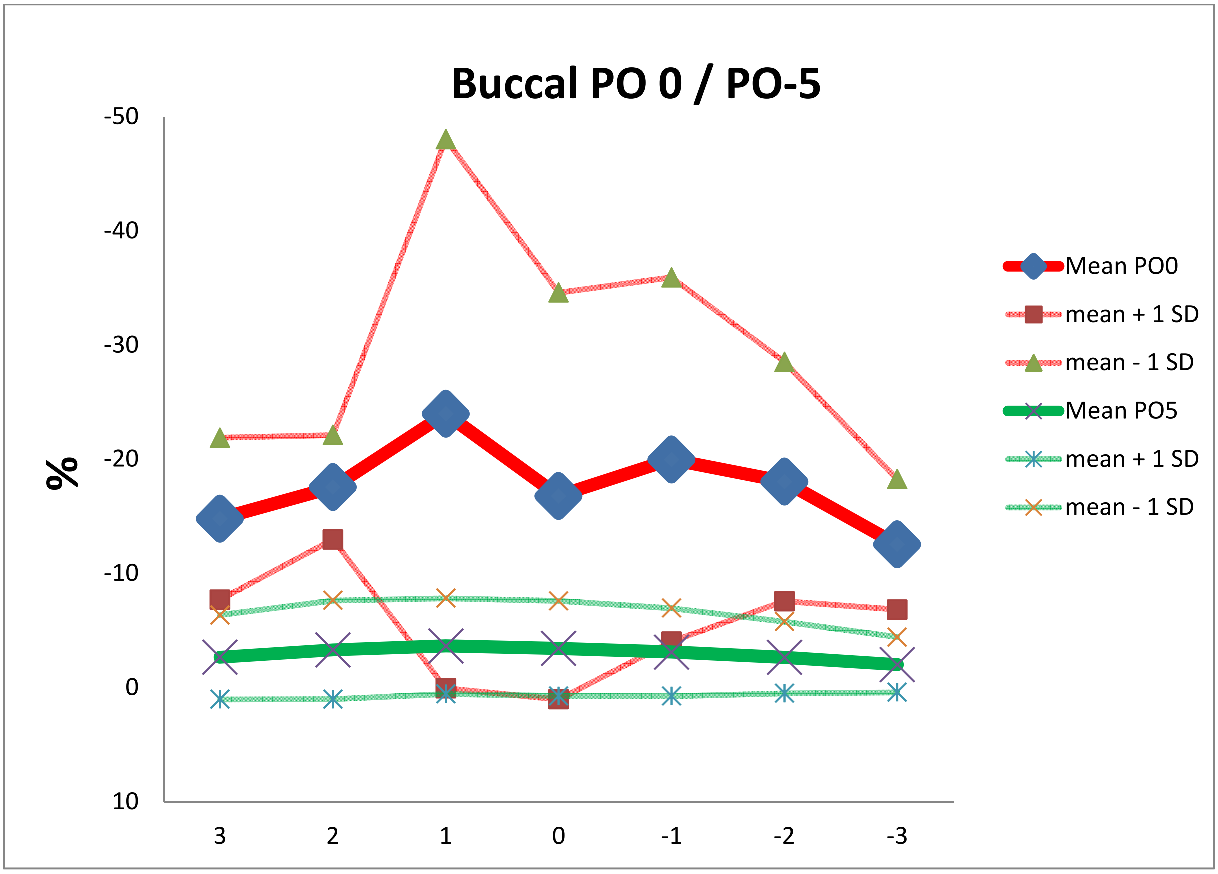
GRAPH 8 HORIZONTAL PLANE -4 WITH +1 AND -1 STANDARD DEVIATIONS AT THE BUCCAL SIDE

Table 11 Horizontal plane -5 at the buccal side represented by the media and +1 and -1 standard deviation

Buccal PO-5			
	mean	mean + 1 SD	mean - 1 SD
3	-2,65	1,04	-6,34
2	-3,29	1,03	-7,61
1	-3,62	0,57	-7,82
0	-3,41	0,76	-7,57
-1	-3,09	0,77	-6,94
-2	-2,62	0,52	-5,76
-3	-1,99	0,43	-4,41



GRAPH 9 HORIZONTAL PLANE -5 WITH +1 AND -1 STANDARD DEVIATIONS AT THE BUCCAL SIDE

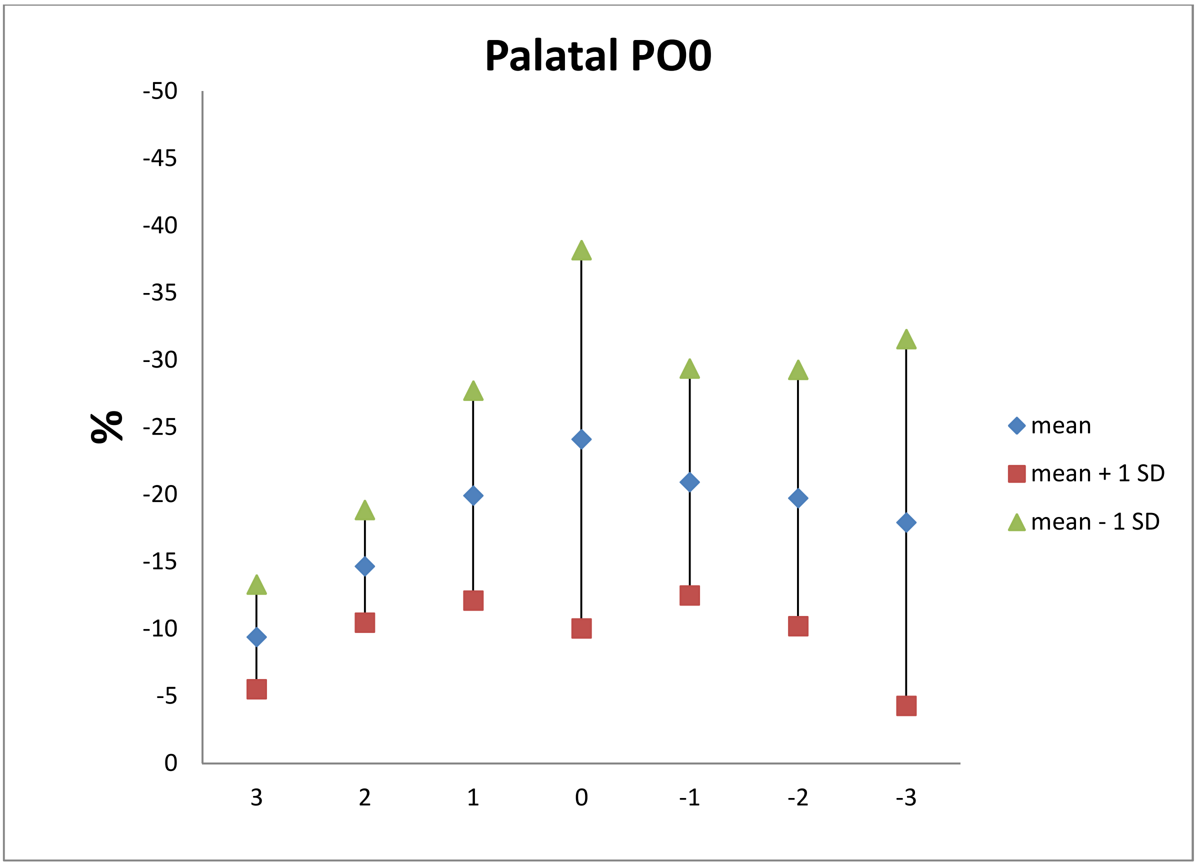


GRAPH 10 COMPARISON BETWEEN FIRST AND LAST HORIZONTAL PLANE AT THE PALATAL SIDE

The investigation was made also at the lingual/palatal side:

Table 12 Horizontal plane 0 represented at the lingual/palatal side by the media and +1 and -1 standard deviation

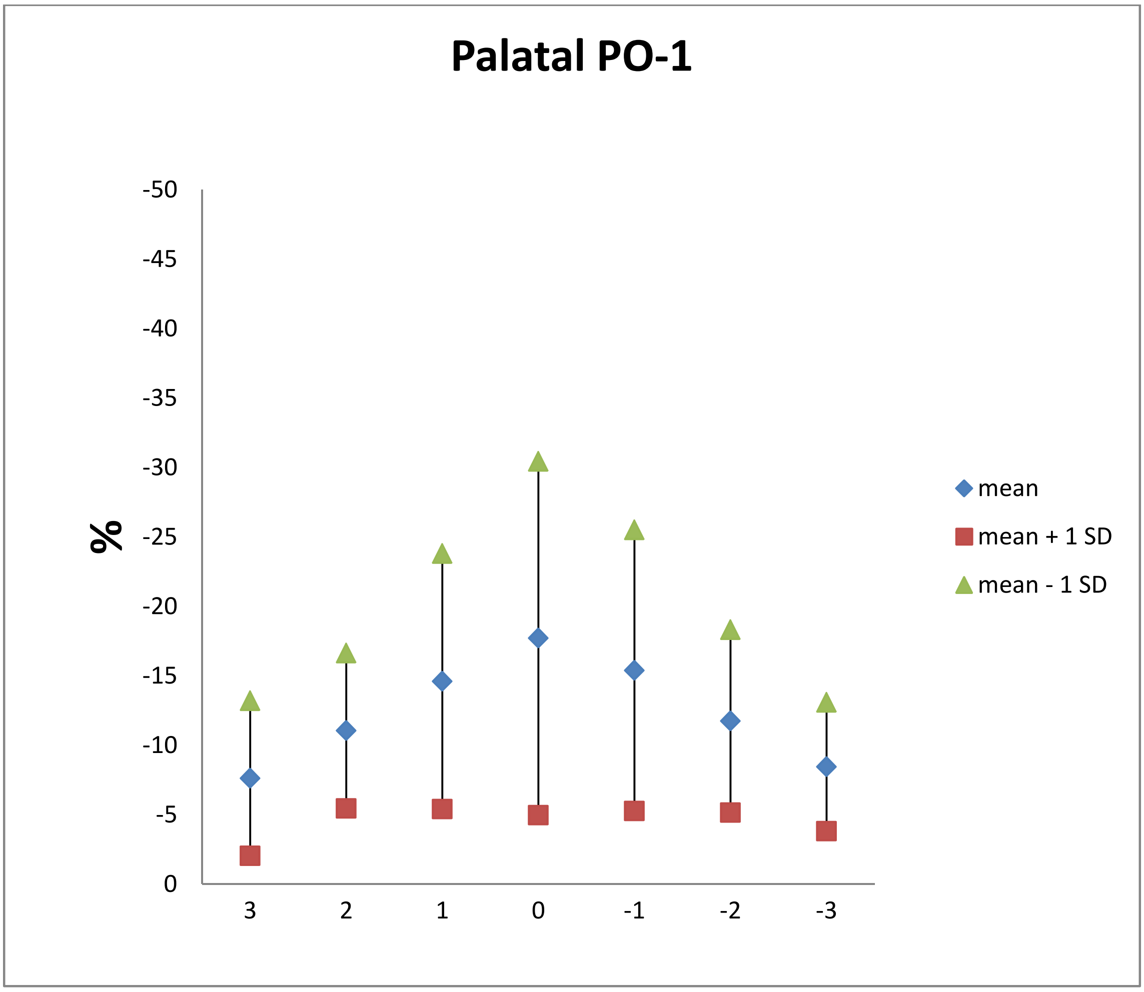
Palatal PO0			
	mean	mean + 1 SD	mean - 1 SD
3	-9,40	-5,50	-13,29
2	-14,65	-10,45	-18,85
1	-19,92	-12,11	-27,72
0	-24,10	-10,02	-38,17
-1	-20,92	-12,48	-29,35
-2	-19,72	-10,19	-29,26
-3	-17,91	-4,28	-31,55



Graph 11 Horizontal plane 0 with +1 and -1 standard deviations at the lingual/palatal side

Table 13 Horizontal plane -1 represented at the lingual/palatal side by the media and +1 and -1 standard deviation

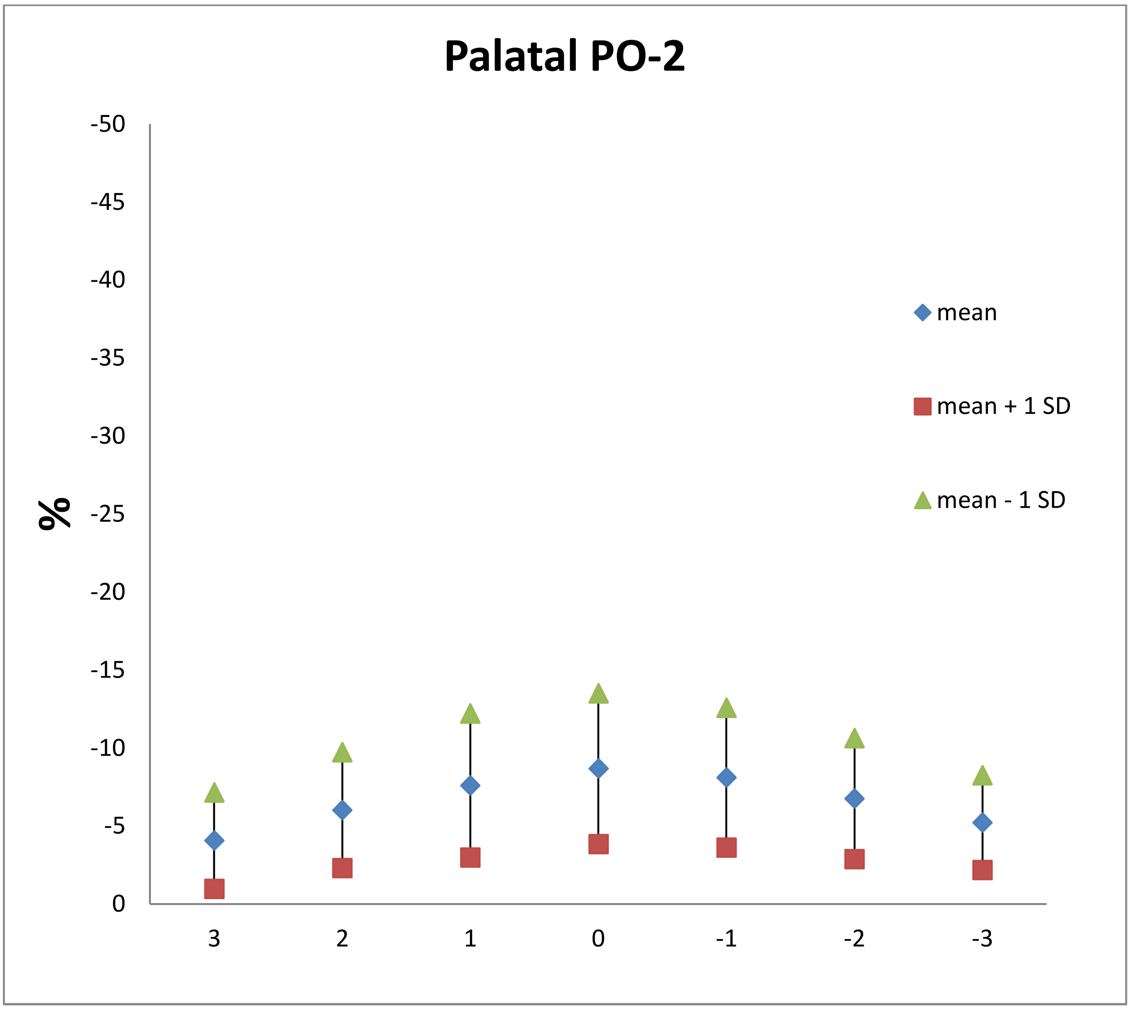
Palatal PO-1			
	mean	mean + 1 SD	mean - 1 SD
3	-7,64	-2,06	-13,22
2	-11,08	-5,49	-16,67
1	-14,63	-5,44	-23,82
0	-17,73	-5,00	-30,46
-1	-15,42	-5,31	-25,53
-2	-11,77	-5,19	-18,34
-3	-8,48	-3,84	-13,12



Graph 12 Horizontal plane -1 with +1 and -1 standard deviations at the lingual/palatal side

Table 14 Horizontal plane -2 represented at the lingual/palatal side by the media and +1 and -1 standard deviation

