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A Method for Improving Dental Crown Fit-Increasing the Robustness

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***Abstract*—**The introduction of mass-customization has enabled new ways to treat patients within medicine. However, the introduction of industrialized treatments has also meant new obstacles. The purpose of this study was to introduce and theoretically test a method for improving dental crown fit. The optimization method allocates support points in order to check the final variation for dental crowns. Three different types of geometries were tested and compared. The three geometries were also divided into three sub-geometries: Current method, Optimized method and Feasible method. The Optimized method, using the whole surface for support points, provided the best results. The results support the objective of the study. It also seems that the support optimization method can dramatically improve the robustness of dental crown treatments.

***Keywords*—**Bio-medicine, Dentistry, Mass-customization, Optimization and Robust design.

I. Introduction

NOT many areas within medicine have eluded the last decade's technological wave. One good example among many medical areas that have adopted the possibilities technological advantages afford is dentistry. The area of prosthetic dentistry, and especially crowns, has integrated many professions and different technologies, both well-established and novel [1-3].

The introduction of novel technologies has also enabled new possibilities for optimizing treatments, in terms of quality, time and treatment method. This is the case, even though geometrical quality has improved significantly since the introduction of CAD/CAM [4-6].

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However, new problems have occurred at the same time, due to mass customization [7-11]. There are several methods on the market today for treating the patient with dental crowns [12-15].

Seen from a general perspective, a high-quality medical treatment is important for both the patient and the treatment provider. Many aspects can be covered within this statement. We have limited our study here to geometrical quality.

The objective of this study is to propose a new method to minimize the geometrical variation for mass-customized dental crowns, thus converging the treatment method, and especially the final assembly of the crown, into a more robust treatment. However, the method presented is not limited to this specific application. Rather, it can be used in several treatments and applications within medical rehabilitation. By using the method proposed in this study, greater control of the fit between the tooth and crown can be achieved. A theoretical method for minimizing the geometrical variation at the final assembly is presented in this study.

There are several motivations for increasing the inner fit between the tooth and crown. Less tooth/crown grinding (due to poor inner fit during the final rehabilitation/assembly) means that the patient can be treated faster. The feeling provided the dentist of assembling a crown with a tight fit can also be seen as an important aspect. In addition, research has revealed that the stress associated with a non-uniform cement layer (space between the crown and ground tooth) is

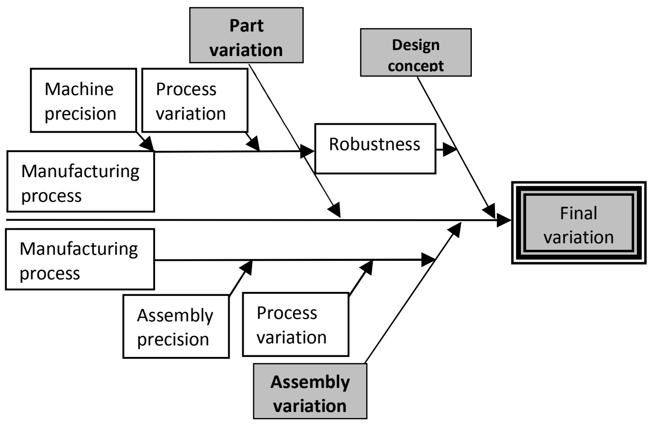


Fig. 1 Cause and effect diagram for the critical product dimension [Söderberg, 1998], in this study the focus is set on the Assembly variation minimization

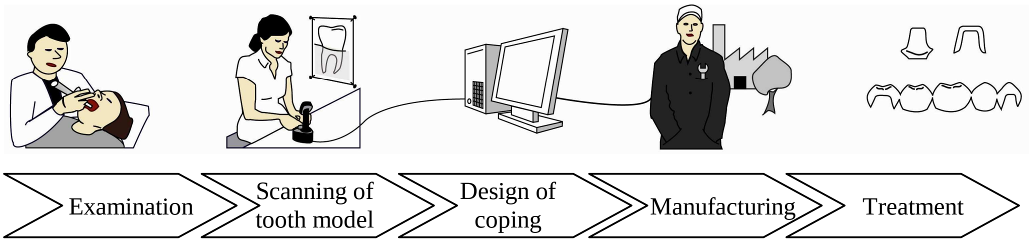


Fig. 2 Illustration of the Procera tooth restoration process

considerably higher than that associated with a uniform layer [16]. This means that control of the cement space can be achieved by introducing the method proposed in this study.

