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## Research Article

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### Evaluation of The Processing Discrepancies Between Dental and Nondental CAD Software Using The Smoothing Design Tool

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## Evaluation of The Processing Discrepancies Between Dental and Nondental CAD Software Using The Smoothing Design Tool

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### **Abstract**

**Statement of the problem:** The advancing computer-aided design/computer-aided manufacturing (CAD/CAM) technology has changed the fabrication protocols of fixed prosthodontic restorations dramatically in the last 25 years. Beside the dental CAD programs open source nondental software have been utilized for prosthodontic purposes. Despite the progress in technology, varying accuracy and precision rates, and lack of standardized workflows are still challenging issues.

**Objective:** No study to the authors' knowledge evaluated the precision of the manually used processing tools of CAD softwares despite the necessity of utilizing multiple tools to design a restoration, thus it was aimed to evaluate the processing discrepancies of smoothing procedures.

**Materials & Methods:** A virtual working cast of a maxilla with six teeth prepared with shoulder finish lines containing irregularities up to 50µm were composed. The irregularities were smoothed manually using the 'brush' tools in the 'sculpt' mode of the DWOS, Blender and Meshmixer softwares. Smoothed virtual working casts were superimposed with the reference virtual working cast.

**Results:** The results of Tukey HSD test revealed significant differences between Meshmixer and Blender ( $P=0.000$ ), and Meshmixer and DWOS ( $P=0.000$ ), no significance was found between DWOS and Blender values ( $P=0.987$ ).

**Conclusion:** The results of the study pointed out that smoothing procedure may lead to significant differences in discrepancy values, nondental CAD software can perform smoothing with less discrepancy thus, commencing further studies including multiple users and softwares for the evaluation of different design tools seems imperative.

**Keywords:** Dental CAD Software Program, Nondental CAD Software Program, Smoothing Tool, Processing Discrepancy, Blender, Autodesk Meshmixer

## **Introduction**

The advancing computer-aided design/computer-aided manufacturing (CAD/CAM) technology has changed the fabrication procedures of the tooth or implant-supported indirect fixed restorations dramatically in the last 25 years.<sup>1,2</sup> A dental CAD/CAM system is composed of an intraoral or extraoral 3D scanner for data acquisition, a CAD software for planning and designing on virtual working casts, and a manufacturing unit that uses additive or subtractive methods.<sup>3</sup>

The primary objectives of dental CAD/CAM systems are enhancing fabrication accuracy and quality, establishing a uniform manufacturing model and workflow, reducing costs, and shortening the time for the fabrication of the restorations. Despite the progress in technology, these systems still have some significant shortcomings such as varying accuracy and precision rates among different data acquisition brands, lack of standardized workflows to guide the fabrication of particular restorations or appliances, challenges in accessing a digitally capable dental laboratory, and time and money need to be spent to achieve high-level manufacturing quality.<sup>1,4-9</sup>

To identify and eliminate the causes of these shortcomings numerous studies were conducted focusing on the effects of data acquisition units,<sup>10-14</sup> CAM strategies,<sup>15-18</sup> restoration types,<sup>19,20</sup> design of the preparation, and the finish line<sup>21-23</sup> and materials on the particular properties of the restorations.<sup>3,24</sup> However, the number of researches evaluated the effects of the CAD software even on the fundamental properties of the restorations is low.<sup>25</sup> The field of interest of these studies is generally about the algorithms used for matching and simulating the morphology of the target tooth with the remaining teeth on the arches.<sup>1,26</sup> Other studies directly related to dental CAD software are concerned only with the impact of operator or program differences on the learning curve and the usability of CAD software.<sup>27,28</sup> The user and software type seem to affect the accuracy or precision of the process performed with dental CAD procedures,<sup>1,9,27-29</sup> just as they do with the conventional manufacturing methods.<sup>30</sup>

Even state-of-the-art programs offer basic templates for the restoration morphology and planning, which generally have to be modified manually by the operator via various software tools.<sup>1,27</sup> At the beginning of the design phase, the restoration margins may need to be drawn manually by the operator on the virtual abutment of the prepared tooth to which the fixed prosthesis will be applied. For none of the dental CAD software on the market could perform margin drawing automatically with great precision in the presence of a distinct and irregular subgingival finish line.<sup>31</sup> In addition, meticulous evaluation and manual contribution of an experienced, and skilled dental professional is needed for the detection and elimination of irregularities or

preparation errors such as undercuts, sharp corners and edges on the virtual models.<sup>27,31-33</sup> However, to the authors' knowledge, comparisons of accuracy, precision, and processing discrepancies at a particular design stage on virtual working casts between different dental CAD software have not been investigated yet. Our lack of knowledge about rapidly evolving CAD software is not limited to the dental field.<sup>34</sup> In recent years, several nondental open-source software with similar design tools have also taken their place in the markets and started to attract the attention of researchers. Our knowledge about them is also insufficient.<sup>34-39</sup> Moreover, no study has been presented comparing the precision and discrepancy of the results of the same procedure with the same settings done by the dental and nondental software which possess similar tools.

