VILNIUS UNIVERSITY

EGLĖ VINDAŠIŪTĖ-NARBUTĖ

FACTORS ASSOCIATED WITH REMOVAL OF THE CEMENT EXCESS IN IMPLANT-SUPPORTED RESTORATIONS

Doctoral dissertation

Biomedical Sciences, Odontology (07B)

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Research project was carried out at Vilnius University and Vilnius implantology center clinic from 2009 to 2015. The doctoral dissertation will be defended externally.

Research consultant – assoc. prof. dr. Tomas Linkevičius (Vilnius University, Biomedical Sciences, Odontology – 07B).

TABLE OF CONTENTS

1. INTRODUCTION

Significance of the study

The most popular way to attach a crown or a bridge to an implant is to cement it. Unfortunately, there is a lack of information and guidelines for clinicians how to perform this procedure in a safe way, meaning that:

a) excess of cement might be left undetected and not removed after cementation. There is an agreement that cement remnants are one of the predisposing factors of peri-implantitis;

b) there are no official guidelines where to locate the abutment margin according to the soft tissues for a cementation;

c) there is no evaluation of other clinical factors (such as implant location, implant diameter), which might also be important in ensuring a safe cementation procedure;

d) the radiographic examination has not been proven yet to be a reliable method to detect and evaluate totally removed cement after cementation.

The aim of the study

To determine and evaluate the factors that influence the removal of cement remnants after cementation of implant-supported cement-retained restorations.

The objectives of the study:

1) to assess if a cementation margin depth has some influence on the quality of the cement removal after cementation;

2) to compare two methods of the evaluation of the undetected cement: the computerized planimetric technique of the cement amount assessment and weighing;

3) to find out the reliability of the radiographic examination of the cement excess after cementation of a crown;

4) to evaluate the role of an implant location in the jaw on the amount of the undetected cement;

5) to determine if an implant diameter has some influence on the efficiency of cement removal;

6) to find out if an undercut is an important factor when cleaning the cement after cementation;

7) to evaluate when an absolute removal of cement is possible.

Hypotheses to be defended:

1. The depth of the cementation margin does influence the quality of the cement removal after cementation.

2. Both methods (the computerized planimetric technique of the cement amount assessment and weighing) of the evaluation of the residual cement amount are equally precise.

3. The radiographic examination can detect the residual cement left after cleaning.

4. An implant location is important in cleaning the cement residues after cementation.

5. An implant diameter plays a role on the efficiency in removing cement excess.

6. An undercut has influence on the amount of the cement left after cleaning.

Relevance of the study

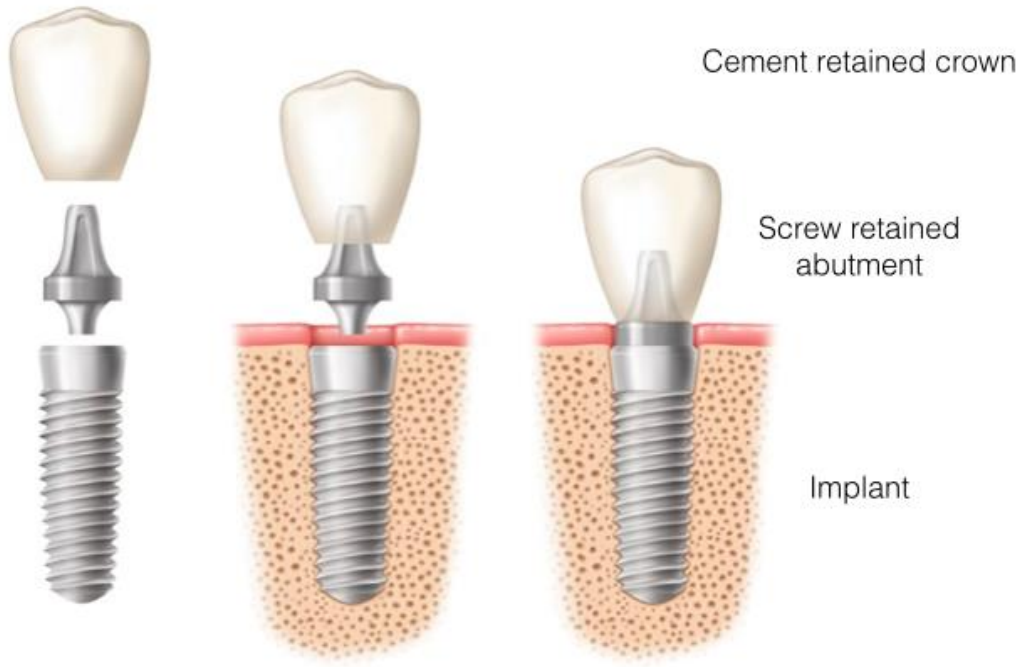
This study could be a very useful scientific prove to formulate some clinical recommendations in this clinical field:

1. Formulated recommendations for prosthodontists how to ensure an absolute cement removal after the cementation of the implant-supported restoration.

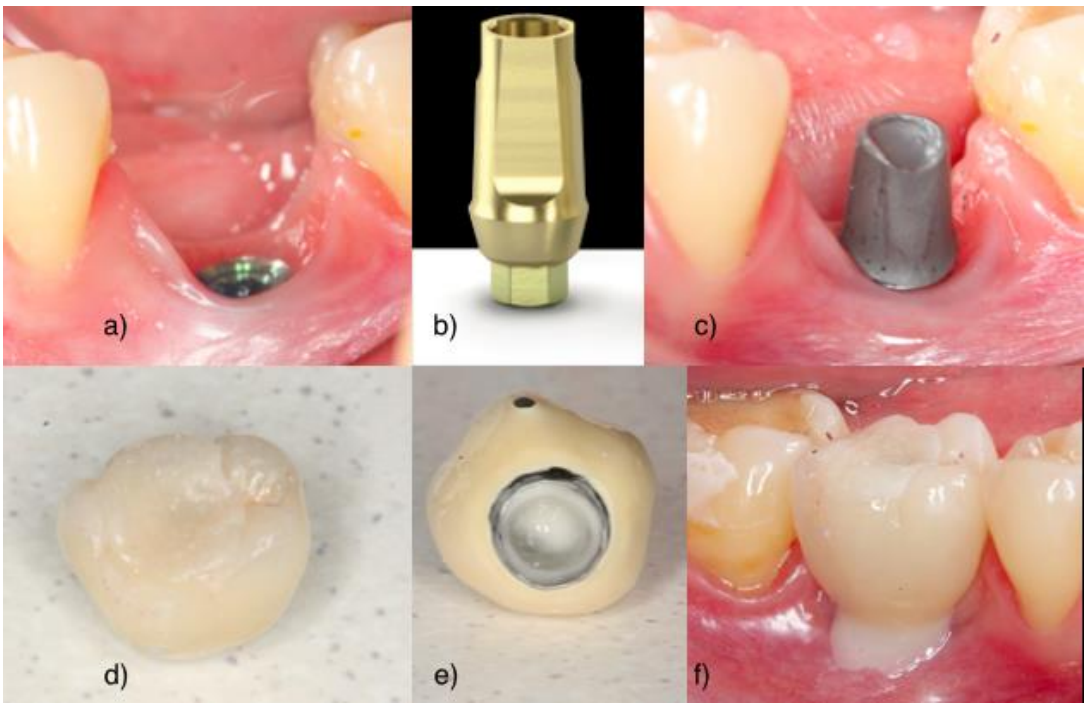
2. A change of current clinical guidelines and the formulation of some new clinical guidelines for the cementation protocol.

2. LITERATURE REVIEW

Dental implants have become a treatment of choice to restore missing teeth for totally or partially edentulous patients. Postoperative patients who have undergone dental restorations using titanium osseointegrated dental implants enjoy results that approximate the look and feel of natural teeth (1). After the osseointegration of a dental implant there are two options how to connect a crown to an implant: the restorative procedure could be either screw-retention, or cementation. In the pictures below it is shown the technique of the cementing restoration technically (Picture 1) and how it looks intraorally (Picture 2).



Picture 1. Schema of the cementation procedure



Picture 2. Cementation procedure intraorally (a-f)

a) An implant with an unattached healing abutment.

b) A standard abutment, provided by an implant company (BioHorizons Internal, Birmingham, AL, USA), which is screw-retained to an implant.

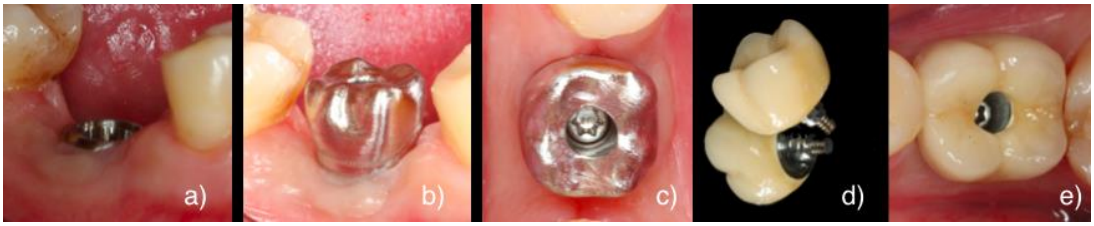
c) A screw access channel (screws head) is being isolated using dental wax - Wax Pak (3M UNITEK, Monrovia, CA, USA).

d) A metal ceramic crown fabricated and ready for cementation.

e) An application of the cement in the inner part of the restoration.

f) The cement excess visible after cementation, which should be removed after the set down.

The other technique to attach a crown to an implant is a screw retention. The method is shown in the sequence of pictures below (Picture 3). The main difference is that abutment and framework is a solid unit in the latter method.



Picture 3. Screw retained crown delivery intraorally (a-e)

a) An implant with an unattached healing abutment.

b) A milled metal framework screwed to the implant from a buccal point of view.

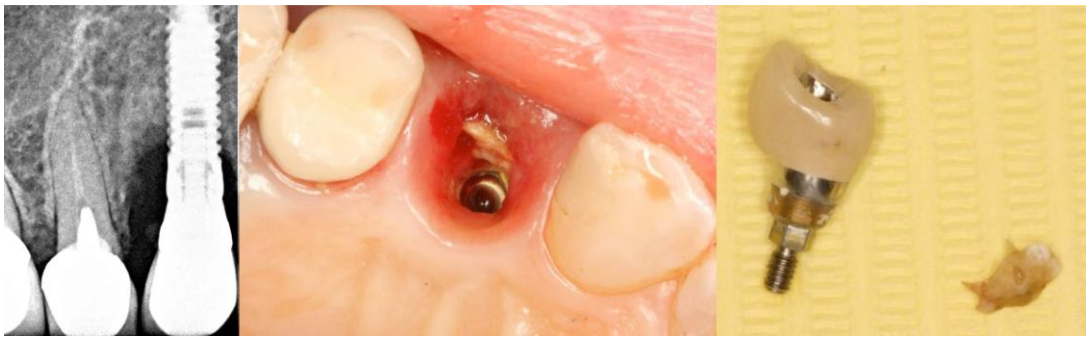
c) A milled metal framework screwed to the implant from an occlusal point of view.

d) A solid crown: a milled framework with a ceramic veneering.

e) A crown screwed to the implant intraorally before the closure of the occlusal opening.

The cement-retained prostheses have gained their popularity due to their simplicity, similarity to natural teeth prosthetics, solid and more esthetical occlusal surface and as a solution of improperly inclined implants problem (2,3). The main overlooked problem of those restorations is the cement excess and a potential risk for it to remain undetected after cementation. This issue arises because the cementations of implant-borne restorations and teeth-borne restorations are not identical and there are no general worldwide clinical guidelines how to perform it. The perpendicular fiber attachment around teeth provides a sufficient barrier and the cement excess does not penetrate further and escapes to the surface of the gingival sulcus. It is well known that peri-implant tissues do not possess a similar protective mechanism (4, 5) and are less resistant to pressure (6). Therefore, the procedures of cementation and, most importantly, how to control and remove it, should be well documented in the implant prosthodontics. Unfortunately, current clinical recommendations

vary a lot, allowing clinicians to place the cementation margins of the implant supported restorations from 0.5 mm up to 3 mm subgingivally (7, 8). This is usually done to hide the abutment-restoration interface and to ensure that it is not going to be visible with a possible peri-implant tissue recession over the time. Moreover, it provides a more natural emergence profile. These benefits have made that cemented prostheses with the subgingivally located margins had become a standard how to restore an implant, even though it may lead to an incomplete cement removal (9). There is an increased awareness among clinicians recently, that undetected cement might be the cause of some serious biological complications. These complications include peri-mucositis, acute or chronic peri-implantitis. Basically, the process of inflammation initiates with peri-mucositis, if not treated it might result in peri-implantitis. There is a lack of the literature concerning acute severe peri-implant bone loss. All the studies found in the scientific databases are case reports (10, 11), showing that the cement left close to the bone may end up even to implant loss. In 2009 Wilson was the first who showed (12), in a clinical study, that an incomplete cement removal might result in a delayed peri-implant bone loss, occurring even many years after the delivery of restorations (Picture 4).



Picture 4. Delayed bone loss, cement in the sulcus and removed crown with cement remnants (13)

The controversy between screw- and cement-retained implant suprastructures has been debated for a long time, but the best type of the connection still stays controversial among dentists (14). This topic has been well analyzed in many scientific literature reviews, clinical cases, but the there

is no answer, which way is better to attach a crown to an implant. Usually, a clinician is the one who selects, whether to screw or cement an implant restoration (15), because patients are showing no preference for either retention type (16). The cement-retained implant supported restorations have been recently getting increasingly popular (17) and have conquered the screw-retained prostheses (18). Therefore, it is really important for prosthodontists to know not only the advantages, but also the disadvantages and possible outcomes and limitations of the cement retained implant supported restorations before offering one to their patients. There are a few factors that need to be analyzed and discussed to see a full picture of the cement versus screw-retained restorations.

2.1. Advantages of cement-retained implant supported restorations

2.1.1. Ease of fabrication and cost

The components necessary for a cemented crown or bridge are supposed to be less expensive than the alternative – screw-retained components (19, 20). Cement retained restorations are very similar in fabrication to natural tooth borne prostheses, meaning that conventional laboratory and clinical techniques are used to fabricate this type of restoration (21). The laboratory cost to make a screw-retained restoration is usually from 1.5 to 2 times higher because of the extra time and materials needed (22), nowadays the price is a bit reduced, but still remains higher.

2.1.2. Occlusion

Occlusion is another factor influencing clinicians' choice about the connection type – screw or cement retained. The occlusal table of the teeth mentioned before is about 4.5 mm for the premolars and 5 to 6 mm for the molars. Fastening a screw the head diameter is around 2 - 3 mm, therefore the screw access hole requires to be the same size. These 2 - 3 mm are 50% of the occlusal table of the molars and more than 75% of the occlusal table of the premolars (23). Screw-retained restorations need an occlusal material to close

the screw access channel, such as amalgam or composite. However, the durability of these restorations is lower if compared to an intact full crown (24, 25). To sum up, the accomplishment of the ideal occlusal contacts in screw-retained prostheses might not be possible to achieve or more difficult to ensure in a long-term perspective.

2.1.3. Esthetics

A solid surface (no screw access hole) ensures a better occlusion and esthetics (17). It is true that the screw access hole is highly unaesthetic, but this problem usually appears only in the visible areas - mandibular premolars and molars.

2.1.4. Passivity

In addition, it is supposed that cement-retained suprastructures are more passive due to the cement layer between the frameworks and implant abutments (26, 27, 28). Moreover, the cement layer might reduce small inaccuracies in the restoration fabrication procedure. A possible distortion of the restoration can appear in any step of laboratory or clinical work: during the impression procedure, the fabrication of the master cast, the fabrication of wax patterns, investing and casting procedures, the firing of the porcelain, or delivery of the prosthesis. Despite the fact that total passivity is really a challenge for a clinician, many authors believe that a cement retained restoration is more likely to achieve passive fit than a screw retained one (22, 23, 29, 30, 31). This increased passivity of cement retained restorations is based on an idea that the cement could act as a shock absorber and reduce stress to a bone and implant – abutment structure (22, 23, 32).

2.1.5. Delivery

Cement-retained restorations offer easier access to the posterior of the mouth, especially for patients whose mouth opening is restricted (23, 33).

2.2. Disadvantages of cement-retained implant supported restorations

2.2.1. Microflora

On the other hand, the screw-retained prostheses have tighter margins than the cement retained restorations. The marginal opening is not associated with the decay of the abutments, but there is always a risk of colonization of this space with microflora. The development of a microflora at the interface of the implant and the abutment may result in chronic gingival inflammation (34). In a recent literature review it has been concluded that biological complication rates (bone loss > 2 mm) were found to be higher in cemented reconstructions (35), which might also be influenced by the development of the microflora.

2.2.2. Delivery

Only a radiographic examination is necessary for screw-retained restorations to check the precision in fitting of the implant supported screw retained restorations before final torqueing of the fastening screws. However, for cemented restorations, not only radiographically proven precise fit is important, but also there is a need to check if any cement remnants are left after a cementation. The removal of cement residues is critical for peri-implant health.

2.2.3. Retrievability

Retrievability is a great advantage if there is a need to dismount a crown from an implant. As the age of patients requiring dental implants is getting younger due to the fact that this procedure has become a treatment of choice for partially edentulous patients, it might be necessary to retrieve the crown from the implant in case of some biological or mechanical complication (36). The main disadvantage of cemented prostheses is the difficulty of their retrievability (23, 37).

2.2.4. Retention

In situations where minimal interocclusal space exists, it may not be possible to achieve an adequate retention for cement retained restorations because these restorations require a vertical component of at least 5 mm to provide a retention and resistance form, these guidelines are the same for teeth supported restorations and for implant abutments (38).