Geometrical variation in critical product dimensions and features results from a number of different sources (see Figure 1). Size and form variation in the geometry of the individual parts originates from the manufacturing process used, which varies over time. The assembly process also contributes to the discrepancies. They originate from a variation in clamping tools, which may also vary over time. The tolerances that contribute to the final variation, from preparation to treatment, design and manufacturing, and clinical procedures, can be defined by different types of probability distributions.

An important contributor to the final variation is also the robustness of the design of the treatment method, from initial examination to finalizing the treatment. A robust design suppresses variation, while a sensitive design amplifies it [17]. For this study, a virtual crown from Procera® AllCeram (Procera® AllCeram, Nobel Biocare AB, Göteborg, Sweden), treatment method was used as an example in order to minimize the geometrical variation theoretically. The optimization was accomplished using virtual variation simulation software RD&T (RD&T; RD&T Technology AB, Mölndal, Sweden).

The Procera® AllCeram method (rigid body) is used to manufacture all-ceramic crowns for single-tooth restorations. Figure 2 illustrates the Procera tooth restoration method. Using computer aided design/manufacturing (CAD/CAM) technology, a densely sintered pure high strength ceramic framework is constructed [7, 14]. First, the patient is examined, and x-rays are taken. The wounded part of the tooth is then prepared, according to guidelines. Next, a gypsum model based on the tooth impression is made in order to enable scanning. Based on the results of that scanning, an outer form for the coping is designed in a computerized environment. The ceramic coping is manufactured, and then finalized to a crown. Finally, the crown is cemented to its place on the prepared tooth by initially guiding it visually to its final position.

Support point optimization has been an obvious part of the product development process within mass-production, for example finding the optimal positions for door hinges. Its goal has been to help realize robust design [18]. However, this is a new method within medical device manufacturing and mass-customization. Recently, robust design methods have been introduced to implant surgery (mass-customization) within the aspects of variation simulation [2, 19]. Since the introduction of industrialization, one of the main difficulties within prosthetic dentistry has been accomplishing a robust design of a mounted crown where each case is individual [1]. Up until now, the solution has been that the ceramic coping (rigid body crown), manufactured on the basis of the scanning result, has been enlarged over the inner surface and decreased at the base. The idea has been to guide the crown to its theoretically-planned position at the base of the tooth and provide it with a close fit. This simultaneously enables the fixation of the crown to the tooth through cementing. However, if this approach is employed, the crown will rest on a set of points (the allocation of the points are unknown) that lock the object (crown) to its six degrees of freedom. Six degrees of freedom refers to the motion of a rigid body in three-dimensional space. A general rule of thumb involves support points being spread as much as possible over the surface and locking the object to its six degrees of freedom in space in order to increase the robustness of the assembly. This means that if the current method explained in the Procera® AllCeram method section above is used, the final variation cannot be checked. Therefore, a new method is proposed that increases the ability to check the final variation, hence converging the process toward more geometrically robust rehabilitation.

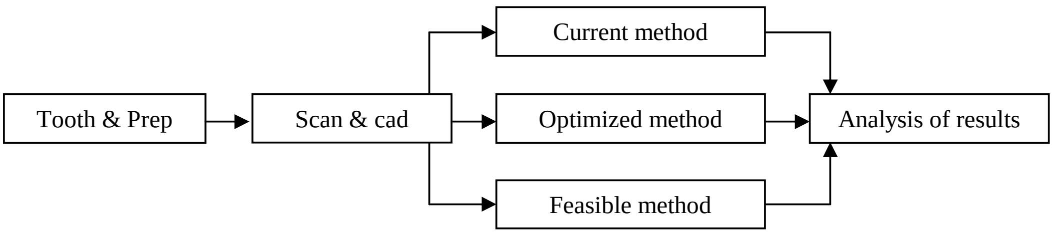


Fig. 3 Workflow of the study

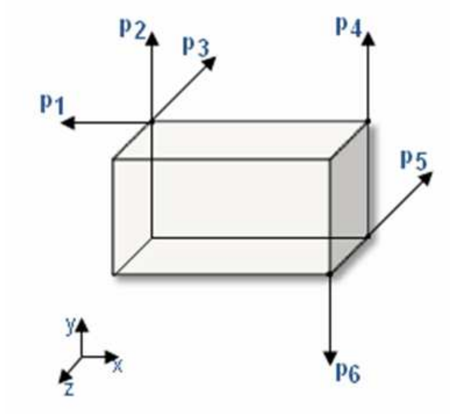


Fig. 4 Box example of the theoretical assembly method, locking the object to the six degrees of freedom in space