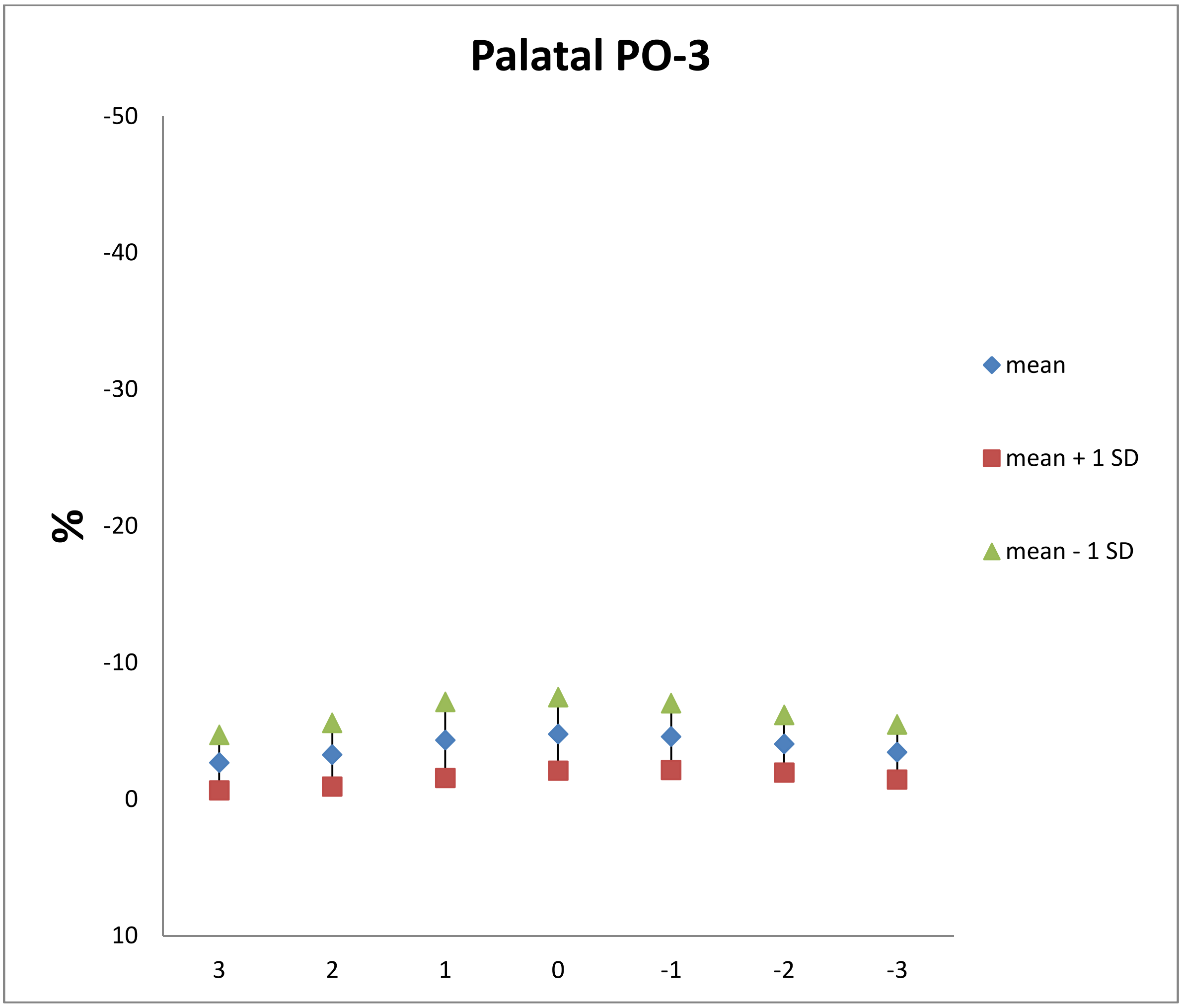
Palatal PO-2			
	mean	mean + 1 SD	mean - 1 SD
3	-4,07	-0,99	-7,16
2	-6,02	-2,31	-9,73
1	-7,60	-2,99	-12,22
0	-8,68	-3,86	-13,51
-1	-8,11	-3,63	-12,60
-2	-6,76	-2,88	-10,63
-3	-5,22	-2,18	-8,26



Graph 13 Horizontal plane -2 with +1 and -1 standard deviations at the lingual/palatal side

TABLE 15 HORIZONTAL PLANE -3 REPRESENTED AT THE LINGUAL/PALATAL SIDE BY THE MEDIA AND +1 AND -1 STANDARD DEVIATION

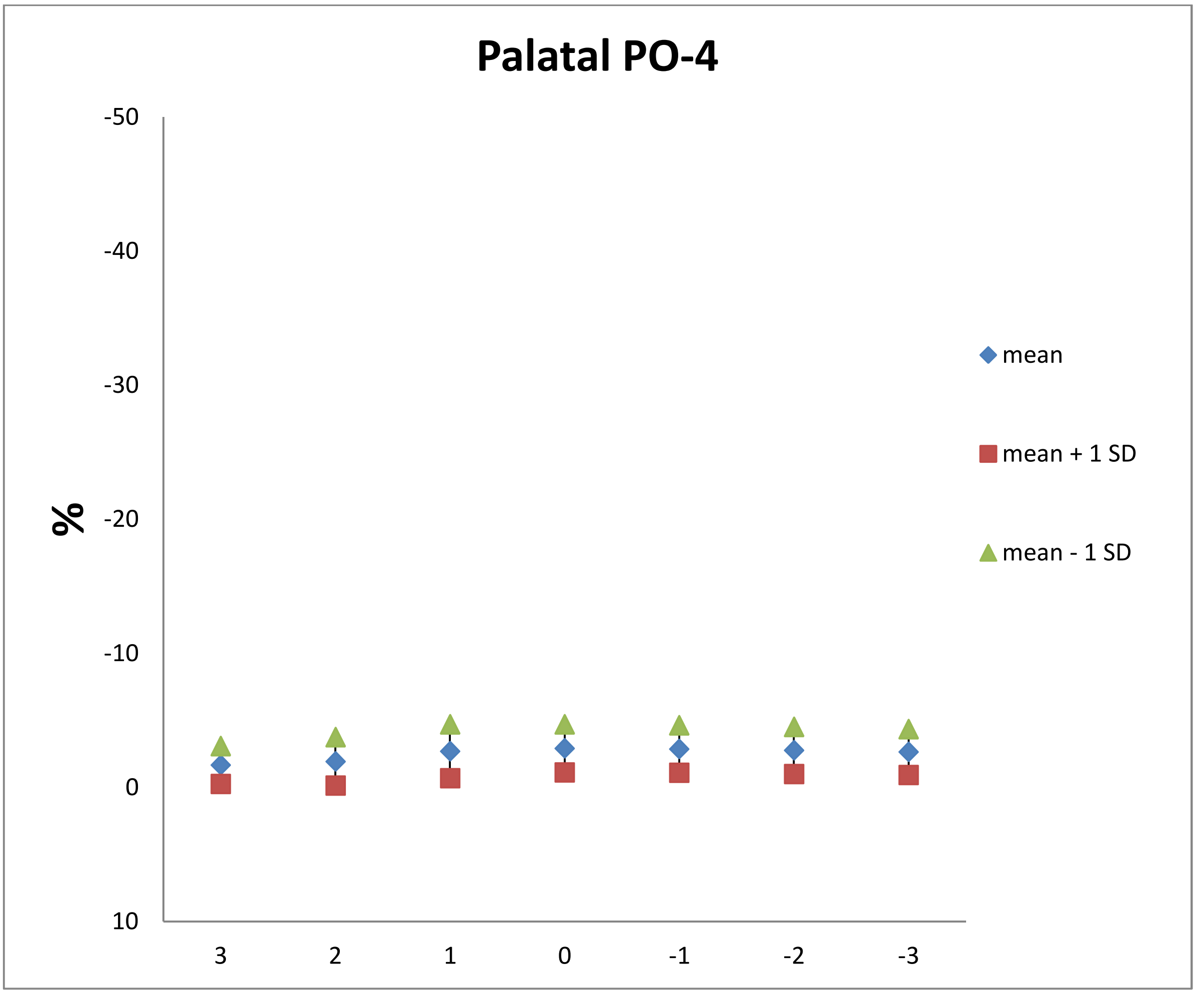
Palatal PO-3			
	mean	mean + 1 SD	mean - 1 SD
3	-2,69	-0,66	-4,72
2	-3,26	-0,93	-5,58
1	-4,33	-1,55	-7,11
0	-4,78	-2,09	-7,47
-1	-4,59	-2,15	-7,03
-2	-4,06	-1,96	-6,16
-3	-3,46	-1,45	-5,46



GRAPH 14 HORIZONTAL PLANE -3 WITH +1 AND -1 STANDARD DEVIATIONS AT THE LINGUAL/PALATAL SIDE

TABLE 16 HORIZONTAL PLANE -4 REPRESENTED AT THE LINGUAL/PALATAL SIDE BY THE MEDIA AND +1 AND -1 STANDARD DEVIATION

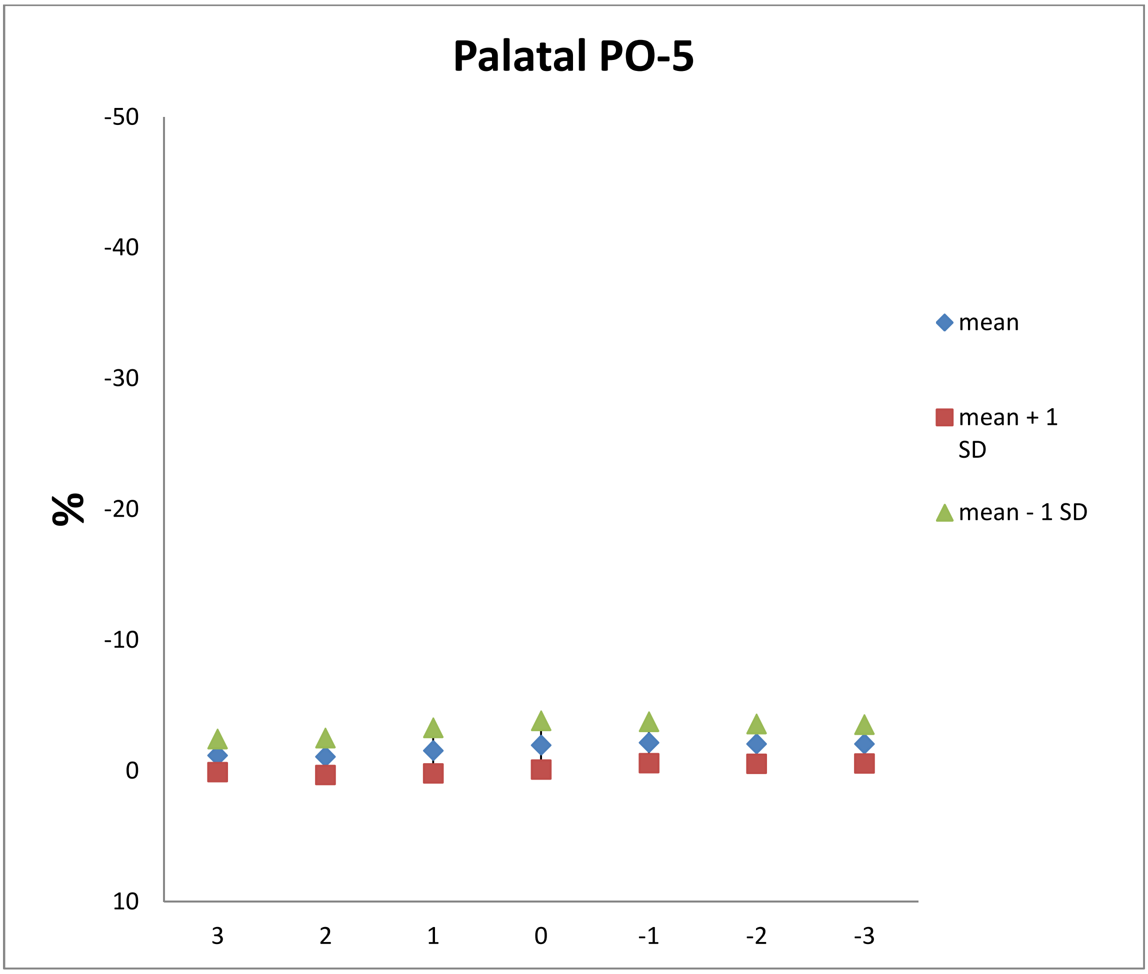
Palatal PO-4			
	mean	mean + 1 SD	mean - 1 SD
3	-1,68	-0,28	-3,08
2	-1,95	-0,15	-3,76
1	-2,71	-0,71	-4,71
0	-2,93	-1,14	-4,72
-1	-2,88	-1,12	-4,64
-2	-2,77	-1,02	-4,52
-3	-2,65	-0,95	-4,35



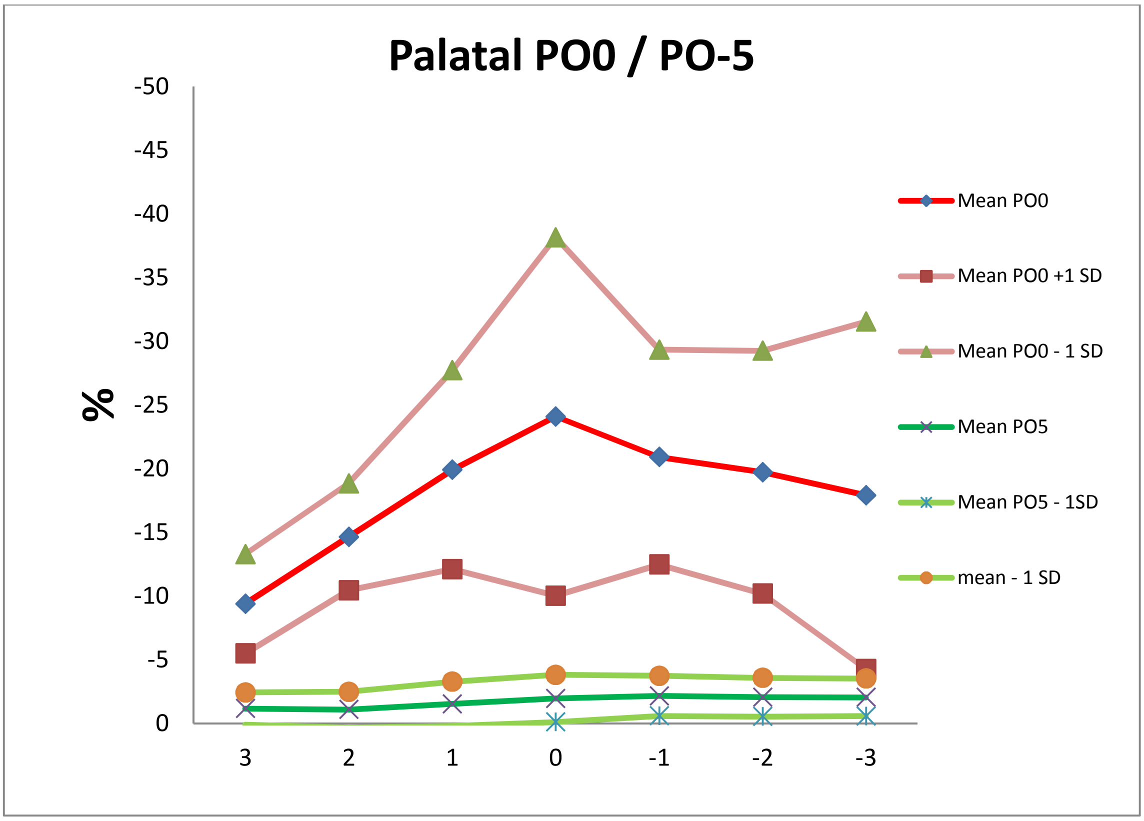
GRAPH 15 HORIZONTAL PLANE -4 WITH +1 AND -1 STANDARD DEVIATIONS AT THE LINGUAL/PALATAL SIDE

TABLE 17 HORIZONTAL PLANE -5 REPRESENTED AT THE LINGUAL/PALATAL SIDE BY THE MEDIA AND +1 AND -1 STANDARD DEVIATION

Palatal PO-5			
	mean	mean + 1 SD	mean - 1 SD
3	-1,18	0,08	-2,44
2	-1,09	0,31	-2,50
1	-1,54	0,19	-3,28
0	-1,97	-0,12	-3,82
-1	-2,17	-0,60	-3,75
-2	-2,07	-0,55	-3,59
-3	-2,06	-0,58	-3,54



GRAPH 16 HORIZONTAL PLANE -5 WITH +1 AND -1 STANDARD DEVIATIONS AT THE LINGUAL/PALATAL SIDE

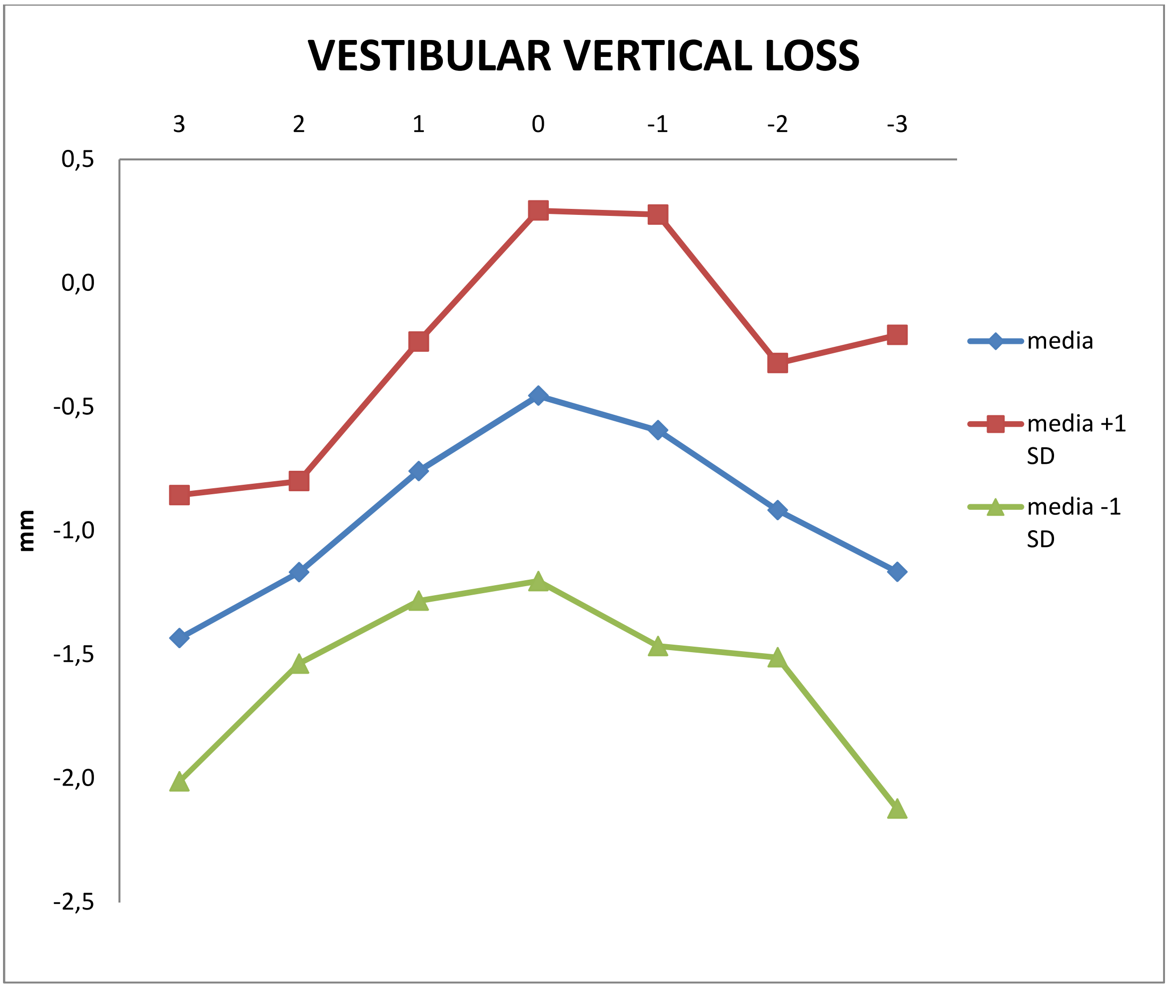


Graph 17 Comparison between first and last horizontal plane at the palatal side

The vertical loss was also investigated like other authors do, but I didn't know which is the proper refer to transform the absolute values in percentages.