All these factors together have made cement retained prostheses restoration of choice in a daily dental practice.

Summarized comparison of screw and cement retained restorations could be visible in a Table 1 below.

Factor	**Screw retention**	**Cement retention**
Esthetics	Ideal implant position necessary	More universal
Retrievability	Yes	Possible, but unpredictable
Retention	Possible even if <4 mm abutment height	>5 mm abutment height necessary
Passivity	Critical technique	Cement space as a shock absorber
Occlusion	Occlusal interferences possible	Better control
Accessibility	More difficult	Easier
Cost	More expensive	Less expensive

Table 1. Comparison between screw-retained and cement-retained restorations

2.2.5. Complications (technical and biological). Survival and success rates

There are several studies analyzing and comparing clinical success rates of screw and cement retained restorations on implants. Nissan et al. provide a long term (18 to 180 months) comparison of these two different concepts of restoring dental implants in regard to prosthetic complications, peri-implant soft tissue conditions, and peri-implant marginal bone levels (39). They found

a higher prevalence of prosthetic complications in screw retained prostheses, one of the causes mentioned having influenced the results is the occlusal hole, which cuts off the structural continuity of porcelain in the screw retained restorations. Same results (higher rate of porcelain fracture in screw retained restorations) are observed in several studies (22, 23, 30, 40, 41, 42). Abutment screw loosening was also more frequent in the screw retained supra structures, this could be explained by reduced passive fit of latter prostheses. Biological parameters recorded in this study – marginal bone loss and gingival index were also significantly better for cement-retained restorations.

The success rate of cement and screw retained implant supported restorations were evaluated in several studies (40, 43, 44, 45). Most of these studies showed that the screw retained restorations have more technical complications during follow-up periods than their cemented counterparts. However, the percentage of these complications was generally small and most of them were controllable.

On the other hand, Weber et al. in their systematic review focused on implant and prosthesis survival, found no statistically significant differences between the screw and the cement retention (46). A recent and comprehensive systematic review on this subject was presented at the European Association of Osseointegration Consensus Conference 2012 (47). This review focused on implant and reconstruction survival, reporting estimated rates for 5 and 10 years, as well as technical and biological complications in studies with a mean follow-up of at least 1 year. No statistically significant differences were reported for restoration survival. Estimated biological complication rates (bone loss > 2 mm) were found to be higher in cemented reconstructions, whereas screw-retained reconstructions exhibited more technical complications. Almost the same results were documented in the systematic review by Wittneben et al., stating that the presence of fistula/suppuration was statistically significantly higher with the cement retention, but they did not find any difference between other biological complications (bone loss, peri-implantitis, recession or implant loss) when comparing the types of retention (48). Generally, it has been

concluded, that the estimated 5-year survival rate of both restorations is similar.

2.3. Cement selection for cement retained restorations

Another important and interesting factor in the cement retained implant supported restorations is cement. Unfortunately, no ideal cement exists to date and there is a lack of consensus in the dental industry regarding implant luting cements. The cement selection available on the market is diverse, with many materials used. Errors in cement selection have been reported with the cements suitable for implant prosthetics cementation selected arbitrarily, usually based on the clinician experiences with natural teeth (49). Another actual problem to identify the ideal cement is that no standardized guidelines for cementation could be revealed, because each study available in the literature used different cements, different protocols, and different implants or analyzed different properties. The recent study done by Wadhwani et al. in 2012 showed the diversity of the cement loading patterns disclosed in this study indicated that there is a lack of uniformity and precision in methods and a lack of consensus in the dental community regarding the appropriate quantity of cement and placement method for a cement-retained implant crown (50). Nevertheless, for cement- retained implant restorations, the choice of cement is one of the most important factors controlling the amount of retention attained (51, 52). It should be understood that a mass of any foreign material adjacent to a dental implant could negatively impact patient's health and implant survival (53). The disease process may also be specific to the material itself, with cement selection having an impact on this process. It is highly likely that cements appropriate for use with natural teeth may not be suitable for the implant restoration (54, 55). No ideal cement exists to date. In general, all cements should be biocompatible, with no or little interaction with body tissues and fluids. They should be nontoxic and have low allergic potential. Unfortunately, all commonly used cements in dentistry have cytotoxic potential as it has been recently proven again by Trumpaite-Vanagiene et al (121). Usually, the choice

of cement for implant-supported restorations is based on clinicians' experience with natural teeth. When restoring a natural tooth, there is often an ability to protect the periodontal tissues from effects of cements with barrier devices; for example, use of rubber dam isolation (latex or nitrile sheet used in dentistry to isolate the operative site from the rest of the mouth) or a retraction cord. However, a retraction cord is not recommended (56) and has been shown to promote cement extrusion into the soft tissues as a result of the peri-implant tissues being far more delicate, with only a weak hemi-desmosomal attachment that is easily stripped from the implant surface. Moreover, fluoride-containing cements offer definite advantage for the natural tooth restoration; however, they may have a negative impact on the implant restoration. Fluoride is commonly used in industry to condition titanium, under the appropriate conditions, it will etch the surface, removing ions from the metal (49). Investigation revealed that polycarboxilate cement actually corrodes the titanium (54).

The last, but not the least property of the cement, is radiopacity. Metal and zirconia implant components should be evaluated prior to a cementation to confirm the acceptance of the fit of the restoration. The sites where residual excess cement is most likely to be detected are interproximal, where an exaggerated effect noted on implants can enhance the radiopacity of the cement. This has been described as the peripheral eggshell effect (57, 58, 107). This happens because implants are generally circular in a cross section, and when the cement flow follows this shape, a circumferential layer results. Because the radiographic beam passes tangentially through the thickness of the thin cement layer many times, an observed attenuation results, creating previously mentioned eggshell effect.

2.3.1. Glass-ionomer cement

Glass-ionomer cement (glass polyalkenoate) was invented in 1969 by Wilson and Kent (59). By the late 1990s it became the most frequently used definitive luting agent worldwide for teeth supported restorations. Its

popularity is based on ease of mixing, good flow properties, adhesion to tooth structure and base metals, cariostatic potential due to fluoride release, good translucency, adequate strength, and relatively low cost per unit dose (60).

Physical properties of glass-ionomer can be highly variable, depending on the powder/liquid mixing ration, so the manufacturer's instructions for measuring should be strictly followed for optimal results (61). Another problem, when dealing with implants, is the surface of the cement after setting. The recent study about bacterial adhesion and cytotoxicity of various dental cements has showed that glass ionomer cement has large quantities of adhering bacteria. Microstructures of glass ionomer cement are more irregular, containing more and deeper pits and grooves than the other materials tested (62).

Radiographic evaluation allows for a non-invasive evaluation of the site, with the potential to locate cement remnants. The detection is influenced by the factors such as composition of the cement and its amount (57). Other disciplines within dentistry have requirements for radiopacity specifications for cements (ISO 2002). No mandatory minimal standard specifications exist for implant cements (ISO 2009). The glass ionomers are expected to have poor radiodensity properties unless specific radiopacifiers are added during formulation. The use of the glass ionomer cement can be considered problematic, as some excess material may occasionally be left in the implant soft tissue sulcus. If the tangential thickness of the remaining cement excess is less than 1-mm, then this type of luting agent would be difficult, if not impossible, to detect by radiographic means (57). It can be detected only when the thickness of the cement is 2 mm.

2.3.2. Resin-modified glass-ionomer cement (RMGI)

It is a hybrid material made by adding water-soluble polymers or polymerisable resins to traditional glass-ionomer cement. This modified cement was invented in the 1980s to eliminate two main disadvantages of the conventional glass ionomer cement: low early strength and high solubility.

This type of cement has superior physical and mechanical properties compared to the conventional glass-ionomers (63). This type of cement has been proved to be a reliable luting agent not only for teeth, but also for implants. In a clinical study, 86 anterior all-ceramic alumina single unit FPDs were placed on natural teeth and on implants (64). The evaluation was performed after 48 months in situ, the success rate for teeth was determined to be 100% and for implants – 98.3%. Probably depending on the advantages of this cement it has been reported to be the most often used luting agent in the United States dental schools either for teeth borne, or implant supported restorations (87% and 67%) (65).

2.3.3. Zinc phosphate cement

Zinc phosphate cement has been used in dentistry for over a hundred years and serves as a successful luting material for metal inlays/onlays and crowns. In general, in comparison to other cements, its compressive strength is relatively high and tensile strength is low, additionally the low price per unit dose should also be mentioned as an advantage (63). The liquid is buffered phosphoric acid so the mixed material reaches the tooth or abutment at a very low pH, which later quickly rises. This high content of phosphoric acid in the cement increases streptococcal adhesion on it, on the other hand, this type of cement releases zinc ions, which has antibacterial effect. Unfortunately, zinc is known to be cytotoxic (due to dispensing of zinc ions and contenting of residual acids) and that is very important in the implant crown cementation due to the fact that cementation line is usually deeper than on the natural dentition (66, 67).

Radiographic detection is a very important factor, when selecting the luting agent for an implant supported crown cementation. In 2010 Wadhwani et al. published an article where they analyzed and tested radiopacity of 8 different cements used in dentistry: TempBond Original (zinc oxide eugenol), TempBond NE (zinc oxide non eugenol), Fleck's (zinc phosphate), Dycal (calcium hydroxide), RelyX Unicem (universal resin), RelyX Luting (glass

ionomer), Improv (resin), and Premier Implant Cement (resin). Specimen disks, 2 mm in thickness, were radiographed (57). Images were made using photostimulable phosphor plates with standardized exposure values. The average grey level of the central area of each specimen disk was selected and measured in pixels using a software analysis program, ImageTool, providing an average grey level value representative of radiodensity for each of the 8 cements. The radiodensity was determined using the grey level values of the test materials, which were recorded and compared to a standard aluminum step wedge. An equivalent thickness of aluminum in millimeters was calculated using the best straight line fit estimates. To assess the contrast effects by varying the exposure settings, another experiment using 1-mm-thick cement specimens radiographed at both 60 kVp and 70 kVp was conducted. Having evaluated the 8 cements, the highest grey level values were recorded for the zinc - containing materials, which was expected due to zinc's high atomic number and electron density. All cements containing zinc could be detected radiographically in both 2-mm and 1-mm thicknesses. At both 60-kVp and 70-kVp settings, the 1-mm-thick zinc-containing cements produced similar aluminum equivalence values.

2.3.4. Resin cements

Resin luting agents are unique in polymer matrix forms to fill and seal the tooth/implant and restoration gap whereas other luting choices are true cements derivers from mixing a powder and liquid which form a hydrogel matrix (68). Nowadays resin luting agents are popular and world-wide used because of their versatility, high compressive and tensile strengths, low solubility and very good esthetic properties. They still have some disadvantages: the cement excess is still difficult to remove, its usage is still technique sensitive and they are expensive per unit dose (68). An excess removal for these types of cement is usually done having a very short (2 to 5 seconds) light cure with final curing completed after the initial cleanup. Care must be taken during the initial bulk removal of excess resin cement to insure the material is not pulled from under

the restoration margin, creating a gap. Agar et al. in their clinical trial compared three different types of cement (glass ionomer, zinc phosphate and resin). They tried to remove cement excess from the implant-supported crown with subgingivally placed margins. The results proved that the resin cement was the most difficult to remove and had the greatest scratches left on the abutment due to cleaning with the probe (9). Resin cements have almost the same poor radiodensity properties as glass ionomers unless specific radiopacifiers are added during formulation. Clinicians should be aware in relying on a radiographic test when choosing resin for cementation as some excess material may occasionally be left in the implant soft tissue sulcus. If the thickness (of the cement remnants) is less than 1-mm, then resin cements would be difficult, if not impossible, to detect by radiographic means (57).

In general, all cements in dentistry should be biocompatible, with no or little interaction with body tissues and fluids. They should be nontoxic and have low allergic potential. There is some data about allergic responses related to the use of the resin modified glass ionomer cement with implant restorations (69). The explanation includes the fact that most of these cements contain 2 hydroxyethylmethacrylate, which is a particularly harsh chemical in its unset form. Therefore, operators handling this material should be very careful and soft tissues should be protected from the contact with this cement either, which might be impossible when implants cementation margin is deep subgingivally.

2.3.5. Polycarboxylate cements

Fluoride containing cements (polycarboxylate) may have a negative influence on the implant prostheses. Fluoride is regularly used in industry to condition titanium. Under the appropriate conditions, it etches the surface, removing ions from the metal (49). Further studies documented that polycarboxylate cement corrodes the titanium (54). This type of cement is only safe to use if a clinician can ensure that there is no cement beyond the implant-restoration margin. Otherwise, metal corrosion products reactivate oxidation species and it causes a destructive inflammation response.

2.3.6. Provisional cements

Every cement available in implant dentistry should be able to withstand comprehensive, tensile and shear forces applied to the restoration in the intraoral environment. Therefore, there has been a discussion among clinicians whether to select provisional or permanent cement for a cementation. Back in 2000s it was recommended to use temporary cements on implant-supported restorations, based on the necessity to retrieve (70, 71, 72). Opponents of this theory claim their truth based on the fact provisional cement in implant-supported restorations can be unpredictable and may necessitate a frequent re-cementation (73). It has been documented that the loss of retention could be from 3.7 to 9.8% (74), reaching up to 22% if short abutments are being used (75). One of the reasons might be the washout of the cement as it might be soluble. Another argument against provisional cementation is that some temporary cements seem to function more like permanent cements when used to lute metallic restorations on metallic abutments (76).

Another study found significantly the lowest amounts of adhering bacteria on TempBond and TempBond NE, this might be explained by extremely smooth surfaces of those two temporary cements (62). Additionally, zinc containing luting agents (TempBond is zinc oxide eugenol and TempBond NE is zinc oxide non-eugenol) has been proved to release zinc ions, which have antibacterial effects by inhibiting various cell activities, such as glycolysis and transmembrane proton translocation that modify the permeability of cell membranes (77, 78, 79).

When analyzing the radiodensity of the temporary cements it has been documented that TempBond and TempBond NE have the highest grey levels (meaning the most visible in the radiographic testing), which is because of the zinc’s high atomic number and electron density.

2.4. Problems associated with undetected cement excess

Implant cementation means of attaching the coronal restoration to the implant fixture has become a routine dental procedure. However, the cementation procedure itself is not without issues. Multiple case reports have highlighted problems with cement excess which could ultimately (may) lead to peri-implantitis and later to implant failure. The role of undetected cement in the development of peri-implant disease is still controversial, but recently it has been associated with higher plaque accumulation (80), due to rough surface of the residual cement, which retains microbes and inhibits the removal of microorganisms (81). The most recent systematic review by Staubli et al. (82) shows that prevalence of peri-implant diseases varies between 1.9 and 75% of the implants with cemented restorations, with proportions of 33-100% associated with the cement excess. Peri-implant disease can be classified as peri-implant mucositis or peri-implantitis (83). Peri-implant mucositis presents with inflammatory lesions of the soft tissues surrounding implants, while peri-implantitis is associated with bone loss in addition to the soft tissue lesions (84). Peri-implantitis is a biologic complication that may lead to a failed implant (85).

Excess cement in subgingival spaces could irritate surrounding tissues by microbiological contamination (86) or by a possible toxic reaction (87). A biofilm may form on the cement left in the peri-implant tissue, which may result in iatrogenic peri-implantitis with bone loss (88, 89).

The analysis of the current literature shows that several types of peri-implant reactions to undetected excess cement might be distinguished – early peri-implantitis, when swelling, bleeding, and accompanying bone loss develop from a week to few months after delivery of restorations (10, 11) or delayed peri-implantitis, when inflammation and bone resorption occur many years after a cementation. Sometimes a complete absence of a peri-implant tissue response to some cement remnants may be expected as well (12). The exact reasons for these differences are still unknown, however, it can be

hypothesized that an individual's susceptibility to periodontal infection may also play an important role in the progress of cement-related crestal bone loss. Another hypothesis is, that bacterial colonization of cement in the peri-implant tissue can be considered the most important cause of an inflammation associated with cement excess (88). Even though, it can be stated by the previous in vitro study (9) that excess cement could remain in subgingival spaces, this does not necessarily lead to peri-implantitis occurrence. This could be explained, Linkevicius et al. in their recent retrospective study proved that the development of peri-implantitis was more frequent for the patients with history of periodontitis if the cement excess was present and for patients having no history of periodontitis remaining cement excess did not cause any inflammatory response (90).

Another interesting factor about cement is that many commonly used cements cannot be seen radiographically (57) and to further compound the detection issue, some manufacturers even go to the extent of making the cements with "aesthetic gingival shading for natural appearance" – these cements are actually pink. This again greatly interferes with the ability of a clinician to find excess cement, since the pink-colored cement easily blends into the surrounding tissues. Therefore, it is even more important to be sure about complete cement removal after cementation without radiographic control.

A recent clinical study has shown that cement excess in subgingival spaces was found in 81% of implants showing signs of peri-implantitis. Interestingly, some of the implants were restored 9 years ago, showing delayed response to the residual cement (12). Another clinical study reports bleeding and suppuration after some weeks or months after the delivery of the crowns (91). They found cement in 59.5% of the implants included in the study (the study was held in the same clinic for more than one year, including all restored implants). They have concluded that the presence of the cement excess is significantly associated with a larger diameter of the implant. No peri-implant attachment loss was found around 46% of the implants. 43% showed a 1 mm

loss in attachment level, 11% - a loss of 2 mm or more. Increasing attachment loss was associated with an increasing residence time of the cement until revision.