This study aims to evaluate the processing discrepancies of smoothing procedures performed with one dental and two nondental CAD software on a maxillary virtual working model that contains six anterior abutment teeth prepared to simulate abutments for an all-ceramic restoration with shoulder finish line, using superimposition software. "The smoothing process performed with the dental CAD software would present more precise results than the nondental software and there would be less discrepancy between smoothed virtual working casts and the reference virtual working model" was the null hypothesis of the study.

## **Materials & Methods**

The present study was approved by the Ethical Committee of the Cappadocia University and executed in accordance with the Helsinki Declaration of 1964 as revised in 2013.

The study was performed in four stages:

1. Composing the mesh structure of the reference virtual working cast (REWOC) of a maxilla with six prepared anterior abutment teeth whose finish lines contain irregularities up to 50µm by using two nondental open-source CAD software.

2. Composing the smoothed virtual working casts (SIWOC) following the smoothing of the irregular finish lines of the six abutments on REWOC. A dental professional with 10-year of experience performed 45 smoothing procedures in total, 15 for each software.

3. Superimposition of SIWOCs with REWOC on software and measurement and recording of the discrepancies.

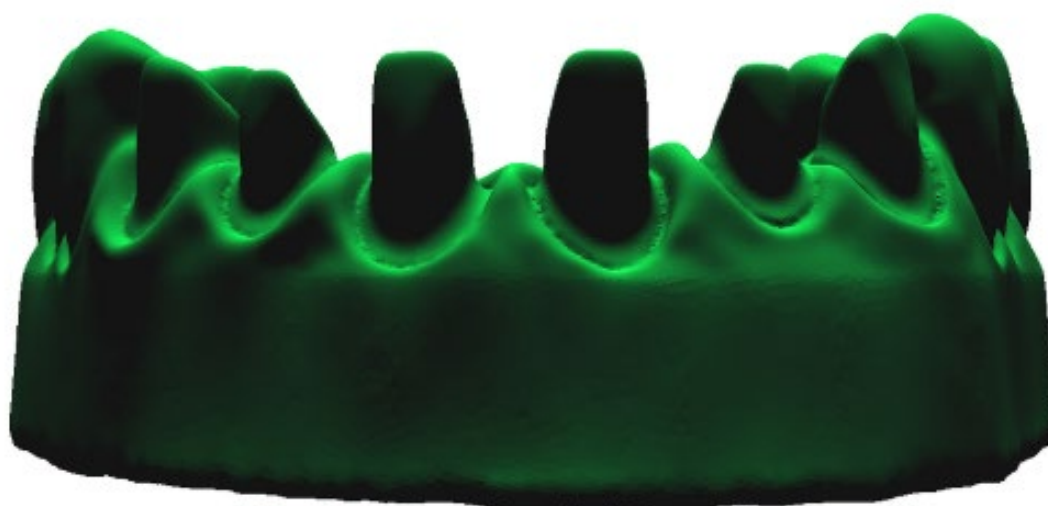
4. Statistical analysis of the obtained data.

1. REWOC, which simulates an upper dental arch without any missing teeth, was created by two experienced software experts and two prosthodontists using Blender® 9.93.0 (Blender

Foundation, Amsterdam, Netherlands), and Autodesk Meshmixer 3.5 (Autodesk Inc., San Rafael, CA, USA) CAD software. Initially, an arch of 62 mm in height, 56 mm in length, and 22 mm in thickness, mimicking the maxillary alveolar crest was created using the 'object' mode of the Blender® (BL) software. Posterior teeth selected from the digital library of the department of prosthodontics were placed on the arch. From the same library six anterior teeth, right central (RCe), left central (LCe), right lateral (RLa), left lateral (LLa), right canine (RCa), and left canine (LCa), with shoulder finish-lines were selected and placed in the arch. In harmony with the posterior teeth, dimensions of the anteriors were scaled using the 'inflate' tool and axis angles were adjusted with the 'pose' tool in the 'sculpt' mode of the software.

STL data of REWOC's initial mesh was transferred to the Meshmixer (MM) software to make the gingival and tooth surface transitions look natural. Corrections were made using the 'falloff' and then the 'brush\*move' tools of 'sculpt' mode. REWOC's STL data was saved and transferred back to BL software. Using the 'edit' mode, indentations not exceeding 50 micrometers were created by changing the vertices on the mesh at the finish lines of all anterior teeth. Finally, REWOC was filed as 24.1 MB STL data of a mesh composed of 253.699 points and 507.394 faces (Figure 1).

