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Potential effect of airborne-particle abrasion (APA) on stainless steel and ceramic bracket base volume

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Konrad Kniaziowski

TABLE OF CONTENTS

Abstract.....3

1. Introduction.....4

1.1 Background.....4

1.2 Bracket adhesion and mesh type.....4

1.3 Retention loss.....5

1.4 Methods of brackets recycling6

1.5 The Airborne-particle abrasion/Sandblasting.....7

1.6 Study purpose.....8

1.7 Research questions.....8

2. Materials and methods.....9

2.1 Bonding and debonding9

2.2 Brackets.....10

2.3 Static sandblasting.....11

2.4 Study workflow.....14

2.5 Micro-CT.....15

2.6 Images.....15

2.7. Ethical consideration15

3. Results.....16

4. Discussion.....22

5. Conclusion.....24

References.....25

Appendix 1.....28

Appendix 2.....30

Appendix 3.....31

Abstract

Background: Bracket failure due to loss of adhesion is common and influences treatment time and patient comfort in orthodontic practice. This pilot study is focused on a widely used adjunctive method for bracket recycling -Airborne-Particle Abrasion (APA) and its impact on the retentive mesh pad volume and surface area in two types of brackets.

Objectivities: To explore potential loss of retention volume on stainless steel and ceramic bracket bases after aluminium oxide Airborne-Particle Abrasion (APA) and limitations of the methods used in this pilot study.

Material and methods: Four stainless-steel and four ceramic brackets were bonded on extracted human teeth and debonded according to manufactures instructions. Sandblasting with an Airborne-Particle-Abrasion (APA) method using 5 bar pressure was performed using particles of 25- and 50- μ m diameter aluminium-oxide with a distance between bracket-base and tip of the micro-etcher of 5 and 10 mm during 10 seconds. A Micro-CT scan of all brackets was completed before and after sandblasting to evaluate potential changes in retention volume. Loss of retention volume and adhesive substance was assessed in a qualitative and a quantitative ways.

Results: None of the test combinations managed to completely remove adhesive material. Loss of retention volume was registered in all brackets.

Ten mm distance and 50 μ m abrasive powder appeared in this study setting as the most beneficial combination in reducing the adhesive substance and a 5 mm distance in combination with 50 μ m abrasive powder seemed to have the highest attrition impact. Loss of mesh pad volume due to ASA showed similar results on SS- and CE brackets.

Lack of appropriate standardization in bonding/debonding and sandblasting procedures clearly biased the results.

Conclusion: Micro- CT could be a useful tool to study volume loss of the bracket bases. However, results show that the methods used to prepare brackets for sandblasting and sandblasting protocol should be improved to answer the research questions posed in this study.

Keywords: Airborne-Particle Abrasion, Stainless-steel bracket, ceramic bracket, x-ray, microcomputed tomography (Micro-CT), retention loss, adhesion, bracket mesh.

1. Introduction

1.1 Background

Prevalence of malocclusions have been presented at rates of 40% to 76% among adults (1). In Norway about 30% children has been referred to orthodontic treatment and received full or partial refund of the National Social Security (2). A majority of orthodontic treatment is performed with fixed appliance (3) and one of the main components during fixed appliances treatment is brackets bonded to the teeth with adhesives materials (4). To optimize treatment efficiency and patient comfort it is crucial that the brackets remain attached to the teeth during the entire course of the orthodontic procedure (5).

Bracket material and design has changed over the years and new adhesive materials has been introduced into orthodontics, improving many treatment aspects (6) (7). However, bracket failure remains one of the major concerns among orthodontists. The failure rate is estimated at 1% to 28% (5) (8) and may have a substantial impact on increased treatment time, cost, and enamel properties (9) (10). Additionally, many patients are dissatisfied with a prolonged treatment (11).

1.2 Bracket adhesion and mesh type

Bonding of brackets to the enamel tooth surface is the initial and an important step in orthodontic treatment using fixed appliances. A variety of bracket is available on the market and share some main components i.e. slot and tie wings used for inserting wires and a mesh pad to facilitate the adhesion to the tooth (12). See fig.1

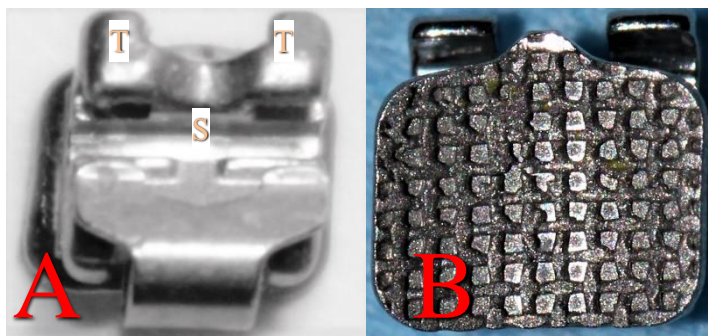


Fig. 1 (a, b). *Main parts of an orthodontic bracket. A: Frontal view of a bracket: (T) tie wings, (S) slot for inserting a wire. B: Mesh pad for adhesion of bracket to the tooth*

The mesh of the bracket provides mechanical retention and there are different designs of mesh pads such as: single-mesh, double-mesh, and integrated metal base. There is however some uncertainty whether the design of the mesh pad affects the retention (shear bond strength) of orthodontic brackets (13).

Below are the two types of brackets used in this study: A) a stainless-steel bracket *GAC's In-Ovation® R* and B) a ceramic bracket *In-Ovation® C*, *Dentsply Sirona Orthodontics, USA*). The Stainless-steel (SS) brackets provides a two-layer mesh, while the ceramic brackets have a single layer of retentive blocks. (Fig.2)

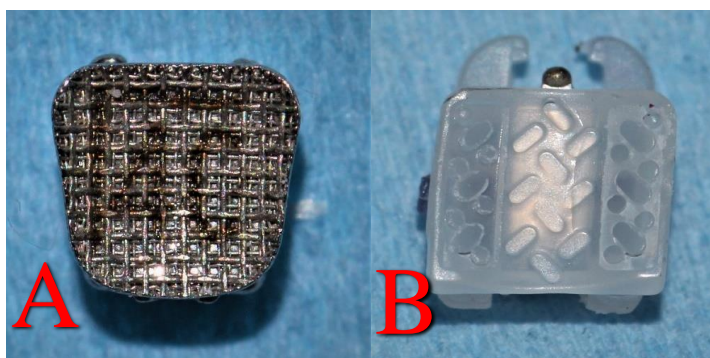


Fig. 2 (a, b). *Mechanical retention illustrated for the two types of brackets used in this study.*

1.3 Retention loss

Optimal adhesion between bracket and tooth means that the retentive material should be strong enough to resist different types of forces during the treatment duration, and debonding should be relatively safe with regards to avoiding tooth substance damage (14). It is desired that adhesive remain on enamel surface after debonding (14). One in vitro study has shown that debonding strength was higher for the metal brackets in comparison to ceramic bracket with mechanical or chemical retention. However, no significant difference was observed regarding enamel damage (15). The most important patient-related factors of bracket failure are operator related insufficient bonding technique and inappropriate force distribution. Bracket failure due to loss of adhesion is more common among molars compared to other tooth-categories (5) (9).