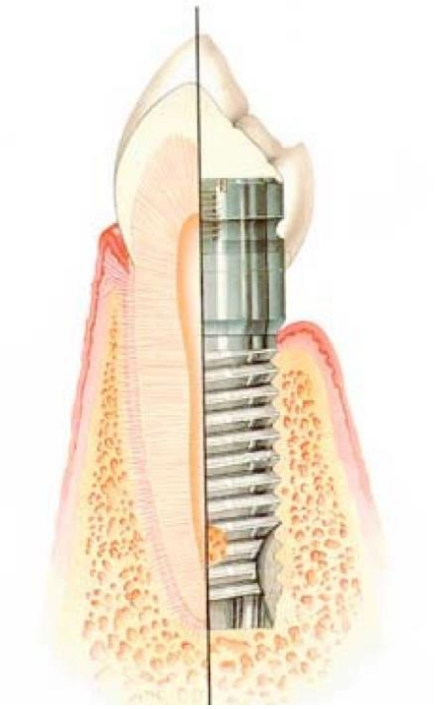
The same research team in 2015 did another clinical study, which was not a planned study. The authors started from casual observations that after cementations clinical complications occurred that were associated with the presence of cement excess and abated after its removal. The study concludes that excess cement was present in a high number of cement retained implant restorations (92). The authors declare that signs of inflammation were present in a large proportion of implants at short- to medium–term follow-up. At the time of restoration revisions, the clinical observation of previously undetected excess cement was associated with increased prevalence of inflammation. The removal of excess cement significantly reduced the signs of inflammation.

To summarize, it is well known that excess cement is an issue in implant prosthodontics, the question remains, is it possible to cement a crown and be sure, that cement excess is removed completely.

2.5. Existing clinical recommendations for safe cementation and ways to minimize cement excess

Despite the type of the cement selected for the luting purposes for implant supported crown or FPD, the removal of the cement excess remains an issue for a clinician. There are several techniques and methods described that either reduce the flow of excessive cement or eliminate it.

Cement excess and its removal procedure has not been identified as a complicated procedure in teeth supported restorations, because the junctional epithelium and connective tissue attachment around natural teeth insert perpendicularly, this tends to limit and compartmentalize the flow of excess cement (Picture 5) (93). This is in contrast to the epithelium and connective tissue around dental implants, where the connective tissue runs parallel and does not insert into the body of the implant. As a result, the flow of cement is not restricted and easily migrates apically.



Picture 5. Different tissues surrounding an implant and a tooth

Not only the difference in surrounding tissues between teeth and implants make the cement procedure more complicated in implant dentistry, but also the position on the cementing shoulder or line of the crown or FPD. Tooth preparations for the cemented restorations commonly have a finish line that is supragingival wherever possible; the only sites that are frequently subgingival are in aesthetic areas. The outline form also follows the tissue height contour as it changes around the tooth, moving higher interproximally where the papillae are. Comparing with implants, the head of an implant is commonly flat and often counter sunk in the anterior region 2 to 4 mm below the level of the midbuccal gingival tissue to allow for emergence profile contour. Because of the scallop of the gingival tissues, this countersinking can be about 5 to 7 mm from the tip of the papilla to the implant platform at the interproximal area of an anterior tooth (94).

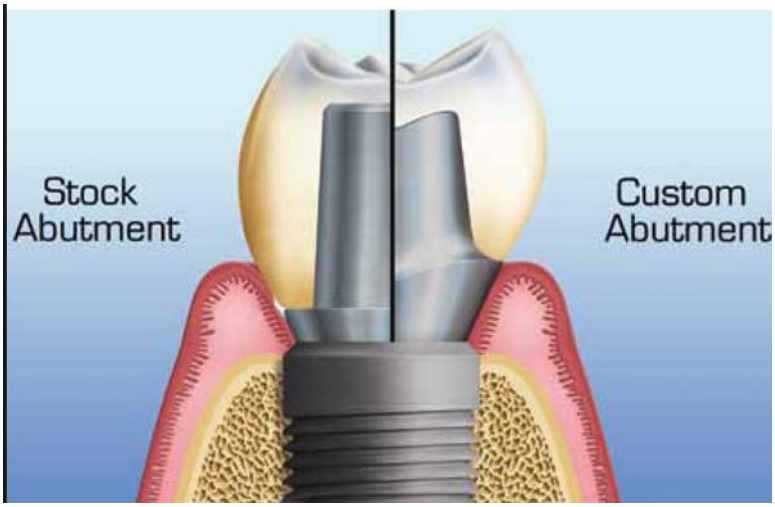
There are no generally accepted clinical recommendations for a safe cementation. Advice found in the present scientific literature vary a lot:

1. Safe cementation margins – individual abutments with various positions of the shoulder.

2. Teflon tape technique.
3. Modification of the implant abutment.
4. Abutment replica.
5. Radiographic evaluation.

2.5.1. Custom made milled individual abutments

They were presented in implant dentistry in the early 90s (95), but it became popular and widely used only in the 2005-2007 (96). These individual abutments were invented to ensure natural emergence profile of the implant supported cement retained crown or bridge and to create the shoulder for cementation at the desired position. In the picture below (Picture 6) it is shown the main difference between standard abutment and custom made abutment.



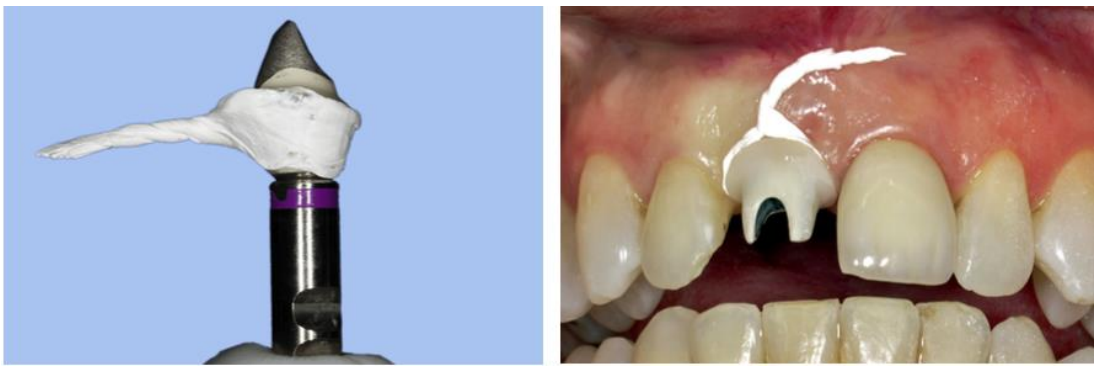
Picture 6. Differences between standard abutment and custom made abutment

The problem with the custom made abutments is that there are no generally accepted guidelines for cement margin, what depth and position it should be placed according to the soft tissues. Many authors in their papers just mention the fact that "cement excess should be removed precisely". De Carvalho et al. in their clinical report chose supragingival finishing line to prevent the presence of excessive cement in the sulcus (97). Lewis et al. recommend equal gingival margins to allow a complete removal of the cement (27). Yap and co-workers select to place cementation margin 1 mm

subgingival for all surfaces except for the palatal surface, where the margin could be placed at the level of the soft tissues (98). Another clinical study (99) states that typically the marginal finish line is placed 0.5 mm below the soft tissue level, but in the latter case report they placed it from 1 to 1.5 mm below crest of the peri-implant soft tissue stating that “it may be acceptable”. Lee and co-authors (14) summarize that in terms of the restoration height, the margins are usually located 2 – 3 mm subgingivally. Taylor et al and Shadid et al. also agree that if cementation margin is located deeper than 3 mm it could cause a difficulty to remove excess cement (17, 21). But there is only scientific prove that there is a positive relation between cementation depth and undetected cement (9). They have demonstrated that there is a distinct possibility for excess cement to remain, especially when the margins are placed from 1.5 to 3 mm subgingivally. Another problem with the custom-made implant abutment is that cement has a potential to migrate from the abutment to the surface of the implant and below the osseous crest (50, 55, 65, 100). Therefore, only abutment itself could not solve the problem with cement removal.

2.5.2. Teflon tape technique

As already mentioned before, retraction cord is not appropriate to use for implant supported restoration cementation (101) due to the fact that it enlarges the sulcus and eases the cement excess flow deeper in the peri-implant tissues. Hess suggests to use polytetrafluroethylene (PTFE) tape around the abutment before seating it to the implant, they believe that this should protect the adhesion or bonding of the cement to the subgingival aspect of the abutment whether it is metal, porcelain or zirconia (102). And it would not enlarge the peri-implant sulcus because it is less than 50 microns thick when stretched.



Picture 7. Teflon tape around individual abutment before cementation

A custom made abutment before screwing to the implant is being stretched with PTFE tape around it (Picture 7). After the cement sets, the tape is removed. The main advantage of the technique is that it does not enlarge the sulcus as the retraction cord does and it does not become entrapped by the cement. But the limitation of this technique is that cementation margins should be supragingival if this technique is selected. The potential problem remains because the cement could adhere to the peri-implant tissues, not just the abutment (102).

2.5.3. Different cement application techniques and amount of the cement

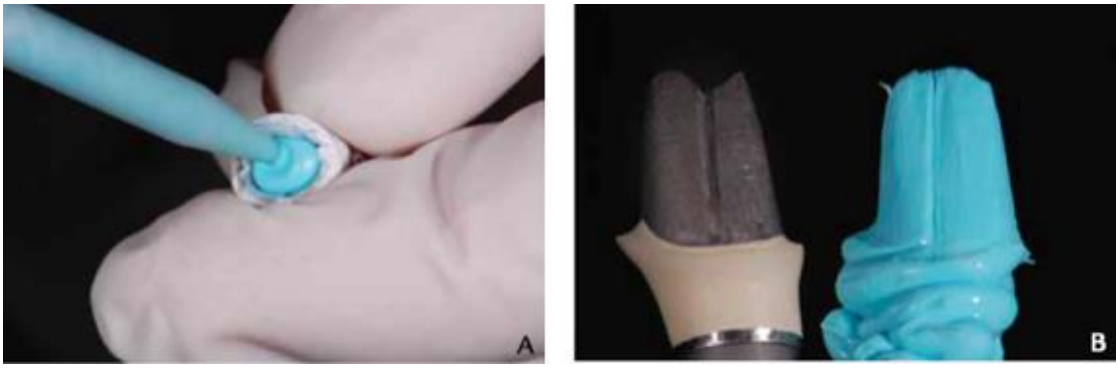
When considering the quantity of cement within the restoration and abutment unit, an absolute space is provided for the cement – the cement lute space – which is commonly provided by the use of a die spacer during crown fabrication, usually it is 50μm (103). It is obvious that any quantity of cement applied within the crown that exceeds the cement lute space extrudes out of the restoration and abutment for complete seating. On the other hand, if the quantity of cement is not enough as required to fill that space, the cementation layer is inadequate to completely close this space. It clinically might end up in potential leakage and loss of retention (104). There are no world-wide accepted recommendations for the quantity of the cement that should be used to cement a crown. Overall range of cement weight used is from 3.2 mg to 506.4 mg, it was shown in a study where dentists tried to use adequate amount of the cement for luting a restoration (50), it proves that some guidelines are totally

necessary in implant dentistry to avoid such a big range of variety. The quantity of cement that is actually required can be calculated by knowing the crown's total volume and the desired cement lute space. The ideal cement lute space has not been studied well with respect to implant abutments. One of the studies available was done by Chee et al., who investigated and compared 4 different methods: a) cement applied on internal marginal area of a crown only; b) cement applied on the apical half of axial walls of a crown; c) cement applied to all axial walls of interior surface of a crown, excluding the occlusal surface; d) a crown filled with cement then seated on putty index formed to the internal configuration of restoration (105). They have found out that the least amount of the cement excess is present in the last option. Their finding was once again proved later in 2016 in the published study by Liang et al. (103). They concluded that the application of a resin abutment replica during the cementation of implant-supported restorations might decrease the discrepancy between the restoration and the abutment, reduce the cement residue, and increase the restoration retention.

2.5.4. Custom made abutment replica

In this way to minimize the cement excess a copy abutment with smaller dimensions is used before cementation intraorally. It can be quickly, easily, and economically fabricated at the time of an implant abutment/crown insertion. The use of polytetrafluoroethylene (PTFE) tape provides a space of approximately 50 microns, which represents the cement space and may be used for both custom and prefabricated abutments. The intaglio surface of the implant restoration should be lined with polytetrafluoroethylene (PTFE) tape (Oatey Co, Cleveland, Ohio). The abutment should be placed in the restoration to facilitate the adaptation of the PTFE tape to the intaglio surface of the implant restoration. A fast setting vinyl polyvinyl siloxane (VPS) should be used to fill the restoration (Picture 8 A). After it sets, a copy of original abutment (VPS model) is made (Picture 8 B). Any cement could be selected for luting. The intaglio surface of the implant restoration should be lined with

cement, then the crown is placed onto the VPS model and the excess cement is wiped off before the cement has exceeded its working time. Then the crown should be removed from the VPS model, and a thin layer of cement in the intaglio of the restoration is remaining. If any voids are present, a small amount of extra luting agent should be added to fill the voids (100). A newer technique how to improve this method was presented in 2016 by Rayyan et al. (106). This article described wherein hot melt thermoplastic material is used for the copy abutment instead of polyvinyl siloxane. This simplifies the technique, making it faster and more reliable. It involves injecting hot melt thermoplastic material into the wetted intaglio surface of the crown, fitting a dowel pin to serve as a removal handle, filling the crown with cement, fitting it onto the copy abutment, and wiping the excess at the margins before intraoral transfer and definitive cementation.



Picture 8. A. Restoration filled with VPS 8. B. VPS model – copy of an original abutment

2.5.5. Radiographic evaluation

It is well known that radiographic evaluation ensures a non-invasive evaluation of the implant/crown site to determine if there is any cement left undetected after cementation (58). Usually, cement detection is based on factors such as the composition of the cement, amount of the excess, and the site (57, 107). Other disciplines within dentistry have required radiopacity specifications for cements, but no mandatory minimal standard specification exists for implant cements (ISO).

There might be some reasons mentioned why cement could not be detected radiographically. Firstly, cement has to be very radio opaque to be detected. The radiographic opacity of a material varies directly with the third power of the atomic number of the absorber elements (107). For this reason the zinc found in zinc phosphate and zinc oxide-eugenol cements is highly detectable. This is in contrast to the low atomic number elements found in acrylic urethane cements that are difficult to detect radiographically, unless the manufacturer purposefully adds agents containing higher atomic numbers to increase the radio-opacity. Unfortunately, if the radio-opacity of the cement is low and the position of the left cement is lingual or facial, the cement remnants might be almost impossible to detect. It could be explained with the fact that superimposition of the cement on the metal or zirconium implant components makes it invisible (57).

There is some data in the literature about the enhanced radiographic detection. Even though cement is being selected less radiopaque than zinc cement if the conditions of the cement flow are right, it could be detectable even though a minimal layer is used. This happens due to previously mentioned peripheral egg-shell effect (57, 58, 107).

2.5.6. Other techniques

Other techniques might involve venting of a crown (108, 109), leaving the abutment almost open (53, 55) or reduction of luting agent placement into the restorations (110). There has been an idea to use rubber dam isolation with the individual abutment to avoid any residual cement to flow into the peri-implant tissues (111). All above-mentioned techniques, certainly have advantages, however, complicated control of the procedures may limit their usage in clinical practice.

3. MATERIAL AND METHODS

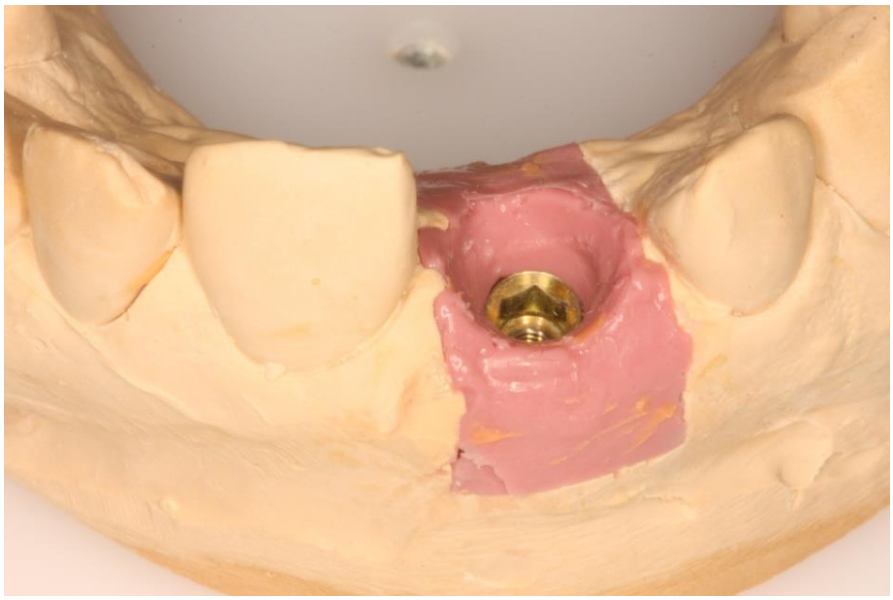
Two studies were initiated: in vitro study and a prospective clinical trial.

3.1. The influence of margin location on the amount of undetected cement excess after delivery of cement-retained implant restorations. In vitro study

In vitro study design

3.1.1. Model preparation and laboratory procedures

Twenty-five models with embedded 3.5mm diameter implant analogs (BioHorizons Internal, Birmingham, AL, USA) in the position of an anterior tooth were used in this study. An impression was taken from the patient, with an implant positioned approximately 5mm below the gingival level. All the casts were mounted with type IV dental stone (Heraeus Kulzer GmbH, Hanau, Germany). A-silicone flexible gingiva mask GumQuick Plus (Dreve Dentamid GmbH, Unna, Germany) was used for the soft tissue imitation (Picture 9).