II. METHOD

Three prosthetic restoration models (gypsum models of the wounded tooth) were scanned with the help of a touch probe scanner (Procera® Forte, Nobel Biocare AB, Gothenburg, Sweden). This was done in order to obtain a virtual representation of the geometry of each individual wounded tooth. Then a virtual crown was designed as an offset surface on the basis of the scanning result. The restorations represent three typical basic geometries, FZ1: Canine, FZ2: Molar, and FZ3: Pre-Molar. In order to minimize the actual geometrical variation, the inner surface of the virtual crown was provided with support points. The support points that guide the crown to its theoretical and planned final position were distributed by an algorithm proposed by Wang and Pelinescu [20] in the software RD&T, (RD&T, RD&T Technology AB, Mölndal, Sweden). Each support point was given a spherically distributed 0.1 mm tolerance, meaning that the variation does not represent the actual tolerance from the manufacturing. The effect of support point allocation is analyzed by comparing the results between the three geometries.

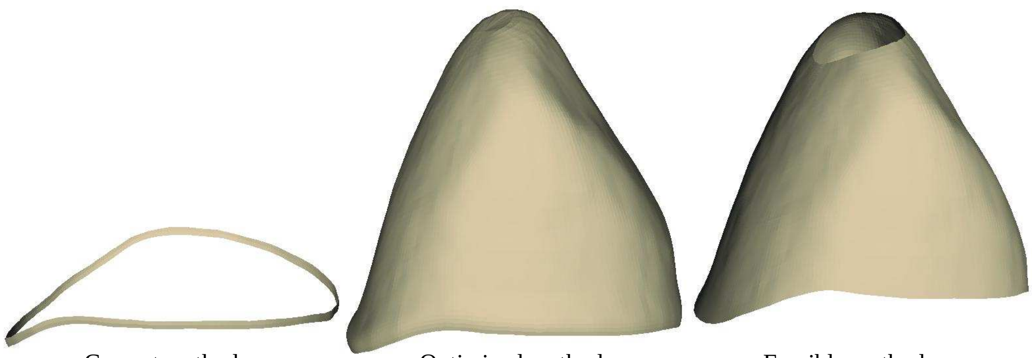
The optimization algorithm proposed by Wang and Pelinescu is based on a method of optimum experiment design. The problem is solved by selecting optimal support points from an initial number of positions at each node of a triangulated surface.

The support points (p_1-p_6 in Fig. 4, A1, A2, A3, B1, B2, C in Figure 6- Figure 12) were allocated with the help of the following method: translation in three perpendicular axes, X, Y and Z, combined with rotation about three perpendicular axes (Fig. 4). This is done in order to lock the object to its six degrees of freedom in space. As the movement along each of the three axes is independent of each other and independent of the rotation about any of these axes, the motion has six degrees of freedom.

The algorithm iteratively improves the robustness of the surface until the most robust solution is found. First all six points are randomly generated and distributed over the surface, then iteratively the point contributing least to an robust design is found an new location is found until this It can also be expected that the surface with no boundary conditions will give the best result, i.e. smallest 6σ and RMS (root mean square), also known as the quadric mean (the most essential result to focus on), the statistical measure of the magnitude of a varying quantity.

For statistical results, each case is virtually manufactured 10,000 times according to the Monte Carlo method [1]. Statistics are then derived from each triangle node and summarized for each case. The Monte Carlo method randomly generates numbers for all input parameters according to pre-defined distributions and creates distributions for the output parameters (critical product dimensions). Then the three following simulations are conducted for each restoration, see Fig. 5:

1. The current method simulates the actual assembly today. Today the crown is mounted by planned connection along the finish line (i.e. the bottom edge of the crown). The



Current method Optimized method Feasible method

Fig. 5 One example of the three surfaces used for calculations. From left to right: Current method, finding the best possible assembly along the finish line. Optimized method, using the whole surface for allocating support points. Feasible method using a part of the surface for allocating the support points, an area along the finish line as well as the top area is excluded for support point allocation simulation is carried out by allocating support points according to optimum experiment design over an area along the finish line, based on machining tools. The best possible solution of the conditions in theory, according to present manufacturing and assembly method, is found. For statistical results, the whole virtual crown is used

2. The optimized method allocates the support points over the whole surface, without restrictions. This means that the most optimized solution in theory regarding robustness is found. This is also the most preferable method to use if possible.
3. The feasible method allocates the support to an area between an upper and lower area. The upper area is defined by a shoulder area. The lower areas are limited to the radii of milling tool, around and above the finish line. It is worth noting that the feasible method is only used as a possible solution area for allocating the support points, might not be needed, for the application in hand.