TABLE 18 THIS TABLE REPRESENT THE VERTICAL LOSS AND +1 AND -1 STANDARD DEVIATIONS

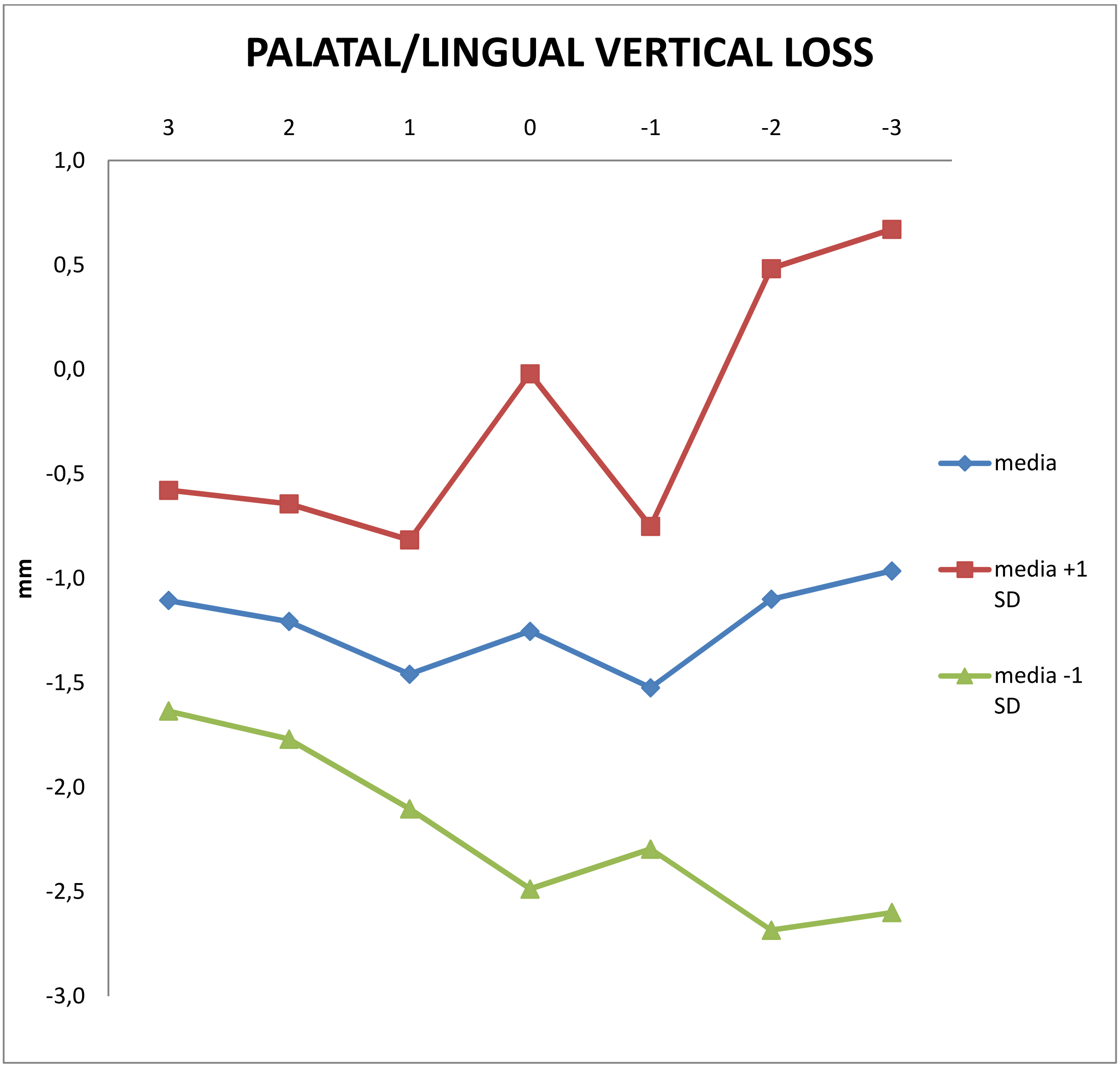
VESTIBULAR VERTICAL LOSS (in mm)			
vertical plane	media	media +1 SD	media -1 SD
3	-1,434	-0,856	-2,012
2	-1,168	-0,799	-1,537
1	-0,759	-0,236	-1,282
0	-0,455	0,294	-1,204
-1	-0,594	0,277	-1,465
-2	-0,917	-0,323	-1,511
-3	-1,166	-0,209	-2,123



GRAPH 18 GRAPHICAL REPRESENTATION OF TABLE 18

Table 19 Palatal/lingual vertical loss +1 and -1 standard deviations

PALATAL/LINGUAL VERTICAL LOSS (in mm)			
vertical plane	media	media +1 SD	media -1 SD
3	-1,106	-0,578	-1,634
2	-1,206	-0,643	-1,769
1	-1,459	-0,816	-2,102
0	-1,253	-0,019	-2,487
-1	-1,523	-0,750	-2,296
-2	-1,100	0,483	-2,683
-3	-0,964	0,671	-2,599



Graph 19 Graphical representation of Table 19

7.2.1 INTERPRETATION OF GRAPHS

Clinician when are arrived at this point often don't stop at thinking on what they are going to do next.

The interpretation of data is a very big and important phase.

With every statistic program is possible to say if there is or not a significant difference among the groups and a lot of them are statistically different if we exclude the first horizontal layer for both sides.

But I would like that you that are reading my work stop for a while and follow me, in my way of thinking: we need to make a step backwards, we have to ask ourselves which is the sense of this work; why we arrived till here and what we want to say.

The objectives of this work were:

- To Standardize
- To simplify
- To Reduce human errors
- To reduce the time required for data elaboration

Which of this objectives are been reach?

For sure now there are some rules and the scripts helps a lot to standardize results, but the procedure isn't that simple and it definitely requires some skills to be performed.

Human errors are surely less than to do it in a traditional way but the elaboration of data is very slow, with so many numbers and with a so big difficult to interpret them.

So only a part of objectives are been reached.

But the real question is: in these 10 clinical cases, which is the final result valuable to be the object of an article like the one of other researcher? How much hard-soft tissue did we lose?

Like we can observe from graph there is a very big variation depending where we investigate the volume loss.

We globally had a horizontal lost from 3 to 43% of volume in the analyzed area.

We can report our medium lost in each point of the grid, but it would end in a very big amount of data, while normally on articles other researchers give a unique reference number. With this method, at the contrary, it is almost impossible to provide a single data.

We can arbitrary decide to give a value that can be the maximum, or to choose only some points of the grid and to give this values but I don't think that this is the correct way to interpret the data.

For the vertical loss I had problems because I don't know which is the referral to transform the data in mm to percentages and I'm not been able to understand how other researchers does.

The only thing that is visible from the graph is that there's a bigger loss when we go mesial and distal from the vestibular side and lingually/palatally there's no difference but what is strange is that standard deviation has a trend at the palatal side: it increase going distally.

I do not have any clinical explanation for this behavior of standard deviation…

7.2.2 PROS AND CONS OF BI-DIMENSIONAL ANALYSIS

Pros:

- Investigation of the defect's shape
- Very good for a local defect analysis

Cons:

- Do not consider the size of the area affected from the resorption
- Slow method , give a big amount of data to evaluate
- Trivialization of the tridimensional aspect to a bi-dimensional number

This system is very good if our attention is to investigate a specific point, or if we want to see which is the form of the defect.

If we consider that the grid is standard and the mouth that we analyze can come from an acromegalic man or from a little lady with small mouth we immediately understand that this system isn't universal and absolutely do not consider the size of the patient.

If we try to give "A" number that can explain in synthesis the problem for sure we are losing a lot of information and are very easy to trivialize the final results assuming a wrong position from the start of the thinking.

This so high variability can also lend us to interpret the data in our favor choosing wrong selection criteria of the data that can falsify the final result.

I’m not saying that this is a wrong method at all and cannot be used, but I’m saying that this method isn’t enough and cannot be used alone.

CAPITOLO 8. 3D METHOD

A tridimensional method that investigates volume without transforming it in a bi-dimensional value has very little support in literature.

For this reason I worked hard to create a novel 3D method that can reach the prefixed objectives where 2D method failed.

I was thinking why I cannot use the 3D scans of the mouths of my patients like other 3D modeled objects that normally are used in industrial engineering?

8.1 BOOLEAN OPERATION

For this reason I treated the mesh correcting defects and closing holes transforming them in solids. So at this point is very easy to find out the difference of volume among them: with a Boolean operator I subtracted the second mesh to the first one and I obtained a resulting mesh that is the difference of them (Figure 49).

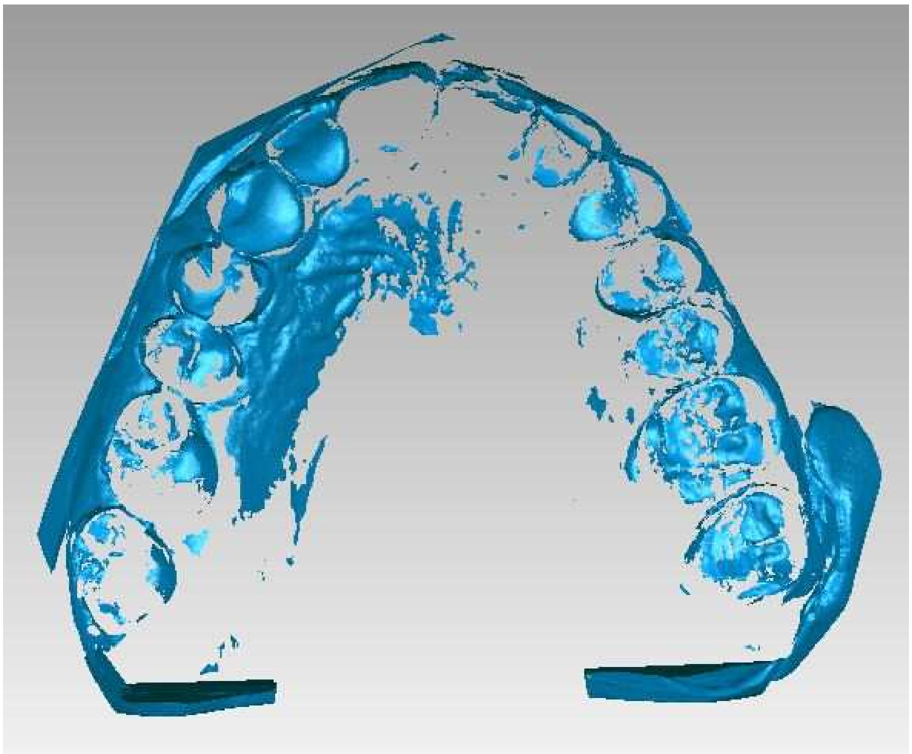


FIGURE 49 THE RESULTING MESH AFTER BOOLEAN DIFFERENCE

Like is visible form Figure 49, what we obtained is the result of all differences on model, for example where there is the base of gypsum, the form is an artifact and has no relation with our impression and also very little differences on teeth, errors in superimposing etc. can affect this method creating some volumes where in reality they are not real.
In this particular case we are studying the 14 element, the first premolar on upper right maxilla.

8.2 SELECTION OF THE REGION OF INTEREST

Which is the area we should investigate?
In literature other studies took like referral only the space that there was the teeth before (Schneider et al. 2014) like is visible in Figure 50.

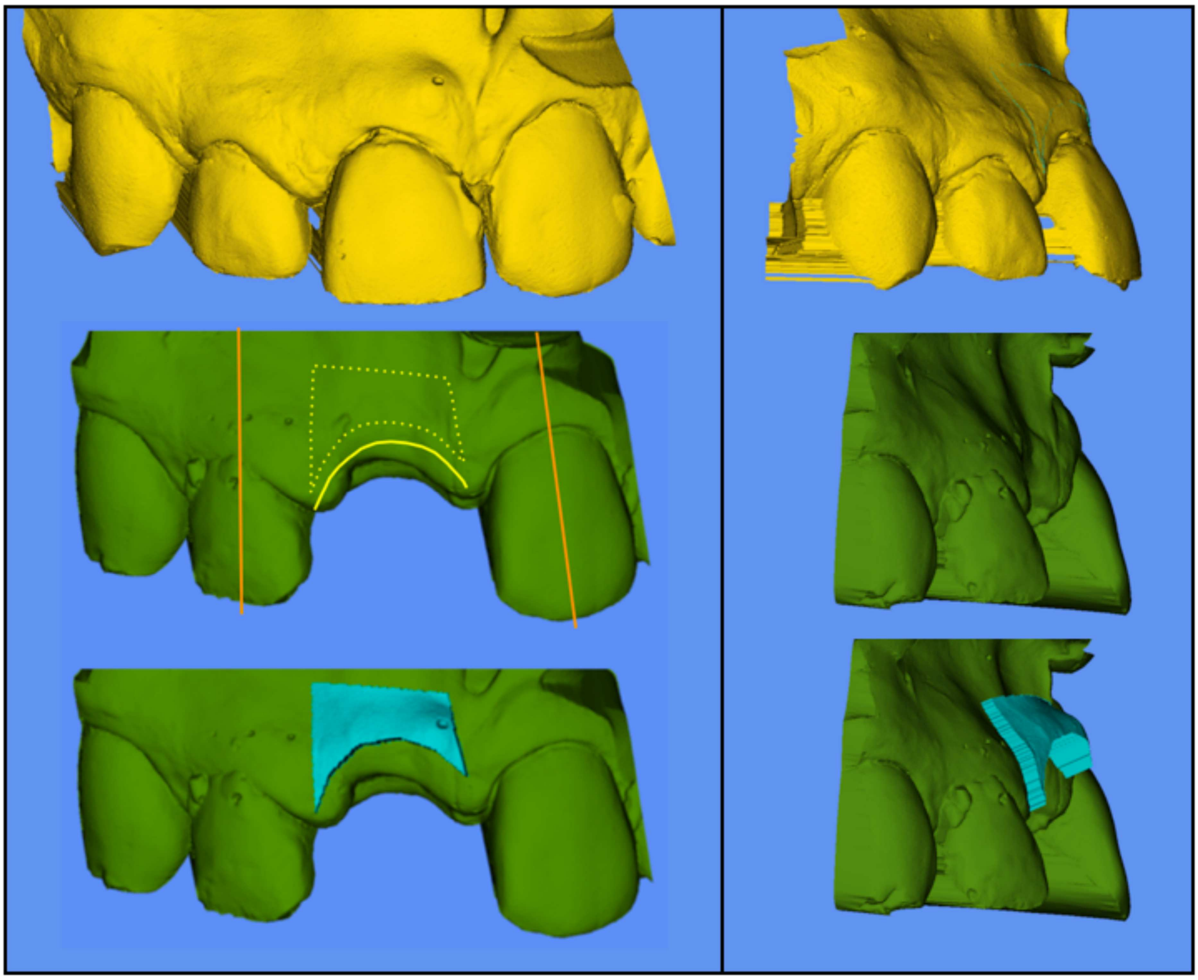


FIGURE 50 PICTURE OF THE AREA OF INTEREST FOLLOWING SCHNEIDER ET AL. 2014

I was asking myself: “why they consider that area? There is a specific reason or they assume it without explaining why?

I made a different choice, at first I wanted to investigate witch was the area affected from resorption and for doing this I used a Rhinoceros tool called mesh to mesh deviation (this tool is a part of Rhino Open Projects author Eng. Giampaolo Savio University of Padova - School of Engineering; Department of Civil, Environmental and Architectural Engineering; Laboratory of Design Tools and Methods in Industrial Engineering).

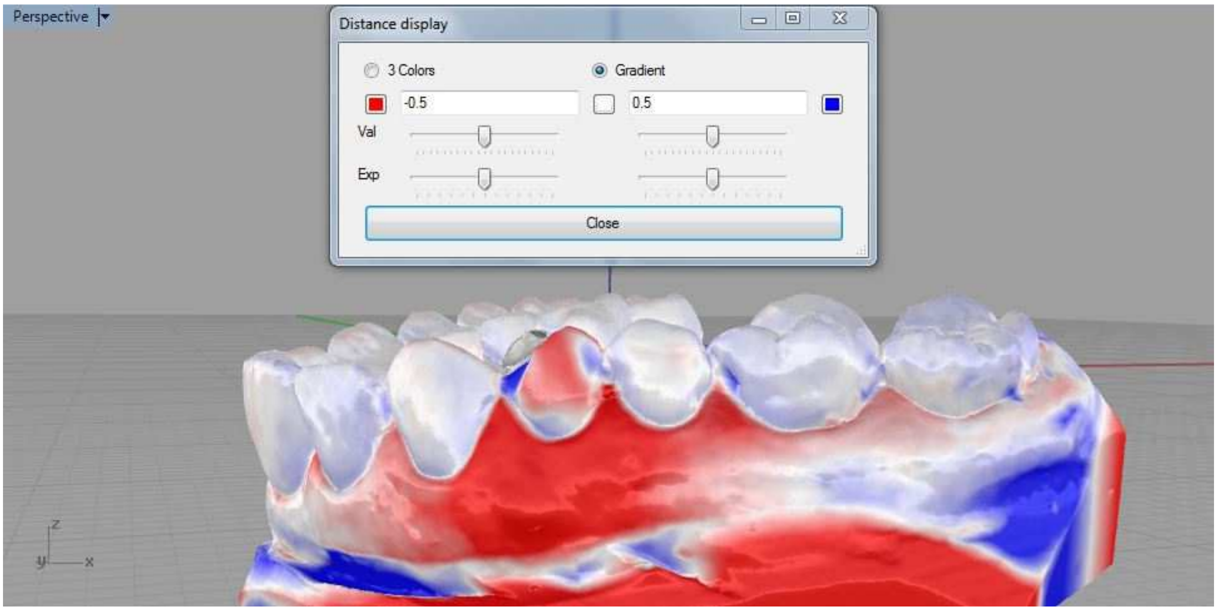


FIGURE 51 MESH TO MESH DEVIATION SHOWS US THE AREA AFFECTED FORM RESORPTION

From Figure 51 is immediately visible how the real area that is affected from the resorption is not just that one included where there was the teeth, but it reach in mesio/distal direction the half of canine and the half of second premolar.