1.4 Methods of brackets recycling

A loose bracket can either be replaced by a new bracket or recycling. There are economic incentives for recycling the bracket as a bracket may reduce treatment cost and time (16). No significant differences in recycled bracket failure in a 12-month clinical study was found. In addition to reducing treatment costs, the ecological aspect was mentioned (17). There are several different methods suggested for removing the adhesive remnants from the brackets base and these have different outcomes (16). In the clinic it can be done by methods such as; flame removal (direct heating) or mechanical methods: airborne-particle abrasion (APA) or tungsten burs (18). Recently, laser has been introduced for bracket recycling, such as: Er:YAG, Nd:YAG, Er,Cr:YSGG and CO₂ in removal of adhesive remnants (19). Development of industrial Er:YAG laser and Er,Cr:YSGG are highly effective in composite removal from the bracket mesh and tooth surfaces completely without destructive side effect. However, this method is under development and bracket must to send to the laboratory where it can be cleaned and again it can increase time and cost of treatment (20).

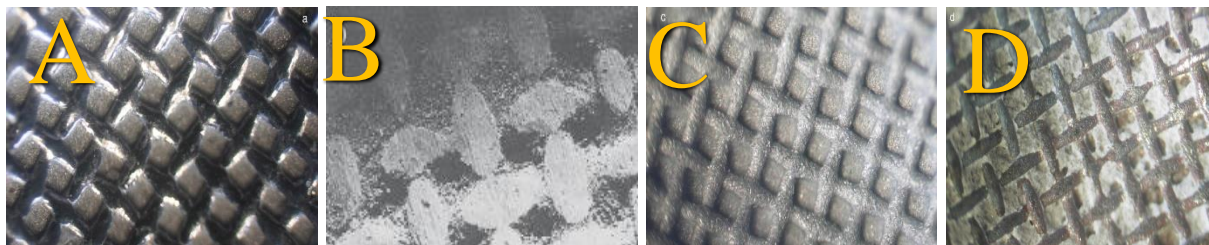


Fig. 2 (a-d). Outcome of recycling after use of different methods. From left (a) base of a new bracket as reference; (b) base after adhesive grinding; (c) base after sandblasting; (d) base after thermal flaming. (21)

1.5 The Airborne-particle abrasion/sandblasting

The Airborne-particle Abrasion (APA), often called *sandblasting* or *micro-etching* is extensively used in dentistry to maintain the mechanical adhesion between the bracket base and the adhesive resin on the tooth (see fig.3) (22). This method is considered as time saving and cheap (23) and uses a high-speed stream of aluminium oxide particles propelled by compressed air from sandblaster to remove unfavourable oxides and contaminants.

Sandblasting increases the surface energy and bonding surface area by increasing the surface roughness (24) but may also sandblasted brackets had higher mean of shear bond strength (25).

Shaza M Hammad *et al.* found that roughening of composite laminate veneer surfaces can provide higher bond strength. In this study the diameter of aluminium oxide particles were 50- μm (26). Montero *et al.*, on the other hand, found that the brackets shear bond strength decreases as the diameter of aluminium oxide sandblasting particle increases. They recommend the use of 25- μm diameter of aluminium oxide with distance of 5 mm between sandblasting tip and bracket (27). However, they stated that “no significant differences were found in the time needed to clean bracket bases clinically using sandblasting with different aluminium oxide particle sizes” and that APA recycling is effective on stainless steel brackets, but it was found that the greater the aluminium oxide particle size and repeated debonding procedures may have impact bond failures at the bracket-adhesive interface (27). The volume loss was only assessed qualitatively in this study. A non-invasive way of assessing volume-loss in both a qualitative and quantitative manner is the use of micro-CT.

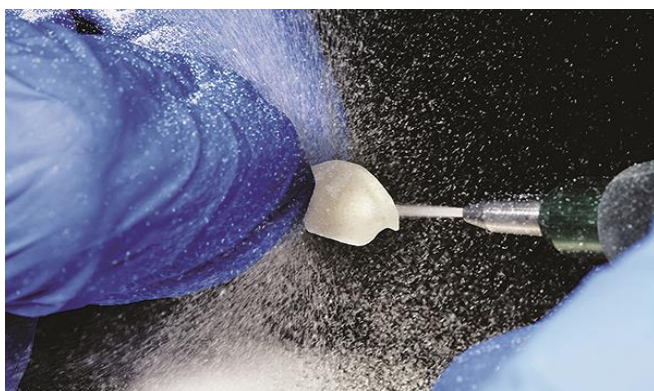


Fig.3. Sandblasting by Aluminium oxide. Image was re-used with permission from *AEGIS Publications*.

Our knowledge about retention volume loss after APA recycling, regarding ceramic brackets is limited. Significant changes in the bracket base morphology may be important for bonding strength and subsequently treatment time and cost (9). That is why, we decided to do this pilot study on potential loss of volume in the mesh pad area of two different types of orthodontic brackets after sandblasting.

1.6 Study purpose

to study potential loss of volume in the mesh pad area of two different types of orthodontic brackets after APA recycling (sandblasting) and potential flaws of the method used in this pilot study.

1.7 Research questions:

- What is the abrasive impact on retention volume using 25- and 50- μ m aluminium oxide?
- What is the abrasive impact on retention volume using 5 mm and 10 mm distance between the tip of the sandblaster and the bracket?
- What is the abrasive impact on retention volume and area on SS and ceramic mesh pads?
- What effect has 25- and 50- μ m static sandblasting on adhesive material removal?

2. Materials and methods

2.1. Bonding and debonding

Teeth

Eight extracted upper third molars with no pathological sign on buccal surface, were selected for their resemblance of upper first premolar anatomy regarding the mesio-buccal area since the brackets used were intended for first upper premolars. Teeth were kept in running tap water for at least 12 hours before the bonding procedure. The bonding procedure was carried out on the mesial vestibular surfaces of the teeth.

Adhesion

Brackets were bonded and debonded by an experienced orthodontist using Transbond Plus Self Etching Primer (*3M Unitek Dental Products*) and Transbond XT Paste (*3M Unitek Dental Products Monrovia, Calif*) in accordance with manufacturer's instructions for each of the products involved. Brackets were polymerized for 10 seconds on each side of the bracket with a polymerization lamp (*Demetron LC, Kerr Corporation, Orange, Calif*).

Debonding

Debonding of brackets were made with a hard wire-cutter plier according to instructions manual for Stainless-steel (28) and Ceramic brackets (29) (30).

2.2 Brackets

The brackets used in this study were new: stainless-steel (SS) brackets (GAC's In-Ovation® R, Dentsply Sirona Orthodontics, USA) and ceramic (CE) brackets (GAC's In-Ovation® C, Dentsply Sirona Orthodontics, USA). All brackets were aimed for upper first premolars (i.e. tooth 14 and 24). The stainless-steel bracket has two-layers mesh net, while the ceramic brackets use single layer of retention blocks (Fig. 4)



Fig.4 Stainless-steel and ceramic brackets *In-Ovation* line, Dentsply Sirona Orthodontics, USA.

2.3 Static sandblasting

A micro-etcher/sandblaster connected to a compressor using fixed 5 bar pressure was used (*Basic Professional Model Sandblaster; Renfert GmbH, Germany*). To ensure best possible performance of the sandblasting device, instructions regarding calibration before usage of 25- and 50- μm aluminium oxide was performed (See Appendix 1). Control and calibration of 5 bar air pressure supply was also implemented (See Appendix 2). Each debonded bracket was placed in a way, so its mesh should be pointed perpendicular to the tip of the micro-etcher at a distance 5 or 10 mm with the help of setsquare and a calliper (see fig. 5). No active movements of the sandblasters tip under entire process. Given distance was controlled before and after sandblasting session.