III. Results

The results of the study have been summarized in Table 1. The figures (Figures 6-14) in appendix present the results as color figures.

Table 1 presents the summarized results from the 10,000 conducted simulations for each case as 6σ w.c. (worst case) and b.c. (best case) as well as RMS (Root Mean Square, most important result to analyze). The 6σ w.c. was found in FZ1 Current method 1.55 mm. The 6σ b.c. was found FZ3 Optimized method, 0.15 mm. If a comparison between each case is done, the greatest deviation was found in FZ3 Current method – Optimized method, RMS factor 0.54.

The colored figures visualize the variation, and are denoted in the bar at the side of each figure. Visually it can be difficult to realize where the largest variation occurs, however it is known that the variation grows with the distance to the support points. The average 6σ w.c. for the current situation was 1.37 mm. For the whole surface situation, it was 1.06 mm, while it was 1.16 mm for the feasible solution. Meanwhile, the average 6σ b.c. for the current situation was 0.35 mm. For the whole surface situation, it was 0.18 mm, and for the Feasible solution, it was 0.29 mm. Finally, the average RMS for the current situation was 0.95 mm, while it was 0.63 mm for the optimized situation and 1.07 mm for the feasible solution.

IV. Discussion

The objective of this study has been to propose a support point optimization method in order to minimize the geometrical variation for mass-customized dental crowns, and in that way converge towards a more geometrically robust treatment. As mentioned earlier, the method presented in this study is not limited to the application in hand. There are several applications (especially within medicine) it can be used for. This is because of the individual geometries.

Table I Results of 10 000 virtual simulations

Case	6σ w.c.	6σ b.c	**RMS**
FZ1 Current Method	1.55	0.37	**1.07**
FZ1 Optimized Method	1.37	0.17	**0.64**
FZ1 Feasible Method	1.06	0.21	**0.73**
FZ2 Current Method	1.12	0.16	**0.65**
FZ2 Optimized Method	0.91	0.18	**0.64**
FZ2 Feasible Method	1.31	0.48	**1.77**
FZ3 Current Method	1.44	0.54	**1.12**
FZ3 Optimized Method	0.89	0.15	**0.61**
FZ3 Feasible Method	1.10	0.17	**0.70**

Three basic tooth geometries were used for this study (Fig. 6 - Fig. 14): FZ1: Canine, FZ2: Molar and FZ3: Pre-Molar.It must be kept in mind when analyzing the results that for the current method, the results present the best possible solution, something unlikely to be found in an actual case. This is due to the fact that the connection is determined only by close fit and where the contact points occur cannot be known. Another important aspect when analyzing the results is to keep in mind that the feasible method results in support point allocation above the base of the base of the surface, conducting sometimes in worse results than for the current method. That effect is due to that the circumference sometimes is larger at the base of the surface.

An upper limit was set for the support point locations for the feasible method. There was no unambiguous definition set for the boundary. However for this study the feasible method was studied in order to increase the knowledge of such surface compromise. Such compromise might be needed if for example minimization of dislodging risk is required. The lower area was not either used for support point allocation, the main reason for the boundary condition was to enable study the effect of such limitation. If such limitations is needed is often a give and take balance, meaning that the limitations often decreases the robustness of the assembly, but however there might be some other reasons for such conditions.

On the other hand, thanks to the increasing knowledge of manufacturing processes and improved machines, new possibilities to distribute support points over the whole surface might be possible in the future.

The optimized method utilizes the whole surface as a distribution area. If the method is proven to distribute the support points in such a manner that the geometrically most robust solution is found, the best solutions regarding RMS ought to be found in the optimized method. However, sometimes the results of the various methods can be close to each other. One such example is found when comparing the FZ2 Current method and the FZ2 Optimized method. In this case, the w.c. is smaller for the optimized method. Moreover, as mentioned, the Current method represents the best possible situation, meaning that it is unlikely to occur in the actual assembly.

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Applying the proposed method to medical device manufacturing achieves new possibilities for inspecting the final geometrical variation. This in turn provides additional quality to products which is a benefit for patients in general. Employing the method could also be supported from an economical point of view: all that needs to be added to an already flexible manufacturing process is a support point optimization.

