



Dimensional Changes of 3-Unit Implant-Supported Zirconia Frameworks of Two CAD/CAM Systems from Scanning to Sintering

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ABSTRACT

Objectives: Internal fit of implant frameworks is an important factor determining the long-term success of dental implant restorations. This in-vitro study aimed to evaluate dimensional changes of implant-supported zirconia frameworks fabricated by two computer-aided design/computer-aided manufacturing (CAD/CAM) systems from scanning to sintering.

Materials and Methods: A master model of a three-unit fixed partial denture was fabricated with two implant abutments. In each CAD/CAM system (AmannGirrbach and Zirkozahn), the master model was scanned 12 times, and data were saved as Standard Transformation Language files (scanning groups). Using semi-sintered zirconia, 12 real-size frameworks (milling groups) and 12 enlarged frameworks, were sintered (sintering groups) and made by each system. Dimensions of the master model and frameworks in each phase were measured. Dimensional changes (compared to the master model) were calculated. Data were analyzed using repeated measures analysis of variance, independent t-test, and paired sample t-test ($\alpha=0.05$).

Results: Comparison of the two systems revealed that although dimensional changes were greater in the milling phase of Zirkozahn, they were larger in the sintering phase of the AmannGirrbach system. Evaluation of fabrication phases revealed greater dimensional changes in the milling phase compared to the other phases in the Zirkozahn system ($P<0.05$). However, in the AmannGirrbach system, the values were not significantly different between milling and sintering phases ($P>0.05$).

Conclusion: Within the limitations of this study, the results showed that fabrication phases, CAD/CAM system type and abutment size had significant effects on dimensional changes.

Keywords: Zirconium; CAD-CAM; Dental Prosthesis; Implant-Supported; Prosthesis Fitting; Dental Abutments; Materials Testing

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INTRODUCTION

Introduction of dental implants revolutionized the prosthetic treatment of edentulous and semi-edentulous patients [1]. However, despite a high clinical success rate, many technical issues have been reported with regard to the use of fixed implant-supported restorations [2,3]. Due to the absence of a periodontal ligament (PDL), the attachment between osseointegrated implants and the surrounding bone is more rigid compared to that in natural teeth [4]. Therefore, passive fit in implant-supported restorations is much more important than that in tooth-supported restorations [5]. Passive fit is now considered an important parameter determining the long-term success of osseointegrated implants [6] and preventing future complications [7].

Misfit of prosthetic frameworks might result in a wide range of biological effects, including bone deformation and remodeling, micro-damage to the bone, progressive bone loss [8], and eventual failure of osseointegration [4,9]. Some finite element analyses have shown that greater amounts of vertical gap in implant-supported fixed partial dentures result in a higher amount of stress applied to the surrounding bone [10,11]. Aside from biological problems, misfit of prosthetic frameworks can cause numerous mechanical problems, including porcelain and abutment fracture, screw loosening or fracture, and framework fracture [4,7,8].

Framework material is another important factor affecting biomechanical responses [12]. Recently, zirconia frameworks were introduced as an aesthetic alternative to metal frameworks for implant restorations because they are highly aesthetic and biocompatible and have a lower risk of microbial plaque accumulation. They are chemically durable and have excellent mechanical properties [13]. They do not have the problems of metal frameworks such as corrosion and poor aesthetics [1]. These advantages have mainly contributed to increasing the use of zirconia frameworks for dental prostheses [4].

Computer-aided design/computer-aided

manufacturing (CAD/CAM) systems are among the most commonly used systems for the fabrication of zirconia frameworks. In these systems, patients' mouth or casts are mechanically or optically scanned, and digital data are transferred to the system. A framework is virtually designed by the CAD program, and then, based on the available data, a restoration is milled by the CAM part of the system out of a zirconia block [14,15]. Several factors may affect the accuracy of zirconia restorations in their fabrication process by a CAD/CAM system, including the process of scanning, processing of collected geometric data, calculation of milling parameters, actual milling process, and shrinkage of zirconia during sintering [14]. Since these factors may vary in different CAD/CAM systems, it should be noted that dimensional changes and marginal fit of zirconia restorations may be affected by the manufacturing system [16].

The final accuracy of zirconia framework fabricated by different CAD/CAM systems has been the topic of many previous studies but errors in each fabrication phase (scanning, milling, and sintering) have not been separately evaluated, and it is not well known that which phase has the highest rate of errors in the process of manufacturing of zirconia frameworks [17-22]. This study aimed to assess the dimensional changes of three-unit implant-supported zirconia frameworks during fabrication by two CAD/CAM systems (AmannGirrbach and Zirkozahn) to compare the accuracy of each fabrication phase in the two systems and find the phase with the highest rate of errors causing misfit in each system. The null hypothesis was that the dimensional change of implant-supported zirconia frameworks is not influenced by abutment size, fabrication phase or type of CAD/CAM system.

MATERIALS AND METHODS

This study compared the accuracy of scanning (SC), milling (MI), and sintering (SI) phases of AmannGirrbach (AG; Amann Girrbach GmbH, Pforzheim, Germany) and Zirkozahn (ZZ; Zirkozahn Deutschland

GmbH, Neuler, Germany) CAD/CAM systems for the fabrication of three-unit implant-supported zirconia frameworks. For this purpose, a master model of a three-unit restoration was fabricated with two-piece straight abutments (Implantium, Dentium, Seoul, South Korea) with a 1.5-mm gingival height and different sizes. The canine abutment had a 4.5-mm diameter and a 5.5-mm height, and the premolar abutment had a 5.5-mm diameter and a 4-mm height. Abutments were connected to fixture analogs and were mounted in an aluminum block. Mounting was done using a surveyor in order to ensure the parallel position of the abutments relative to each other and the parallel position of their finish line relative to the block surface.