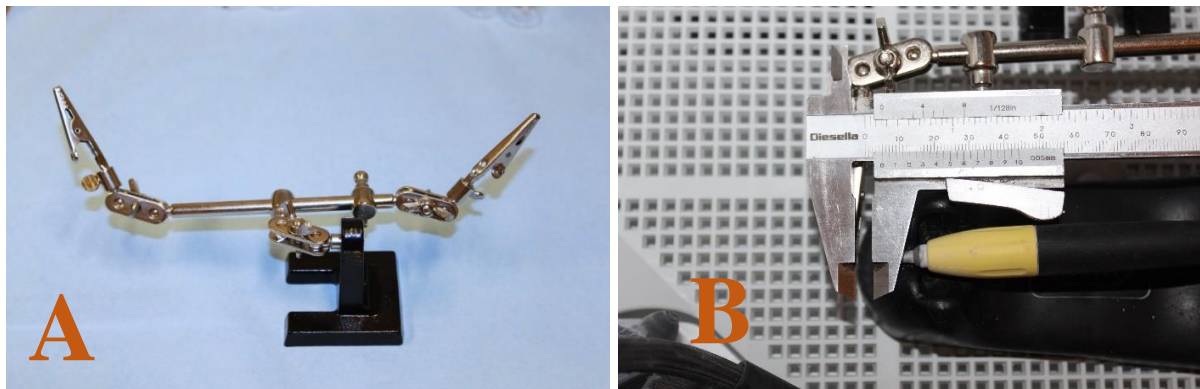


Fig. 5 (a, b). *A: The “third-hand stative” B: a bracket is placed in the stative and tip of sandblaster is adjusted.*

Sandblasting was performed using 5.0 bar pressure for 10 seconds. Abrasive material: 25- and 50- μm diameter aluminium-oxide (*Cobra®*, *Renfert, Germany*) was used for sandblasting. (see Fig.7 Study workflow).

A calibration of the setting was made between the blasting with 25- and 50- μm aluminium oxide. Hence, the whole procedure described above had to be repeated and 10-seconds activation of the machine was done with aim to fill up all tubes by aluminium oxide, control pressure and proper working after calibration. Additionally, 2-3 seconds pre-test of sandblasting machine was provided just before for each of the bracket was sandblasted. The aim of this procedure was to avoid any remaining remnants of aluminium oxide particles inside the tubes, since these were not in active movement (static sandblasting).

TIME CONTROL

One university employee was asked to measure time, 10 seconds for each sample and commanded the sandblasting.

Command “START”: Sandblasting was activated, and the pressure rose from 0 bar to default 5 bars within 0.2 sec.

Command “STOP” Sandblasting was disrupted by moving the point away from the bracket. This was because the air pressure drop from 5.0 to 0 bar took 2 seconds.

All samples were cleaned after sandblasting from rest of aluminium oxide with 5 bar compressed air for 20 seconds. Brackets were managed using vinyl glove to avoid contamination with organic substance and transported in a glass jar for Micro-Ct scanning.

EXCLUDED

One stainless steel bracket sandblasted with 50 μm powder from a 10 mm distance showed an excess of adhesive material after debonding in comparison to the other samples and was excluded and replaced.



***Fig.6 (A, B)** Excluded stainless-steel sample A: Substantially thicker adhesive material compared to the other samples before sandblasting. B: The excluded sample after sandblasting and the test parameters were far from enough to remove adhesive material.*

2.4 Study workflow

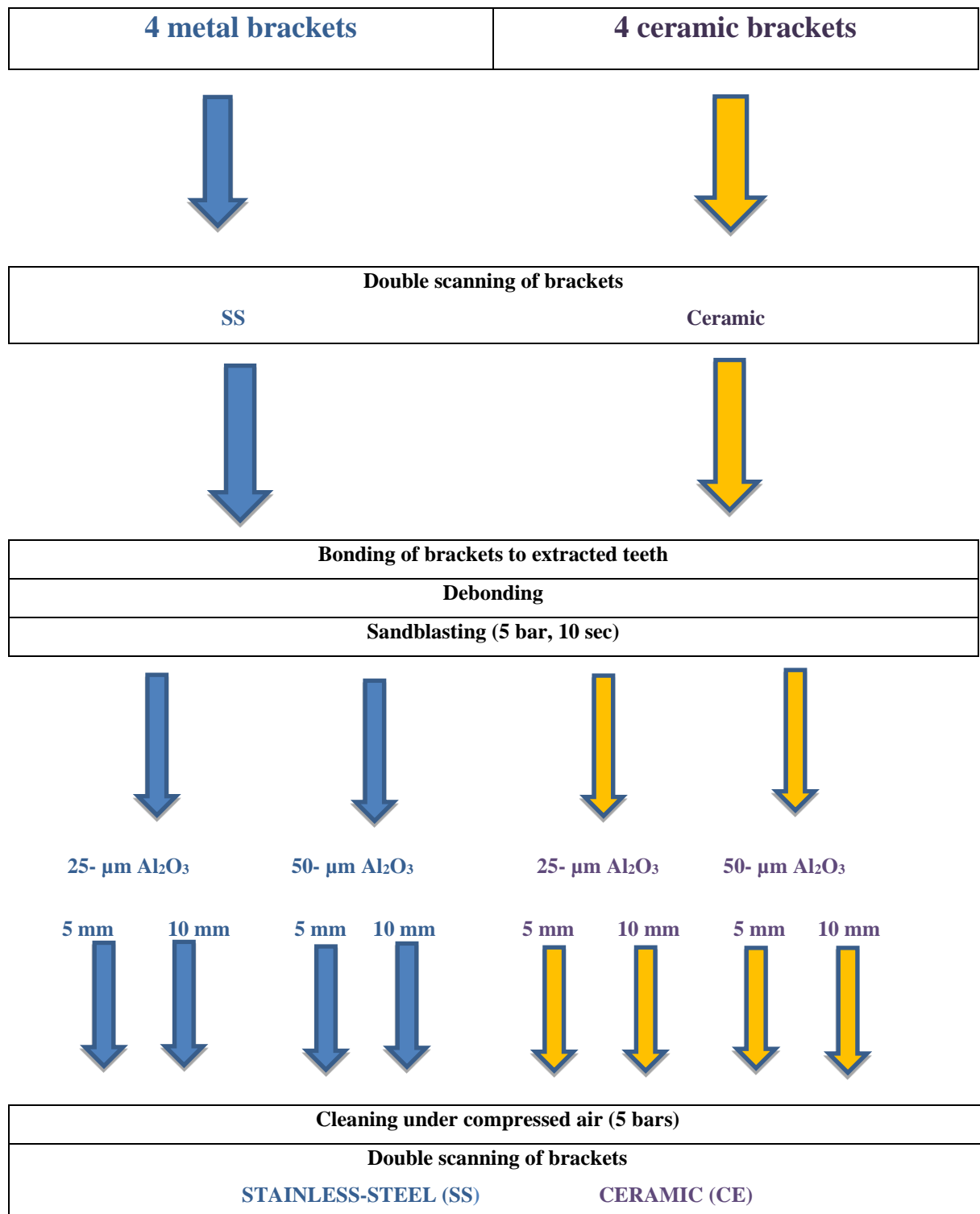


Fig 7. Study workflow

2.5 Micro-CT

A high-resolution desktop Micro-CT (*Skyscan 1272, Bruker, Kontich, Belgium*) was used to scan the brackets (n=8). The scanning was performed with the isotropic pixel size of 7 μm with the following settings: 100 μA , 100 kV voltage and a 0.11 mm Cu filtration. 360° rotation was used, with an angular step of 0.40°. At each step, a shadow projection 16-bit image was taken. The projection was an average of four images. Pixel binning was set to 3-by-3. Flat field correction was done before every scan. The projection images were reconstructed into cross-sectional 8-bit bitmap file format images using NRecon computer software (*Bruker, Kontich, Belgium*). The same reconstruction settings (smoothing, beam hardening, histogram) were used for all brackets.