**Figure 1.** REWOC from the frontal plane.

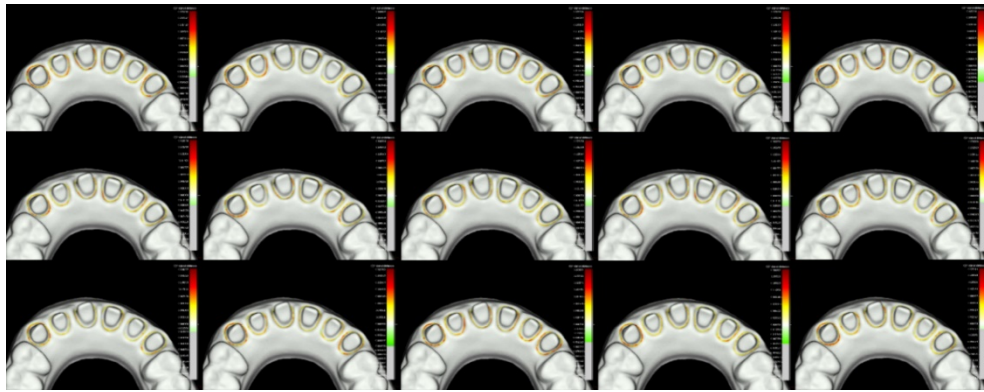


2. BL (nondental), MM (nondental), and DWOS (DW) (Dental Wings Inc., Montreal, Quebec, Canada) CAD software were used at the 2nd stage of the study. A dental professional with ten years of experience in dental CAD softwares (Dental Wings and Exocad) was informed and trained by a software specialist on the BL, and MM for 16 hours each. REWOC STL data was loaded to BL and the dental professional manually smoothed the irregularities on the finish lines using the “brush tools” in the “sculpt” mode of the software. The brush settings were as follows; Radius: 15, Strength: 35, Depth; 0, Laziness; 0.

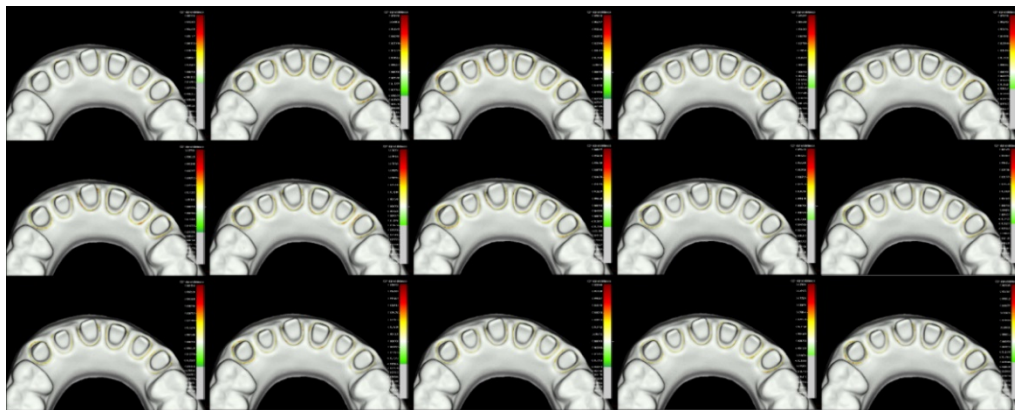
The procedure was repeated 15 times and smoothed virtual working casts (SIWOC) were saved as STL data and filed entitled from BL1 to BL15 respectively. No time limit was applied during the smoothing process. The same operator also performed a total of 30 smoothings in MM and DW with the same protocols and settings applied in BL software. SIWOC STL files obtained from MM were numbered from MM1 to MM15. SIWOCs obtained from DWOS were numbered from DW1 to DW15 and saved as STL files. The operator completed all 45 smoothing procedures in 43.6 hours.

3. At the 3rd stage of the study, 45 SIWOCs obtained from smoothing procedures performed in 3 different CAD software programs were superimposed with the REWOC using CloudCompare v2 2.6.1 (Crunchbase Inc., Dublin, Ireland) software. For superimposition, the STL files of the REWOC and SIWOC were transferred to the software. In order to ensure the correct alignment of REWOC and SIWOC, the automatic recording tool working with the iterative closest point algorithm was used. As the superimpositioning software performs a rough alignment prior to the superimposition, does not require a reference point selection, and records the two virtual entities as they are the same object, instead of defining the number of iterations, the root-mean square difference parameter (which was set to  $1.0e-0.6$ ) was used to terminate the iterative procedure. No restriction is applied on translational and rotational axes. The point cloud of the SIWOC was formed using the mesh-to-cloud tool of the software. The next step was the formation of the point cloud for the SIWOC STL model. A cloud of 5 million points was formed to secure the detailed and accurate representation of the mesh. The maximum discrepancy between the mesh and the point cloud was  $1 \times 10^{-5}$   $\mu\text{m}$ . Finally, distances between the point cloud of each SIWOC and the STL of REWOC were obtained and recorded. Images with color scales obtained by the superimposition of the SIWOCs of BL, MM, and DW with REWOC using CloudCompare software were given in the Fig. 2, Fig. 3, and Fig. 4 respectively.