This observation was confirmed from the visual evaluation on other models.

I selected the area that was not suitable for the investigation Figure 52 and I deleted it obtaining the mesh in Figure 53.

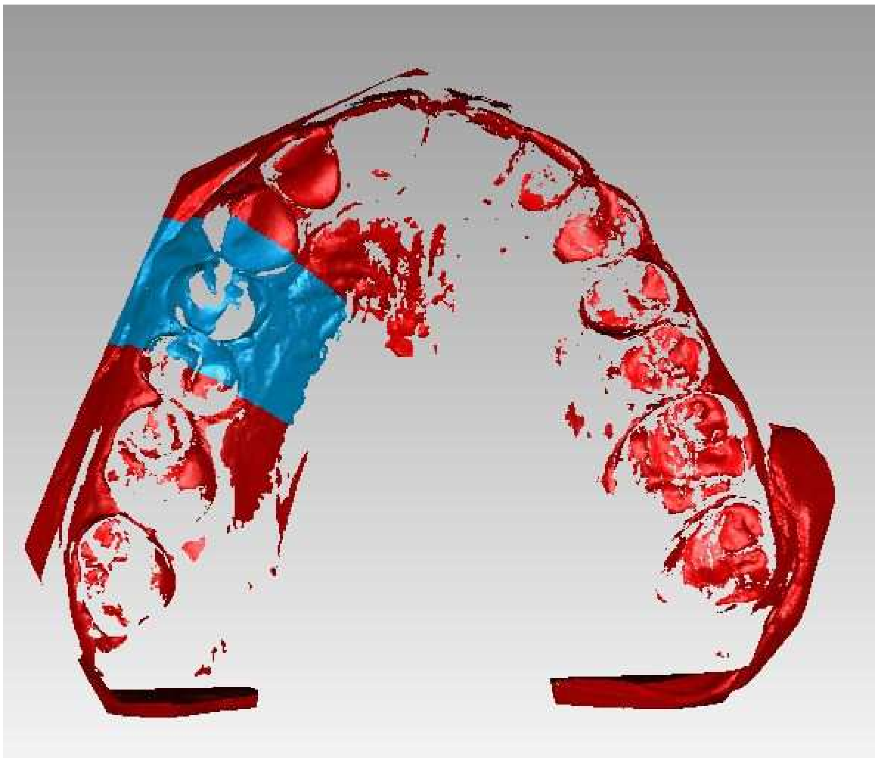


FIGURE 52 THE SELECTION OF THE AREA THAT HAS TO BE DELETED

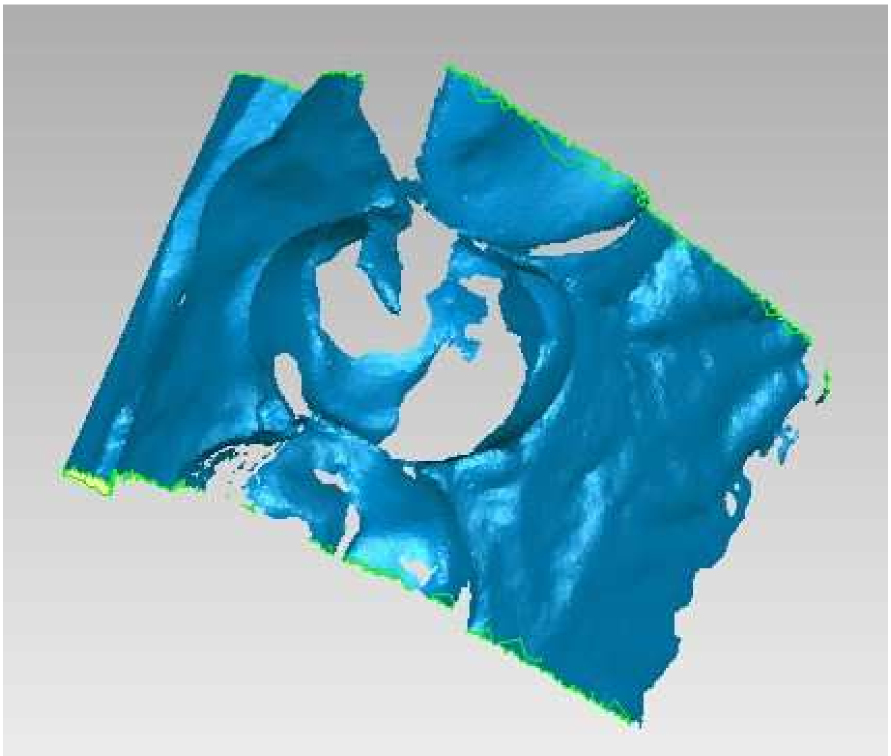


FIGURE 53 THE REMAINING MESH AFTER THE SELECTION

8.3 CLEANING AND PREPARATION OF THE MESH

At this point it is necessary that an expert operator continues the following steps because some skills are required to clean and to decide correctly witch parts will be kept and witch one has to be deleted: apically often the model continue with an artifact of gypsum, so is the operator that need to clean it and also is necessary to select the teeth and other little components deleting them (Figure 54).

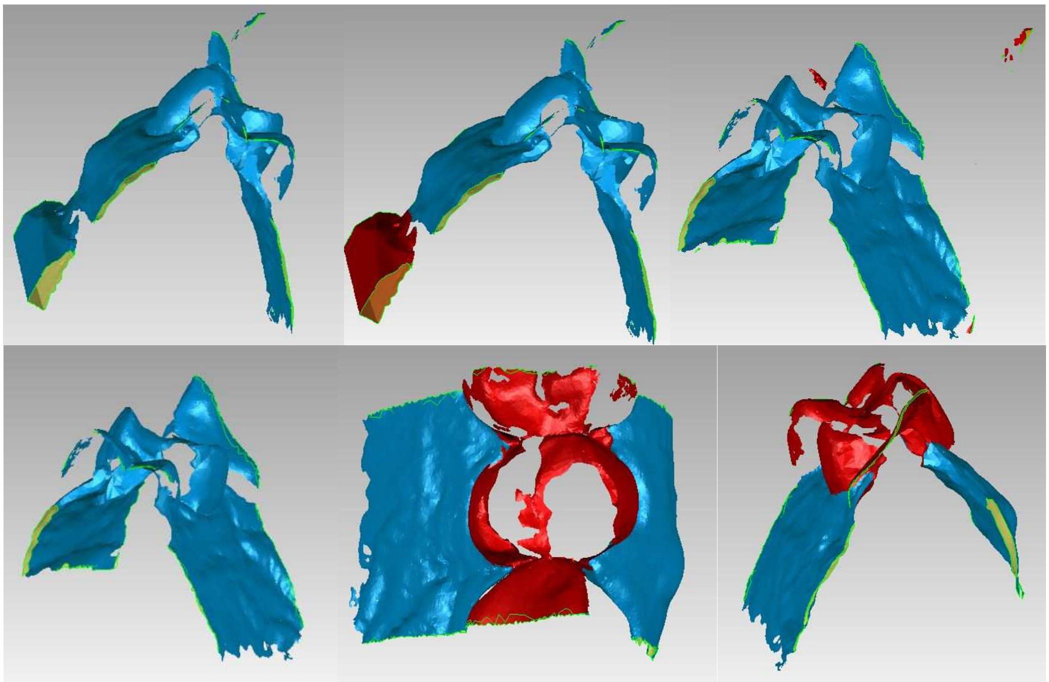


FIGURE 54 CLEANING PASSAGES OF SELECTED MESH THE RED PARTS ARE THE SELECTION THAT WILL BE DELETED

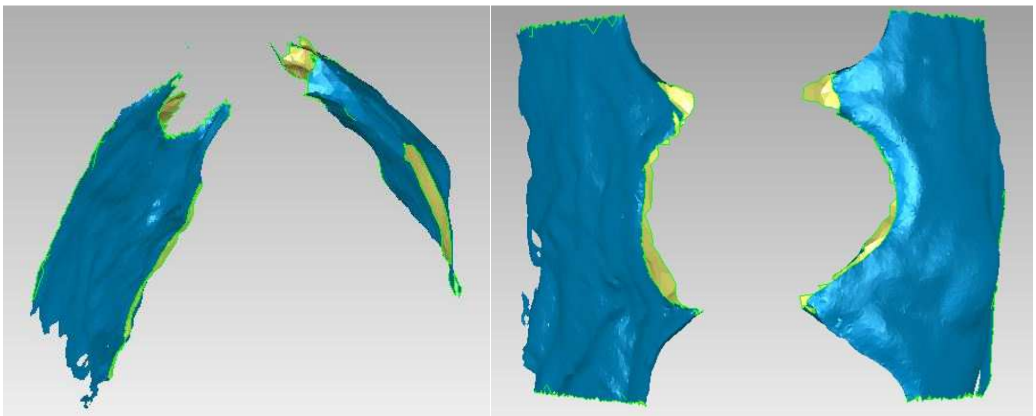


FIGURE 55 DIFFERENT VIEWS OF RAW VOLUMES JUST EXTRACTED

When finally the surfaces of volumes extracted from mesh are obtained (raw volumes Figure 55) is possible to start the elaboration that will lend us to define how many cube mm we lost in each side (buccal and lingual/palatal).

This elaboration consists in making some bridges among the surfaces that will permit us to close the volumes with the holes repair tool of Geomagic.

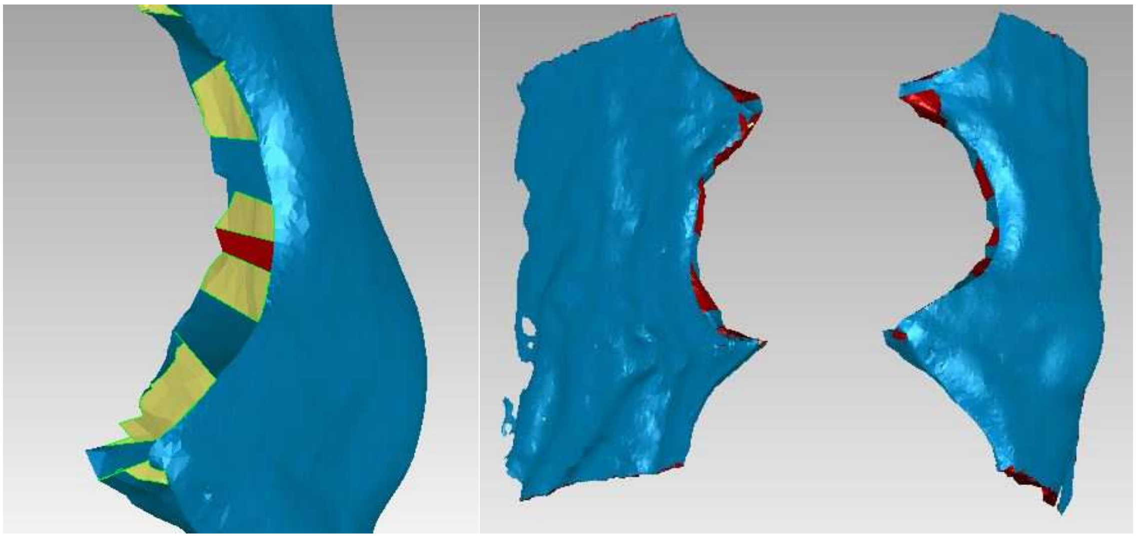


FIGURE 56 BRIDGES AND HOLE REPAIRING TOOLS OF GEOMAGIC ARE USED TO CLOSE THE SURFACES IN SOLIDS

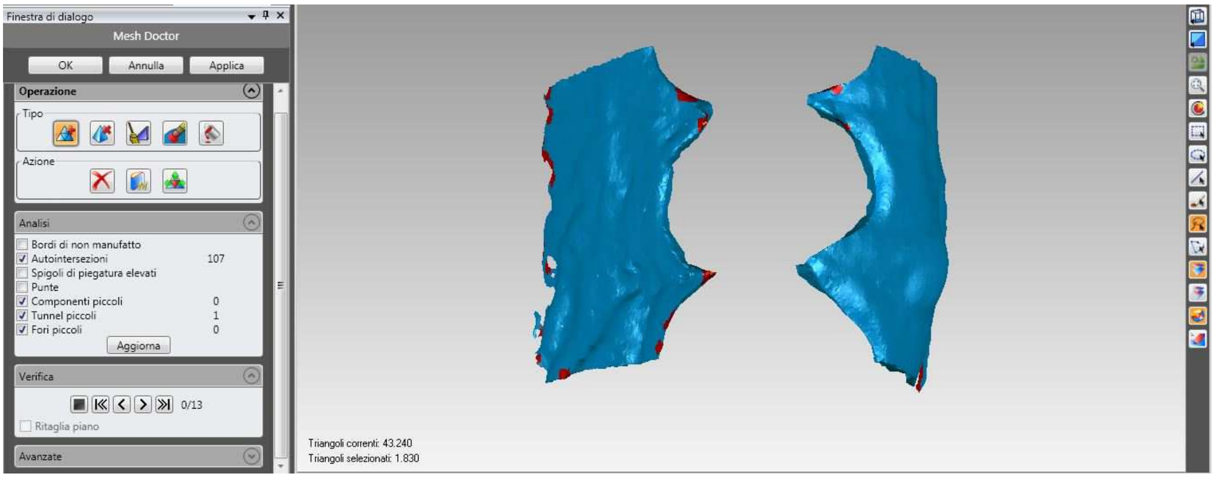


FIGURE 57 CORRECTING DEFECTS OF THE MESH WITH MESH DOCTOR

8.4 VOLUME ANALYSIS

When the volumes extracted are cleared from defects is possible to import them in Rhinoceros software and to perform the volume analysis: on menu Analyze → Mass properties → Volume.

Is very important that the volume exported is a closed volume or Rhinoceros won't be able to make this operation.
When the volume data is obtained, returning on Geomagic the elaboration continue, because to have an absolute value in cube millimeters is sense-less.
I want to give a percentage value of volume loss but how can we do it? Which could be a good referral volume that allows us to transform the absolute value in percentage?
The distance from half aside teeth changes each clinical case, and depend on how big is the mouth of the patience; The distance from the buccal and palatal/lingual volume also depends on how big is the mouth and how is anatomically made the mouth.
For this reason I choose to take the outer surfaces of volumes extracted and to use them like referral for the build of a volume that represents the volume of the region of interest (R.O.I.).

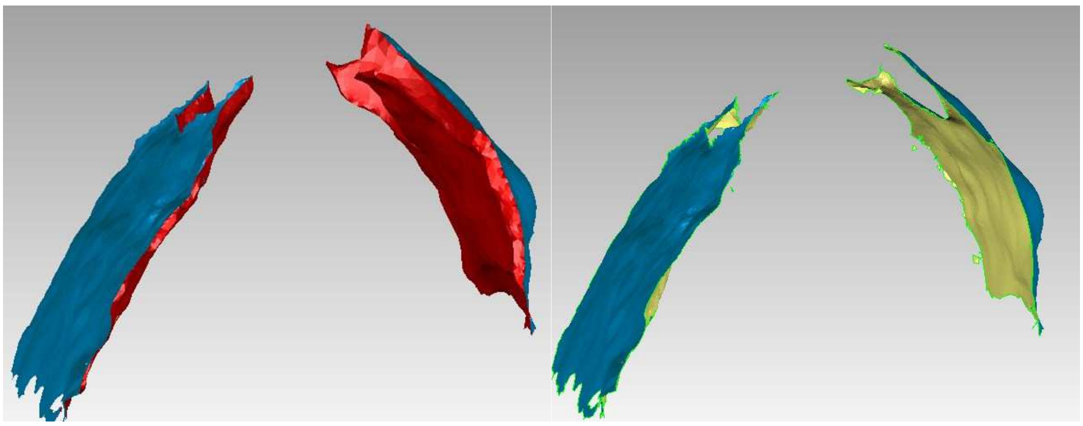


FIGURE 58 EXTRACTION OF OUTER SURFACES OF VOLUMES

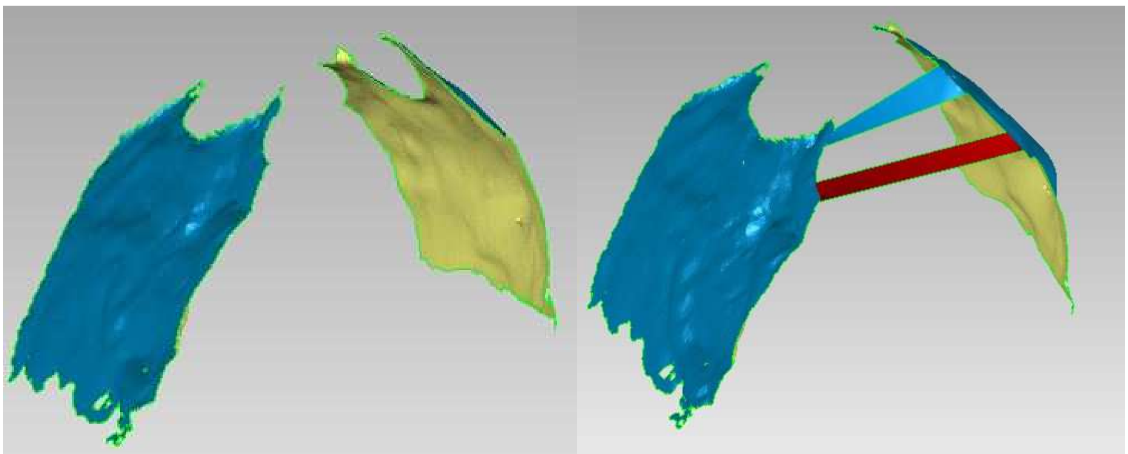


FIGURE 59 CREATING BRIDGES FROM OUTER SURFACES TOGETHER TO GENERATE THE VOLUME OF THE REGION OF INTEREST (R.O.I)

To create the volume lot of bridges was made and after the repair holes tool was used to fill the gaps.