Finally, future work mainly consists of two scientific phases in the line of this work.

The first phase is to set up a pilot study in order to test the proposed method of this study. Roughly, it would consist of collaboration with a dental crown manufacturer in order to enable the manufacturing of a set of crowns with support points. In that case, both the optimized and the feasible method would be provided with support points. The current method in that case would be represented by the actual crown manufacturing today without modifications. An initial fit test would then be done.

The second phase would be verifying the method through clinical tests. That would require collaboration with medical device manufacturers as well as clinicians.

V. Conclusion

A new method for optimizing the inner fit for mass-customized dental crowns has been presented. The results also support the objective of finding the best results for the whole surface and, in that way, converge toward more geometrically robust solutions. Within the limitations of this study, the final variation is not static, nor were the support points found in the same locations. This means that unique solutions need to be found for each geometry.

Ultimately, it appears as the optimization method proposed can dramatically improve the fit for dental crowns, as presented in the results the variation was near halved.

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References

[1] Andersson M, Odén A. A new all-ceramic crown. A dense-sintered, high-purity alumina coping with porcelain. Acta Odontol Scand. 1993;1:59-64.

[2] Kero T, Söderberg R, Andersson M, Lindkvist L. Process optimization regarding geometrical variation and sensitivity involving dental drill- and implant-guided surgeries. Int J Biomed Sci 2007;4:237-43.

[3] Schep NWL, Broeders IAMJ, Werken CVD. Computer assisted orthopaedic and trauma surgery state of the art and future perspectives. Int. J. Care Injured 2003;34:299-306.

[4] Duret F, Bloudin JL, Duret B. Cad/cam in dentistry. J Am Dent Assoc 1998;117:715-20.

[5] Mormann WH, Brandestini M, Lutz F, Barbakow F, Gotsch T. Cad-cam ceramic inlays and onlays: A case report after 3 years in place. J Am Dent Assoc 1990;120:517-20.

[6] Rekow ED. Cad/cam for dental restorations-some of the curious challenges. IEEE Trans Biomed Eng 1991;38:314-8.

[7] Dahlmo K, Andersson M, Gellerstedt M, Karlsson S. On a new method to assess the accuracy of a cad program. Int J Prosthodont 2001;3:276-83.

[8] Jaeger ND, Pallav P, Feilzer AJ. The influence of design parameters on the fea-determined stress distribution in cad-cam produced all-ceramic dental crowns. Dent Mater 2005;21:242-51.

[9] Kero T, Söderberg R, Andersson M. Method for analyzing probe scanned surfaces 10th WSEAS International conference on automatic control, modelling & simulation (ACMOS'08) 27-30 May 2008.

[10] Persson A, Andersson M, Oden A, Sandborgh-Englunda G. Computer aided analysis of digitized dental stone replicas by dental cad/cam technology. Dent Mater 2008;8:1123-30.

[11] Pfeiffer J. Dental cad/cam technologies: The optical impression (ii). Int J Comput Dent 1999;1:65-72.

[12] Christensen G. In office cad/cam milling restorations: The future? J Am Dent Assoc 2008;1:83-5.

[13] Ender A, Wiedhahn K, Mormann WH. Chairside multi-unit restoration of a quadrant using the new cerec 3d software. Int J Comput Dent 2003;1:89-94.

[14] Kokubo Y, Ohkubo V, Tsumita M, Miyashita A, Vult Von Steyern P, Fukushima S. Clinical marginal and internal gaps of procera allceram crowns. J Oral Rehabil 2005;7:526-30.

[15] Wen MY, Mueller HJ, Chai J, Wozniak WT. Comparative mechanical property characterization of 3 all-ceramic core materials. Int J Prosthodont 1999;12:534-41.

[16] Luthardt RG, Koch R, Rudolph H, Walter MH. Qualitative computer aided evaluation of dental impression in vivo. Dent Mater 2006;22:66-76.

[17] Söderberg R, Lindkvist L, Carlson J. Virtual geometry assurance for effective product realization. Nord PLM' 06 25-26 January 2006.

[18] Söderberg R, Lindkvist L, Carlson J. Managing physical dependencies through location system design. J Eng Design 2006;4:325-46.

[19] Kero T, Lindkvist L, Söderberg R, Andersson M. Variation simulation toolkit for virtual verification of dental drill-guided surgeries. III International Congress on Computational Bioengineering 333-9, 2007.