Picture 9. Experimental model with implant analog and flexible gingiva mask

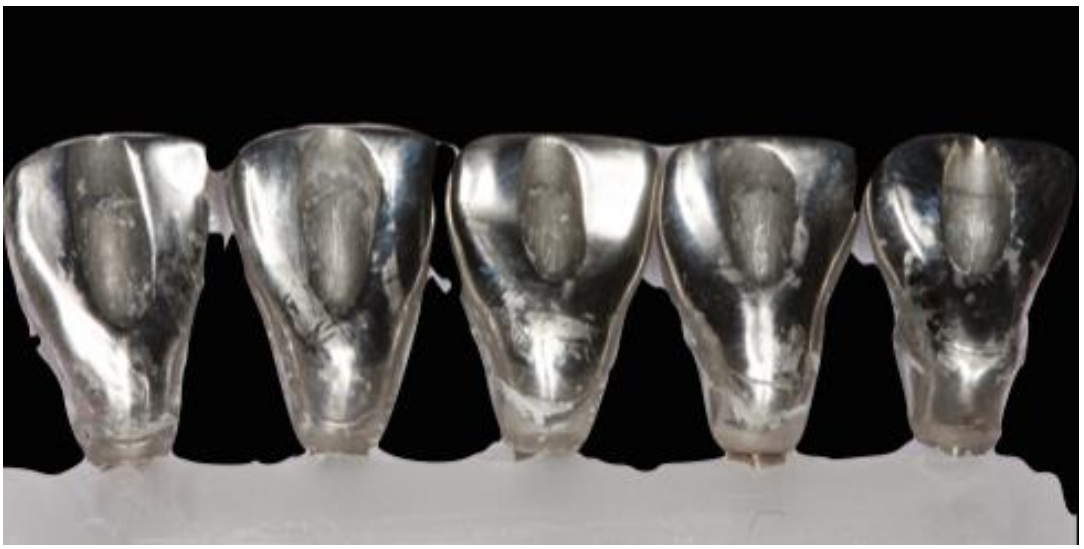
Twenty-five individually casted abutments following the line of gingiva and the same number of metal crowns were fabricated using Starbond CoS

alloy (S&S Scheftner GmbH, Mainz, Germany), consisting of Co 59%, Cr 25%, W 9.5% and Mo 3.5%, by the same operator. The abutments were modeled with various positions (Picture 10) of the margin for the restorations (five groups of five specimens):

1. Group 1 (control) – 1 mm above the gingival level.
2. Group 2 – at the soft-tissue margin.
3. Group 3 – 1 mm below the marginal level.
4. Group 4 – 2 mm below the gingival level.
5. Group 5 – 3 mm subgingivally.

Picture 10. Individually casted prosthetic abutments with different location of cementation margins

Palatal openings were made in the crowns in order to have access to the abutment screw after cementation (Picture 11).



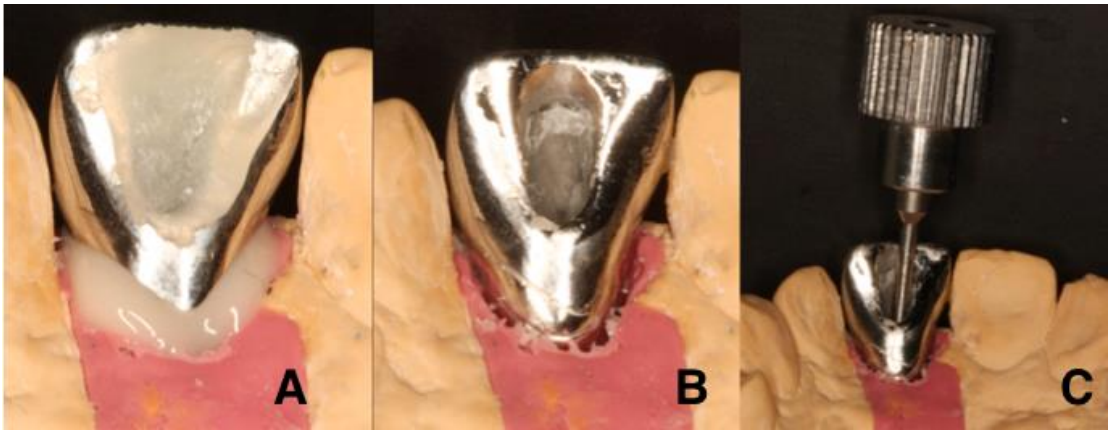
Picture 11. Abutments and crowns with palatal openings

This was necessary to ensure the retrievability of abutment-restoration system. The crowns and the part of the abutment contacting soft tissue were polished with rubber dental polishing wheels Polysoft (Renfert, Hilzinger, Germany) of 3 mm in thickness and 22 mm in diameter.

3.1.2. Cementation and cement cleaning procedures

Resin-modified glass-ionomer cement Fuji Plus (GC, Tokyo, Japan) was selected as a luting agent in this study. Before the cementation, the top of each prosthetic abutment was covered using dental wax – Wax Pak (3M UNITEK, Monrovia, CA, USA) – to protect the abutment screw. The palatal openings were closed with composite material Gradia Anterior (GC) to obturate the screw access space and prevent venting of luting agent during cementation. The cement was mixed according to the manufacturer's instructions; a thin layer was applied to all internal surfaces of the crowns and seated onto the abutment with gentle finger pressure (Picture 12 A). After setting, the excess was removed with a stainless steel explorer (Dentsply International Inc., Milford, DE, USA) and super-floss (Curaprox, Kriens, Switzerland) until the researcher decided it had been completely cleaned (Picture 12 B). Then, the composite and the wax were removed, the abutment screw was unscrewed and the suprastructures were dismounted for assessment (Picture 12 C). The

amount of the cement excess according to the location of the cementing line could be seen in Picture 13.



Picture 12. A, B, C Steps of the procedure

Picture 13. Amount of the cement when location got deeper "subgingivally"

3.1.3 Evaluation of the amount of undetected cement

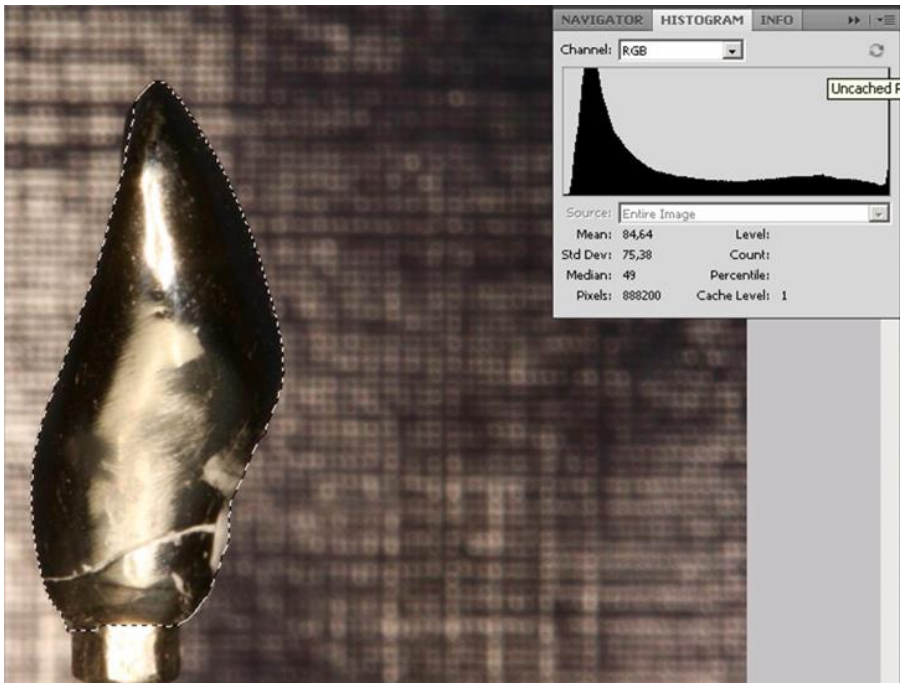
Two techniques were selected to evaluate the excess of the cement left after cleaning – the computerized planimetric method of cement assessment and weighing. The planimetric method is very useful when there is a need to evaluate the proportion of the total surface of specimen (tooth, crown etc.) and its surface covered with something after intervention (plaque, cement etc.).

Firstly, all four quadrants (mesial, distal, labial and lingual) of the specimens were photographed using a specially constructed device to keep the

standardized distance between the photo camera (Canon, Lake Success, NY, USA) and the specimen (Picture 14).

Picture 14. Standardized distance between camera and specimen

The images were imported and analyzed using Adobe Photoshop (Adobe Systems Ltd, Europe, Uxbridge, UK). Each surface area of the specimen was measured manually with the drawing facility to outline the boundaries of each quadrant. To calculate the area covered with cement remnants, the "pen tool" and "make path" were used. The total surface area was marked and the number of pixels was recorded from the histogram option (Picture 15), the same was applied to the area covered with the cement remnants. The ratio between the area covered with the cement and the total surface area of the specimen was calculated. A surface of the specimen was considered as a statistical unit, therefore each specimen had four measurements, resulting in a sample size of 20 for each group. The second method was to weigh the cement remnants removed from each specimen. Analytical digital scales Vibra (Shinko Denshi, Tokyo, Japan) with a readability of 0.0001 g were chosen for that purpose (Picture 16). A specimen was considered as a statistical unit, thus we had five specimens in each group.



Picture 15. Calculating pixels of the surface

Picture 16. Analytical digital scales

3.1.4. Statistical analysis

A statistical analysis was carried out using SPSS software for Windows v.17 (SPSS Inc., Chicago, IL, USA). First, mean values with standard deviation were calculated. Owing to small sample size, independent K (Kruskall-Wallis) test for nonparametric data was used to determine the

influence of the margin location on the amount of the undetected cement. If significant, Mann-Whitney test was applied to compare the groups. A simple scatter plot graphical visualization and Spearman's correlation coefficient were used to determine the relation between the two assessment techniques. The level of significance was set at p=0.05.

3.2. Clinical factors influencing removal of the cement excess in implant-supported restorations. A prospective clinical study

3.2.1. Patients

Subjects were selected among partially edentulous patients, who attended Vilnius Implantology Center Clinic (Vilnius, Lithuania) for implant treatment. The major inclusion criterion was the need to restore missing single teeth.

Inclusion criteria were as follows:

1. Not less than 18 years old.
2. Missing single tooth in any region of the mouth, having both, mesial and distal adjacent teeth.
3. No medical contraindication for implant surgery.
4. Signed informed consent form for participation and a permission to use the obtained data for the research purposes.

Patients were excluded, if they did not meet the requirements listed above and additionally had:

1. Poor oral hygiene.
2. Poor co-operation.
3. Smoking.
4. Alcoholism.
5. Diabetes.

The study included 65 consecutively treated patients (33 male and 35 female) with the age ranging from 20 to 75 years old (mean 37.4±1.2 yr.). Patients requiring only single implant restorations were included in the study. The study was approved by the Vilnius regional bioethical committee (No.

158200-02-457-132). The patients provided written informed consents with a permission to use their data for the scientific purposes.

3.2.2. Study design

A controlled prospective randomized clinical trial was initiated. Patients requiring only single implant restorations (both, mesial and distal, adjacent teeth were present) were included in the study and therefore 65 internal hexagon implants (BioHorizons Internal, Birmingham, AL, USA) were installed, 35 in the lower and 30 in the upper jaw. The location of the implants was as follows: 4 in the anterior (incisors and canines) region (6.2%), 22 premolars (33.8%) and 39 molars (60%). 21 implant had a diameters of 3.5 mm (32.3%), 34 of 4.0 mm (52.3%) and 10 of 5.0 mm (15.4%).

3.2.3. Implant placement

Implants with regular horizontally matching implant-abutment interface (Internal Tapered BioHorizons, Alabama, USA) were placed. All the patients received a prophylactic dose of antibiotics of 2 g amoxicillin (Ospamox; Biochemie, Austria) 1 hour prior to the surgery. The placement of the implants was planned after a clinical and radiographic examination. After the administration of 4% articaine solution (Ubistesin; 3M ESPE, Germany) for local anaesthesia, a mid-crestal incision on the centre of edentulous ridge was performed, leaving at least 2mm width of keratinized gingiva buccally. The implants were placed according to manufacturers' recommendations 1mm above the bone level. The osteotomy site was measured to allow a minimum 1,5 mm range from adjacent tooth/teeth and 1 mm space between buccal and lingual crest of the alveolar ridge and implant. Implants of a different diameter (3.5/4.0/5.0) were placed in one stage approach. The implants used in the study were made from Ti-6Al-Nb 49 alloy; the implant surface was roughened with RBM. The top of the implant neck had 0.5 mm polished part for connection with the abutment. After the implant placement, healing abutments were

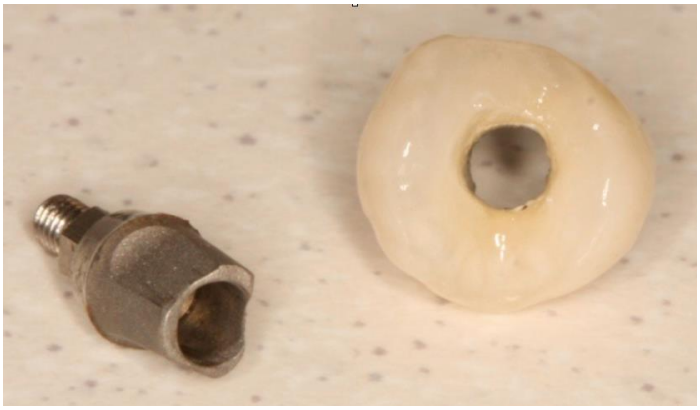
connected. Flaps were approximated without any tension and sutured with 5/0 interrupted sutures (Assucril, PGA, Switzerland).

3.2.4. Restorative protocol and cementation procedure

Prosthetic procedures were initiated following 2 months of the healing process in the lower jaw and 4 months in the upper jaw. Before starting prosthetic treatment, implant success criteria were applied. The implants were considered successful and suitable for restoration, if they had:

1. Absence of radiolucency around the implant.
2. No clinically detectable mobility.
3. No suppuration, pain, or ongoing pathologic processes.

No temporary implant restorations for tissue conditioning were used. Impressions were taken using a polyvinylsiloxane impression material (Variotime; Heraeus Kulzer, Hannau, Germany) with the open-tray technique. Cement- and screw-retained implant prosthesis was selected as a restorative option for implants, as this technique allows withdrawal of the crown after cementation (112) (Picture 17).

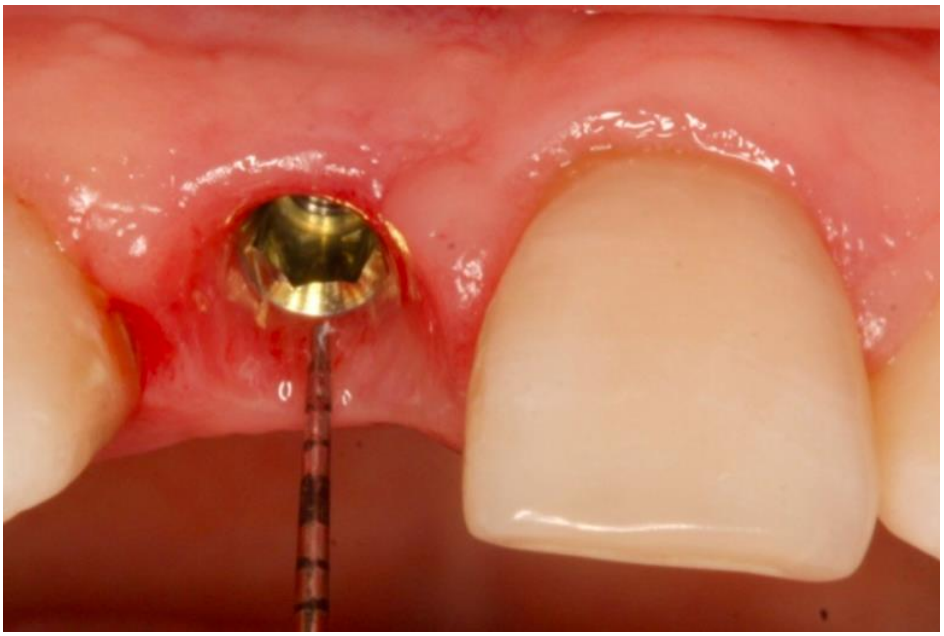


Picture 17. Standard abutment and crown with occlusal opening before cementation

3.2.5. Depth of the cementation margin

Evaluation of the implant depth mesially, distally, lingually, and buccally was performed after the removal of the healing abutment. The measurements

were taken with a 1.0 mm marked periodontal probe (Hu-Friedy, Chicago, IL, USA). In the final data evaluation, the depth of the cementation margin was considered to be the measurement with the probe minus 1.5 mm, as the shoulder of a standard abutment is 1.5 mm above the implant/abutment connection point and this predetermined location was not altered in any case. Four measurements of the shoulder position were calculated on every restoration (Picture 18): buccally, lingually, mesially, and distally.