An automatized solution with a Rhino-Python script was also performed trying to use a two binary sweep on the duplicated border of the mesh, but the results that was obtained was really low level respect to the method with bridges, so was not suitable for this application.

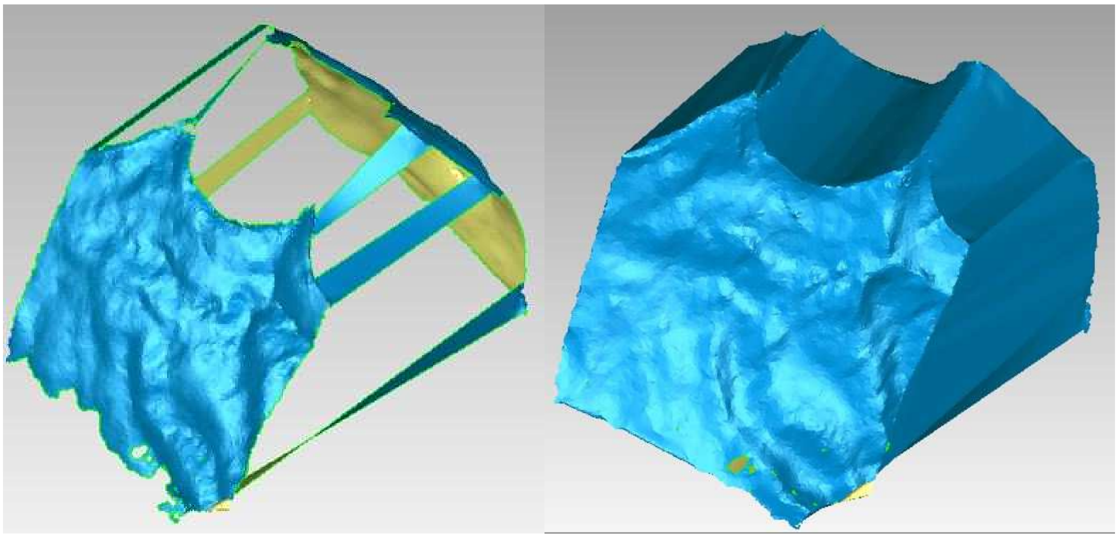


FIGURE 60 REGION OF INTEREST CREATED LIKE A SOLID

When the volume of R.O.I. was created a mesh doctor was performed on it cleaning defects like in Figure 61.

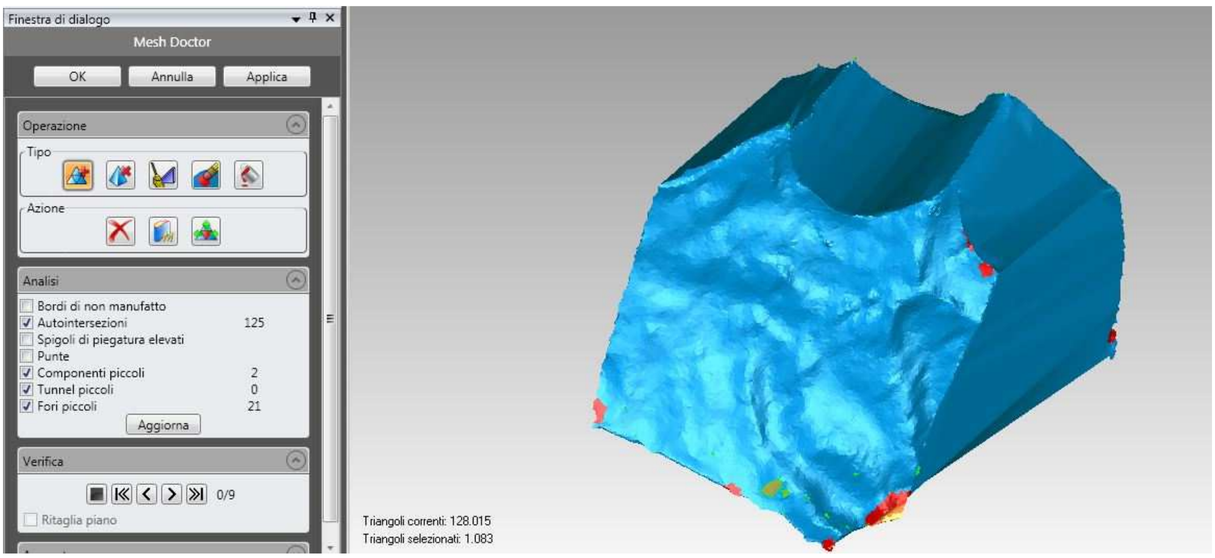


FIGURE 61 CORRECTION OF DEFECTS OF R.O.I.

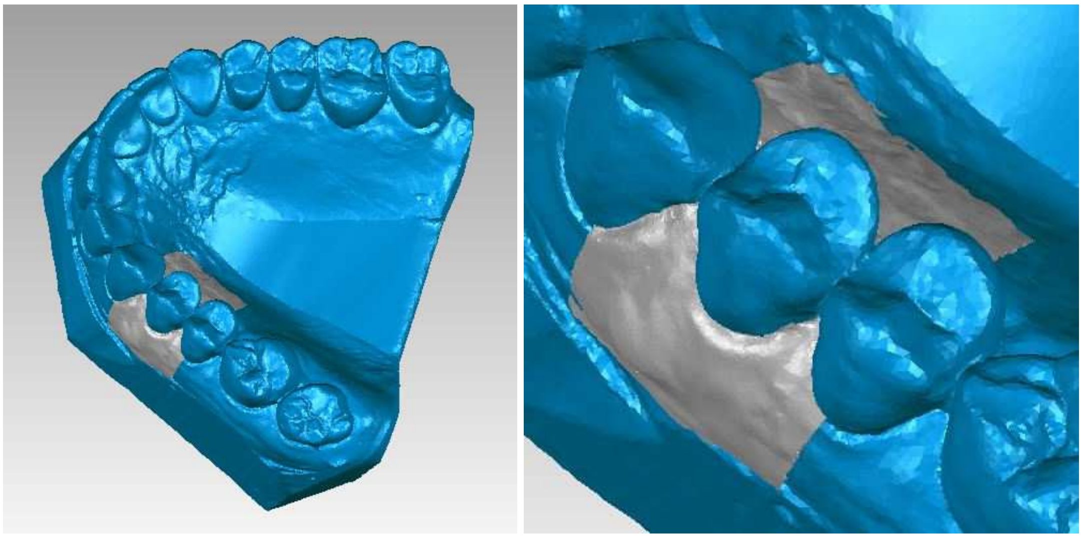


FIGURE 62 THESE IMAGES SHOWS THE VOLUME LOSS IN POSITION ON THE SECOND MODEL

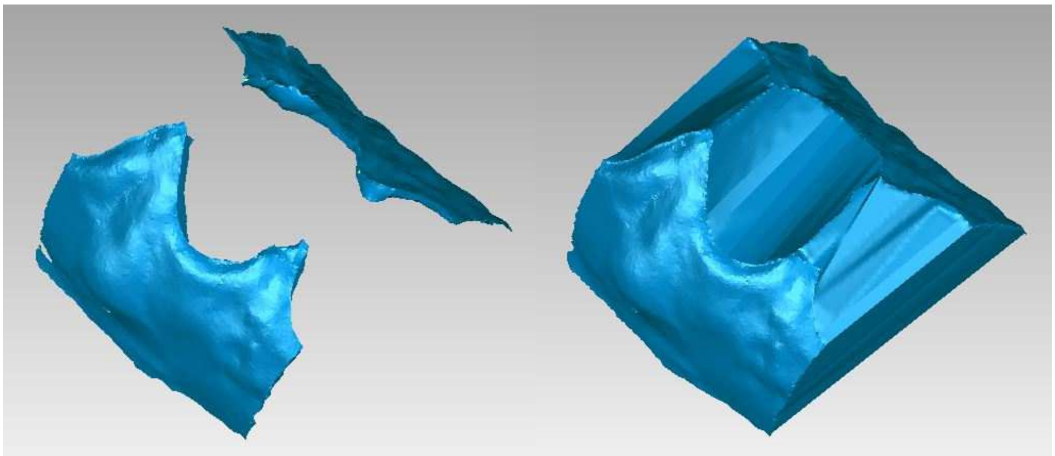


FIGURE 63 VOLUME LOSS AND VOLUME OF **R.O.I.**

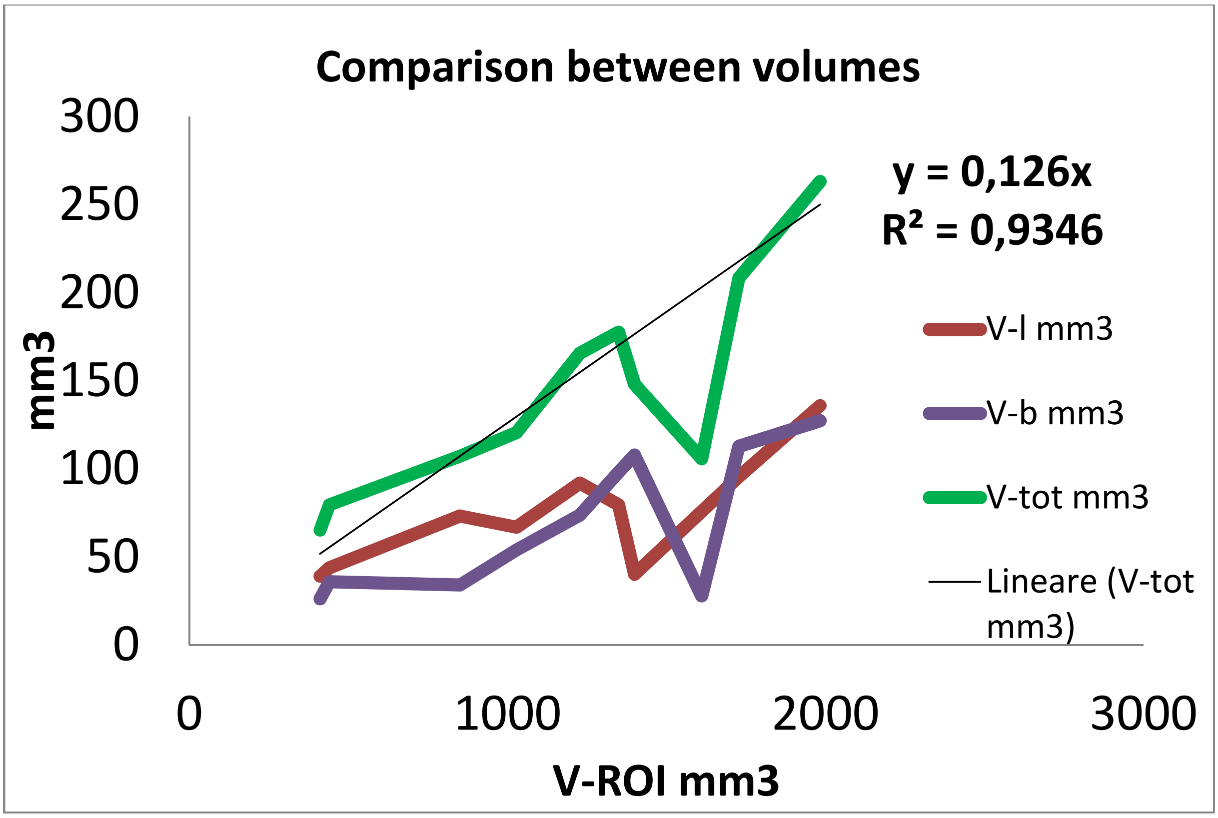
8.5 INTERPRETATION OF RESULTS

In Table 20 is possible to see the data of 3D evaluation of raw volumes and percentages calculated putting in relation volume loss and the volume of R.O.I.

TABLE 20 RAW DATA AND PERCENTAGES OF 3D ANALYSIS

Patient code	Teeth N°	V-b mm3	V-l mm3	V-tot mm3	V-ROI	V-b %	V-l %	V tot %
2	25	112,7	95,5	208,2	1727,8	6,5	5,5	12,1
4	14	73,8	91,8	165,6	1227,3	6,0	7,5	13,5
6	35	34,0	73,2	107,2	850,8	4,0	8,6	12,6
12	25	27,8	77,8	105,6	1610,6	1,7	4,8	6,6
13	35	98,0	79,5	177,5	1349,7	7,3	5,9	13,2
18	45	53,9	66,8	120,6	1029,1	5,2	6,5	11,7
19	14	107,9	40,0	147,9	1399,5	7,7	2,9	10,6
23	45	35,7	43,8	79,6	440,2	8,1	10,0	18,1
25	45	26,2	39,0	65,2	410,9	6,4	9,5	15,9
26	25	127,3	135,9	263,2	1983,3	6,4	6,9	13,3
Mean		69,7	74,3	144,1	1202,9	5,9	6,8	12,7
SD		39,1	29,8	61,2	524,4	1,9	2,2	3,1
Median		63,8	75,5	134,3	1288,5	6,4	6,7	12,9
Quart 25th		34,4	49,6	106,0	895,3	5,4	5,6	11,8
Quart 75th		105,4	88,8	174,5	1557,8	7,1	8,3	13,4

Observing the table of data, was observed that the volume of R.O.I. and the volume loss are not two independent variables: If we observe the ratio between media/Standard Deviation for example of the total volume (V-tot) in absolute values is 144,1 / 61,2 = **2,35** but if we try to do the same with percentages is: 12,7 / 3,1 = **4,09.**
To have such a difference was evident that the volume of the alveolar crest called R.O.I. and the volume loss are correlated in some way.
I try to explain what happens in Graph 20.



GRAPH 20 COMPARISON OF VOLUME LOSS AND VOLUME OF R.O.I.

In Graph 20 Is possible to see how the volume loss is correlated linearly with the R.O.I. and this is also logic because if we have a patient with a big mouth will lose for sure more volume in absolute value than a small patient mouth.

The patient number 12 was an outlier because was more than 1.96 Standard Deviation distant than other, so was not consider for the construction of the trend line.

This observation of correlation between volume loss and mouth size is so logic that nobody in literature ever observed it.

Another observation can be done: we had the same volume loss at the buccal side versus Palatal/lingual side (T-test V-b vs. V-l gives us a p value = 0.34) because the two samples are not statistically different and this also is a very important observation.

Literature says that at the palatal/lingual side the resorption is very little or there isn't.

But this is false. The resorption is equal to the vestibular area, can change the shape of the defect, but not the amount of volume loss.

What does it means? Why nobody has ever made and reported this observation?

My Idea is because the method used to investigate the resorption is mostly histological, where in a bi-dimensional section an operator has to perform a 3D analysis or worse, a 2D measure is applied in radiography to a three-dimensional DICOM file, losing all the potential of real 3D analysis.

So I believe that till now someone did something wrong at start, and the instrument and methods that are used to perform measurements from the later researchers was not good, or not used in the correct way. Only this can be the reason that explains why nobody ever observed so big evidence and all authors just repeated what was said at start without investigate better.

A Kolmogorov Smirnov test was made to understand if the phenomena follow a normal distribution and all values resulted to be normal.