[20] Wang M, Pelinescu D. Optimizing fixture layout in a point-set domain. IEEE T ROBOTIC AUTOM 2001;3:312-23.

APPENDIX

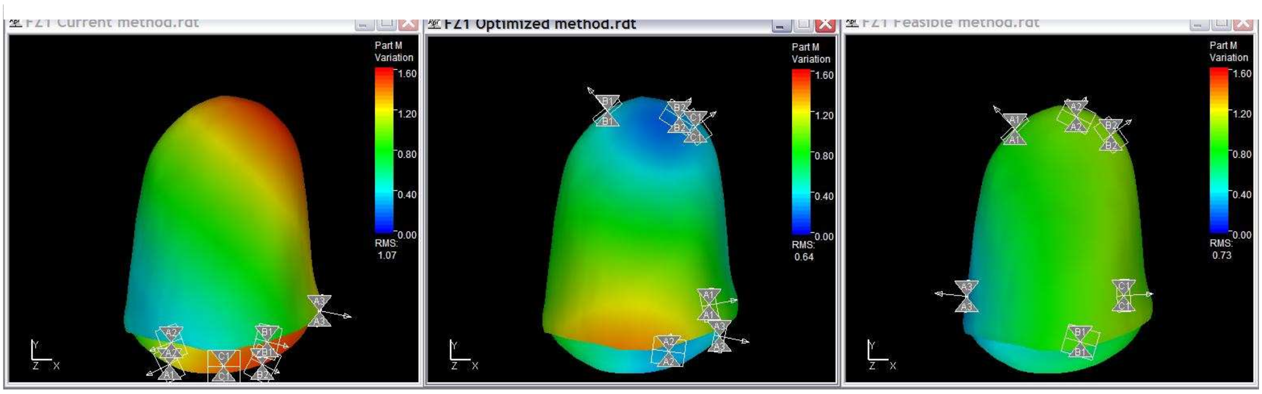

Fig. 6 FZ1 results, front view, Distance, y-direction 7.22 mm

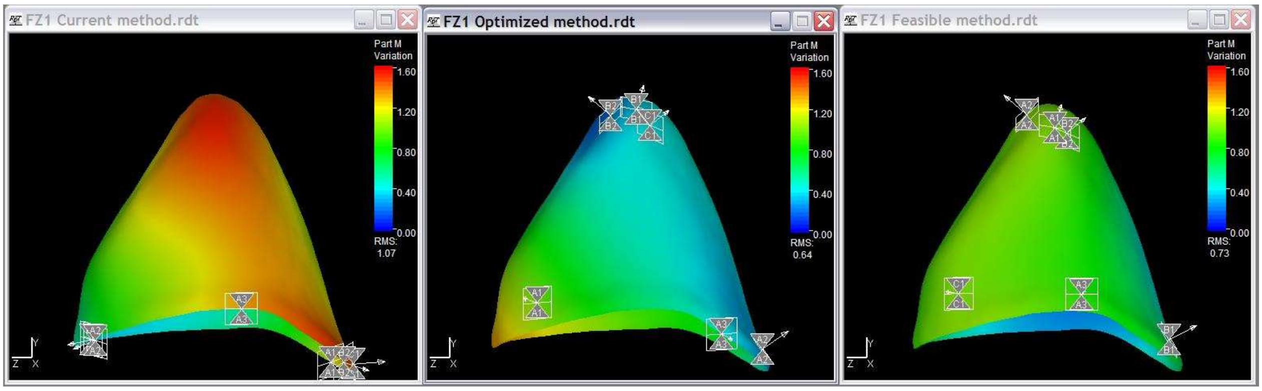

Fig. 7 FZ1 results, side view, distance, z direction: 7.30

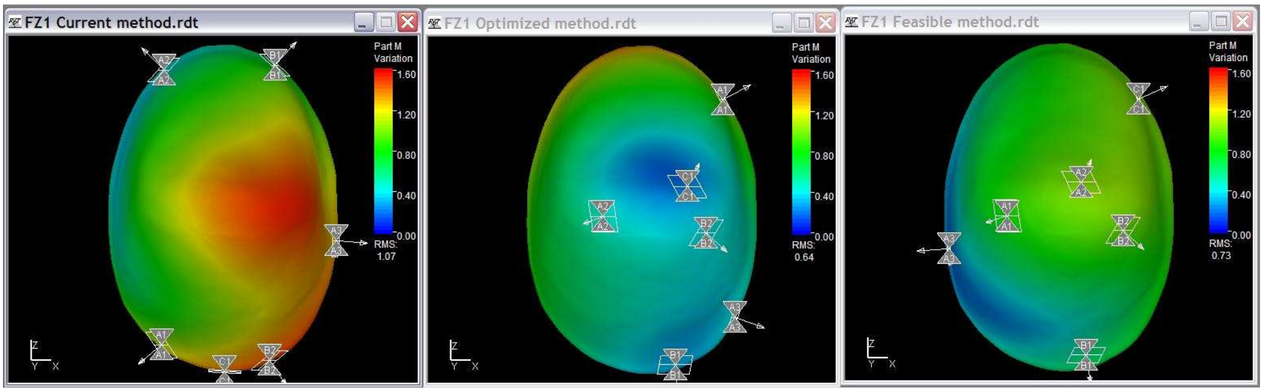