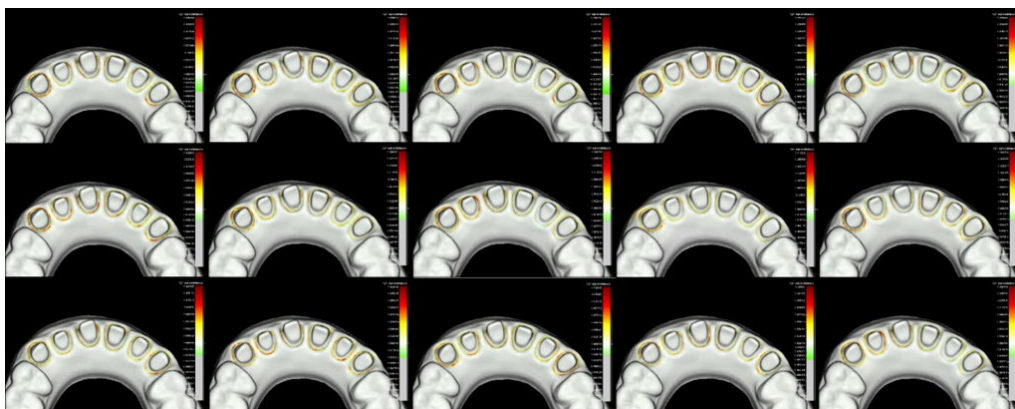
**Figure 2.** Images of discrepancy values of BL SIWOCs-REWOC superimpositions.



**Figure 3.** Images of discrepancy values of MM SIWOCs-REWOC superimpositions.



**Figure 4.** Images of discrepancy values of DW SIWOCs-REWOC superimpositions.



4. Obtained data were statistically analyzed with Statistical Package for the Social Sciences 21 (SPSS, IBM Inc., New York, USA). Following the descriptive analysis of the discrepancies of the superimpositions of SIWOCs and REWOCs, significance was tested on the mean values obtained from the procedures performed with different CAD software on six abutments with One-way ANOVA. For the multiple comparisons of the scores of the BL, MM, and DW groups Tukey HSD test was used. The significance value was set to .05 for all statistical comparisons.

## Results

The lowest, highest and total discrepancy values of the BL CAD smoothing for each abutment obtained after 15 superimpositions were given in Table 1.

**Table1.** Discrepancy values after BL CAD\* smoothing for each abutment.

	RCa <sup>†</sup>		RLa <sup>‡</sup>		RCe <sup>§</sup>		LCe <sup>¶</sup>		LLa <sup>**</sup>		LCa <sup>††</sup>	
	Lowest	Highest	Lowest	Highest	Lowest	Highest	Lowest	Highest	Lowest	Highest	Lowest	Highest
BL1	-0.03103	0.154426	-0.01158	0.145748	-0.01892	0.159317	-0.00512	0.156015	-0.00992	0.151187	-0.03315	0.17523
BL2	-0.00407	0.134917	-0.01181	0.116808	-0.01226	0.121593	-0.00346	0.13449	-0.00777	0.16199	-0.0238	0.189187
BL3	-0.01042	0.14632	-0.01668	0.134386	-0.02292	0.150125	-0.00721	0.133883	-0.01252	0.152485	-0.02788	0.177559
BL4	-0.05011	0.144064	-0.01714	0.137811	-0.01686	0.121181	-0.00481	0.142862	-0.01543	0.121858	-0.00819	0.175139
BL5	-0.04784	0.149832	-0.00905	0.12232	-0.00575	0.108629	-0.00601	0.167634	-0.00855	0.141588	-0.02268	0.163903
BL6	-0.0133	0.133072	-0.01022	0.125665	-0.01553	0.10932	-0.00265	0.106179	-0.00363	0.094046	-0.03276	0.137858
BL7	-0.00222	0.138992	-0.00853	0.125381	-0.01489	0.139985	-0.00407	0.138301	-0.00864	0.12218	-0.03253	0.160804
BL8	-0.03106	0.119185	-0.01771	0.123585	-0.01561	0.108136	-0.00709	0.121721	-0.01569	0.145016	-0.02383	0.17273
BL9	-0.02889	0.131234	-0.01523	0.13498	-0.01225	0.148546	-0.00163	0.122048	-0.01291	0.117611	-0.02091	0.163154
BL10	-0.01048	0.141657	-0.01306	0.123009	-0.01253	0.099198	-0.00377	0.123398	-0.01975	0.136919	-0.01864	0.1743
BL11	-0.00463	0.147405	-0.00654	0.103816	-0.01122	0.121686	-0.0066	0.12231	-0.00927	0.115104	-0.0251	0.184257
BL12	-0.06405	0.137501	-0.02016	0.11519	-0.0071	0.125854	-0.00412	0.121179	-0.00791	0.121202	-0.0158	0.162085
BL13	-0.05192	0.15769	-0.01371	0.130179	-0.01426	0.123503	-0.00225	0.126179	-0.02441	0.163921	-0.03456	0.157909
BL14	-0.02051	0.119497	-0.01314	0.134623	-0.01363	0.116745	-0.00675	0.127831	-0.01316	0.122038	-0.06317	0.186892
BL15	-0.01173	0.142367	-0.00685	0.129174	-0.0116	0.122478	-0.00401	0.153029	-0.01594	0.133875	-0.01603	0.172215
Total	-0.06405	0.15769	-0.02016	0.145748	-0.02292	0.159317	-0.00721	0.167634	-0.02441	0.163921	-0.06317	0.189187

The lowest, highest and total discrepancy values of the MM CAD smoothing for each abutment obtained after 15 superimpositions were given in Table 2.