All analyses were conducted using proprietary software (*CTAn computer software, Bruker, Kontich, Belgium*). The full protocol for the analysis is found in the appendices (Appendix 3) The protocol contains detailed instructions on scanning, processing and analysis for SS and CE.

2.6 Images

We used a volume-rendering software (*CTvox, Bruker, Kontich, Belgium*) to display the set of reconstructed slices in for of realistic 3D object with an option to rotate and navigate the object. The program provides also transfer function control to adjust colours and transparency. Nevertheless, in the case of stainless-steel brackets, differentiation of adhesive material and metal was problematic by use of *CTvox*. For this purpose, we supplemented information by the clinical pictures taken by a camera (*Canon EOS 700D, focal length-90mm*) taken before and after sandblasting.

2.7 Ethical consideration

Since human teeth were used in this study, an application was sent to The Regional Ethical Committee (REK) for medical and health research ethics. REK concluded that this study was not a subject of health research legislation. (2019/1002/REK nord)

3. Results

In this study we observed diverse quantities of adhesive material remnants on all studied brackets before and after sandblasting (Table 2). Sandblasting removed between 39.0% and 87.0% of the adhesive material volume. Mesh pad volume was reduced with 3.8% to 11.5% and the mesh surface area was reduced with 3.8% to 13.5% (Table 1).

Ten mm distance and 50 μm abrasive powder appeared in this study setting as the most beneficial combination in reducing the adhesive substance with a 64.5%-87.0% reduction. A 5 mm distance in combination with 50 μm abrasive powder seemed to have the highest attrition impact on mesh pad volume and area in both SS and ceramic brackets.

Loss of mesh pad volume due to ASA showed similar results on SS- and CE brackets with a reduction of 5.7% -10.7% for SS and 3.8%-11.5% for CE.

Aspects that most certainly have had an impact on the results are given in tables 2 and 3. The main findings were noticeable differences in remaining amounts of adhesive material after debonding, fractures of ceramic mesh pads and that the intended perpendicular direction of the sandblaster tip to the centre of the mesh pad was not obtained for all brackets. (Fig. 8 and Table 2)

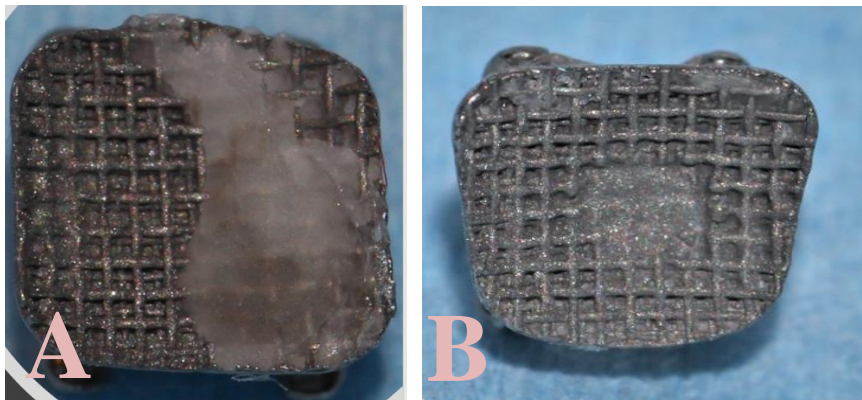


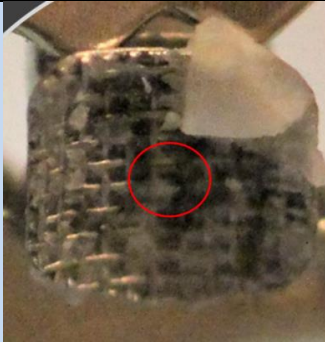
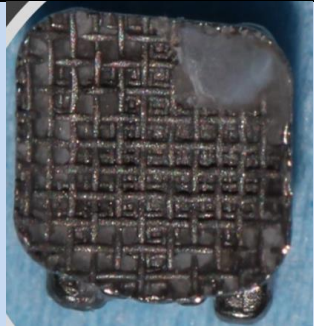
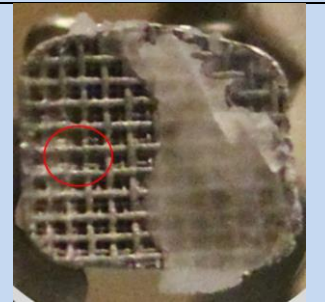
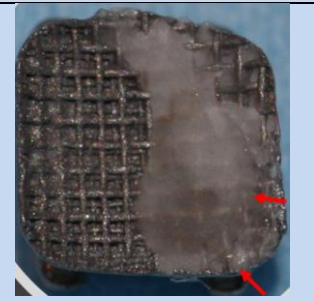
Fig. 8. Two different brackets after debonding. Sample “A” with remaining adhesive on the right side and a slightly reduced mesh pad on the left side probably due to non-centred pointing of the sand blaster tip. Sample “B” exhibits moderate loss of mesh pad in the centre sector, indicating proper pointing of the tip

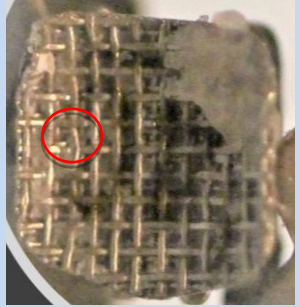
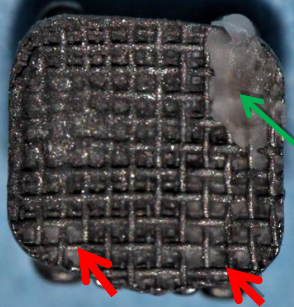


Table 1. Results. *Impact of sandblasting on adhesive removal and a bracket mesh pad. Stainless-steel and ceramic brackets.*


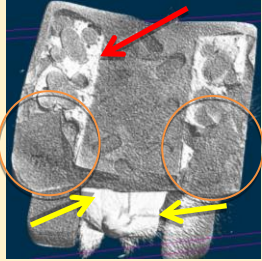




Type of bracket	Stainless-Steel (SS)				Ceramic (CE)			
	25- μm Al ₂ O ₃		50- μm Al ₂ O ₃		25- μm Al ₂ O ₃		50- μm Al ₂ O ₃	
Diameter of abrasive particles	25- μm Al ₂ O ₃		50- μm Al ₂ O ₃		25- μm Al ₂ O ₃		50- μm Al ₂ O ₃	
Distance between tip of sandblaster and mesh pad	5 mm	10mm	5 mm	10mm	5 mm	10mm	5 mm	10mm
Reduction in volume of adhesive *	59 %/0,6 mm ³	64,5%/ 1,1 mm	39% / 0,2 mm	80,4 % / 0,6 mm	62,4% / 0,1 mm	60,6 %/ 0,1 mm	54,6 % / 0,1 mm	87 % / 1,6 mm
Volume of adhesive remaining after sandblasting *	0,4 mm ³	0,6 mm	0,4 mm	0,1 mm	0,1 mm	0,1 mm	0,1 mm	0,2 mm
Reduction in volume of mesh-pad after sandblasting *	6,8 %/0,2 mm	5,7 % /0,2 mm	10,7 % /0,3 mm	8,7 % /0,3 mm	6,2 % /0,2 mm	3,8 % /0,2 mm	11,5% /0,6 mm	3,8 % /0,2 mm
Reduction in surface-area of mesh-pad after sandblasting**	3,7 %/ 2,3 mm	6,4 % / 4,3 mm	13,4 % 9,1 mm	9,3 % 6,3 mm	8,7 % / 4,5 mm	6,7 % / 5,1 mm	9,5 % / 4,9 mm	3,7 %/2mm





* in (%/mm³), **in(%/mm²)

Table 2. Visual estimations of remaining adhesive material and attrition of mesh pad before and after sandblasting of Stainless-Steel (SS) and Ceramic brackets (CE).