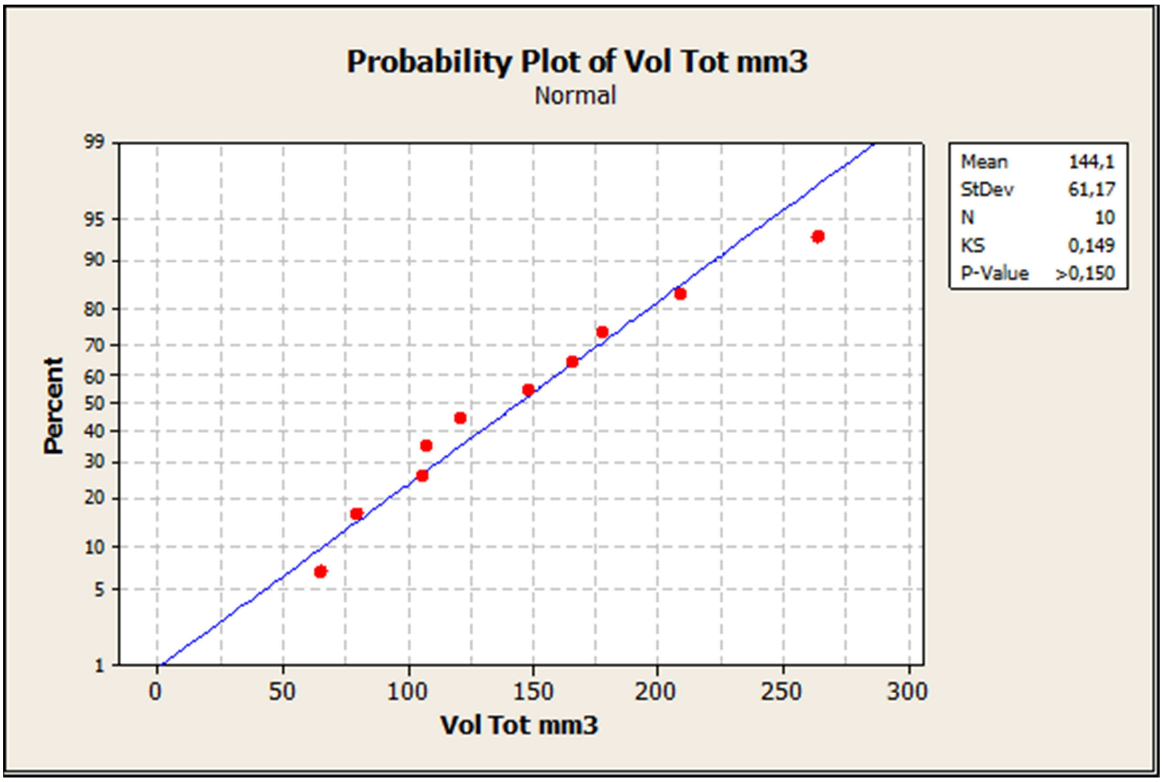


FIGURE 64 KOLMOGOROV SMIRNOV TEST OF TOTAL VOLUMES

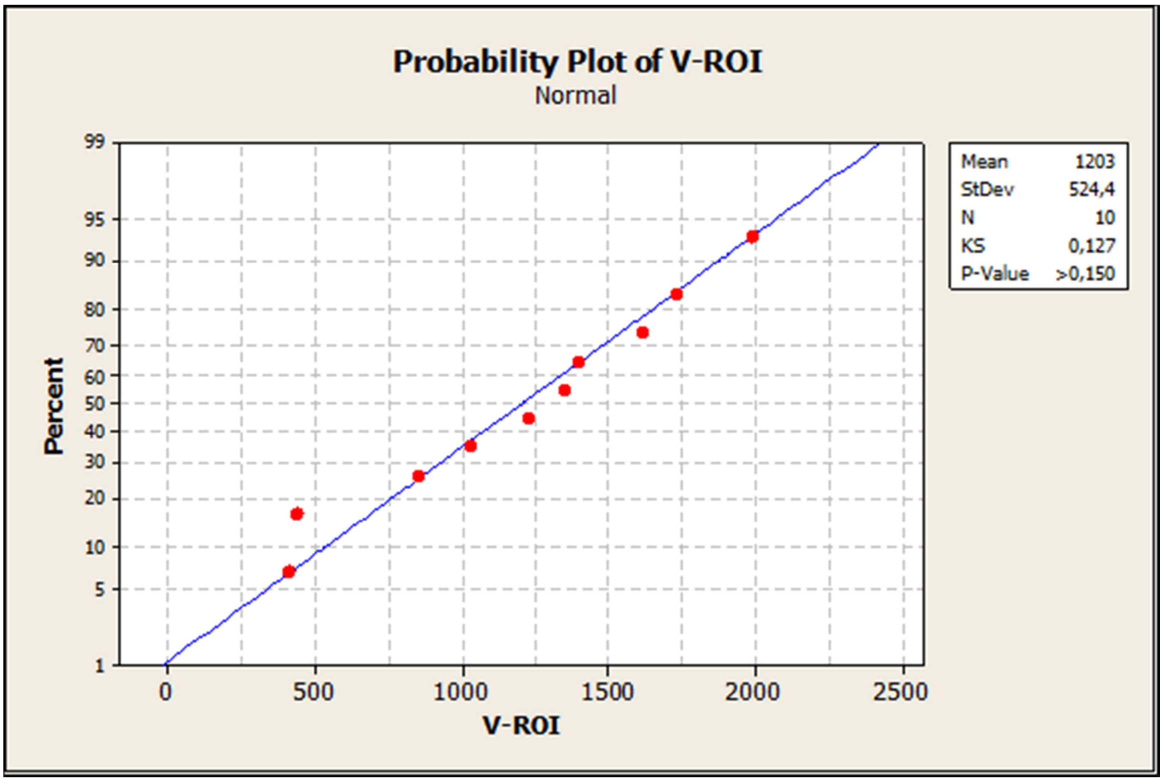


FIGURE 65 KOLMOGOROV SMIRNOV TEST OF ROI VOLUMES

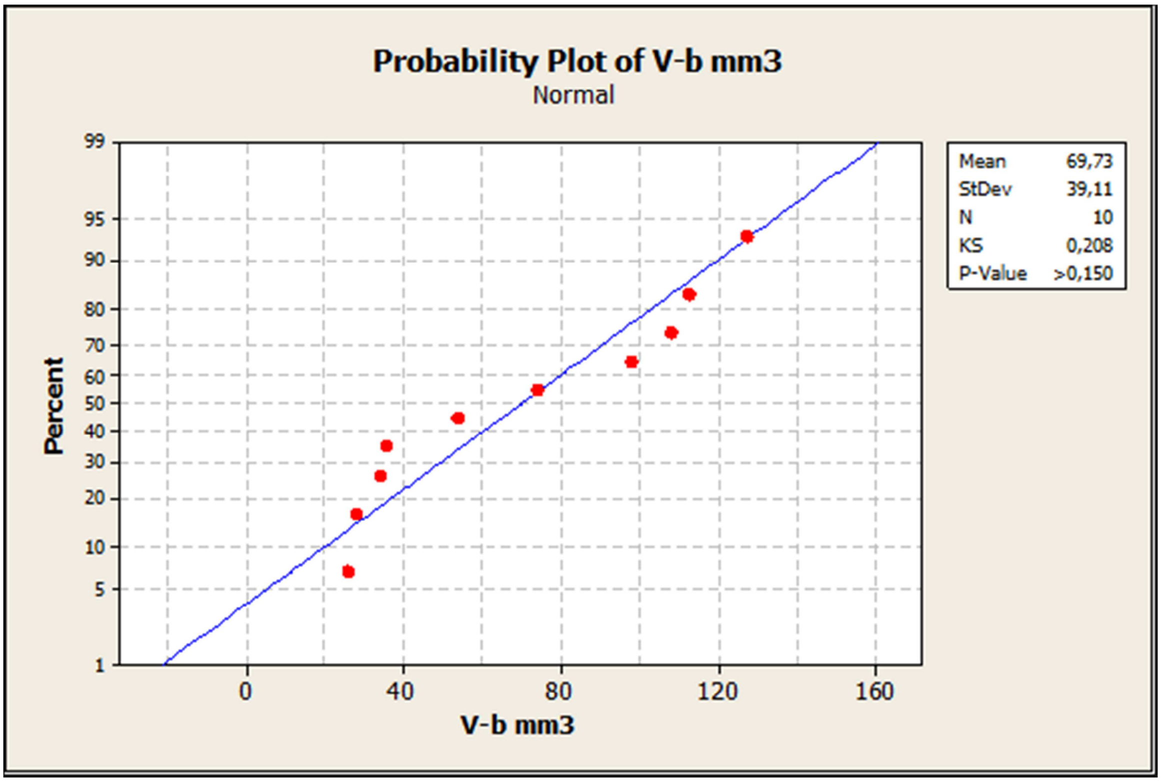


FIGURE 66 KOLMOGOROV SMIRNOV TEST OF BUCCAL VOLUMES

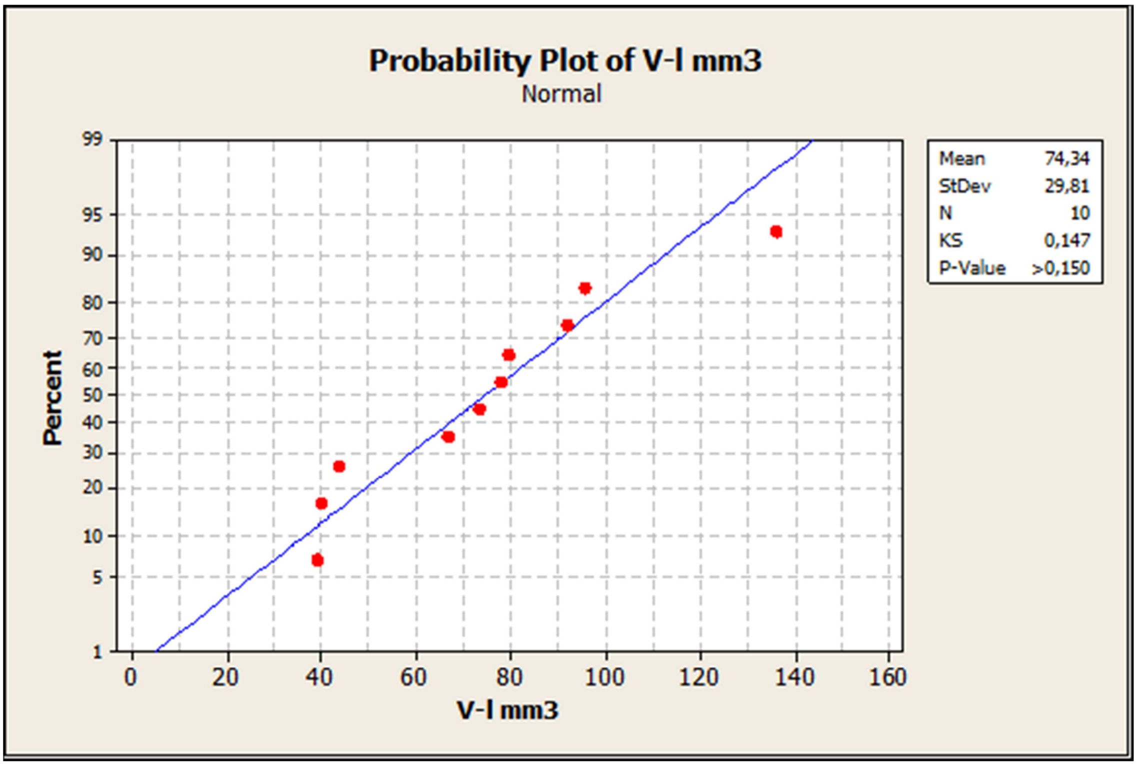


FIGURE 67 KOLMOGOROV SMIRNOV TEST OF LINGUAL/PALATAL VOLUMES

The investigated phenomena follow a normal distribution.

To validate the methodology controlateral tooth was analyzed also to understand how much all processes (impression, optical acquisition, superimposion etc.) can affect this method (Figure 68):

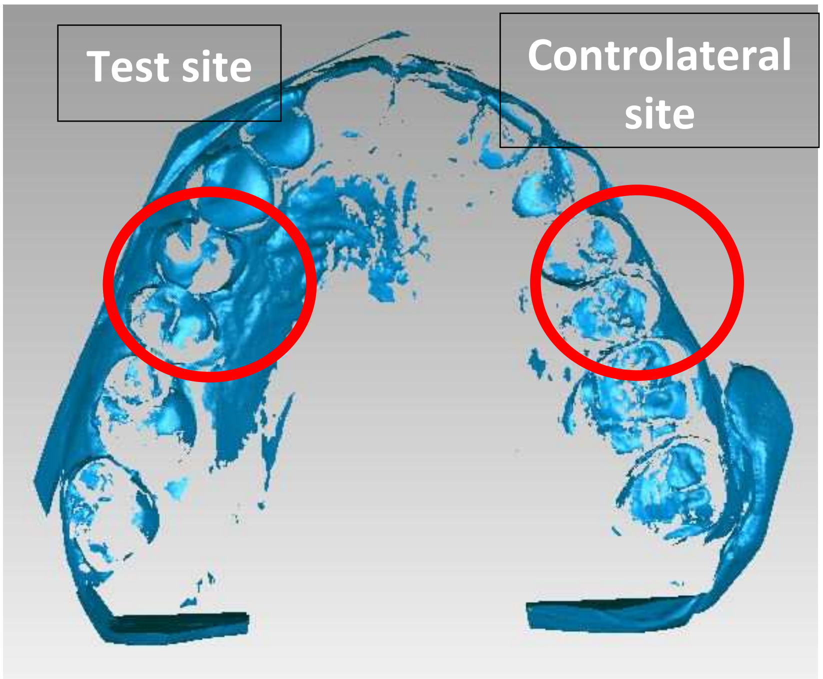


FIGURE 68 INVESTIGATION OF THE CONTROLATERAL VOLUME TO EVALUATE THE ERRORS OF THIS PROCEDURE

In theory at the controlateral side, we should have 0 like volume change, but is not so and analyzed values are shown in Table 21 and are expressed in absolute values and percentages.

TABLE 21 CONTROLATERAL VOLUMES TO THE TEST AREA

Patient code	Teeth N°	V-b ctrl mm3	V-l ctrl mm3	V-tot ctrl mm3	V-b ctrl %	V-l ctrl %	V-tot ctrl %
2	25	4,05	2,13	6,18	0,23	0,12	0,36
4	14	4,94	12,75	17,69	0,40	1,04	1,44
6	35	1,40	7,32	8,73	0,16	0,86	1,03
12	25	0,00	0,00	0,00	0,00	0,00	0,00
13	35	3,70	3,72	7,43	0,27	0,28	0,55
18	45	2,13	0,65	2,77	0,21	0,06	0,27
19	14	2,05	0,01	2,06	0,15	0,00	0,15
23	45	0,41	3,27	3,68	0,09	0,74	0,84
25	45	1,15	3,21	4,36	0,28	0,78	1,06
26	25	0,00	0,00	0,00	0,00	0,00	0,00
Mean		1,98	3,31	5,29	0,18	0,39	0,57
SD		1,74	4,04	5,24	0,13	0,42	0,50
Median		1,73	2,67	4,02	0,19	0,20	0,45
Quart 25th		0,60	0,17	2,23	0,11	0,02	0,18
Quart 75th		3,31	3,61	7,11	0,26	0,77	0,98

We have seen that with Kolmogorov Smirnov test the analyzed volumes of test site are normal, so a T-test was performed but also a Wilcoxon non parametric test was done (due to the little sample N=10) and results are explained with colors in

Table 22.

TABLE 22 COMPARISON BETWEEN VOLUMES FROM TEST SIDE AND CONTROLATELATERAL SIDE

Patient code	V-b %	V-l %	V tot %	V-b ctrl %	V-l ctrl %	V-tot ctrl %
2	6,523	5,527	12,050	0,234	0,123	0,358
4	6,011	7,483	13,494	0,402	1,039	1,441
6	3,996	8,604	12,600	0,165	0,861	1,026
12	1,727	4,830	6,556	0,000	0,000	0,000
13	7,259	5,893	13,152	0,274	0,276	0,550
18	5,236	6,488	11,724	0,207	0,063	0,269
19	7,707	2,861	10,569	0,146	0,000	0,147
23	8,114	9,960	18,074	0,093	0,744	0,837
25	6,381	9,491	15,873	0,280	0,782	1,062
26	6,420	6,852	13,272	0,000	0,000	0,000
Mean	5,937	6,799	12,736	0,180	0,389	0,569
SD	1,897	2,183	3,051	0,127	0,417	0,499
Median	6,401	6,670	12,876	0,186	0,200	0,454
Quart 25th	5,430	5,619	11,805	0,107	0,016	0,177
Quart 75th	7,075	8,324	13,438	0,264	0,772	0,979
t-test	4,33E-06	1,92E-06	2,29E-07			
Wilcoxon test	0,005	0,005	0,005			

Like is visible from the table above Lingual/palatal volume, buccal volume and total volume has a highly significant in both T-test and Wilcoxon test, that means that the volume differences we found are not due to the case, or errors, but is a real biologic phenomena that we are observing.

We can conclude that three-dimensional method can be affected from all errors that can be done during: the impression taking, the plaster model fabrication, 3D scanning (reverse engineering phase), mesh creation, 3D elaboration and superimposion, etc. But if all those passages are correctly made the final error that we make in all these passages is not statistically relevant and do not affect the output of data that this method can give us.

8.6 DISCUSSION OF RESULTS

In modern times, implantology became year after year a surgical procedure always more largely spread, while materials and techniques keep on evolving.

Nowadays there are thousands of companies that produce and put in commerce implants that are different from each other, in term of form, dimensions, surface typology and each company claims his product as the best on the market.

We are clinician, and we need to understand and choose the more appropriate system, because we have and want to, make our best for our patients.

For this reason we need to have some instruments that can help us to decide which implants are good and which are not. For making this we need a scientific evidence to perform the so called “evidence based medicine”.

An implant treatment is very hard to evaluate, we have seen how many methods are been developed and studied from my colleagues for trying to be complete in the implant analysis.

The method that I created can help the clinicians to understand in a more objective way what happens to the hard and soft tissue together. Our methodology evaluate the global volume change of soft and hard tissues together, we can’t know if the volume loss is due exclusively to the soft or hard tissue, to make this we need the radiographic support.

This methodology actually cannot be used alone, but is surely a big help to understand in a more objective way what happens around implants.

Once an operator learn how to use the 3D method, after being used to it he will appreciate how this method results in being fast and accurate, plus a very important thing is that it is very little invasive for the patience: no X-ray, no surgical procedures at all, just a very simple impression.

Within the limits of this study is possible to say that using Sweden & Martina Premium Khono TG implants with an immediate implantation technique (like described above in the clinical chapter) there is a volume loss that globally is 12,7% with a 5,9% at the vestibular side and a 6,8% at the palatal/lingual side.

Among vestibular and palatal sides there is no statistically difference.

Most important thing is that there is a linear correlation among the volume loss with the dimension of the mandibular/jaw that is analyzed.

This observation make senseless to investigate the volume loss with a superimposed standard system of analysis. A grid that investigate 2D dimensions or that cut volume in multiple little volumes is senseless.

Can have a sense to investigate the shape in the middle of the defect because is easy to detect on all models and if we want to find other points probably we need to take other landmarks from the adjacent teeth and to make a grid that need to be customized on each clinical case. This is necessary if we want to reduce the variability in the bi-dimensional analysis because the standard deviation that we found between the 10 clinical cases is in part due to the application of the standardized grid.

Is necessary to make more work if we want to perform a better 2D evaluation because the rhino python script need to be modified and some landmarks need to be added to be able to generate a customized grid that can adapt itself to the space between the two adjacent teeth.

Another innovative observation of this work is that we can say that there is the same resorption of volume both palatal/lingual and vestibular and this is a very innovative observation that goes against most of the literature.

Probably the real use of tridimensional instrument will lend to discover and observe other behaviors of tissues that weren't known yet.

This methodology has been developed applied to implants, but what's more important is that can be applied to all the situation in which we need to know what happens to the tissue volume such as in grafts, augmentation procedures, in prosthesis etc.

I hope parodontologist also will appreciate my efforts and will enjoy using this method to check if the parodontal therapy is successful or not.

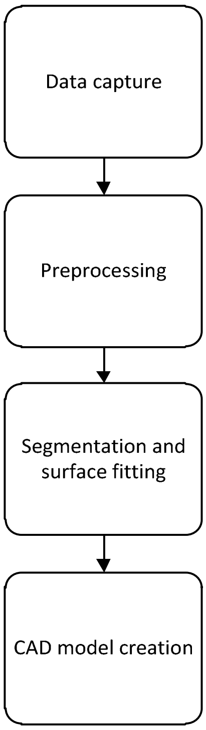
APPENDIX THECNICAL ANALYSIS OF METHOD

OVERVIEW

In this part are been summarized all important steps that the method represent.
Reading this section will allow to understand what happen in every passage from a more technical point of view.