**Table 2.** Discrepancy values after MM CAD\* smoothing for each abutment.

	RCa <sup>†</sup>		RLa <sup>‡</sup>		RCe <sup>§</sup>		LCe <sup>¶</sup>		LLa <sup>**</sup>		LCa <sup>††</sup>	
	Lowest	Highest	Lowest	Highest	Lowest	Highest	Lowest	Highest	Lowest	Highest	Lowest	Highest
MM1	-0.01028	0.074237	-0.00865	0.068424	-0.01243	0.068763	-0.01186	0.080233	-0.00881	0.082266	-0.01438	0.061743
MM2	-0.0175	0.064928	-0.01027	0.058918	-0.01756	0.053549	-0.00776	0.074058	-0.00872	0.059055	-0.03055	0.054544
MM3	-0.03268	0.058004	-0.00789	0.05567	-0.01825	0.066619	-0.00793	0.070169	-0.02625	0.056754	-0.01704	0.064297
MM4	-0.01353	0.075177	-0.00845	0.067641	-0.01619	0.062371	-0.017	0.061453	-0.02062	0.059075	-0.01767	0.073411
MM5	-0.01748	0.071728	-0.00725	0.051824	-0.02083	0.040924	-0.02006	0.05413	-0.00761	0.048346	-0.01635	0.050588
MM6	-0.02538	0.044462	-0.00739	0.045927	-0.0111	0.049763	-0.01524	0.057531	-0.02364	0.049456	-0.0095	0.043405
MM7	-0.01052	0.055048	-0.00829	0.052652	-0.01769	0.048699	-0.01843	0.056561	-0.00901	0.044988	-0.0132	0.046293
MM8	-0.00869	0.040277	-0.00865	0.037923	-0.01739	0.045589	-0.01756	0.044307	-0.01594	0.038073	-0.01629	0.048957
MM9	-0.01736	0.034678	-0.01358	0.046789	-0.01526	0.037138	-0.01627	0.05909	-0.00739	0.033636	-0.01396	0.073423
MM10	-0.0172	0.062473	-0.00933	0.044676	-0.0192	0.039949	-0.01598	0.045884	-0.00752	0.039924	-0.01444	0.048467
MM11	-0.02612	0.048303	-0.00958	0.035783	-0.01543	0.048008	-0.01617	0.061184	-0.00985	0.034588	-0.01164	0.045274
MM12	-0.02199	0.039912	-0.01088	0.044469	-0.01562	0.048713	-0.01319	0.058953	-0.02317	0.036312	-0.01318	0.054047
MM13	-0.02267	0.040488	-0.01071	0.042565	-0.02354	0.036698	-0.01842	0.053849	-0.02399	0.036655	-0.0113	0.04221
MM14	-0.01232	0.057681	-0.01017	0.047318	-0.0146	0.044678	-0.01451	0.037341	-0.0067	0.034374	-0.01328	0.05058
MM15	-0.02334	0.043316	-0.00884	0.031115	-0.01637	0.04289	-0.01121	0.065243	-0.01723	0.036364	-0.01152	0.053021
Total	-0.03268	0.075177	-0.01358	0.068424	-0.02354	0.068763	-0.02006	0.080233	-0.02625	0.082266	-0.03055	0.073423

The lowest, highest and total discrepancy values of the DW CAD smoothing for each abutment obtained after 15 superimpositions were given in Table 3.