Group	Before sandblasting	After sandblasting	Findings
<p>SS 25 μm. 5 mm.</p>			<p>Before sandblasting: Major part of adhesive material is seen on upper right sectors of the mesh.</p> <p>After sandblasting: Adhesive remnants mainly on outer sectors of mesh. Minor loss of mesh pad</p> <p>Sandblasting tip: centred on the brackets mesh (red circle).</p>
<p>SS 25 μm. 10 mm</p>			<p>Before sandblasting: Thick adhesive layer is seen on right side of mesh before sandblasting</p> <p>After sandblasting: Visible loss of mesh on the left side. Markable reduction of adhesive on the right side (red arrows).</p> <p>Sandblasting tip: pointed towards the left side (red circle).</p>

<p>SS 50 μm. 5 mm</p>			<p>Before sandblasting: Major part of adhesive material on right side of the mesh</p> <p>After sandblasting: Reduction of mesh pad adhesive on the left side. Small islands of remain after sandblasting (red arrows), adhesive layer on the right side is reduced as well (green arrow).</p> <p>Sandblasting tip: slightly skewed towards left sectors (red circle).</p>
<p>SS 50 μm. 10 mm</p>			<p>Before sandblasting: Thin layer of adhesive material is covering almost whole mesh surface.</p> <p>After sandblasting: Well effect on adhesive material removal. Markable reduction of mesh pad in central sector (dotted sector).</p> <p>Sandblasting tip: projected on central sector (red circle).</p>

<p>CE 25 μm. 5 mm</p>	 	 	<p>Before sandblasting: Adhesive material is seen on left (thicker layer) and right sides of the bracket, central sector remain unprotected.</p> <p>After sandblasting: Removed adhesive material from right sectors and reduction of mesh pad is seen.</p> <p>Sandblasting tip: slightly skewed to the right (red circle).</p> <hr/> <p>Micro-CT images. The orange circles show lack of the bracket material before and after sandblasting. Note x-ray blurring (yellow arrows) which could be wrongly recognised as adhesive material. Valid measurement of the bracket base was not possible.</p>
<p>CE 25 μm. 10 mm</p>			<p>Before sandblasting: Adhesive material on the left and right sectors.</p> <p>After sandblasting: Reduction of adhesive material on right sector of the mesh pad.</p> <p>Sandblasting tip: slightly skewed towards right side (red circle).</p>

<p>CE 50 μm. 5 mm</p>			<p>Before sandblasting: Adhesive material is on the left and right sides.</p> <p>After sandblasting: amount of adhesive material is removed. Mesh pad affected.</p> <p>Sandblasting tip: directed almost on central (adhesive free) sector (red circle).</p>
<p>CE 50 μm. 10 mm</p>			<p>Tip of sandblaster was slightly skewed downward.</p> <p>Before sandblasting: Thick layer of the adhesive material on whole mesh pad.</p> <p>After sandblasting: Large amount of adhesive material is removed. Mesh pad minimally affected.</p> <p>Sandblasting tip: minimally skewed downward (red circle).</p>

4. Discussion

The purpose of a pilot study is to examine the feasibility of an approach in a small-scale test that is intended to ultimately be used in a larger study (31). We started this study to collect information on potential negative effects of a common orthodontic method (sandblasting of brackets), to provide additional research questions and to test the feasibility to use a new method in doing so. Micro-CT has to our knowledge not been used to evaluate potential loss of retention volume/area on orthodontic brackets. An inherent limitation of this study is the small sample size and that pilot studies do not test a hypothesis (31).

The reduction of adhesive material and loss of retention volume due to sandblasting are presented in a qualitative and a quantitative way (descriptive and numerical). The qualitative assessments (i.e. by images) should be considered only as adjunctive information, mainly due to lack of accurate criteria taking photographs. Problems connected to distinguishing the interface between translucent adhesive material and the ceramic bracket (CE) were also detected. Since Micro-CT analysis has proven useful in a wide variety of applications in dental research. We intended to use this method to provide high-resolution 3D images of the bracket mesh pads and adhesive material in order to accurately separate these two materials. Micro-CT analysis provides a possibility to repeat procedures on the same sample without any effect on adhesive material or bracket and to deliver precise numerical outcomes (32). The Micro-CT provided us with both images and data for calculations of volume and area of adhesive material and mesh pad. However, we limited our Micro –CT analysis to the mesh-pad, i.e. 0.266 mm from the mesh pad into the bracket, because of artefacts from other parts of the bracket. (*see Table 2: CE 25 um 5 mm*). By rotating all the samples to the same position, we could standardize the analyses to the region of interest for both SS and CE, following the analysis protocol (Appendix 3).

The static sandblasting protocol was in our opinion considered to have less procedural bias compared to a ‘‘clinical procedure’’ which is characterized by dynamic movements of the sandblaster tip at different distances from the mesh pad and continues until no adhesive remnants are visual. Our results imply that the static settings we used were not sufficient to clean the mesh pads adequately and, in many cases, finding small remnants of adhesive after debonding. A visual control after the 10-second blasting in the protocol followed by repeated 10-second blasting’s until the desired visual result was obtained could be one way to avoid

bias and maintain a protocol. Limitation with a visual check is primarily on ceramic brackets with less contrast and can lead to too much or too little sandblasting. Magnifying glasses/equipment may be considered as a supplementation tool to enhance visual evaluation.

If a static setting is used, a more precise setting and control of the blaster tip projection is mandatory for accurate results. A more clinical approach could be to use manual dynamic movements of the sandblaster tip and a visual check of the brackets base to ensure that the adhesive material is adequately removed. A major limitations with this procedure are the complexity to assess the proper time for sand blasting and not to overdo it.

Aluminium oxide powder with a diameter of 90 μm has been found efficient to use in removing adhesive material from mesh pads with sandblasting using 10 mm distance between tip of sandblaster and bracket mesh (33). However, the amount of attrition on the mesh pad must be controlled Montero et al (27) recommended use of 25 μm powder and 5 mm distance for recycling of brackets, finding these parameters increasing shear bond strength in recycled bracket.

In our study, sandblasting with 50 μm aluminium oxide from a 10 mm distance seemed to be the most effective combination to reduce adhesive material and 50 μm aluminium oxide from a 5 mm distance appeared to result in an adverse attrition effect on the mesh pad. Altered distances and projecting the abrasive air stream on to a black metal plate could lead to valuable information and necessary calibrations in further studies. The abrasive impact on retention volume was similar on SS and CE brackets. This may indicate that the same sandblasting procedures could be used for both types of brackets in the clinic. The effect of sandblasting on the mesh pads was probably mainly biased by dissimilar volume and especially the different thickness of adhesive material on the SS and CE brackets. A study with comparably thick and extended layers of adhesive material would be beneficial. This could be managed by bonding on to plastic teeth or teeth with enamel surface processed in a way not to present strong retention.

An advantage by using a plastic tooth is that ethical permission is not necessary to start the study. The issue of intra- and/or inter examiner reliability test was not provided in this study. This aspect may also be considered as a part of next study.

Non-destructive microcomputed tomography (Micro-CT) method of analyse has been previously discussed as an advantage that allows to test the same sample many times (32).