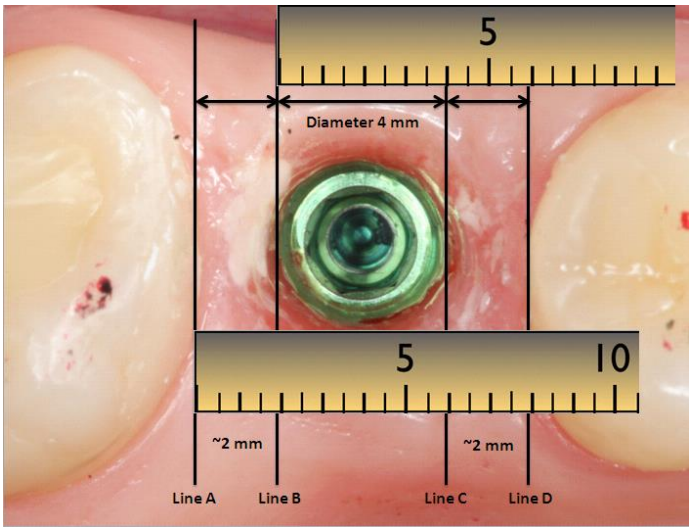


Picture 18. Measurement of the implant depth lingually

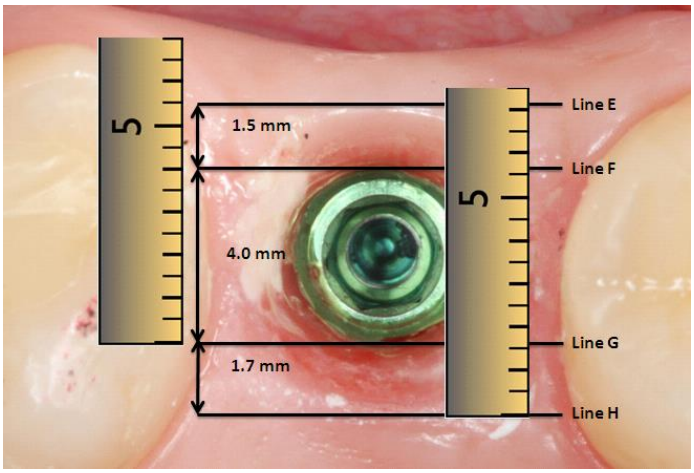
3.2.6. Undercut

According to the glossary of prosthodontic terms undercut is defined as an angle formed by any surface of the tooth below the survey line of the height of contour, with the selected path of insertion of prosthesis. However, in this study the undercut definition was specified to be the distance from the most marginal implant neck point (Line B, C, F, G) to the gingival margin of the restorations emergence profile (Line E, H) or to the adjacent teeth (Line D, A) in the horizontal plane (Picture 19 and 20) or definition used by Tomas Linkevicius “undercut is the distance between cementation (cement extrusion)

line and emergence profile line of the restoration" (Linkevicius personal communication).



Picture 19. Measurement of the undercut mesially and distally



Picture 20. Measurement of the undercut buccally and lingually

This undercut was measured in 4 locations. The distance from the most marginal implants neck point to adjacent tooth mesially and distally (distance between lines: from A to B and from C to D) and the distance from the most marginal implant neck point to the outer margin of the soft tissues buccally and lingually (distance between lines: from E to F and from G to H). The measurements were performed on perpendicularly taken intraoral picture of an implant (a picture was considered appropriate when all 6 angles of the internal

implant hex were clearly visible). The implant diameter was chosen as a parameter to calibrate pictures. The evaluation was performed with Microsoft PowerPoint for Windows 2010, using grids, digital ruler and guide options. The digital ruler was calibrated according to the implant diameter.

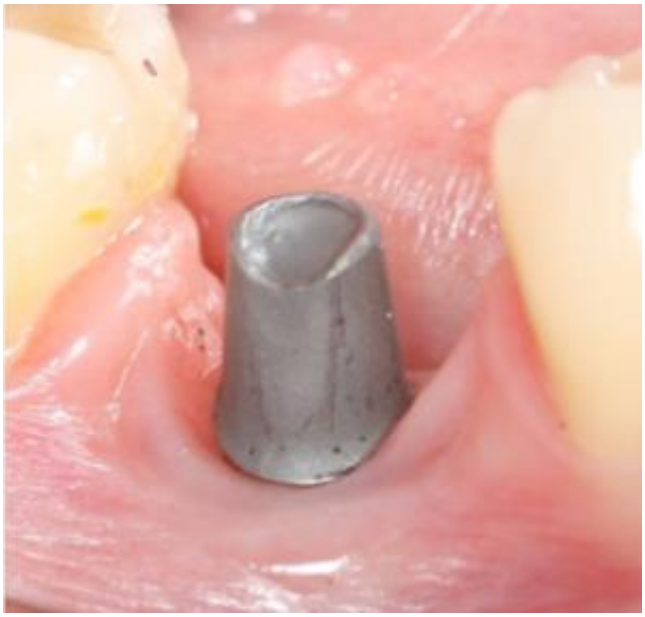
The ruler was added to the picture and in that way the distance from the implants most marginal point to the adjacent teeth was measured mesially and distally (Picture 10). The buccal and the lingual undercuts were measured from the most buccal and lingual implant marginal points to the outer soft tissue line visible in the picture buccally and lingually (Picture 11). Therefore, 4 measurements of the implant position were calculated on every restoration: buccally, lingually, mesially and distally.

Undercuts in the study were as found:

1. Group A – 1 mm in 118 sites.
2. Group B – from 1 to 2 mm in 96 sites.
3. Group C – 3 mm and more in 46 sites.

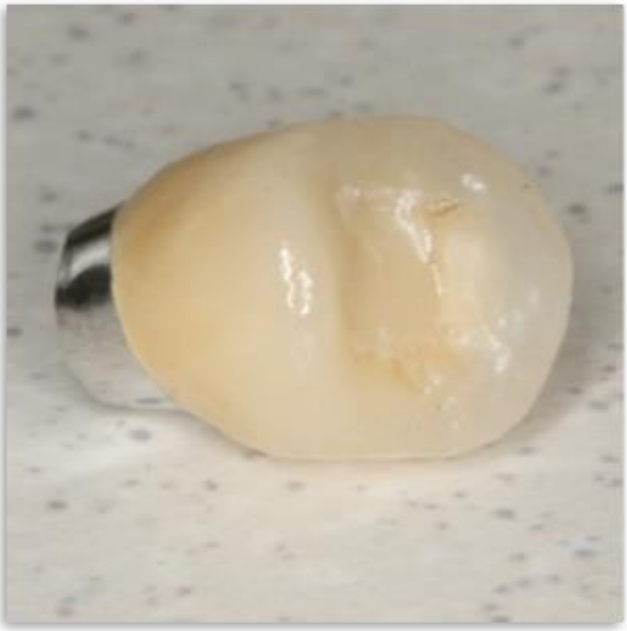
3.2.7. Cementation and cement cleaning procedures

The cementation procedure and the cement remnants evaluation technique were very similar to the preceding one in vitro study (it is described later in this chapter). Before cementation, a standard abutment was torqued to the implant and the screw channel isolated with dental wax (Wax Pak, 3M Unitek; Monrovia, CA, USA) (Picture 21).



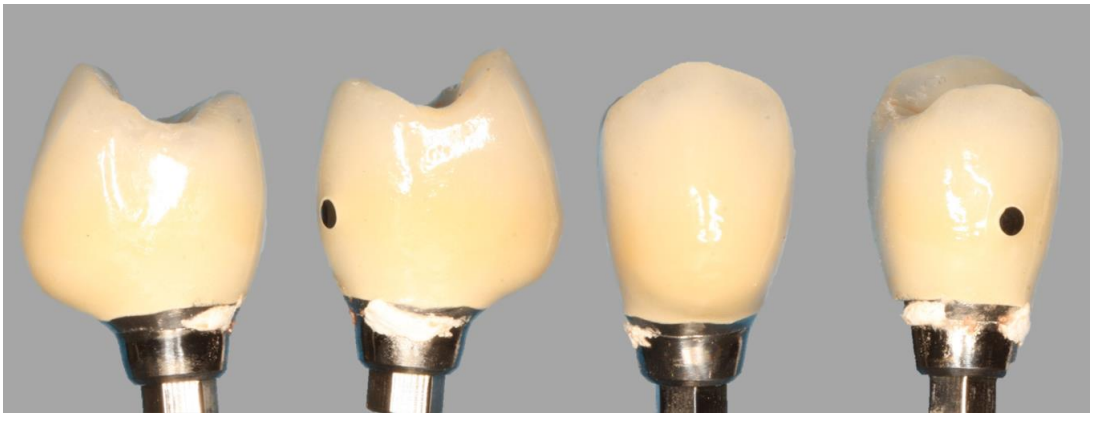
Picture 21. Torqued standard abutment in place

The occlusal openings of the crowns were closed with composite material Gradia Anterior (GC, Tokyo, Japan) to prevent venting of luting agent during the cementation (Picture 22).

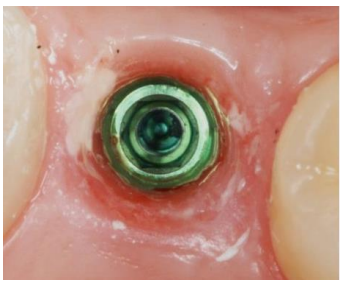


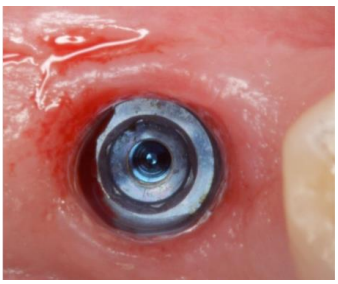
Picture 22. Composite was used to close the occlusal opening during cementation

The resin-modified glass-ionomer cement (Fuji Plus; GC) was mixed according to the manufacturer's instructions, taking the same ratio (1 little scoop of powder and 1 drop of liquid, as recommended by the manufacturer) for each crown. A thin layer was applied to all the internal surfaces of the crowns and seated onto the abutment with gentle finger pressure. When the setting cement reached rubbery (bulk) consistency, the excess was removed using a stainless steel explorer (Dentsply International Inc., Milford, DE, USA), a dental floss (Vitis; Dentaid, Barcelona, Spain), and a super-floss (Curaprox; Kriens, Switzerland) until the researcher decided it had been completely cleaned. The cement removal in all cases was performed by the same prosthodontist. Radiographic images were taken with RVG Windows Trophy 5.0 (Trophy Radiologie Inc., Paris, France) using a paralleling technique with Rinn-like film holder in high-resolution mode. If residual cement was detected on a radiograph, cleaning procedures were repeated until a radiographic evaluation showed no cement remnants. Then the composite and the wax were removed, the abutment screw was unscrewed and the suprastructures were dismounted for the final evaluation (Picture 23). Also perpendicularly taken pictures of the implant intraorally were done (Picture 24).



Picture 23. Crown ready for evaluation



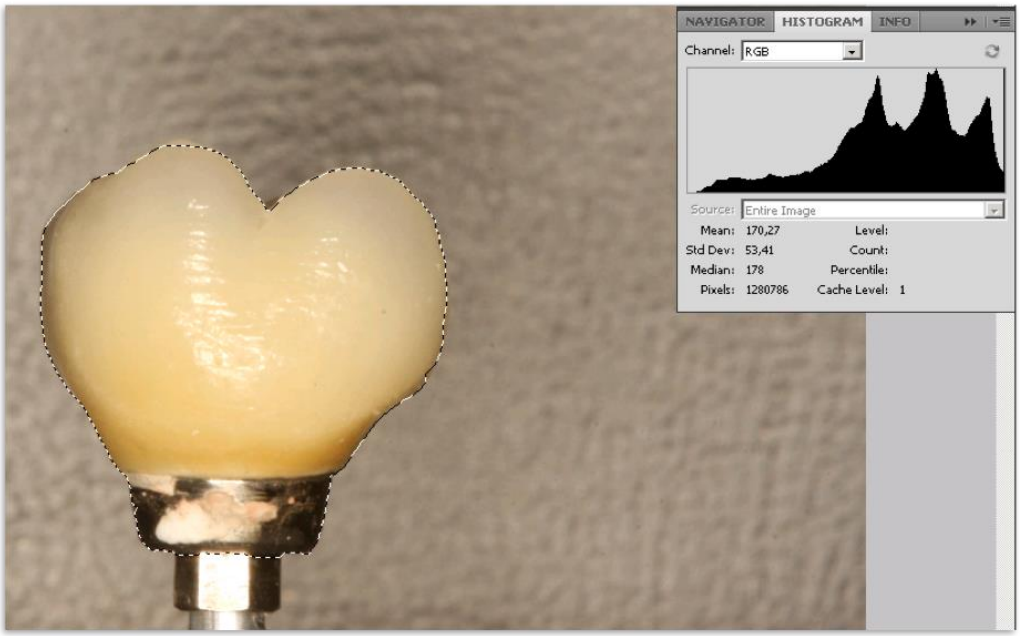


Picture 24. View intraorally before for evaluation

3.2.8. Evaluation of the amount of undetected cement

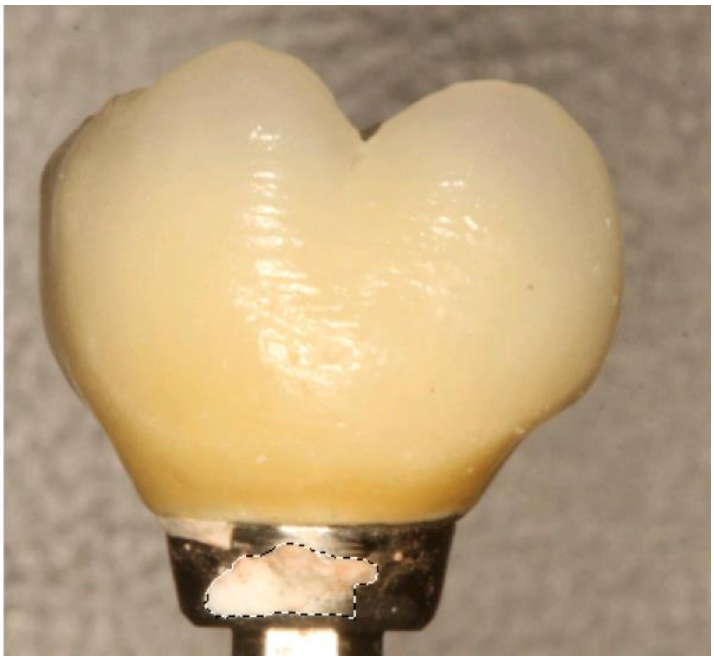
After the removal of the restoration, a photograph of the implant and the surrounding tissues was taken perpendicularly (picture was considered appropriate when all 6 angles of the internal implant hex were clearly visible) using an intraoral occlusal dental mirror (Novus Dental Supplies, Commerce, CO, USA) for evaluation of the cement remnants left in the tissues. All 4 quadrants (mesial, distal, buccal and lingual) of the abutment/crown complex were photographed using a specially constructed device to keep the standardized 16 cm distance between the photo camera (Canon, Lake Success, NY, USA) and the restoration.

The images were imported and analyzed using Adobe Photoshop (Adobe Systems Ltd, Europe, Uxbridge, UK). Each surface area of the prostheses was marked with the drawing facility to outline the boundaries of each quadrant. To calculate the area covered with the cement remnants, the “pen tool” and “make path” options were used. The total surface area was marked and the number of pixels was recorded from the histogram option, the same was applied to the area covered with cement remnants (Picture 25).



Picture 25. Pixels of the total crown area

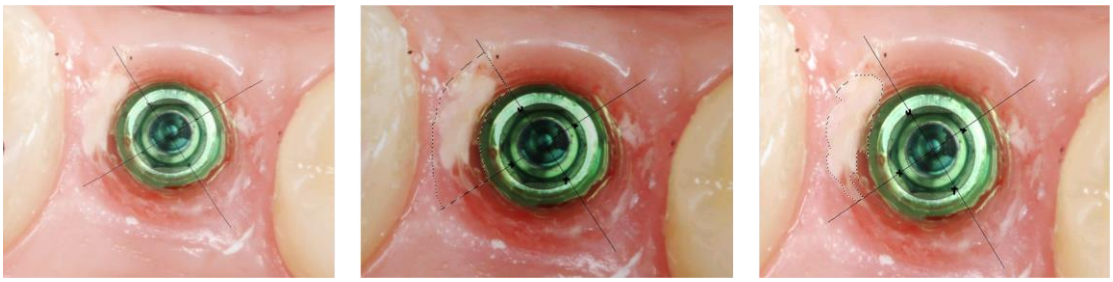
The ratio between the area covered with the cement and the total surface area of the crown was calculated (Picture 26).



Picture 26. Pixels of the area covered with cement

Next, the perpendicularly taken photograph of occlusal view of the implant and the surrounding tissues was evaluated. Four points, which separate

implant hex into four equal parts were marked. Two oblique lines crossing the midpoint of the implant were drawn to divide peri-implant sulcus into four equal quadrants: mesial, distal, buccal, and lingual. The surface area of every quadrant (implant part not included) and the cement area were marked to calculate the proportion (Picture 27).



Picture 27. Total area (in pixels) of the quadrant and area (in pixels) covered with cement remnants to count the proportion

After the evaluation, the restorations were sent to the laboratory for the cement removal and meticulous polishing. The remnants from peri-implant tissues were removed, the implant and the surrounding tissues were rinsed with 0.12% chlorhexidine solution (Perio-Aid 0.12%; Dentaid). After the polishing, the same restorations were disinfected and tightened to the implants, the screw access was isolated with polytetrafluoroethylene tape, as proposed by (Moraguez & Belser 2010), and permanently closed with light-cured composite (Gradia Anterior; GC).

3.2.9. Statistical analysis

A statistical analysis was carried out using SPSS software for Windows v.17 (SPSS Inc., Chicago, USA). The statistical unit was selected to be a quadrant of the implant due to the fact that the same implant had different undercuts and cementation depths in different locations.