**Table 3.** Discrepancy values after DW CAD\* smoothing for each abutment.

	RCa <sup>†</sup>		RLa <sup>‡</sup>		RCe <sup>§</sup>		LCe <sup>¶</sup>		LLa <sup>**</sup>		LCa <sup>††</sup>	
	Lowest	Highest	Lowest	Highest	Lowest	Highest	Lowest	Highest	Lowest	Highest	Lowest	Highest
DW1	-0.00705	0.124876	-0.0222	0.116822	-0.02685	0.119108	-0.01172	0.118838	-0.0235	0.130376	-0.03936	0.215964
DW2	-0.00981	0.112367	-0.01544	0.121002	-0.02961	0.114548	-0.01012	0.095058	-0.00528	0.107573	-0.02153	0.161726
DW3	-0.0144	0.167377	-0.02476	0.130192	-0.02939	0.13558	-0.015	0.144993	-0.01542	0.104284	-0.03583	0.157249
DW4	-0.03561	0.128734	-0.0214	0.128582	-0.02169	0.122691	-0.01056	0.126099	-0.01792	0.126616	-0.01925	0.144318
DW5	-0.01441	0.1441	-0.02107	0.106481	-0.02825	0.105356	-0.01427	0.12197	-0.02276	0.141832	-0.02584	0.155669
DW6	-0.04132	0.118747	-0.01406	0.095607	-0.02559	0.111245	-0.01196	0.137587	-0.00821	0.113162	-0.02787	0.145421
DW7	-0.01898	0.11603	-0.01692	0.092372	-0.01358	0.120799	-0.01351	0.109876	-0.00763	0.116278	-0.0237	0.148195
DW8	-0.01086	0.097456	-0.02208	0.100139	-0.02672	0.108406	-0.01465	0.151256	-0.01425	0.176038	-0.03987	0.181374
DW9	-0.02383	0.120369	-0.02867	0.127189	-0.02004	0.136936	-0.00662	0.140696	-0.02551	0.117271	-0.03497	0.180382
DW10	-0.01644	0.141677	-0.02528	0.11746	-0.02189	0.133228	-0.01398	0.144678	-0.01458	0.153179	-0.02858	0.154892
DW11	-0.01035	0.128855	-0.0197	0.144949	-0.02759	0.110554	-0.02096	0.147244	-0.02321	0.149746	-0.03142	0.174845
DW12	-0.01059	0.144383	-0.01659	0.134102	-0.01952	0.147757	-0.01036	0.172412	-0.03117	0.144545	-0.02974	0.16992
DW13	-0.03362	0.154672	-0.02164	0.107011	-0.03226	0.101046	-0.01125	0.098461	-0.01777	0.136848	-0.05446	0.156654
DW14	-0.05548	0.124912	-0.01802	0.127545	-0.02841	0.15352	-0.01829	0.143485	-0.02188	0.139846	-0.04559	0.178735
DW15	-0.01445	0.140788	-0.02166	0.108189	-0.03329	0.130342	-0.0092	0.126276	-0.02226	0.126953	-0.04501	0.151896
Total	-0.05548	0.167377	-0.02867	0.144949	-0.03329	0.15352	-0.02096	0.172412	-0.03117	0.176038	-0.05446	0.215964

Descriptive analysis results of the discrepancy values obtained from all 45 superimpositions of the SIWOCs with the REWOC were given in Table 4.

**Table 4.** Descriptive statistical results of 45 SIWOC\*-REWOC† superimpositions.

						95% Confidence Interval of Mean	
	N	Mean	Standard Deviation	Minimum	Maximum	Lower Bound	Upper Bound
BL‡	90	.00010315	.000020899	.000059	.000166	.00009878	.00010753
MM§	90	.00003094	.000011943	.000010	.000079	.00002844	.00003345
DW¶	90	.00010152	.000120107	.000033	.001195	.00007636	.00012667
Total	270	.00007854	.000078114	.000010	.001195	.00006918	.00008790

The lowest significant discrepancy scores were recorded in the group smoothed with MM software. The effect of CAD software on the discrepancy caused by the smoothing procedure was evaluated using the one-way ANOVA test. A significant difference was found between the mean values ( $P=0.000$ ). For the detection of which group pairs had a significant difference, multiple comparisons were performed with the Tukey HSD test. Values over .05 were accepted statistically significant. Results revealed significant differences between MM and BL ( $P=0.000$ ), and MM and DW ( $P=0.000$ ) groups. However, no significance was found between DW and BL values ( $P=0.987$ ).

The descriptive analysis data of the discrepancy values of the RCa, RLa, RCe, LCe, LLa, and LCa abutments of BL, MM and DW SIWOCs are given in Table 5.

**Table 5.** Descriptive analysis results of the discrepancy values of BL, MM and DW CAD softwares smoothing.

						95% Confidence Interval of Mean	
	N	Mean	Standard Deviation	Minimum	Maximum	Lower Bound	Upper Bound
Blender CAD Software							
RCa	15	.00009249	.000016847	.000059	.000115	.00008316	.00010182
RLa	15	.00010626	.000009468	.000088	.000125	.00010101	.00011150
RCE	15	.00008251	.000011633	.000064	.000104	.00007607	.00008895
LCE	15	.00009395	.000011578	.000076	.000118	.00008753	.00010036
LLa	15	.00013030	.000019110	.000097	.000166	.00011972	.00014088
LCa	15	.00011341	.000013656	.000083	.000132	.00010585	.00012097
Total	90	.00010315	.000020899	.000059	.000166	.00009878	.00010753
Meshmixer CAD Software							
RCa	15	.00002866	.000013659	.000014	.000052	.00002110	.00003623
RLa	15	.00003667	.000010351	.000021	.000056	.00003094	.00004240
RCE	15	.00002379	.000008604	.000010	.000042	.00001903	.00002856
LCE	15	.00003200	.000010098	.000017	.000050	.00002641	.00003759
LLa	15	.00003383	.000016533	.000014	.000079	.00002468	.00004299
LCa	15	.00003070	.000007622	.000019	.000047	.00002648	.00003492
Total	90	.00003094	.000011943	.000010	.000079	.00002844	.00003345
DWOS CAD Software							
RCa	15	.00016469	.000285672	.000057	.001195	.00000649	.00032289
RLa	15	.00009298	.000014351	.000073	.000121	.00008504	.00010093
RCE	15	.00007206	.000015059	.000049	.000097	.00006372	.00008040
LCE	15	.00004862	.000009189	.000033	.000065	.00004353	.00005371
LLa	15	.00012304	.000022361	.000083	.000174	.00011066	.00013542
LCa	15	.00010769	.000016148	.000082	.000152	.00009875	.00011664
Total	90	.00010152	.000120107	.000033	.001195	.00007636	.00012667

The one-way ANOVA test was used to determine whether the discrepancy values of RCa, RLa, RCE, LCE, LLa, and LCa abutments caused by the smoothing process at the finish lines show a significant change depending on the CAD software program. Significant difference was found between the average of the discrepancy values caused by 3 different CAD software ( $P=0.000$ ). Tukey HSD test was used to determine which CAD software programs caused significant changes in which abutments. P values greater than 0.05 were considered statistically significant. The results are given in Table 6.