We regard the Micro-CT as a suitable method to answer research questions connected to this study. However, a chain is no stronger than its weakest link and as pointed out earlier, more adequate procedures for controlling thickness of adhesive layer, accurate pointing or the sandblaster tip and suitable time sequences must be improved.

5. Conclusion

Use of Micro-CT is a suitable method to study volume loss of bracket bases. However, the variability in the obtained results suggest that the methods used to prepare brackets for sandblasting, and the sandblasting protocol itself, should be improved to be able to answer the research questions.

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Appendix 1. Calibration of Sandblasting Machine

Calibration of sandblasting machine is recommended for correct function, indications and proper outcome. At the beginning containers have been emptied from the aluminium oxide particles (Fig. 9) Afterwards, all rest of different types materials like dust, aluminium oxide, metal shavings etc. was removed by laboratory hoover from the inner compartment of the machine, as well under protective pad, walls and supporting tubes to avoid any interference during sandblasting (Fig. 10).



Fig. 9 Empty container for abrasive material (aluminium oxide) of sandblasting machine.

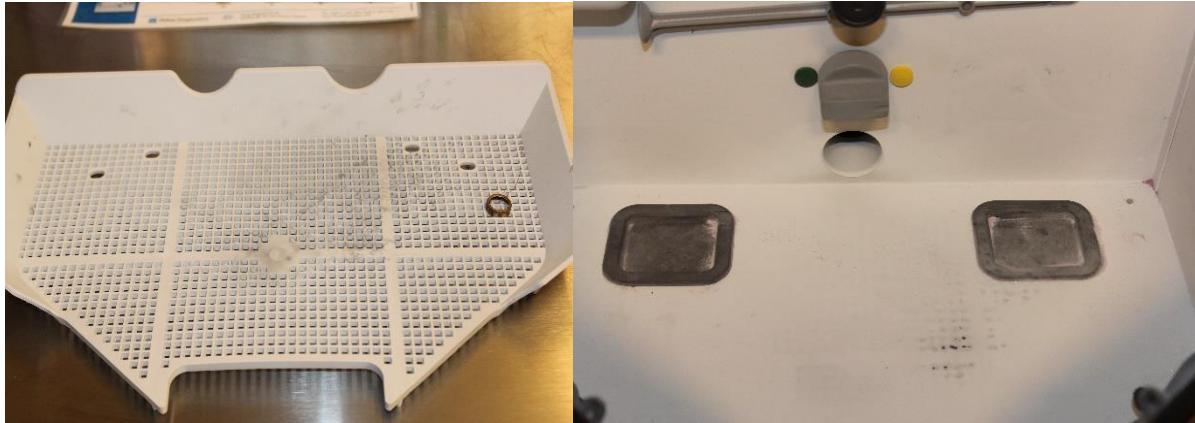


Fig. 10 The pad is taken out. All surfaces are hoovered and dust-free

The machine was started to sandblast but without aluminium oxide particles inside, with the aim to blow out the rest of the material the tubes inside. This air-emptying procedure took 1 minute. Sandblasting machine is hoovered once again, to keep the machine as less particle-free inside as possible. Absence of the abrasive material was controlled by a smooth and shining piece of plastic. Lack of mat effect on the plastic piece indicated no abrasion on it, hence aluminium oxide particles were inside. After this, the container could be filled up with the proper size of aluminium oxide, in this chronology first four brackets have been sandblaster by 25 μm aluminium oxide.

For the next group of four brackets (50 microns) a new calibration was necessary because they were sandblasted by different aluminium oxide diameter, hence whole procedure described above had to be repeated and 10-seconds activation of the machine was done with the aim to fill up all tubes by aluminium oxide, control pressure and proper working after calibration.

Additionally, 2-3 seconds start-test was provided just before for each of the bracket. The aim of this start-test procedure was to avoid any stuck of aluminium oxide inside the tubes since the hose was not in active movement (static sandblasting). See Fig. 5, p.10

Appendix 2. Pressure control

Micro-etcher/sandblaster connected to the compressor using fixed 5 bar pressure was used (*Basic Professional Model Sandblaster; Renfert GmbH, Germany*). For this study additional manometer has been installed to avoid eventual incorrect indication from one of them (see fig. 10). Installation of the additional manometer was done by a technician.

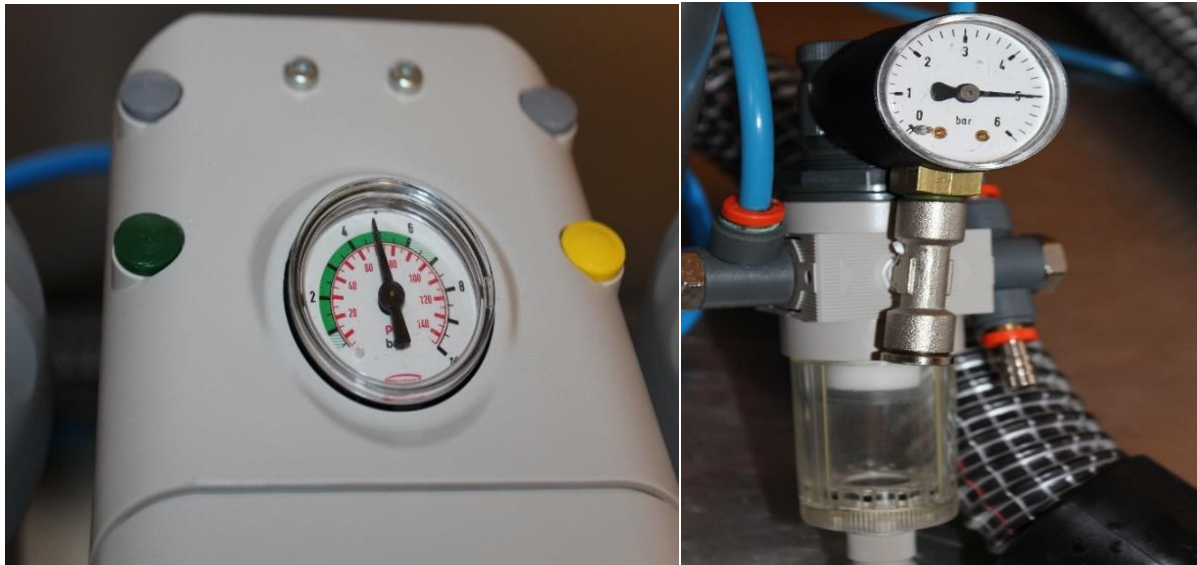


Fig.10 (a, b) Two manometers. On the left originally build-in, on the right additionally installed for study purpose. Like in this case both indicate 5 bars pressure before sandblasting and the same should be after 5 or 10 seconds respectively. During this study no disturbance in pressure supply was noticed.