Fig. 8 FZ2 results, top view

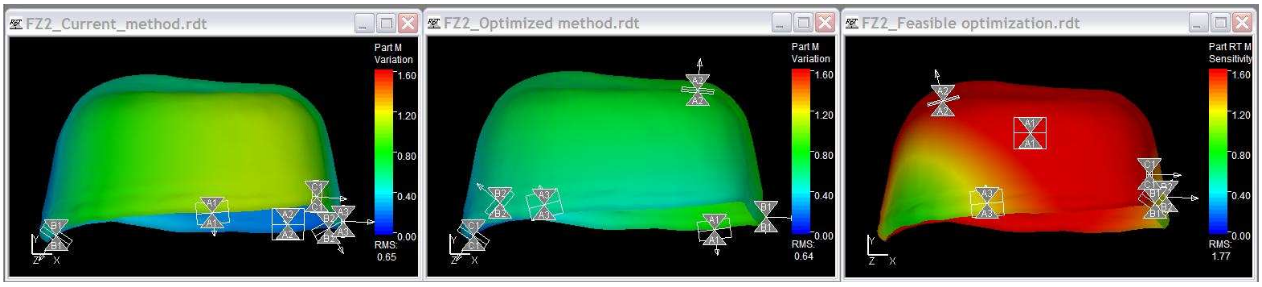

Fig. 9 FZ2 results, front view, maximum distance y-direction 4.80 mm

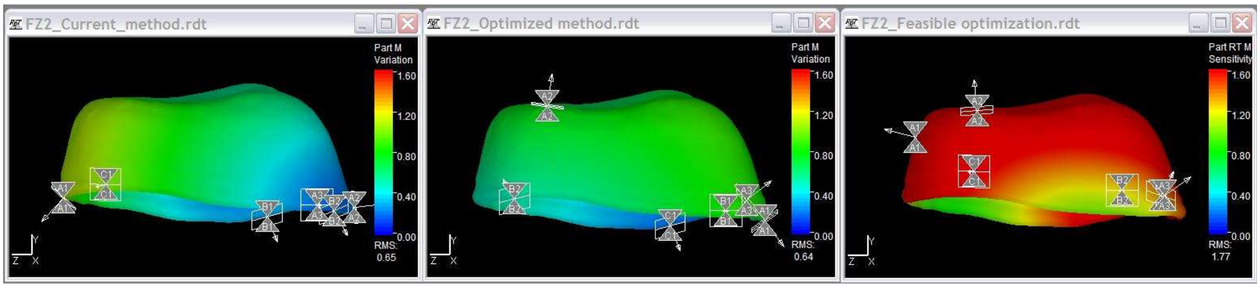

Fig. 10 FZ1 results, side view

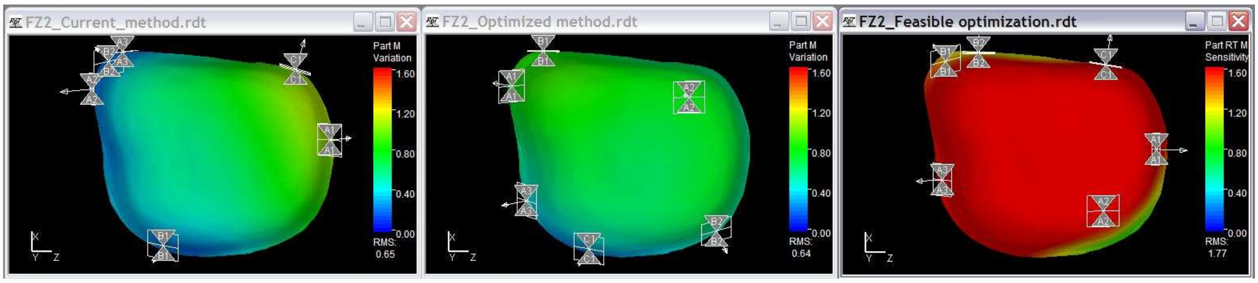

Fig. 11 FZ2 results, top view, maximum distance, z-direction: 10.26 mm