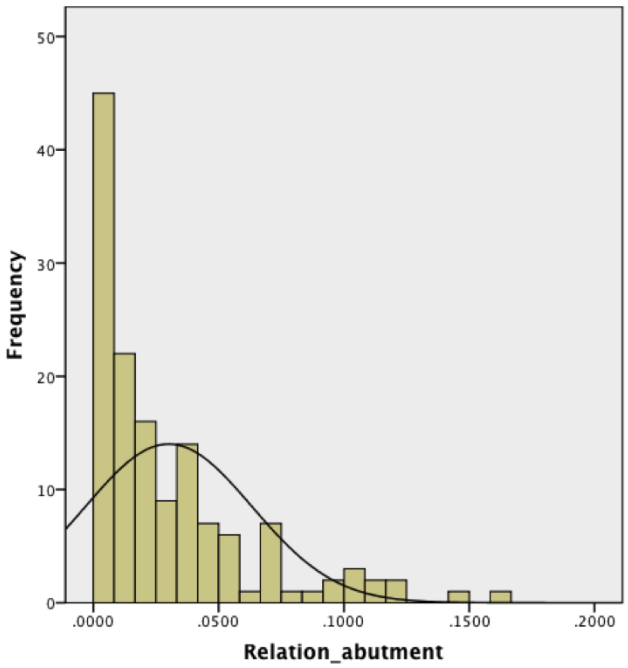


Figure 1. Histograms of the cement pixels proportion on the abutment

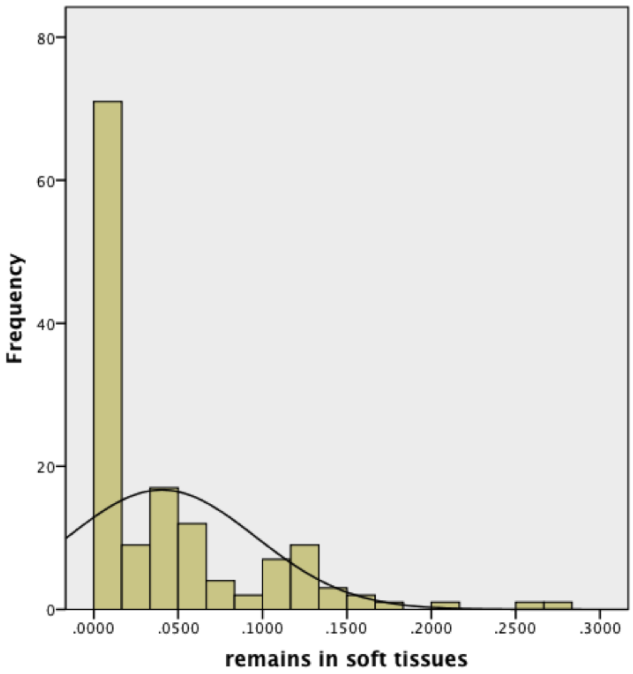


Figure 2. Histograms of the cement pixels proportion in the soft tissues

First, the descriptive statistics was performed, to find out the frequencies of the data, mean and standard errors for every group analyzed. Secondly, a histogram graph was applied to determine if the data is distributed normally (Figures 1 and 2). The results showed that the data was non parametric. Therefore, the independent K (Kruskall-Wallis) test for the nonparametric data was used to find out the correlation between the cementation depth, undercut and the amount of the undetected cement left on the crown and in the soft tissues intraorally. Thirdly, it was necessary to find out if more cement is left when a margin is located deeper subgingivally and when the undercut is getting greater and then if the correlation was positive (Kruskall-Wallis test showed significance), Mann-Whitney test was applied to compare the data between the groups. Mean differences were considered statistically significant at $P \leq 0.05$ with a confidence interval of 95%.

The implant diameter, undercut and depth of the cementation margin were considered to be ordinal variables, as the location variable was considered to be nominal variable. Therefore, only the Mann-Whitney test was performed to compare each location to the others when the location and residual cement relation analysis was performed.

4. RESULTS

4.1. In vitro study

Various amounts of cement remnants were found on all specimens. The results in all groups consisted of (1) the weight of cement remnants in grams and (2) the proportion between the surface covered with the cement excess and the total surface of the specimen quadrant (Table 2).

Group	Cement weight ± SE (gr)	Proportion ± SE
1 (supragingival)	0.0003 ± 0.0001	0.0111 ± 0.0212
2 (at the soft tissue level)	0.0008 ± 0.0003	0.0165 ± 0.0192
3 (1 mm below)	0.0013 ± 0.0005	0.0572 ± 0.0288
4 (2 mm below)	0.0051 ± 0.0013	0.1158 ± 0.0547
5 (3 mm below)	0.0063 ± 0.0021	0.1171 ± 0.0594

Table 2. Cement remnants dependence on the location of the margin

The Kruskall-Wallis test showed significant increase of undetected cement quantity, as the restoration margins were located deeper subgingivally, using weighing (P=0.00) and calculation of proportion (P=0.00) (Table 3).

	Depth	N	Mean rank
Proportion	-3 mm	20	74.30
	-2 mm	20	76.60
	-1 mm	20	53.98
	0	20	27.53
	1 mm	20	21.10
	Total	100	
Weight	-3 mm	5	21.40
	-2 mm	5	19.60
	-1 mm	5	12.60
	0	5	8.40
	1 mm	5	3.00
	Total	25	
Statistics		**Proportion**	**Weight**
X^2		64.476	21.825
Df		4	4
Significance (P)		0.00	0.00

Table 3. The increase of cement remnants in weight (P=0.00) and proportion (P=0.00) as the restoration margins were located deeper subgingivally

The Mann-Whitney test revealed statistically significant differences between all the groups (P≤0.05) except groups 4 and 5 (P>0.05), when the cement excess weight was evaluated (Figure 3, Table 4).

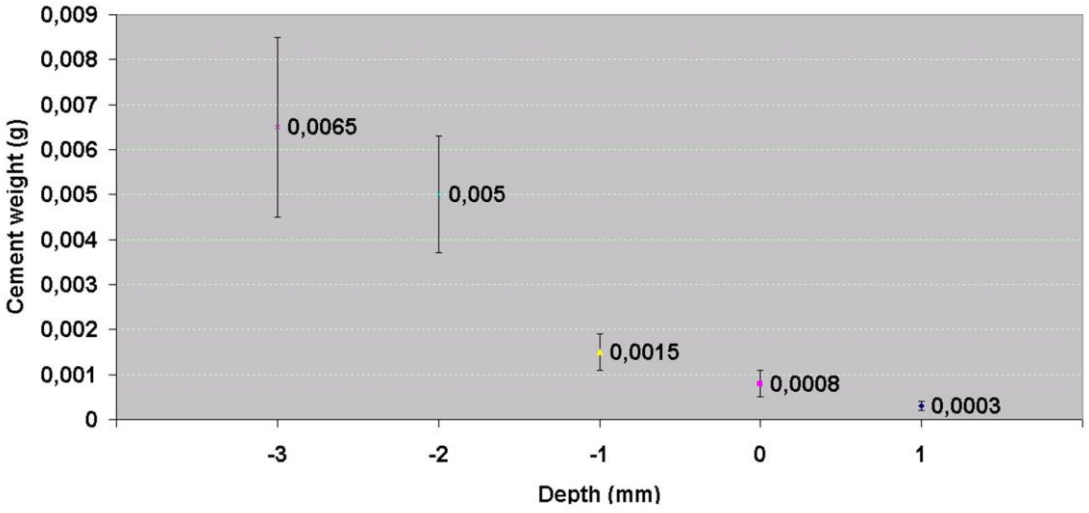


Figure 3. The dependence of undetected cement remnants (weight in grams) on the location of the margin

Group	Cement weight	Proportion
1 and 2	P=0.008	P=0.054
2 and 3	P=0.025	P=0.000
3 and 4	P=0.009	P=0.000
4 and 5	P=0.344	P=0.910
Underlined values show statistical significance		

Table 4. Difference between the groups

The assessment of the proportion showed statistically significant differences between all the groups (P≤0.05), except groups 1 and 2, and groups 4 and 5 (P>0.05) (Figure 4, Table 4).

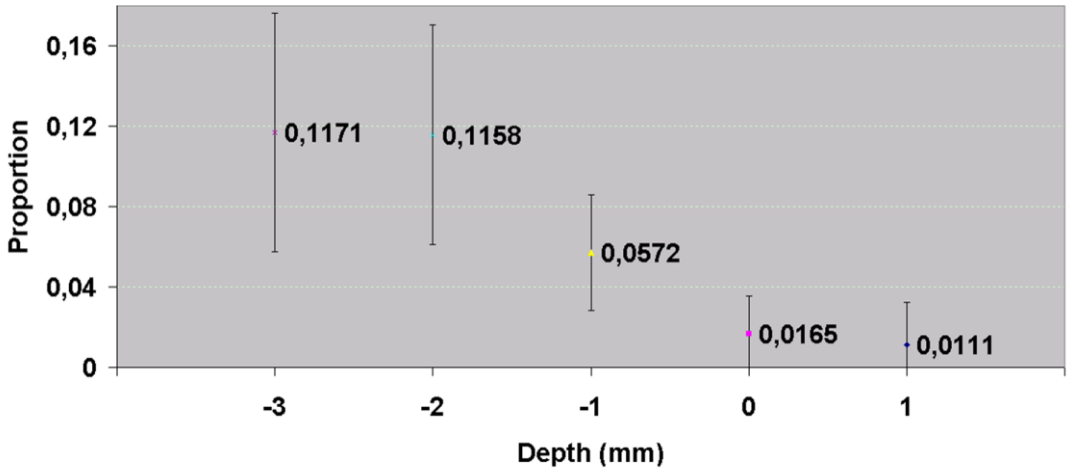


Figure 4. The dependence of undetected cement remnants (proportion of pixels) on the location of the margin

The greatest amount of the undetected cement was found, when the margin was positioned 2 and 3 mm below the gingival level, the smallest – when the margin was visible – 1 mm above the soft-tissue level.

A simple scatter graphic revealed a positive distribution of the measurements (Figure 5) and Spearman's correlation coefficient showed a significant relation between both measuring techniques (r=0.889; P=0.00).

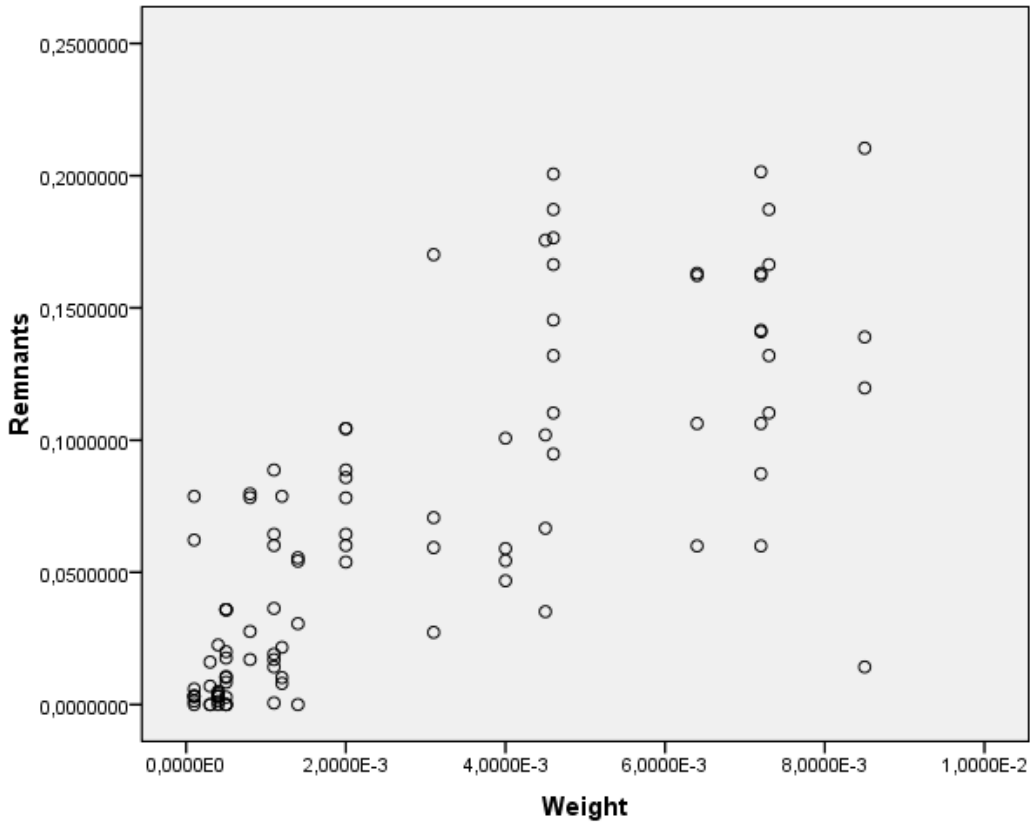


Figure 5. Scatter plot of the measurements

4.2. Clinical study

The data has increased from 65 (number of implants installed) to 260 (four measurements for each implant). The data were divided into four groups according to the depth of the margin position:

1. Group 1 - at the soft tissue margin (16 sites).
2. Group 2 - 1 mm subgingivally (58 sites).
3. Group 3 - 2 mm below marginal level (90 sites).
4. Group 4 - 3 mm subgingivally (96 sites).

Data frequencies in the study could be seen in Table 5.

Depth of the margin	Undercut	Location	Diameter
0 mm – 16 sites	1 mm – 118 sites	4 anteriors (6.2%)	21 of 3.5 mm (32.3%)
-1 mm – 58 sites	2 mm – 96 sites	22 premolars (33.8%)	34 of 4.0 mm (52.3%)
-2 mm – 90 sites	≥3 mm – 46 sites	39 molars (60%)	10 of 5.0 mm (15.4%)
-3 mm – 96 sites	-	-	-
260 sites	260 sites	65 implants	65 implants

Table 5. Data frequencies

4.2.1. Cementation margin depth

The proportion of the cement/restoration and the cement/peri-implant tissues in pixels can be seen in Table 6.

Group	Cement/crown pixels proportion ± SE	Cement/soft tissues pixels proportion ± SE
Depth 0 mm	0.002 ± 0.001	0.014 ± 0.006
Depth -1 mm	0.024 ± 0.005	0.052 ± 0.011
Depth -2 mm	0.036 ± 0.004	0.057 ± 0.009
Depth -3 mm	0.055 ± 0.007	0.071 ± 0.012

Table 6. Proportion in pixels

There was statistically significant increase of excess cement quantity on the abutment/restoration complex, as the restoration margins were located deeper subgingivally ($P = 0.000$). There was a significant dependence of the cement remnants amount in peri-implant sulcus and the location of the margin ($P = 0.0045$) (Table 7).

Cement/crown	N	Median
Group 1	16	0.002
Group 2	58	0.009
Group 3	90	0.027
Group 4	96	0.043
Total	260	
P=0.000		
Cement/soft tissues		
Group 1	16	0.000
Group 2	58	0.023
Group 3	90	0.035
Group 4	96	0.035
Total	260	
P=0.045		

Table 7. The increase of undetected cement excess (increase of the proportion of the pixels) when margins were located deeper (P=0.00) and statistical dependence of the excess (proportion of the pixels) left in the soft tissues and location of the margin (P=0.045)

There were statistically significant differences among all the groups ($P \leq 0.05$), when the cement excess was evaluated on abutment/restoration complex (Table 8) and between group 1 and 2 ($P \leq 0.05$), when the cement was evaluated in peri-implant tissues (Table 8).

Group	Excess of the cement (pixels proportion)	
	On the crown	In the soft tissues
1 and 2	P = 0.000	P = 0.005
2 and 3	P = 0.014	P = 0.439
3 and 4	P = 0.003	P = 0.491

Table 8. Difference between the groups concerning pixels relation between cement excess on the crown and in the soft tissues

4.2.2 Implant location

Group	Cement/crown pixels proportion ± SE	Cement/soft tissues pixels proportion ± SE
Anteriors	0.030 ± 0.008	0.034 ± 0.012
Premolars	0.038 ± 0.004	0.073 ± 0.011
Molars	0.040 ± 0.004	0.070 ± 0.009

Table 9. Results in pixels depending on the implant location

There was no a statistically significant difference between the residual cement found on the abutment and in the soft tissues depending on the location of the implant (all p values were greater than 0.05). Table 10.

Group	Excess of the cement (pixels proportion)	
	On the crown	In the soft tissues
Anteriors and premolars	P = 0.497	P = 0.061
Premolars and molars	P = 0.798	P = 0.754
Anteriors and molars	P = 0.425	P = 0.065

Table 10. Difference between the groups concerning pixels relation between cement excess on the crown and in the soft tissues

4.2.3. Implant diameter

Group	Cement/crown pixels proportion ± SE	Cement/soft tissues pixels Proportion ± SE
Diameter 3.5 mm	0.033 ± 0.004	0.074 ± 0.013
Diameter 4.0 mm	0.077 ± 0.004	0.077 ± 0.009
Diameter 5.0 mm	0.039 ± 0.008	0.021 ± 0.007

Table 11. Results in pixels depending on the implant diameter

Decrease of the remaining cement in the soft tissues when implant diameter got wider (p=0.026) was found to be statistically significant.

However, there was no a significant correlation between the cement left on the abutment and the increase of the implant diameter (p=0.600). Each group comparison could be seen in Table 12.

Group	**Excess of the cement (pixels proportion)**	
	On the crown	In the soft tissues
3.5 mm and 4.0 mm	P = 0.011	P = 0.754
4.0 mm and 5.0 mm	P = 0.012	P = 0.009
3.5 mm and 5.0 mm	P = 0.050	P = 0.012

Table 12. Comparison of each group of implant diameter based on cement amount left

4.2.4. Undercut

Group	**Cement/crown pixels proportion ± SE**	**Cement/soft tissues pixels proportion ± SE**
Undercut 1 mm	0.035 ± 0.004	0.054 ± 0.009
Undercut 2 mm	0.040 ± 0.004	0.081 ± 0.010
Undercut 3 mm	0.048 ± 0.012	0.084 ± 0.022

Table 13. Results in pixels depending on the implant undercut

There was a strong relationship between the undercut and the residual cement not only in the soft tissues (p=0.004), but also on the crown/abutment complex (p=0.046).