Appendix 3. The analysis protocol. *Prepared by Bo Wold Nilsen*

Objectives of the analysis, briefly summarized:

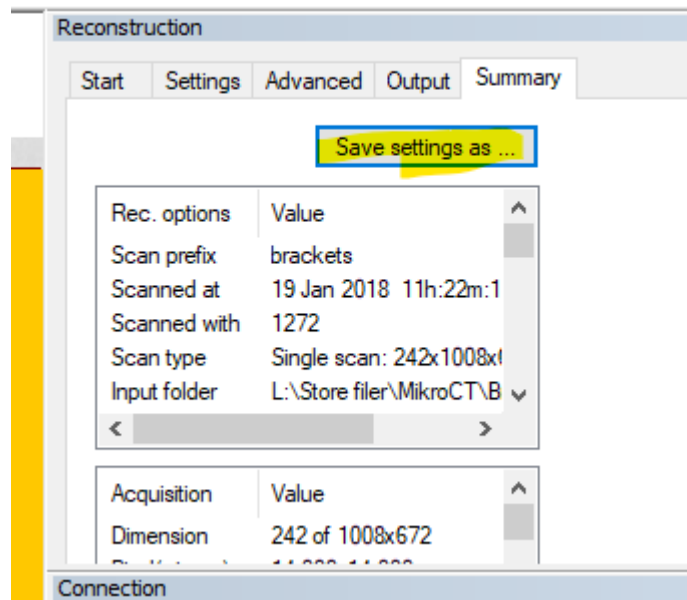
- Quantify the amount/volume of the adhesive that is on the bracket before and after sandblasting
 - Quantify the volume and surface of the bracket before and after sandblasting
 - o total volume
 - o lower part of the bracket: “mesh pad”
-

1) Scan the SS brackets at the same setting. The CE brackets are scanned with their own settings.

a) Remember flatfield correction

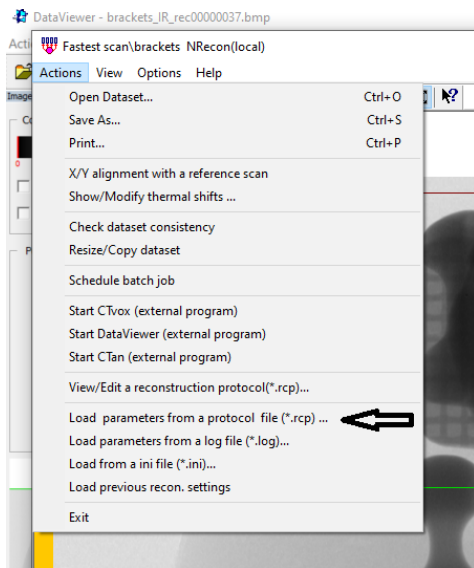
2) Reconstruct the SS and CE brackets.

a) Reconstruct an SS bracket and a CE bracket. Save the settings as a protocol file



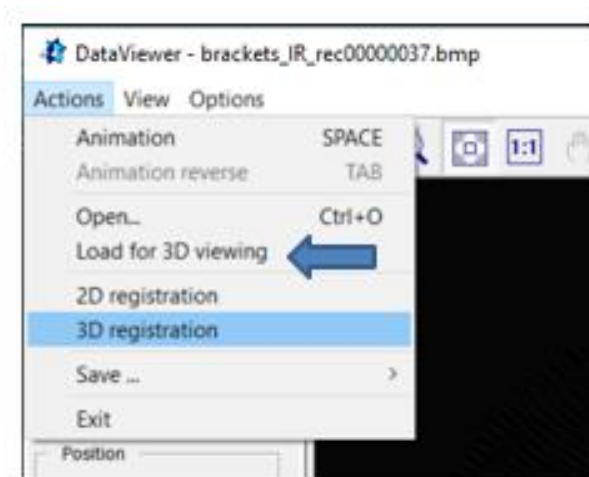
b) For the following brackets (SS or CE), the same setting must be used.

Objectives of the analysis, briefly summarized:

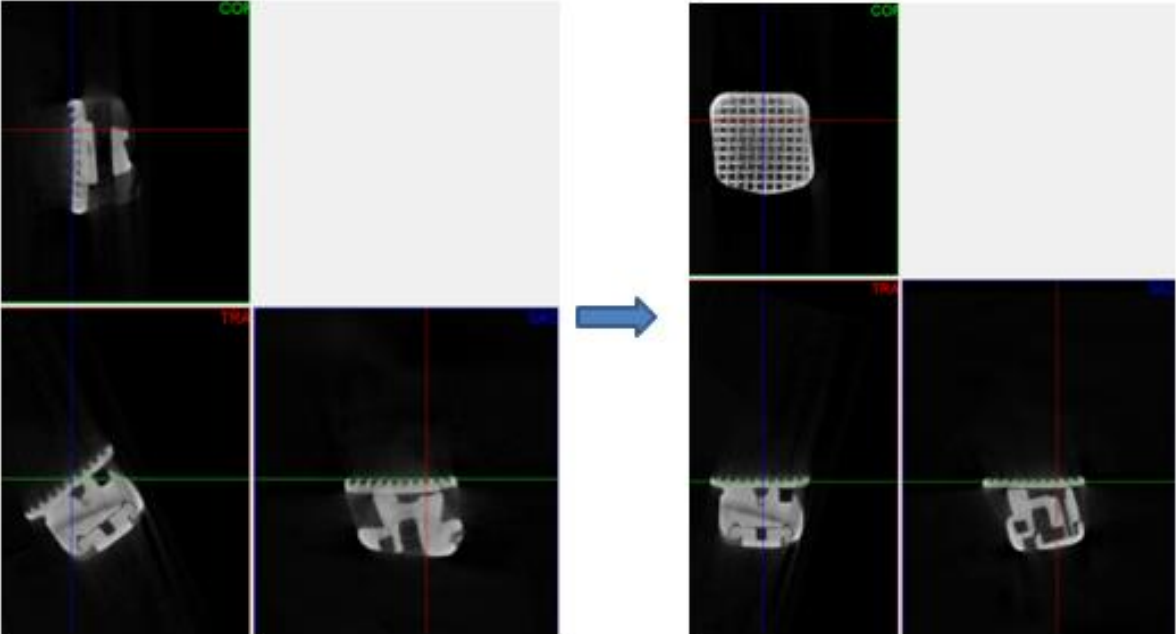


Rotate the bracket so that the mesh is parallel to the horizontal plane.

c) Load for 3D view in data viewer.