REVERSE ENGINEERING OF GYPSUM CAST MODELS

The fundamental phases of reverse engineering are represented in the following workflow (Vàrady 1997):



DATA CAPTURE

There are many methods used to acquire the data of the shape of objects and every method use different interaction mechanisms and phenomenon with the surface of the object.
There are two big families of methods: tactile methods and contact less methods.
In our cases we are working with a gypsum cast model and the gypsum is a fragile and friable material that can be damaged from the mechanic action of a tactile methods.

The tactile methods can be the acquisition of a point cloud using a mechanical arm or a coordinated measuring machine (called CMM) but both of these methods are been discard for the damage risk and for the complex shape that we are investigating.
Contact less method involves optical, acoustic and magnetic instruments; each method has strengths and weakness so the choice of the right method is not easy and depends mostly from the object shape and physical properties.

OPTICAL SCANNERS

In dentistry the dental scanner present on the market are mostly using optical devices.
An optical device also operates with different methods that are subdivided in:

- Triangulation methods
- Structured light methods
- Image analysis methods
- Ranging methods
- Interferometry methods

The dental laboratory scanners used mostly the triangulation method and the structured light one, the intraoral scanners such as Sirona Cerec uses image analysis methods.
Triangulation is the method that uses location and angle between the light source (typically a laser source) and the photo sensing device to deduce the relative position of objects. The accuracy of these devices is determined by the resolution of the photosensitive device
Structured light scanners uses a projector that produces patterns of light upon the surface of the model and the images acquired are analyzed by measuring the distance between the contour lines; this will give the relative position of the point in the space.
The image analysis is similar to the structured light method in which frames are analyzed to determine coordinate data. This method does not require a projected pattern so this method is also called passive. Active methods are distinguished from passive ones for the artificial light use.

According to Cerardi A. 2010, a Dental wings laser scanner was used to perform 3D acquisition of data. The precision of scanning is ≤ 0,015 mm (the company declared precision is ≤ 0,020 mm).

POST PROCESSING OF DATA

There are many problems while acquiring data that can summarize in categories:

- Calibration problems: this is an essential phase of setting up the measuring device (depends how is made the scanner);
- Accuracy problems: when calibration is not the problem, the resolution of the video system is fundamental to gain a higher accuracy of measurement (also this point depends from the choices that are made from the company that produce the scanner);
- Accessibility and occlusion: this problems are due to the object conformation, from shadowing or obstruction (in case of a jaws model this is a relatively problem the areas are quite easy to be acquired) and this problem can be solved with multiple acquisition In different position of the object;
- Fixturing: This means to have in the mesh the shape of objects that are been used to fix the model on the scanning plate (see Figure 26), this problem do not influence the method analysis;
- Multiple view: this means to acquire data from different positions. This different point clouds needs to be registered each other and this insert an error every time the registration process is performed (normally we do not have the control of this phase, acquiring a bigger area we help the software to have referral point for successive registration and can implement the precision but anyway this happens without our control using common dental scanners);
- Noise and incomplete data: this can happen when some vibrations interfere with the acquisition process or there are some specular reflection etc. Dental software often has some noise filtering settings that can destroy the "sharpness" of the object (when measuring the gingiva we do not need sharp profiles because the gingiva is a very smooth surface); incomplete data is a big problem for our investigation because often can happen that some holes are

present in the model and some automatic function of scanner's software automatically closes them creating an artifact surface that do not represent the real model, this part can be solved being very careful in the positioning of the model in the scanning plate or eliminating the option of automatic closing holes from the software so we can repeat the scan with different orientation or increasing the number of scan cycles;

- Statistical distribution of parts: every surface represented in a 3D mesh is made from a sample of points extracted from that area and the tolerance distribution of the scanned part must be considered;
- Surface finish: in case of use of optical scanners, reflective coatings can adverse affecting this method, to solve this problem we use gypsum that have a little reflecting properties.

An ideal scanner should have a "floating model in the 3D space" so makes it accessible from all directions, with a very accurate acquisition system with no noise and no needs of registration process. A system like this does not exist but dental scanners are a good compromise for the dimensions that we are analyzing.

PRE-PROCESSING

After the phase in which data are collected is very important to have a priori information about the object as possible, this priori information is crucial for the efficiency of computation.

We need needs to know which the informations to keep are and which one not.

We know which the test tooth is so we have to concentrate in that area.

The pre-processing phase consists in the selection of the region of interest (ROI) of the model.

This part need to be performed manually by the operator selecting the area affected form resorption.

To understand what happen in the test area after superimposing the two meshes a visual analysis was performed on models with the help of a rhinoceros tool called mesh to mesh deviation. The color coded difference among models (Figure 51) show us that the area affected from resorption is comprised between the half of the adjacent teeth.

So the part of the model we are interested for is comprised between the two adjacent teeth both at the vestibular side and at the palatal/lingual side.

SEGMENATION AND SURFACE FITTING

Segmentation is the process that divides the original point set in subsets, one for each natural surface, so that each subset contains just those points sampled from a particular surface. During classification the program decide what type of surface each subset of points belong (e.g. planar, cylindrical) and fit subsequently the best fit surface taken from the given subset.

The segmentation process can have basically two different approaches edge-based and face-based. Laser based scanners suffer from edge based approach because there are really little points on edges so makes this zones unreliable.

This part has got a particular relevance in rebuild a geometric object in reverse engineering but is not present in dentistry: we use straight the mesh done from the triangulation of point cloud acquired and elaborated in the precedent phases.

In spite we do not use a real segmentation process, the model need to be recognized from his parts: an expert operator need to select and delete the parts that are artifact from gypsum or are defects produced by the impression taking phase.

After the recognition on the model of the relevant parts, is necessary to perform some operation of selection and processing of the mesh.

Closing holes, making some bridges and transforming the mesh in a closed volume are some of the operation than need to be done (Figure 27, Figure 28, Figure 29).

At this point some boolean operators are used to extract the difference of volume in an objective way.

Normally the simplest solid objects used for the representation are called primitives. Typically they are the objects of simple shape: cuboids, cylinders, prisms, pyramids, spheres, cones. It is said that an object is constructed from primitives by means of allowable operations, which are typically Boolean operations on sets: union, intersection and difference, as well as geometric transformations of those sets.

These primitives can be combined into compound objects using operations like in Figure 69.

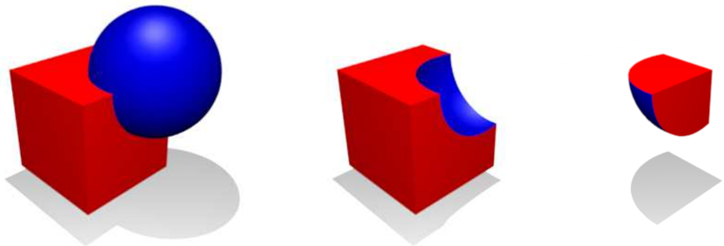


FIGURE 69 BOOLEAN UNION, BOOLEAN DIFFERENCE AND BOOLEAN INTERSECT (BY USER CAPTAIN SPRITE ON EN.WIKIPEDIA - OWN WORK).

The idea was to use the same operators for not primitive surfaces but with complex shape objects and it worked.

The model obtained from the second impression was subtracted from the model of the first impression and the difference of volume was obtained (Figure 49).

CAD MODEL CREATION

At this point we have various CAD models:

- The first mesh (obtained from the reverse engineering of the gypsum cast model of first impression);
- The second mesh (obtained from the reverse engineering of the gypsum cast model of second impression);
- The model of the total volume loss (composed from a vestibular portion and from a palatal/lingual one)
- The model of the ROI (Figure 60, Figure 63) (that represent the volume of the region of interest before to perform the analysis).

In modern times fortunately is possible to operate directly on STL files making boolean and other operations without rebuilding the object in other formats.

This is a particular advantage of progress in reverse engineering and CAD software that lend the use of these applications to perform such a precise work.

For this reason our CAD models that we use in this elaboration are straight STL files like they come out from dental scanners.

CAPITOLO 9. BIBLIOGRAPHY

- Anusavice, Kenneth J. (2003). *Phillips' Science of Dental Materials*. St. Louis, Missouri: Saunders Elsevier. p. 6. ISBN 978-0-7020-2903-5.
- Araujo MG, da Silva JCC, de Mendonca AF, Lindhe J (2014). Ridge alterations following grafting of fresh extraction sockets in man. A randomized clinical trial. Clin. Oral Impl. Res. 00, 2014, 1–6 doi: 10.1111/clr.12366
- Araujo, M., Linder, E., Wennstrom, J. & Lindhe, J. (2008) The influence of bio-oss collagen on healing of an extraction socket: An experimental study in the dog. The International journal of periodontics & restorative dentistry 28: 123-135.
- Araujo, M.G., Sukekava, F., Wennstrom, J.L. & Lindhe, J. (2005) Ridge alterations following implant placement in fresh extraction sockets. An experimental study in the dog. Journal of Clinical Periodontology 32: 645–652.
- Araujo, M.G., Sukekava, F., Wennstrom, J.L. & Lindhe, J. (2006) Tissue modeling following implant placement in fresh extraction sockets. Clinical Oral Implants Research 17: 615–624.
- Arcuri MR (Apr 1995). "Titanium implants in maxillofacial reconstruction". *Otolaryngol Clin North Am* **28** (2): 351–63.
- Arturo N. Natali (ed.) (2003). "Dental Biomechanics". Taylor & Francis, London New York, 273 pp., ISBN 978-0-415-30666-9, pp. 69-87.
- Assaf M, Abu Gharbyeh AZ. Screw-retained crown restorations of single implants: A step-by-step clinical guide . Eur J Dent 2014;8:563-70 http://www.eurjdent.com/text.asp?2014/8/4/563/143645
- Atieh, M. A.; Atieh, A. H.; Payne, A. G.; Duncan, W. J. (2009). "Immediate loading with single implant crowns: A systematic review and meta-analysis". *The International journal of prosthodontics* **22** (4): 378–387.
- Atieh, M. A.; Ibrahim, H. M.; Atieh, A. H. (2010). "Platform Switching for Marginal Bone Preservation Around Dental Implants: A Systematic Review and

Meta-Analysis". *Journal of Periodontology* **81** (10): 1350–66. doi:10.1902/jop.2010.100232. PMID 20575657.

- Attin, T. & Schmidlin, P. (2013) Radiographic evaluation of different techniques for ridge preservation after tooth extraction: A randomized controlled clinical trial. Journal of clinical periodontology 40: 90-98.
- Balaji, S. M. (2007). *Textbook of Oral and Maxillofacial Surgery*. New Delhi: Elsevier India. pp. 301–302. ISBN 9788131203002.
- beagle dog. Journal of clinical periodontology 35: 356-363.
- Belser U, Buser D, Higginbottom F (2004); Consensus statements and recommended clinical procedures regarding esthetics in implant dentistry. Int J Oral Maxillofac Implants. 2004;19 Suppl:73-4.
- Belser UC, Grütter L, Vailati F, Bornstein MM, Weber HP, Buser D; Outcome evaluation of early placed maxillary anterior single-tooth implants using objective esthetic criteria: a cross-sectional, retrospective study in 45 patients with a 2- to 4-year follow-up using pink and white esthetic scores. J Periodontol. 2009 Jan;80(1):140-51. doi: 10.1902/jop.2009.080435;
- Berglundh, T.; Persson, L.; Klinge, B. (2002). "A systematic review of the incidence of biological and technical complications in implant dentistry reported in prospective longitudinal studies of at least 5 years". *Journal of clinical periodontology* **29** (Suppl 3): 197–212. doi:10.1034/j.1600-051X.29.s3.12.x. PMID 12787220.
- Binon PP (2007); Treatment planning complications and surgical miscues. J Oral Maxillofac Surg. 2007 Jul;65(7 Suppl 1):73-92. doi: 10.1016/j.joms.2007.03.014.
- Botticelli D, Berglundh T, Lindhe J: Hard-tissue alterations following immediate implant placement in extraction sites. J Clin Periodontol 2004; 31: 820–828
- Botticelli D, Renzi A, Lindhe J, Berglundh T. Implants in fresh extraction sockets: a prospective 5-year follow- up clinical study. Clin. Oral Impl. Res. 19, 2008; 1226–1232
- Botticelli, D., Berglundh, T. & Lindhe, J. (2004) Hard-tissue alterations following immediate implant placement in extraction sites. Journal of clinical periodontology 31: 820-828.

- Bozini, T.; Petridis, H.; Garefis, K.; Garefis, P. (2011). "A meta-analysis of prosthodontic complication rates of implant-supported fixed dental prostheses in edentulous patients after an observation period of at least 5 years". *The International journal of oral & maxillofacial implants* **26** (2): 304–318.
- Branemark, Per-Ingvar Worthington, Philip, ed (1992). *Advanced osseointegration surgery: applications in the maxillofacial region (in english)*. Carol Stream, Illinois: Quintessence Books. ISBN 0867152427.
- Branemark, Per-Ingvar; Zarb, George (1989). *Tissue-integrated prostheses (in English)*. Berlin, German: Quintessence Books. ISBN 0867151293.
- buccal overbuilding: An animal study. Journal of clinical periodontology 36: 442 448.
- Buser D, Wittneben J, Bornstein MM, Grütter L, Chappuis V, Belser UC (2010); Stability of contour augmentation and esthetic outcomes of implant-supported single crowns in the esthetic zone: 3-year results of a prospective study with early implant placement postextraction. J Periodontol. 2011 Mar;82(3):342-9. doi: 10.1902/jop.2010.100408. Epub 2010 Sep 10.
- Buser, Daniel; Schenk, Robert K (1994). *Guided bone regeneration in implant dentistry (in english)*. Hong Kong: Quintessence Books. ISBN 0867152494.
- Caneva M, Botticelli D, Morelli F, Cesaretti G, Beolchini M, Lang NP. Alveolar process preservation at implants installed immediately into extraction sockets using deproteinized bovine bone mineral – an experimental study in dogs. Clin. Oral Impl. Res. 00, 2011, 1–8
- Cardaropoli G, Lekholm U, Wennstro¨m JL. (2006). Tissue alterations at implant-supported single-tooth replacements: a 1-year prospective clinical study. Clin. Oral Impl. Res. 17, 2006; 165–171 doi: 10.1111/j.1600-0501.2005.01210.x
- Cerardi Andrea. Caratterizzazione meccanica, geometrica e funzionale di dispositivi biomedicali. Doctoral thesis (2010) university of Padua Italy. http://paduaresearch.cab.unipd.it/2833/
- Chang M, Odman PA, Wennström JL, Andersson B (1999); Esthetic outcome of implant-supported single-tooth replacements assessed by the patient and by prosthodontists. Int J Prosthodont. 1999 Jul-Aug;12(4):335-41.

- Chang M, Wennström JL, Odman P, Andersson B (1999); Implant supported single-tooth replacements compared to contralateral natural teeth. Crown and soft tissue dimensions. Clin Oral Implants Res. 1999 Jun;10(3):185-94.
- Chang M, Wennström JL. Soft tissue topography and dimensions lateral to single implant-supported restorations. a cross-sectional study. Clin Oral Implants Res. 2013 May;24(5):556-62. doi: 10.1111/j.1600-0501.2012.02422.x. Epub 2012 Feb 15.
- Chappuis V., O. Engel, M. Reyes, K. Shahim, L.-P. Nolte, and D. Buser (2013); Ridge Alterations Post-extraction in the Esthetic Zone: A 3D Analysis with CBCT; JDR Clinical Research Supplement vol. 92 suppl no. 2; DOI: 10.1177/0022034513506713.
- Chen ST, Buser D (2009) Clinical and esthetic outcomes of implants placed in postextraction sites. Int J Oral Maxillofac Implants.; 24 Suppl:186-217.
- Chen, Y.; Kyung, H. M.; Zhao, W. T.; Yu, W. J. (2009). "Critical factors for the success of orthodontic mini-implants: A systematic review". *American Journal of Orthodontics and Dentofacial Orthopedics* **135** (3): 284–291. doi:10.1016/j.ajodo.2007.08.017. PMID 19268825.
- Cho HL, Lee JK, Um HS, Chang BS. Esthetic evaluation of maxillary single-tooth implants in the esthetic zone. J Periodontal Implant Sci. 2010 Aug;40(4):188-93. doi: 10.5051/jpis.2010.40.4.188. Epub 2010 Aug 30.
- Christopher J. van Kesteren, John Schoolfield, Jason West, Thomas Oates. Prospective Randomized Clinical Study of Changes in Soft Tissue Position Following Immediate and Delayed Implant Placement. The International Journal of Oral & Maxillofacial Implants.
- Cosyn J, De Bruyn H, Cleymaet R. Soft tissue preservation and pink aesthetics around single immediate implant restorations: a 1-year prospective study. Clin Implant Dent Relat Res. 2013 Dec;15(6):847-57. doi: 10.1111/j.1708-8208.2012.00448.x. Epub 2012 Feb 29.
- Cosyn J, De Rouck T. Aesthetic outcome of single-tooth implant restorations following early implant placement and guided bone regeneration: crown and soft tissue dimensions compared with contralateral teeth. Clin. Oral Impl. Res. 20, 2009; 1063–1069. doi: 10.1111/j.1600-0501.2009.01746.x

- Cosyn J, De Rouck T. Aesthetic outcome of single-tooth implant restorations following early implant placement and guided bone regeneration: crown and soft tissue dimensions compared with contralateral teeth. Clin Oral Implants Res. 2009 Oct;20(10):1063-9. doi: 10.1111/j.1600-0501.2009.01746.x. Epub 2009 Jun 10.
- De Brandão, M. L.; Vettore, M. V.; Vidigal Júnior, G. M. (2013). "Peri-implant bone loss in cement- and screw-retained prostheses: Systematic review and meta-analysis". *Journal of Clinical Periodontology* **40** (3): 287–295. doi:10.1111/jcpe.12041. PMID 23297703.
- Esposito, M.; Grusovin, M. G.; Chew, Y. S.; Coulthard, P.; Worthington, H. V. (2009). "One-stage versus two-stage implant placement. A Cochrane systematic review of randomised controlled clinical trials". *European journal of oral implantology* **2** (2): 91–99.
- Esposito, M.; Grusovin, M. G.; Maghaireh, H.; Worthington, H. V. (2013). "Interventions for replacing missing teeth: Different times for loading dental implants". *The Cochrane database of systematic reviews* **3** (CD003878): CD003878. doi:10.1002/14651858.CD003878.pub5. PMID 23543525.
- Esposito, M.; Grusovin, M. G.; Polyzos, I. P.; Felice, P.; Worthington, H. V. (2010). "Timing of implant placement after tooth extraction: Immediate, immediate-delayed or delayed implants? A Cochrane systematic review". *European journal of oral implantology* **3** (3): 189–205. PMID 20847990.
- Esposito, M.; Grusovin, M. G.; Talati, M.; Coulthard, P.; Oliver, R.; Worthington, H. V. (2008). "Interventions for replacing missing teeth: antibiotics at dental implant placement to prevent complications.". *Cochrane Database of Systematic Reviews* **3** (CD004152): CD004152. doi:10.1002/14651858.CD004152.pub2. PMID 18646101.
- Esposito, M.; Murray-Curtis, L.; Grusovin, M. G.; Coulthard, P.; Worthington, H. V. (2007). "Interventions for replacing missing teeth: different types of dental implants". *Cochrane Database of Systematic Reviews* **4** (CD003815): CD003815. doi:10.1002/14651858.CD003815.pub3. PMID 17943800.
- Esposito, M.; Worthington, H. V. (2013). "Interventions for replacing missing teeth: dental implants in zygomatic bone for the rehabilitation of the severely

deficient edentulous maxilla". *Cochrane Database of Systematic Reviews* **9** (Cochrane Database of Systematic Reviews): CD004151. doi:10.1002/14651858.CD004151.pub3. PMID 24009079.