**Table 6.** The results of the Tukey HSD multiple comparison test.

Abutment	(I) Group	(J) Groups	Mean Difference (I-J)	Significance	95% Confidence Interval	
					Lower Bound	Upper Bound
RCa	1-BL	2-MM	.000063822	.546	-.00008292	.00021056
		3-DW	-.000072208	.462	-.00021895	.00007453
	2-MM	1-BL	-.000063822	.546	-.00021056	.00008292
		3-DW	-.000136030	.074	-.00028277	.00001071
RLa	1-BM	2-MM	.000069587	.000	.00005931	.00007987
		3-DW	.000013274	.009	.00000300	.00002355
	2-MM	1-BL	-.000069587	.000	-.00007987	-.00005931
		3-DW	-.000056313	.000	-.00006659	-.00004603
RCe	1-BL	2-MM	.000058717	.000	.00004802	.00006941
		3-DW	.000010455	.057	-.00000024	.00002115
	2-MM	1-BL	-.000058717	.000	-.00006941	-.00004802
		3-DW	-.000048263	.000	-.00005896	-.00003757
LCe	1-BL	2-MM	.000061948	.000	.00005278	.00007112
		3-DW	.000045327	.000	.00003616	.00005450
	2-MM	1-BL	-.000061948	.000	-.00007112	-.00005278
		3-DW	-.000016621	.000	-.00002579	-.00000745
LLa	1-BL	2-MM	.000096467	.000	.00007918	.00011375
		3-DW	.000007261	.568	-.00001002	.00002454
	2-MM	1-BL	-.000096467	.000	-.00011375	-.00007918
		3-DW	-.000089207	.000	-.00010649	-.00007192
LCa	1-BL	2-MM	.000082711	.000	.00007120	.00009422
		3-DW	.000005717	.456	-.00000580	.00001723
	2-MM	1-BL	-.000082711	.000	-.00009422	-.00007120
		3-DW	-.000076994	.000	-.00008851	-.00006548

For all abutments except RCa, significant differences were found between the discrepancy values in the comparisons of MM- BL ( $P=0.000$ ) and MM- DW ( $P=0.000$ ). For the abutment RCa, discrepancy differences were not significant in any of the comparisons; MM- BL ( $P=0.546$ ), MM- DW ( $P=0.074$ ) ve DW- BL ( $P=0.462$ ). Furthermore, in BL-DW discrepancy comparison, no significant difference was found for the RCe ( $P=0.057$ ), LLa ( $P=0.568$ ) ve LCa ( $P=0.456$ ) abutments either. MM CAD software caused significantly less discrepancy in smoothing procedures.

## Discussion

According to the results of the study, nondental CAD software produced less discrepancy than the dental software in a particular stage of the design procedure. Thus, the null hypothesis was rejected.

The competitive nature of the demanding market has caused the development of several dental CAD programs with annually updated similar modular tools.<sup>27,32</sup> In these systems, particular algorithms are used for certain processes, and some features of the design procedure are performed by dental professionals manually. It is possible to state that using a medical device successfully depends on complex interactions as learning curves and human factors.<sup>9,28,32</sup> Moreover, the level of computer literacy and the type of the operating dental professional are effective parameters on the proper use of the CAD software.<sup>9,28,29</sup>

Yet, there is no study to our knowledge that compared the capacities of dental and non-dental CAD software. The reason for the low study numbers on dental CAD software is thought to be the tendency of the researchers to avoid this field of interest with quite complex algorithms. In our opinion, this is the most important reason why indirect methods have been used, far from achieving specific results, in studies investigating the success of different dental CAD software so far. Examining the very few studies in this field, it is seen that only the dental CAD software was changed where other variables were kept constant in different experimental groups, and the software that produced the most successful restoration was tried to be determined.<sup>25</sup> In a randomized clinical trial, Gintatute et al<sup>25</sup> evaluated the performance of different workflows generated by three dental CAD programs to determine the success rate of ZrO<sub>2</sub> based fixed prostheses. In this well-designed study, laboratory cross-mounting analysis and time required for chairside fitting were used as two success indicators. However, it seems very difficult to determine the effect of dental CAD software in this type of study design. Studies evaluating the marginal fit and mechanical properties of metal substructures produced with different CAD-CAM systems have been used as another indirect way to define the accuracy of dental CAD software. However, it is seen that data acquisition devices and CAM systems are the main variables of those studies when the applied methods are examined carefully.<sup>38,39</sup>