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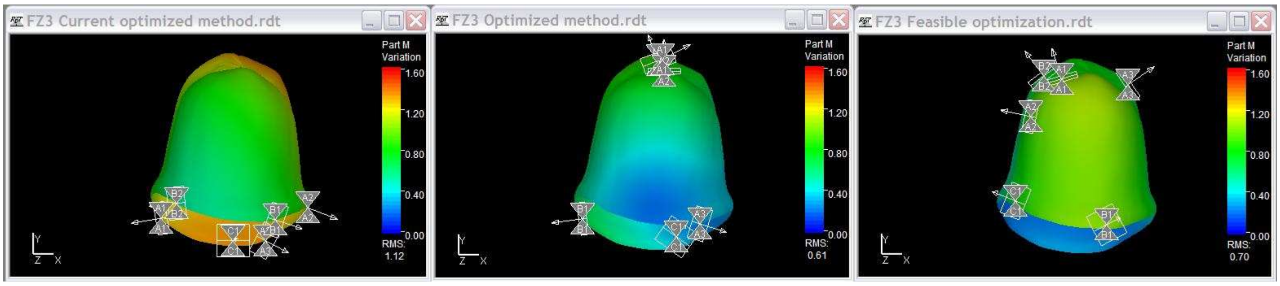

Fig. 12 FZ3 results, front view, maximum distance, y-direction: 5.94 mm

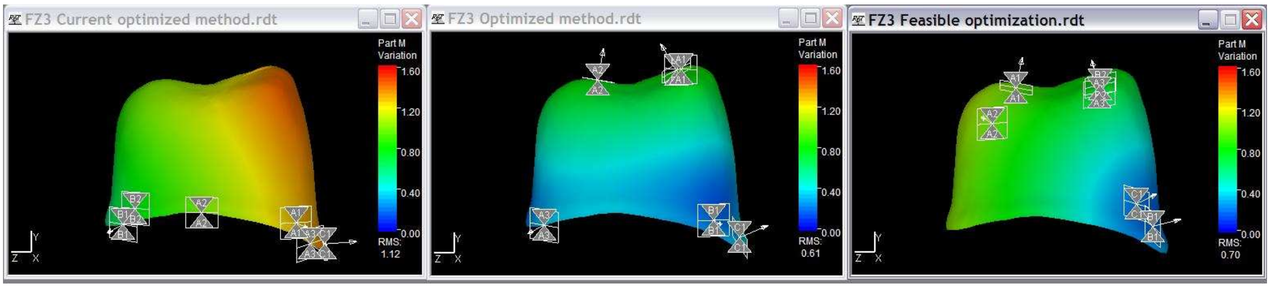

Fig. 13 FZ3 results, side view

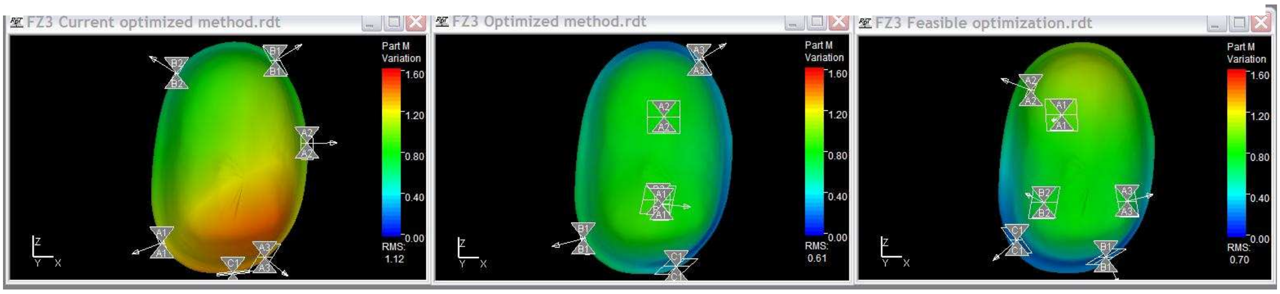

Fig. 14 FZ3 results, top view, maximum distance, z-direction: 7.18 mm