Group	**Excess of the cement (pixels proportion)**	
	On the crown	In the soft tissues
1 mm and 2 mm	P = 0.005	P = 0.002
2 mm and 3 mm	P = 0.049	P = 0.039
1 mm and 3 mm	P = 0.003	P = 0.002

Table 14. Comparison of each group of implant undercut based on undetected cement left

4.2.5. Total removal of the cement

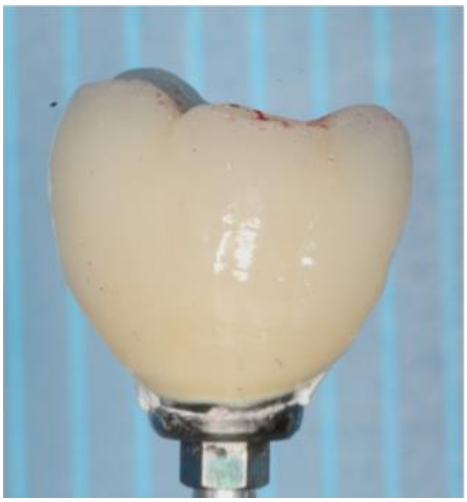
Various amounts of the cement remnants were located on almost all retrieved suprastructures and in the peri-implant tissues of the restored implants. The results of the absence of the cement on the abutment and in the soft tissues could be seen in Table 15. It should be noticed that even though the cement was absent in many cases, the percentage decreased dramatically when the absence of the cement remnants was analysed in the soft tissues and the crown together. The analysis shows that the cement might adhere either on the abutment/crown complex, or stay in the soft tissues.

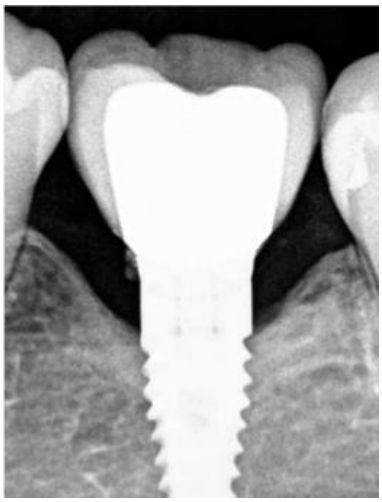
Groups	Absence of the cement on the abutment	Absence of the cement in the soft tissues	Both
Depth 0 mm (N=16)	5 (31.2%)	15 (93.8%)	4 (25%)
Depth -1 mm (N=58)	3 (5.2%)	22 (37.9%)	3 (5.2%)
Depth -2 mm (N=90)	6 (6.7%)	28 (31%)	3 (3.3%)
Depth -3 (N=96)	1 (1.0%)	35 (36%)	0 (0%)
Undercut 1 mm (N=118)	13 (11.0%)	65 (55.1%)	9 (7.6%)
Undercut 2mm (N=96)	6 (6.3%)	34 (35.4%)	2 (2.1%)
Undercut 3 mm (N=46)	1 (2.2%)	12 (26.1%)	1 (2.2%)
Anteriors (N=16)	0 (0.0%)	9 (56.3%)	0 (0.0%)
Premolars (N=88)	8 (9.1%)	34 (38.6%)	4 (4.5%)
Molars (N=156)	12 (7.7%)	68 (43.6%)	8 (5.1%)
Diameter 3,5 mm (N=84)	7 (8.3%)	33 (39.3%)	3 (3.6%)
Diameter 4,0 mm (N=136)	11 (8.1%)	59 (43.4%)	8 (5.8%)
Diameter 5,0 mm (N=40)	2 (5.0%)	19 (47.5%)	1 (2.5%)

Table 15. Total absence of the cement depending on the factors analysed in the study

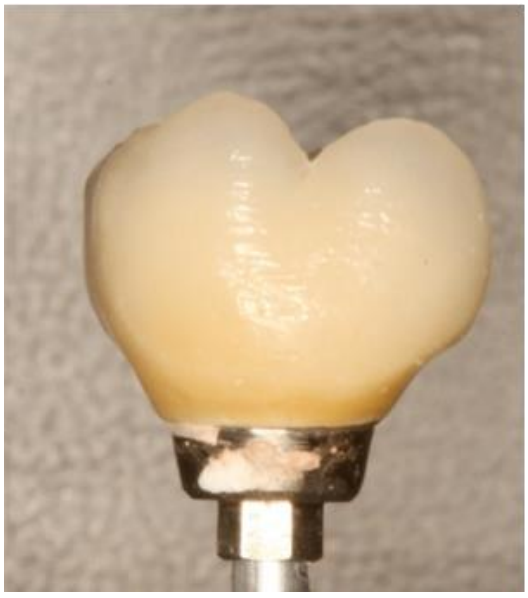
4.2.6. Radiographic evaluation

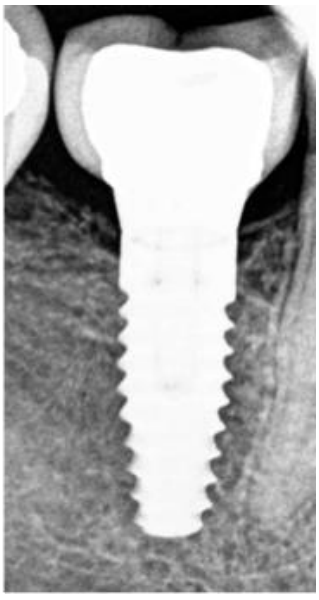
During the first radiographic evaluation the cement remnants mesially were visible in five cases of 65 or 7.7%, and in seven cases of 65 distally or 10.7%. The pictures below show some cases from the study (Pictures 28-33). They illustrate the difference between the radiographic images of the same analyzed crown intraorally and when it was retrieved.



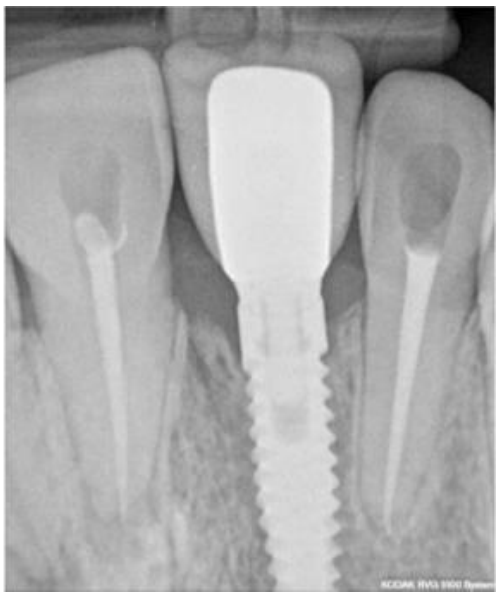


Pictures 28 and 29. Only mesially left cement was visible in the radiographic examination





Pictures 30 and 31. If cement is present buccally it is impossible to see it in the X-ray



Pictures 32 and 33. If cement is present buccally it is impossible to see it in the X-ray

5. DISCUSSION

There are still very few clinical studies dealing with this problem, which indicates that it may possibly be underestimated. This is one of the first clinical studies performed when analysing different factors influencing cement removal after a cementation, not only from the quality point of view, but also from quantity. It has been worldwide discussed that the undetected cement left after delivering the final crown might be associated with some clinical problems, but there are still no specific guidelines for clinicians to follow to avoid these problems. It has been only proven that such factors as the implant crown margin for cementation directly correlates with the amount of the cement left undetected after all cementation protocol. Unfortunately, cementation depth is not the only factor that might be important in this field.

First of all, what we have found out is that despite the efforts of the researchers in our study, the entire removal of the cement remnants in the "in vitro" study failed to be successful. It was impossible to clean excess cement around the implant restorations with subgingival margins, especially those positioned 2 mm or deeper. On the contrary, the restorations with visible margins - 1 mm supragingivally or at the tissue level had almost all cement removed. So it has been proven, that cementation margin position according to the soft tissues is a very important factor. The results of our study correlate with the findings of Agar et al., who were the first to state that cementation of the prostheses with 1.5 – 3.0 mm subgingivally placed margins may lead to insufficient cement removal, even though they performed only the in vitro study. In addition, the study has revealed that cleaning of cement may result in extensive scratching of the abutment (9), which might increase the mechanical attachment of the plaque on the abutment, which may result in peri-implant-mucositis. In the current study, residual cement was most present around the abutments with margins positioned 3 mm subgingivally; however, no statistical difference was determined with the case of the 2 mm margin abutment. The same results were found not only in the in vitro, but also in the in vivo

research. It can be suggested that 2 mm below the gingival level is a dangerous choice for a restoration margin to be located and the existing recommendations to have (to allow to be) margins at that depth should be abandoned. Almost the same results were observed by Korsch et al., who evaluated the possibility to remove the cement after cementation in the implant supported restorations intraorally from the crowns that were cemented not deeper than 1.5 mm subgingivally. They found out that in 54.8% of the cases there was bleeding on probing (probing was performed from 116 days to 640 days after cementation). Suppuration was diagnosed around 12.7% of all implants in the study. After the removal of the crowns they have found that the residues of the cement used in the study could not be removed without retrieving of the crown including the abutment in almost 60 percent of the cases (113). It could not totally be compared to our study, as Korsch et al. used different systems of implants and they evaluated only presence or absence of the cement on the crown-abutment complexes.

One more clinical study using the resin-based cement for trial proves that cementation at the soft tissue level placed margins does not ensure absolute cement removal (114). The cement was found in all cases (20 cases at the soft tissue level, 20 cases 1.5 below soft tissue level and 20 cases 3 mm below soft tissue level). Of course the greatest amount of the undetected cement was found when margins were placed 3 mm below the soft tissue level, that finding absolutely correlates with the findings of our study.

The result of the current study contradicts the proposed criteria for the crown margin location, suggesting that the cemented implant restoration should have a more coronal position. Andersson with colleagues were probably the first to alert that the deep subgingival margins can lead to insufficient cement removal. The authors have recommended careful placement of margins deeper than 2 mm below the gingival level, as the risk of leaving the cement is not eliminated (8). Back in 2009 Caudry et al. in their study stated that the location of the abutment collar margin is very important to achieve not only a good esthetical result but also to ensure total cement removal (115),

unfortunately they did not offer any clinical recommendations. Another study by Blatz and his co-workers says that they typically place the marginal finish line about 0.5 mm below the gingival margin (99), which now seems to be scientifically proven. Nevertheless, in the aesthetic area they accept the placement from 1 to 1.5 mm subgingivally, which according to the findings of Agar et al. and the current study is precarious.

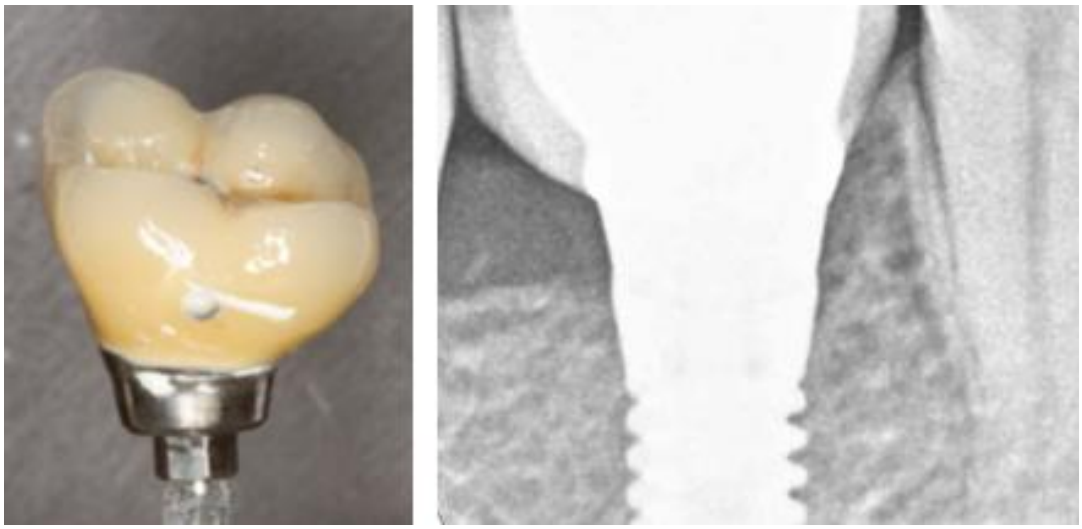
Another study that corresponds to our findings was performed by Wasiluk et al. (116), they analysed cementation protocol and cleaning procedures using individually CAD/CAM made abutments with the cementation margin placed 1 mm subgingivally. They found out that there was no any cement remnants left in the soft tissues as the individual abutment ensured the emergence profile and eliminated the undercuts, but there was some cement left on the abutment/crown complex in 73.3% of the cases. Once again, it has been proved the importance of the cementation margin depth in comparison to all other factors.

It was a difficult choice to select cement remnants amount evaluation technique. Authors wanted to have an easy, quick and reliable method to determine the quantity of the undetected cement in each case. Therefore, when performing the in vitro case two methods were selected. The first one was to remove the cement manually and weigh it with micro scales. The second method was performed following previous study done by Aleksejuniene et al. in 2006. They have evaluated the dental plaque accumulation on the teeth surface (117). What is important and similar between both studies is that it is more important to find out the relation between the whole surface and the surface covered either with cement or plaque, because teeth are different in size, so are our samples or crown/abutment units. The in vitro study found statistically significant correlation linking the weight of the cement excess to the mathematical ratio between the surface area of the cement remnants and the abutment-restoration assembly as both of the methods showed statistically significant increase of the amount of the undetected cement as the location of the cementation margin got deeper. The greatest disadvantage of the weighing

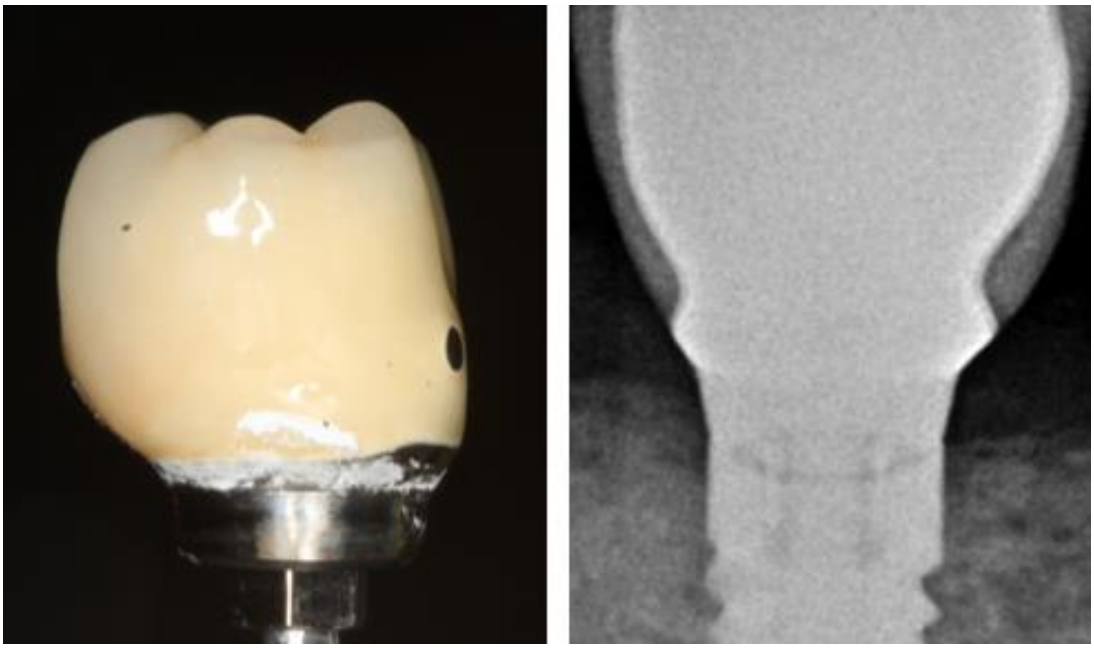
method is that it could not evaluate every quadrant of the specimen separately. In the in vitro study it was acceptable as all the abutments where custom made and they circumferentially had the same depth of the cementation margin. In the intraoral environment it could be a problem due to the fact that authors used standard prefabricated abutments with no alteration of the cementation margin, and the soft tissue amount and the cementation depth might be different circumferentially. Therefore, in the clinical study we have chosen to use only computerized photo analysis with a special program as it was also a reliable, but a quicker method, and most importantly it could evaluate every quadrant of the specimen separately.

An interesting finding was that radiographic examination could not be trusted to detect pieces of cement. It is obvious that it is impossible to inspect palatal/lingual and facial areas due to the obstruction of the implant/abutment complex. Also, the cement was visible medially only in four cases and in six cases distally of 65 radiographic images, what makes 7.7% and 10.7%, respectively. A partial explanation to that may be found in the study by Wadhwani (57), who has proved that radiographic density of the implant restorative cements is rather poor and greatly depends on the thickness of the specimens. For example, the glass-ionomer and the resin cements could be detected only if the fragment was 2 mm or more in thickness, whereas smaller pieces would remain unseen. It means that probably the only way to detect an excess of cement is to use an abutment with a visible margin for cementation. Similar or even worse results were published by Sancho-Puchades et al. (114) who showed that cement remnants were found in almost all areas studied of all specimens when using the resin based cement (Panavia 21, Kuraray, Osaka, Japan). These cement remnants were not detected by the operator on the control peri-apical X-rays. Recently, Wadhwani et al. (58) represented a few reasons, why cement could not be detected radiographically, which could also explain the findings of our study. Firstly, if the cement is predominantly located on the buccal or lingual aspect, such that the superimposition of the cement is on the metal or zirconia implant component, it becomes almost

impossible to detect the cement remnants radiographically (Picture 34). Secondly, the cement might penetrate circumferentially and therefore could not be detected as it spreads evenly in a thin layer (Picture 35). Thirdly, the cement could be radiolucent. A dentist should know very well the cement properties before selecting one for cementation.