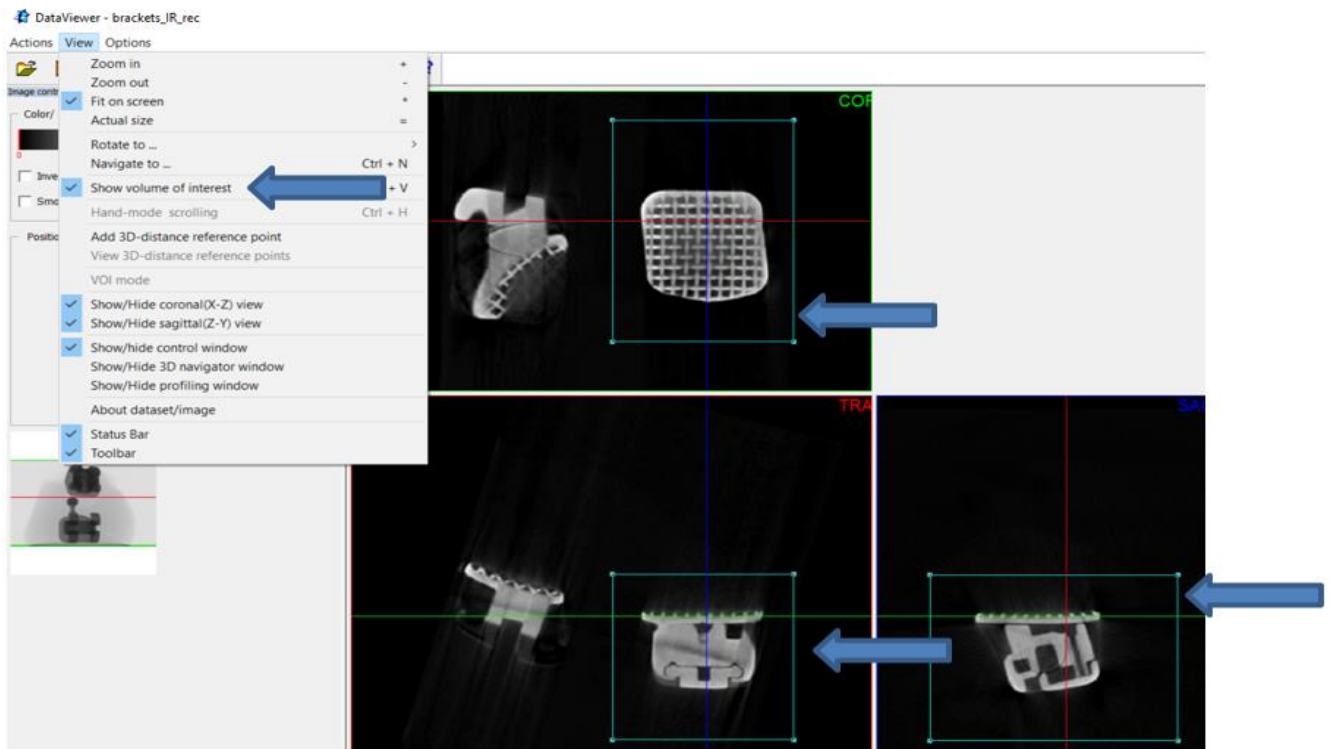


d) Click on the mesh. Hold *Ctrl* and rotate the bracket parallel to the horizontal



e) Save the bracket where you see cross sections of the bracket (in this case the coronal plane)

NOTE 2: You can save space and make subsequent analyses faster by creating a smaller volume of interest.

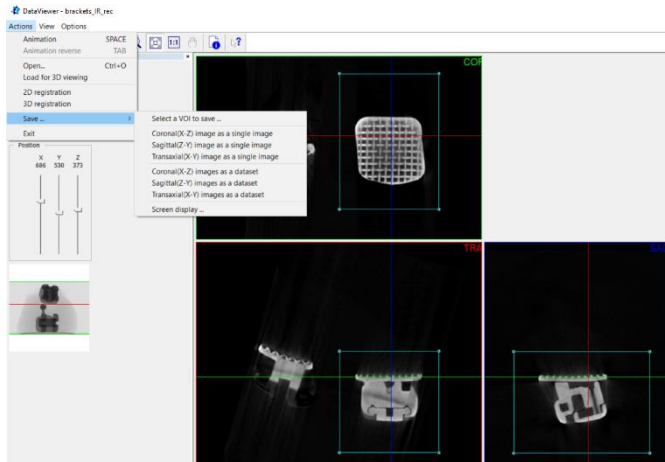


3) Save the dataset

a) See image below. Select a VOI to save. Select resize 1. View to save it provides cross section.

REMEMBER TO CREATE AN OWN FOLDER IN THE SAME FOLDER AS THE RECONSTRUCTED IMAGE! DON'T store it right in the same folder

NOTE: It is difficult to say whether to save COR, TRA or SAW plane, as it depends on the orientation of the bracket when scanning. In this case, the coronal dataset should be stored.

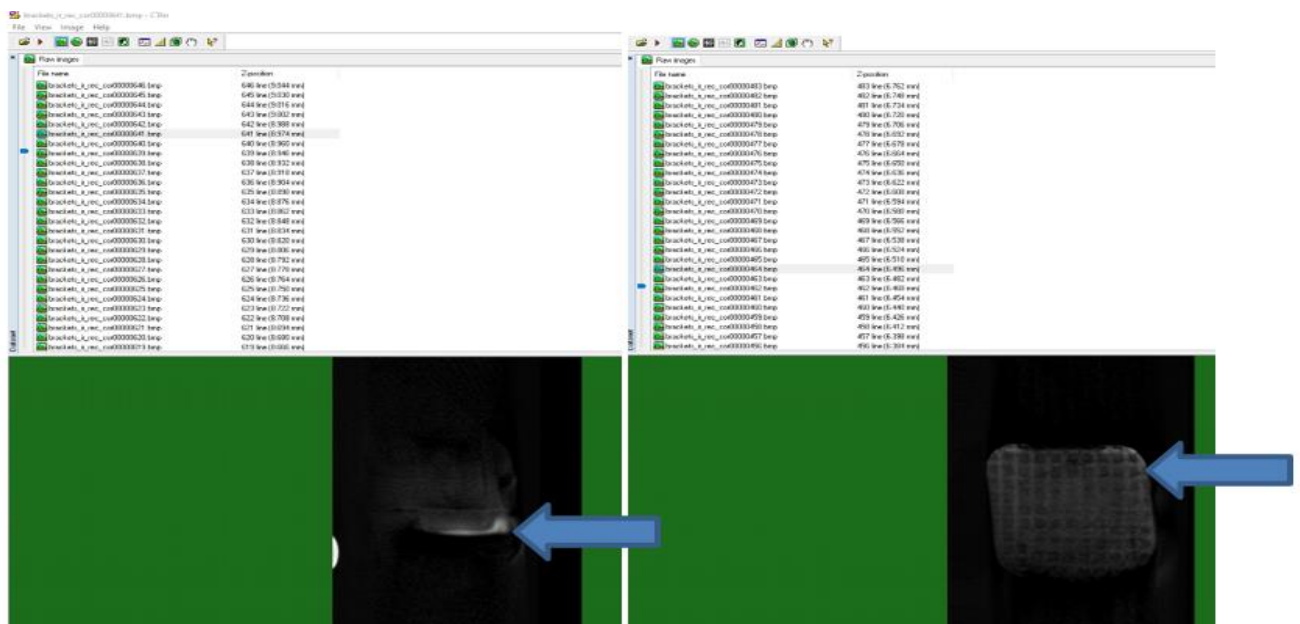


4) Analysis (preparation)

a) In the CT, define these limit values for analysis. Use these values for all further analyses

- i) Stainless- steel bracket
- ii) Ceramic bracket
- iii) The adhesive (mesh pad region) of the SS bracket
- iv) The adhesive (mesh pad region) for the CE bracket

b) Define the number of images where the analysis will take place. First define the top point, it is the first point where you see metal (blue arrow), then define the bottom point, by the mesh



- i) In this case, there are: $641 - 464 = 177$ lines from the top of the bracket to the bottom of the bracket.
- ii) Add 30 lines below the bracket to be able to analyse the adhesive as well (That is, subtract 30 lines to add 30 \square $464 - 30 = 434$)
- iii) If the whole bracket was to be analysed in this case, then it should be done from Figures 641 and 434 ($464 - 30$). You should analyse the entire bracket as a reference, although for the CE bracket there will be artefacts in the upper bracket.

When comparing the bracket before and after sandblasting, only the lower part of the bracket is a region of interest. In this example, you know that there should be 177 lines (rom the top of the bracket to the mesh pad). You can therefore orient yourself when/ if the mesh pad gets lost due to sandblasting. For example, the mesh in this example only extends over 23 images

After sandblasted you can determine how many images to include from the bottom (the mesh side) by orienting themselves from the top. The same number of slides should be included for each group (SS and CE). Example: In the SS group, check all the brackets for which line you see the bottom (oriented from the top). The bracket that has lost most mesh should be used as reference for all brackets. For example, if you do not see the lower part of the bracket before line 155 (oriented from the top), add 20 lines to the analysis (the analysis area will then be from picture 135 to picture 170 for all SS and CE. Now you can calculate volume removed from lower part of the bracket (and surface area).

Summary of what to calculate for each bracket both before AND after sand blasting:

- Total volume and surface of the bracket
- Total volume and surface of adhesive
- Volume and surface of the lower part of the bracket, closest to the mesh (follow the points described: 5, b) iii