- Evans CDJ, Chen ST. Esthetic outcomes of immediate implant placements. Clin. Oral Impl. Res. 19, 2008; 73–80 doi: 10.1111/j.1600-0501.2007.01413.x
- Ferguson, M (May 23, 2014). "Rhinosinusitis in oral medicine and dentistry.". *Australian dental journal* **59** (3): 289–95. doi:10.1111/adj.12193. PMID 24861778.
- Ferracane, Jack L. (2001). *Materials in Dentistry: Principles and Applications (in English)*. Lippincott Williams & Wilkins. ISBN 9780781727334.
- Fickl S, Schneider D, Zuhr O, Hinze M, Ender A, Jung RE, Hu¨rzeler MB (2009). Dimensional changes of the ridge contour after socket preservation and buccal overbuilding: an animal study. J Clin Periodontol 2009; 36: 442–448. doi: 10.1111/j.1600-051X.2009.01381.x.
- Fickl S, Zuhr O, Wachtel H, Stappert CFJ, Stein JM, Hu¨rzeler MB (2008). Dimensional changes of the alveolar ridge contour after different socket preservation techniques. J Clin Periodontol 2008; 35: 906–913. doi: 10.1111/j.1600-051X.2008.01305.x.
- Fickl, S., Schneider, D., Zuhr, O., Hinze, M., Ender, A., Jung, R. E. & Hurzeler, M. B. (2009) Dimensional changes of the ridge contour after socket preservation and
- Fickl, S., Zuhr, O., Wachtel, H., Bolz, W. & Huerzeler, M. (2008) Tissue alterations after tooth extraction with and without surgical trauma: A volumetric study in the
- Fürhauser R, Florescu D, Benesch T, Haas R, Mailath G, Watzek G. Evaluation of soft tissue around single-tooth implant crowns: the pink esthetic score. Clin Oral Implants Res. 2005 Dec;16(6):639-44.
- Gehrke P, Degidi M, Lulay-Saad Z, Dhom G. Reproducibility of the implant crown aesthetic index--rating aesthetics of single-implant crowns and adjacent soft tissues with regard to observer dental specialization. Clin Implant Dent Relat Res. 2009 Sep;11(3):201-13. doi: 10.1111/j.1708-8208.2008.00107.x. Epub 2008 Jul 23.

- Gehrke P, Lobert M, Dhom G. Reproducibility of the pink esthetic score--rating soft tissue esthetics around single-implant restorations with regard to dental observer specialization. J Esthet Restor Dent. 2008;20(6):375-84; discussion 385. doi: 10.1111/j.1708-8240.2008.00212.x.
- Goodacre, C. J.; Bernal, G.; Rungcharassaeng, K.; Kan, J. Y. K. (2003). "Clinical complications with implants and implant prostheses". *The Journal of Prosthetic Dentistry* **90** (2): 121–132. doi:10.1016/S0022-3913(03)00212-9. PMID 12886205.
- Greenstein G, Cavallaro J, Romanos G, Tarnow D. (Aug 2008). "Clinical recommendations for avoiding and managing surgical complications associated with implant dentistry: a review.". *J Periodontol* **79** (8): 1317–29. doi:10.1902/jop.2008.070067.
- Guidance for Industry and FDA Staff - Class II Special Controls Guidance Document: Root-form Endosseous Dental Implants and Endosseous Dental Abutments. FDA. 2004-05-12. Retrieved 2013-11-11.
- Guo, Cecilia Yan; Matinlinna, Jukka Pekka; Tang, Alexander Tin Hong (2012). "Effects of Surface Charges on Dental Implants: Past, Present, and Future". *International Journal of Biomaterials* **2012**: 1–5. doi:10.1155/2012/381535. ISSN 1687-8787.
- Higginbottom F, Belser U, Jones JD, Keith SE (2004); Prosthetic management of implants in the esthetic zone. Int J Oral Maxillofac Implants. 2004;19 Suppl:62-72.
- Horvath, A., Mardas, N., Mezzomo, L. A., Needleman, I. G. & Donos, N. (2013) Alveolar ridge preservation. A systematic review. Clinical oral investigations 17: 341- 363.
- Javed, F.; Romanos, G. E. (2010). "The role of primary stability for successful immediate loading of dental implants. A literature review". *Journal of Dentistry* **38** (8): 612–620. doi:10.1016/j.jdent.2010.05.013. PMID 20546821.
- Jokstad, Asbjorn, ed. (2009). *Osseointegration and Dental Implants (in English)*. John Wiley & Sons. ISBN 9780813804743.
- Jung, R. E., Philipp, A., Annen, B. M., Signorelli, L., Thoma, D. S., Hammerle, C. H.,

- Jung, R. E.; Pjetursson, B. E.; Glauser, R.; Zembic, A.; Zwahlen, M.; Lang, N. P. (2008). "A systematic review of the 5-year survival and complication rates of implant-supported single crowns". *Clinical Oral Implants Research* **19** (2): 119–130. doi:10.1111/j.1600-0501.2007.01453.x. PMID 18067597.
- Juodzbalys G, Sakavicius D, Wang HL. Classification of extraction sockets based upon soft and hard tissue components. J Periodontol. 2008 Mar;79(3):413-24. doi: 10.1902/jop.2008.070397.
- Juodzbalys G, Wang HL. Esthetic index for anterior maxillary implant-supported restorations. J Periodontol. 2010 Jan;81(1):34-42. doi: 10.1902/jop.2009.090385.
- Kourkouta S (2011). Implant therapy in the esthetic zone: smile line assessment. Int J Periodontics Restorative Dent. 2011 Apr;31(2):195-201.
- Kumar, M. N.; Honne, T. (2012). "Survival of dental implants in bisphosphonate users versus non-users: A systematic review". *The European journal of prosthodontics and restorative dentistry* **20** (4): 159–162.
- Kushel R. Morjaria, BDS, MSc; Ron Wilson, PhD; Richard M. Palmer, PhD, BDS, FDS, RCS; Bone Healing after Tooth Extraction with or without an Intervention: A Systematic Review of Randomized Controlled Trials; Clinical Implant Dentistry and Related Research, Volume 16, Number 1, 2014;
- Lai HC, Zhang ZY, Wang F, Zhuang LF, Liu X, Pu YP. Evaluation of soft-tissue alteration around implantsupported single-tooth restoration in anterior maxilla: the pink esthetic score. Clin. Oral Impl. Res. 19, 2008; 560–564 doi: 10.1111/j.1600-0501.2008.01522.x
- Lars Schropp, Lambros Kostopoulos, Ann Wenzel. Bone Healing Following Immediate Versus Delayed Placement of Titanium Implants into Extraction Sockets: A Prospective Clinical Study. The International Journal of Oral & Maxillofacial Implants. Int J Oral Maxillofac Implants. 2003 Mar-Apr;18(2):189-99.
- Laskin, Daniel (2007). *Decision making in oral and maxillofacial surgery*. Chicago, IL: Quintessence Pub. Co. ISBN 9780867154634.

- Leblebicioglu B, Rawal S, Mariotti A (2007); A review of the functional and esthetic requirements for dental implants. J Am Dent Assoc. 2007 Mar;138(3):321-9.
- Lee, SL (2007). *Applications of orthodontic mini implants*. Hanover Park, IL: Quintessence Publishing Co, Inc. pp. 1–11. ISBN 9780867154658.
- Lehmann KM, Kasaj A, Ross A, Kämmerer PW, Wagner W, Scheller H. (2012) A new method for volumetric evaluation of gingival recessions: a feasibility study. J Periodontol. 2012 Jan;83(1):50-4. doi: 10.1902/jop.2011.110143. Epub 2011 May 12.
- Lindhe, Jan; Lang, Niklaus P; Karring, Thorkild, eds. (2008). *Clinical Periodontology and Implant Dentistry 5th edition (in English)*. Oxford, UK: Blackwell Munksgaard. ISBN 9781405160995.
- McCracken, Michael S.; Mitchell, Lillian; Hegde, Rashmi; Mavalli, Mahendra D. (2010). "Variability of Mechanical Torque-Limiting Devices in Clinical Service at a US Dental School". *Journal of Prosthodontics* **19** (1): 20–24. doi:10.1111/j.1532-849X.2009.00524.x. ISSN 1059-941X.
- Meijer HJA, Stellingsma K,Meijndert L, Raghoebar GM. A new index for rating aesthetics of implant-supported single crowns and adjacent soft tissues – the Implant Crown Aesthetic Index. A pilot study on validation of a new index. Clin. Oral Impl. Res. 16, 2005; 645–649 doi: 10.1111/j.1600-0501.2005.01128.x
- Meijndert L, Meijer HJA, Stellingsma K, Stegenga B, Raghoebar GM. Evaluation of aesthetics of implant supported single-tooth replacements using different bone augmentation procedures: a prospective randomized clinical study. Clin. Oral Impl. Res. 18, 2007; 715–719 doi: 10.1111/j.1600-0501.2007.01415.x
- Misch, Carl E (2007). *Contemporary Implant Dentistry*. St. Louis, Missouri: Mosby Elsevier.
- Newman, Michael; Takei, Henry; Klokkevold, Perry, eds. (2012). *Carranza's Clinical Periodontology (in English)*. St. Louis, Missouri: Elsevier Saunders. ISBN 9781437704167.
- Palattella P, Torsello F, Cordaro L. Two-year prospective clinical comparison of immediate replacement vs. immediate restoration of single tooth in the esthetic zone. Clin. Oral Impl. Res. 19, 2008; 1148–1153

- Pallaci, Patrick (1995). *Optimal implant positioning and soft tissue management for the Branemark system (in english)*. Germany: Quintessence Books. pp. 21–33. ISBN 0867153083.
- Papaspyridakos, P.; Chen, C. - J.; Singh, M.; Weber, H. - P.; Gallucci, G. O. (2011). "Success Criteria in Implant Dentistry: A Systematic Review". *Journal of Dental Research* **91** (3): 242–248. doi:10.1177/0022034511431252. PMID 22157097.
- Papaspyridakos, P.; Mokti, M.; Chen, C. J.; Benic, G. I.; Gallucci, G. O.; Chronopoulos, V (Jan 2013). "Implant and Prosthodontic Survival Rates with Implant Fixed Complete Dental Prostheses in the Edentulous Mandible after at Least 5 Years: A Systematic Review". *Clinical Implant Dentistry and Related Research* **11**. doi:10.1111/cid.12036. PMID 23311617.
- Patzelt, S. B. M.; Bahat, O.; Reynolds, M. A.; Strub, J. R. (2013). "The All-on-Four Treatment Concept: A Systematic Review". *Clinical Implant Dentistry and Related Research*. doi:10.1111/cid.12068. PMID 23560986.
- Peterson, LJ. Miloro, M (2004). *Peterson's Principles of Oral and Maxillofacial Surgery, 2nd Edition*. PMPH-USA.
- Pjetursson, B. E.; Thoma, D.; Jung, R.; Zwahlen, M.; Zembic, A. (2012). "A systematic review of the survival and complication rates of implant-supported fixed dental prostheses (FDPs) after a mean observation period of at least 5 years". *Clinical Oral Implants Research* **23**: 22–38. doi:10.1111/j.1600-0501.2012.02546.x. PMID 23062125.
- Renouard, Frank (1999). *Risk Factors in Implant Dentistry: Simplified Clinical Analysis for Predictable Treatment*. Paris, France: Quintessence International. ISBN 0867153555.
- Reza, M (2007). *Nanomaterials and Nanosystems for Biomedical Applications [Mozafari] (in English)*. SpringerLink: Springer e-Books. ISBN 9781402062896.
- Ruggiero, S. L.; Dodson, T. B.; Assael, L. A.; Landesberg, R.; Marx, R. E.; Mehrotra, B. (2009). "American Association of Oral and Maxillofacial Surgeons Position Paper on Bisphosphonate-Related Osteonecrosis of the Jaws—2009 Update". *J Oral and Maxillofac Surg* **67** (5): 2–12. doi:10.1016/j.joms.2009.01.009. PMID 19371809.

- Schneider D, Schmidlin PR, Philipp A, Annen BM, Ronay V, Hämmerle CH, Attin T, Jung RE (2014). Labial soft tissue volume evaluation of different techniques for ridge preservation after tooth extraction: a randomized controlled clinical trial. J Clin Periodontol. 2014 Jun;41(6):612-7. doi: 10.1111/jcpe.12246. Epub 2014 Mar 26.
- Schneider, D., Grunder, U., Ender, A., Hammerle, C. H. & Jung, R. E. (2011) Volume gain and stability of peri-implant tissue following bone and soft tissue augmentation: 1-year results from a prospective cohort study. Clinical oral implants research 22: 28-37.
- Sclar, Anthony (2003). *Soft tissue and esthetic considerations in implant dentistry (in english)*. Carol Stream, IL: Quintessence Books. ISBN 0867153547.
- Sinn, D. P., Bedrossian, E., Vest, A. K. (2011). "Craniofacial Implant Surgery". *Oral and Maxillofacial Surgery Clinics of North America* **23** (2): 321–335. doi:10.1016/j.coms.2011.01.005. PMID 21492804.
- Spector, L (2008). "Computer-Aided Dental Implant Planning". *Dental Clinics of N Amer* **52** (4): 761–775. doi:10.1016/j.cden.2008.05.004. PMID 18805228.
- Steigmann M; Treatment sequencing for the multiunit restoration: hard and soft tissue considerations. J Oral Maxillofac Surg. 2007 Jul;65(7 Suppl 1):53-63.
- Tan, W. L., Wong, T. L., Wong, M. C. & Lang, N. P. (2012) A systematic review of post-extractional alveolar hard and soft tissue dimensional changes in humans. Clinical oral implants research 23 Suppl 5: 1-21.
- Ten Heggeler, D. E. Slot, G. A. Van der Weijden (2010); Effect of socket preservation therapies following tooth extraction in non-molar regions in humans: a systematic review; Clin. Oral Impl. Res. doi: 10.1111/j.1600-0501.2010.02064.x
- Thalmair, T., Fickl, S., Schneider, D., Hinze, M. & Wachtel, H. (2013) Dimensional alterations of extraction sites after different alveolar ridge preservation techniques - a volumetric study. Journal of clinical periodontology 40: 721-727.
- Thoma, D. S., Jung, R. E., Schneider, D., Cochran, D. L., Ender, A., Jones, A. A., Gorlach, C., Uebersax, L., Graf-Hausner, U. & Hammerle, C. H. (2010) Soft tissue volume augmentation by the use of collagen-based matrices: A volumetric analysis. Journal of clinical periodontology 37: 659-666.

- Ugo Covani, Claudia Bortolaia, Antonio Barone, and Ludovico Sbordone. Bucco-Lingual Crestal Bone Changes After Immediate and Delayed Implant Placement.. J Periodontol December 2004
- Van der Weijden F, Dell'Acqua F, Slot DE. Alveolar bone dimensional changes of post-extraction sockets in humans :a systematic review. J Clin Periodontol 2009; 36:1048–1058. doi: 10.1111/j.1600-051X.2009.01482.x.
- Vanhoutte V, Rompen E, Lecloux G, Rues S, Schmitter M, Lambert F. (2014) A methodological approach to assessing alveolar ridge preservation procedures in humans: soft tissue profile. Clin Oral Implants Res. 2014 Mar;25(3):304-9. doi: 10.1111/clr.12144. Epub 2013 Apr 4.
- Vàrady T, Martin R, Cox Jordan. (1997) Reverse engineering of geometric models – an introduction. Computer-Aided Design Vol 29, No. 4, pp. 255-268 1997 Elsevier Science Ltd.
- Vignoletti, F., Matesanz, P., Rodrigo, D., Figuero, E., Martin, C. & Sanz, M. (2012) Surgical protocols for ridge preservation after tooth extraction. A systematic review. Clinical oral implants research 23 Suppl 5: 22-38.
- Vittorini Orgeas G, Clementini M, De Risi V, de Sanctis M. (2013) Surgical techniques for alveolar socket preservation: a systematic review. Int J Oral Maxillofac Implants. 2013 Jul-Aug;28(4):1049-61. doi: 10.11607/jomi.2670.
- Zembic A, Sailer I, Jung RE, Ha¨mmerle CHF. Randomized-controlled clinical trial of customized zirconia and titanium implant abutments for single-tooth implants in canine and posterior regions: 3-year results. Clin. Oral Impl. Res. 20, 2009; 802–808. doi: 10.1111/j.1600-0501.2009.01717.x

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