Picture 34. Cement is lingually on the metal component



Picture 35. Evenly distributed thin layer of the cement circumferentially

According to the study, it is clear that the location of the implant did not influence the amount of the residual cement. It meets the results of the Korsch et al. study (91) affirming that the implant location does not affect the excess cement to stay undetected. This means that a clinician must clean meticulously the cement excess in any area of the mouth. Additionally, the anterior area is rather more important because any peri-implant tissue inflammation associated with the cement excess may result in severe aesthetical problems. However, the number of anterior and posterior implants was different in this study, therefore, future investigations focusing on this aspect are highly recommended. Korsch et al. faced the problems such as the sample size of the anterior, premolars and molars was as following 16, 39 and 71 cases each. The same results, showing that the implant location did not influence the quality of the cement removal is shown by Wasiluk et al. (116).

A greater implant diameter reduced the amount of the cement in the soft tissue group. However, statistically significant difference has been noticed only between 4.0 mm and 5.0 mm groups. Another interesting fact in the paragraph might be that a greater implant diameter always results in a bigger crown, nevertheless, we have evaluated relation/percentage area of the cement covered crown/abutment and the soft tissues to the total area. This fact could be the reason why our findings are totally different form Korsch et al. (91). Korsch et al. in their clinical study got totally different results, concerning implant diameter. They state that with increasing implant diameter, the excess cement was found with increasing frequency. Another reason for different conclusions could be that we have evaluated the undercuts influence as bigger diameter could decrease the undercut, therefore, it is easier for a clinician to reach and clean the cement, especially in the interproximal areas. As the sample size is not very big, the critical diameter at which disadvantages outweigh benefits has yet to be determined by future research. The same results, showing that implant diameter did not influence the quality of cement removal, are shown by Wasiluk et al. (116).

Surprisingly, no studies analyze the influence of the undercuts on the

cement removal. Nevertheless, it seems that the impact of this factor is obvious. The study data show that the greater the undercut, the more undetected cement will be left after cleaning. Even though the amount of the cement remnants increased when the undercut became greater, statistical significance was detected only between 1 and 2 mm in both areas examined (on the abutment and in the soft tissues). Our study found out that the amount of the undetected cement was greater when the undercut was >2 mm, and that was the case even when the cementation margin was not deep. This proves that the usage of standard abutments to support cement-retained implant restorations must be strictly avoided, because the shoulder of the standard abutment does not follow the line of the gingiva or the emergence profile of the implant. There could be found one clinical study, which compared featheredge and chamfered abutments used for the cementation (118). They have compared not only different abutments for cementation, but also different cementation techniques: intraoral (crown was directly seated on to the abutment without any additional procedures) and extra oral (when a crown was seated with cement inside on to the abutment replica first and then intraorally). The researches evaluated the cement remnants on the abutment/crown complex and the voids left in the soft tissues. They retrieved crowns not directly after a cementation, but 2 months later. Findings on the one hand correlate with our study. They have proved that there is always some cement left if the margins are being placed subgingivally (they placed 1.5 mm below soft tissue level). Also they found out that if the standard (feather-edge) abutment is being used, more cement is present compared to the chamfered abutments (0,45 mm^2 and 0,38 mm^2 compared to 0,065 mm^2 and 0,072 mm^2). This proves that the undercut is an important factor in association with the cement cleaning. On the contrary, they found out that there were more cement left in the soft tissues when the chamfered abutments were used (feather-edge 0.4 mm^2 and 0.41 mm^2 compared to chamfered 0,48 mm^2 and 0,47 mm^2). Those findings might be different from our study because they used eugenol-free zinc oxide cement (Tempo Bond, Kerr, US), as mentioned before this cement is considered to be

temporal, is soluble in the intraoral fluids (as the results were analyzed after 2 months of the crown service) and its capacity to be retentive for a long time is controversial, therefore, it could not be directly compared to the findings of our study. As mentioned before, the implant diameter and the undercut are strongly dependable on each other, therefore, further investigations concerning the correlation between those two factors are strongly advisable. Another interesting study shows a difference in the cement remnants found in different quadrants of the crown (mesial, distal, oral and buccal). They prove that most cement is left undetected in the interproximal areas, this correlates with our finding that undercut is an issue in those areas (114). Wasiluk et al. in their study of the year 2016 proved that if margins are being placed 1 mm subgingivally, when using individual abutment, the greatest amount of the cement remnants is found on the mesial (15%) and the distal (17.9%) aspects, once again showing the importance of the undercut, which is always bigger in the interproximal spaces (116).

One more interesting finding was noticed when analyzing total cement removal. In the in vitro study the results were based only on the amount of the cement left according to one factor – the cementation depth. The first data analysis performed in the clinical study was also done based on the amount of the undetected cement influenced on different factors (depth, location and diameter). What is more important, we analyzed the results separately: the cement found on the abutment and the cement found in the soft tissues. This was done for the reason that only in this way a precise comparison between the groups could be done, in other cases the number of groups would increase a lot and sample size would not be enough in every group to ensure proper statistical analysis. When focusing on the total cleanup of the cement (when it was absent in the soft tissues and on the abutment), it could be concluded that it was absolutely impossible to clean the cement when the cementation margin was 3 mm (0%). When the margin was 2 mm subgingivally the percentage increased to 3.3%, when 1 mm – 5.2% and when it was at the soft tissue level it was – 25%. In the undercut group the results were almost the same: undercut

3 mm – only 1% cases where cement free, undercut 2 mm – 2.1% and 1 mm undercut – 7,6%. In the location group the anteriors, premolars and molars percentage was as following 0%, 4.5% and 5.1%. And finally, in the diameter section (3.5, 4.0 and 5.0 mm) was 3.6%, 5.8% and 2.5%. It actually shows that the better results of the cleanup are reached when analyzing every factor and the location of the cement separately. Therefore, all the results given previously should be taken in mind in the more serious way, as they would increase a lot if analyses were performed combining the data.

Limitations

The results of the clinical study strongly correlate with the findings from the in vitro experiment. The clinical study overpassed the limitations of a laboratory trial, as the cement remnants were cleaned in the intraoral environment and its conclusions have a direct clinical validation. The present study has several limitations. Not equal distribution of the sample sizes between the groups could have influenced the results, however, such allotment reflects clinical reality, as the most frequent location of the margins are 1 mm or 2 mm subgingivally. And most diameters of the implants are narrower due to the situation of the remaining bone after a loss of the teeth.

The amount of the cement loaded into the crown was not weighed, however, all efforts were put to have as equal conditions as possible – the ratio of liquid/powder was always the same and the application of the cement inside the restoration was alike. For further and more detailed conclusions, more types of cement should be analyzed and compared.

On the other hand, the consistency of the peri-implant tissues should also be kept in mind, as the resilience of gingiva in different individuals may vary. Therefore, in spite of aforementioned limitations, the study has significant theoretical and practical implications.

The clinical study reported that cement remnants might be found in the peri-implant sulcus, not only adhered to an abutment or restoration. This is

quite opposite to the results of the laboratory trial, where no cement was found in the imitation of the soft peri-implant tissues on the model. The results have shown that there was statistically significant increase of the cement excess in the peri-implant sulcus as the margin got deeper. It shows that even if cement is detached from the abutment/restoration surface during cleaning, it may reside in the peri-implant sulcus. Large amounts of the uncleaned cement around the implants with deep subgingival margins can be explained by the following factors: too deep margin location, properties of luting agent, false convictions of the researcher, and inability of radiographic examination to reveal the remnants of the cement.

One more interesting finding of the study was the fact that some cement was left around the restorations, although the researcher was convinced to have removed all the cement. A similar observation was made in a previously-mentioned *in vitro* study, where 6 researchers were confident that they had cleaned the cement; however, the specimen examination showed considerable amounts of the undetected luting agent around the abutments and the restorations (9). Even in some recent clinical studies by Korsch et al., where 9 prosthodontists delivered the 126 cement retained implant supported crowns (margins were placed not deeper than 1.5 mm subgingivally) a lot of cement was found to be left undetected. In almost 60% of them some residual cement was present (92). This corresponds to the result of a clinical investigation which showed that over 80% of implant restorations contained residual excess cement, although, as it can be expected, operators thought that they had removed it (119). It is obvious that clinicians are prone to overestimate their ability to completely remove excess cement from the restorations with subgingival margins. One of the factors to explain this phenomenon probably lies in the process of the conventional cementing restorations on teeth. During seating, hydraulic pressure builds up and cement gets in to the direction of the least resistance (108) path – through the margin to the gingival sulcus. However, the perpendicular fiber attachment around teeth provides a sufficient barrier and cement excess does not penetrate further and escapes to the surface

of the gingival sulcus, where it is easy to detect. It is well known that peri-implant tissues do not possess similar protective mechanism (4,5) and are less resistant to pressure (6). Thus, cement excess may be pushed further subgingivally with only a tiny part of it escaping to the external surface.

The properties of dental cement may also have had influence on the results of this clinical and laboratory trial. The most commonly used luting agent for the definitive cementation of implant restorations was reported to be the resin-modified glass ionomer, followed by zinc oxide eugenol-based cement, glass ionomer, resin, zinc phosphate, and polycarboxylate cement (65). There are some studies showing that temporary cement (as described in manufacturers' description) is the best option for cementation if the margins are being placed deep subgingivally as this cement dissolves in the contact with oral liquids. They show that after the retrieval of the crown cemented with eugenol free zinc phosphate cement there was no cement excess left in any case (120). It could be interesting to compare retentiveness of the crown after sometime intraorally as all studies about temporary cement retention are in vitro studies. Therefore, further clinical studies should be beneficial to evaluate if different cements are prone to penetrate in the sulcus equally.

6. CONCLUSIONS

Within the limitations of the study, the following conclusions could be drawn:

1. The deeper the position of the margin, the more undetected cement could be found after cleaning, adhered to the abutment/ restoration complex and in the peri-implant tissues.

2. Both methods of evaluation of the cement remnants are precise and show the same results.

3. Radiographic examination is not a reliable method to detect the cement remnants in most of the cases.

4. Location of the implant was not important in the cement cleaning quality.

5. There was less cement left in the soft tissues, when the implant diameter got bigger, but it did not influence the cement amount on the abutment/crown complex.

6. Greater undercut resulted in more cement left undetected.

7. Absolute cement removal was not possible as many factors influenced that result.

7. PRACTICAL RECOMMENDATIONS

1. If the cement retained restoration is selected, the cementation line should be visible to ensure precise clean-up of the cement remnants, therefore, individual abutments should be chosen.

2. X-ray control should not be taken as a reliable method for the cement excess evaluation if the cementation line is under the soft tissue level.

3. Undercut should be eliminated if possible, so that the line of the cement extrusion and the restoration emergence profile line would coincide.

4. Screw-retained restorations should be used whenever possible.

8. PUBLICATIONS

Clinical Factors Influencing Removal of the Cement Excess in Implant-Supported Restorations. Vindasiute E[1], Puisys A, Maslova N, Linkeviciene L, Peciuliene V, Linkevicius T. Clin Implant Dent Relat Res. 2013 Nov 14. doi: 10.1111/cid.12170. [Epub ahead of print]

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9. PRESENTATIONS

2013 m. Factors influencing removal of the cement excess in implant-supported restorations. A prospective clinical study. Eastern Ukraine Dental Congress. Kharkov, Ukraine.

2012 m. Factors influencing removal of the cement excess in implant-supported restorations. A prospective clinical study. Fourth International Baltic Association for Osseointegration Congress. Kaunas, Lithuania.

2011 m. “Influence of cementation margin position on the amount of undetected cement. A prospective clinical study”. Third International Baltic Association for Osseointegration Congress. Kaunas, Lithuania.

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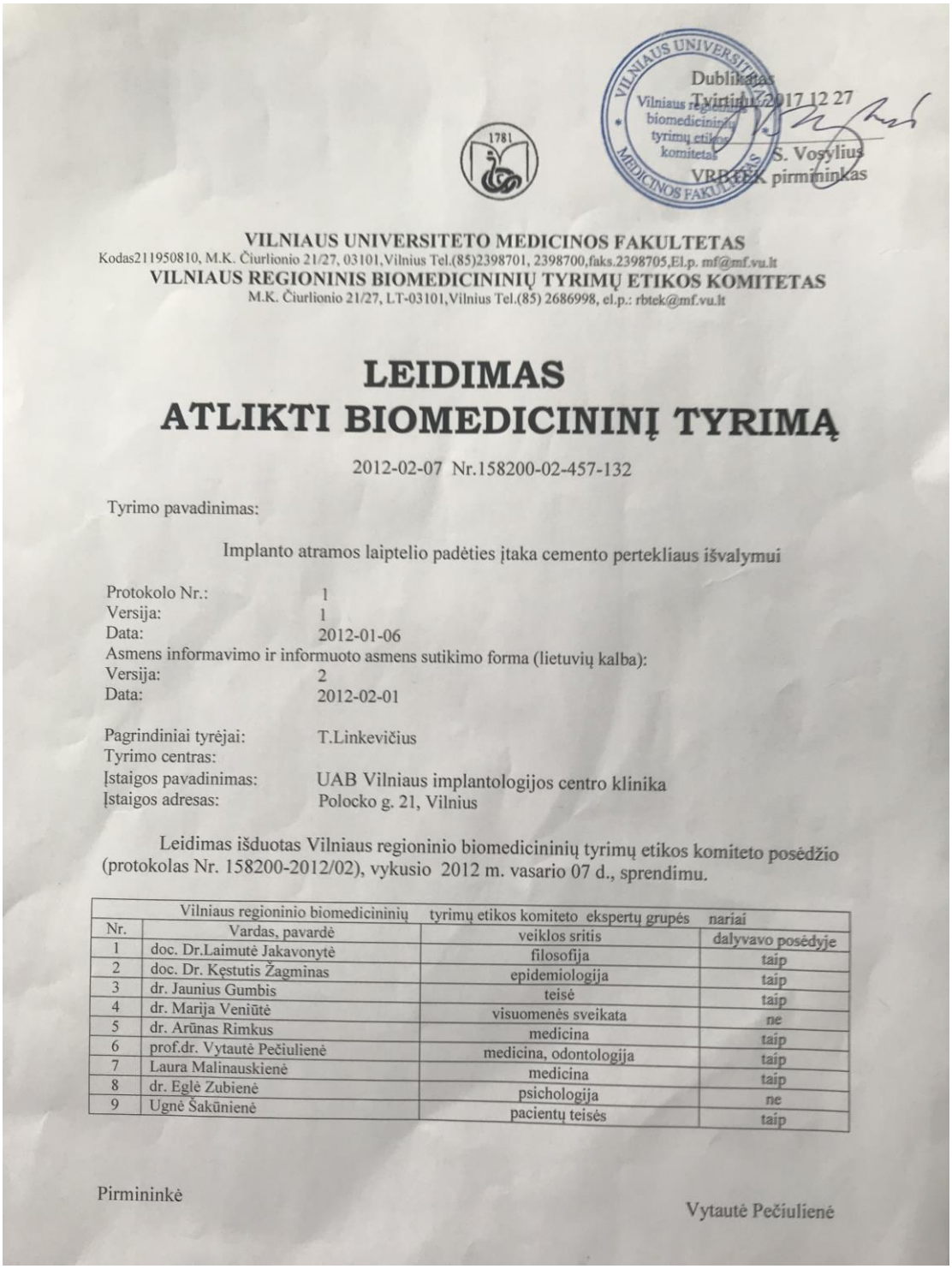
11. APPENDIX

Approval by Vilnius regional bioethical committee No. 158200-02-457-132



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S. Vosylius
VRBTEK pirmininkas

VILNIAUS UNIVERSITETO MEDICINOS FAKULTETAS
Kodas211950810, M.K. Čiurlionio 21/27, 03101,Vilnius Tel.(85)2398701, 2398700,faks.2398705,El.p. mf@mf.vu.lt
VILNIAUS REGIONINIS BIOMEDICININIŲ TYRIMŲ ETIKOS KOMITETAS
M.K. Čiurlionio 21/27, LT-03101,Vilnius Tel.(85) 2686998, el.p.: rbtek@mf.vu.lt

LEIDIMAS
ATLIKTI BIOMEDICININĮ TYRIMĄ

2012-02-07 Nr.158200-02-457-132

Tyrimo pavadinimas:

Implanto atramos laiptelio padėties įtaka cemento pertekliaus išvalymui

Protokolo Nr.: 1
Versija: 1
Data: 2012-01-06
Asmens informavimo ir informuoto asmens sutikimo forma (lietuvių kalba):
Versija: 2
Data: 2012-02-01

Pagrindiniai tyrėjai: T.Linkevičius
Tyrimo centras:
Įstaigos pavadinimas: UAB Vilniaus implantologijos centro klinika
Įstaigos adresas: Polocko g. 21, Vilnius

Leidimas išduotas Vilniaus regioninio biomedicininių tyrimų etikos komiteto posėdžio (protokolas Nr. 158200-2012/02), vykusio 2012 m. vasario 07 d., sprendimu.

Vilniaus regioninio biomedicininių	tyrimų etikos komiteto ekspertų grupės	nariai
Nr.	Vardas, pavardė	veiklos sritis	dalyvavo posėdyje
1	doc. Dr.Laimutė Jakavonytė	filosofija	taip
2	doc. Dr. Kęstutis Žagminas	epidemiologija	taip
3	dr. Jaunius Gumbis	teisė	taip
4	dr. Marija Veniūtė	visuomenės sveikata	ne
5	dr. Arūnas Rimkus	medicina	taip
6	prof.dr. Vytautė Pečiulienė	medicina, odontologija	taip
7	Laura Malinauskienė	medicina	taip
8	dr. Eglė Zubienė	psichologija	ne
9	Ugnė Šakūnienė	pacientų teisės	taip

Pirmininkė Vytautė Pečiulienė

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