In one of the few studies on the capabilities of different CAD software, Farook et al<sup>35</sup> observed significant changes in the number of vertexes, surface area, and volume of the mesh structure following the mesh optimization of the virtual model with nondental CAD software. The results of Farook et al's<sup>35</sup> fully automated, human-factor-free research are parallel with the present study in which the design tools of the same software were used by a dental professional. In the present study, statistically significant discrepancy values were found after the procedures carried out by an experienced operator with the same tools and settings in a dental and two nondental CAD software. The discrepancy scores of the smoothing procedures performed with MM CAD were significantly lower than both BL and DW (P=0.000, P=0.000). Only the discrepancy recorded for RCa was found insignificant among all other five abutments after the

smoothing. The reason behind this specific result is thought to be generated from its location in the REWOC. When the model was re-evaluated, the finish line of the RCa was found more subgingivally prepared than its symmetric, LCa. Although during the design procedures, shaded areas were observed on the distal side of the RCa with nondental programs, none was reported by the operator with the dental CAD software. To produce a model based on natural abutment teeth and dental arches with exact symmetry seems impossible unlike the previous studies<sup>22,30</sup> that utilized geometric figures instead of anatomical features.

Another substantial result of the study is the more accurate smoothing performance of the nondental software over dental CAD. Kim et al<sup>27</sup> reported significant changes in the usability of the dental CAD software in their study that employed 20 dental technicians and 12 dentistry students as users. They also stated that changes were observed depending on the different software tools. However, variations in the trueness and precision of the obtained data were reported to be seen by changing the scan strategy in the intraoral scanning stage where the users don't interfere with the CAD software.<sup>10,12,13</sup>

Therefore, to identify the causes of the differences in accuracy and precision between CAD programs, studies that evaluate both process precision and usability have to be designed. Though the brush diameter and strength settings of the tools may be nominally the same, the impacts of the same settings may be unequal in different CAD software. Thus, this probable anomaly of calibration between different CAD systems also deserves to be assessed in further researches. The reliability of the present study depends on the employment of a dental professional with 10-years of CAD experience for manual smoothing who underwent training and performed 15 procedures on each system.

Son and Lee<sup>28</sup> pointed out the importance of basic computer skills of the users that would use the CAD software for the first time. However, the authors also emphasized that if the users have clinical experience, the significance of computer literacy would be less. The training the user got on the CAD programs contributed to the reliability of the results. Moreover, reaching more precise results with nondental CAD software which the user was unfamiliar with until the training may be accepted as another indication of an accurate research method.

The reasons behind the preference of the 'smoothing' tool for the processing precision evaluation were the easy detectability of its effects with superimposition software and its availability in all CAD systems with setting opportunities for diameter, strength, depth, and laziness features.

Whereas smoothing on the virtual working casts of abutments with equ-gingival and supragingival shoulder finish lines is unnecessary and even undesired, subgingivally prepared

knife-edge finish lines may turn out to be a different matter.<sup>14</sup> Dental technicians may have to zoom in and use the smoothing design tool on the region to locate and/or bring out the finish lines.<sup>32</sup>

The chief objection points out the risk of marginal fit of the restoration posed by smoothing even before the design starts. However, numerous factors may affect the precision of the design in the early stages of the CAD procedure before the smoothing. The study that compared pre-sectioned and post-sectioned die positions on a reference working model with five geometric conic abutments revealed significant differences in positions, particularly of the anterior abutment. It was also reported that gingiva was not simulated, and no trimming was applied on the margins of the abutments in the same research.<sup>30</sup> Besides, the irregularities of the mesh structure on the outmost section of the finish lines of the abutments in Figure 1 is in the region that would be trimmed during a die fabrication.

There are some limitations of the present study. For the comparison of the processing precision, one design tool was used. Although the most frequently used tool for the fabrication of a fixed restoration is the margin drawing tool, not all nondental CAD software include one.<sup>32</sup> Moreover, creating an STL file of the drawn margins and comparing these using superimposition software is not available yet. Another limitation is the utilization of only three CAD programs in the study. Despite the difficulties of comparing higher numbers of software, further studies may improve the know-how on the issue.

Employing one operator as the user of the software may also be considered a limitation. However, methodological approaches of the numerous studies evaluated the marginal fit of the indirect restorations fabricated using CAD/CAM systems are no different than the methodology of the presented study and no details were given on the number or the specialities of the CAD operators.<sup>11,16,17,20-22</sup> As establishing a group of CAD users with similar levels of experience and skill sets is quite challenging, the situation is similar in evidence-based researches benefited from as major references.<sup>3,18,19</sup> Consequently, the lack of studies with similar aims and design in the literature limited the writing of a comprehensive discussion section.

## **Conclusion**

1. Smoothing procedure performed by the same operator in nondental, and dental CAD software may lead to different discrepancy values despite the same brush diameter and strength settings.

2. Nondental CAD software can perform smoothing with less discrepancy.

3. Commencing further studies including multiple users and software for the evaluation of different design tools seems imperative.

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