In each system, after calibration, the master model was scanned by the scanner (S600 ARTI Scanner for ZZ and Ceramill Map 400 for AG), and data were saved in a file with Standard Transformation Language (STL) format. These files represented the scanning data for the two groups (scanning groups, namely, AG-SC and ZZ-SC).

Data obtained by scanning were transferred to the software of the respective system, and the external framework surface was designed using a framework pattern. The frameworks were designed in the form of a maxillary three-unit fixed partial denture supported by a canine and a second premolar abutment with a 12-mm² connector and a 1.1-mm veneer space.

Based on the data obtained by scanning, an actual size (same size as the master model) framework was milled out of a semi-sintered zirconia block by the two systems (M5 heavy milling unit in ZZ and Ceramill Motion 2 in AG) and remained without sintering (milling groups, namely, AG-MI and ZZ-MI).

Using the same data obtained by scanning, another framework was milled out of semi-sintered zirconia in a larger size (to compensate for 20% sintering shrinkage) and was sintered in the respective furnace (Zirkonofen 600/V3 for ZZ and Ceramill Therm 3 for AG). The master model size was achieved after sintering (sintering groups,

namely, AG-SI and ZZ-SI). The sintering temperature for zirconia was 1450°C and 1500°C in AmannGirrbach and Zirkonzahn systems, respectively. The duration of sintering was eight hours. These steps were repeated 12 times for each system. Thus, we had 12 STL files containing scanning data of the master model (AG-SC and ZZ-SC groups), 12 frameworks in the milling phase (AG-MI and ZZ-MI groups), and 12 frameworks in the sintering phase (AG-SI and ZZ-SI groups) (Fig. 1 and Table 1).

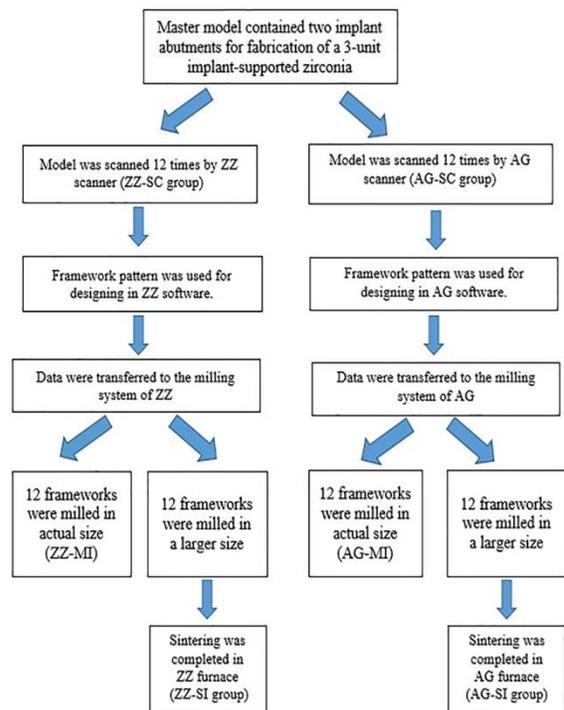


Fig. 1. Fabrication of frameworks with Zirkonzahn (ZZ) and AmannGirrbach (AG) systems

Dimensions of the master model were measured by the Video Measuring System(VMS; ARCS, Taiwan, Taichung) in certain areas (inter-abutment and intra-abutment distances) and were used as a reference for the assessment of possible changes during fabrication steps (Fig. 2).

Using the scanning files, dimensions of the master model were measured by CATIA software (Dassault Systèmes), and dimensional changes (compared to the master model) were calculated. These

Table 1. Description of study groups

Group	CAD/CAM system	Fabrication phase	Steps performed
AG-SC	AmannGirrbach (AG)	SC	SC
AG-MI		MI	SC+MI
AG-SI		SI	Sc+MI+SI
ZZ-SC	Zirkonzahn (ZZ)	SC	SC
ZZ-MI		MI	SC+MI
ZZ-SI		SI	SC+MI+SI

SC: Scanning, MI: Milling, SI: Sintering, CAD/CAM: Computer-Aided Design/Computer-Aided Manufacturing

changes indicated errors up until the scanning phase. Dimensions of the milling phase (not yet sintered) frameworks and sintered frameworks were measured as well

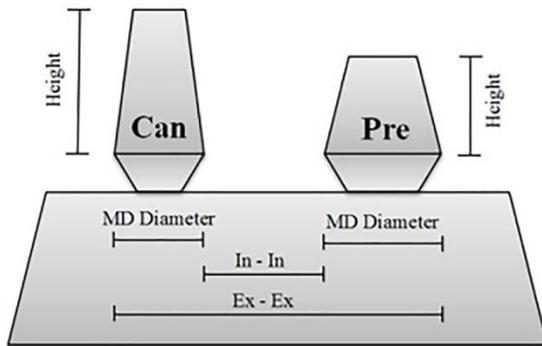


Fig. 2. Measured distances: Intra-abutment distances included the height, the buccolingual (BL) diameter (not seen in the Figure), and the mesiodistal (MD) diameter for each of the canine (Can) and premolar (Pre) abutments; inter-abutment distances included the internal to internal distance (In-In) and the external to external distance (Ex-Ex)

by the VMS device, and dimensional changes (compared to the master model) were calculated.

Dimensional changes before sintering and after sintering (the final error rate) were determined as well (Fig. 3).

The effect of three factors, namely, type of CAD/CAM system, manufacturing phase, and abutment size, on dimensional changes of frameworks was analyzed using repeated measures analysis of variance (ANOVA).

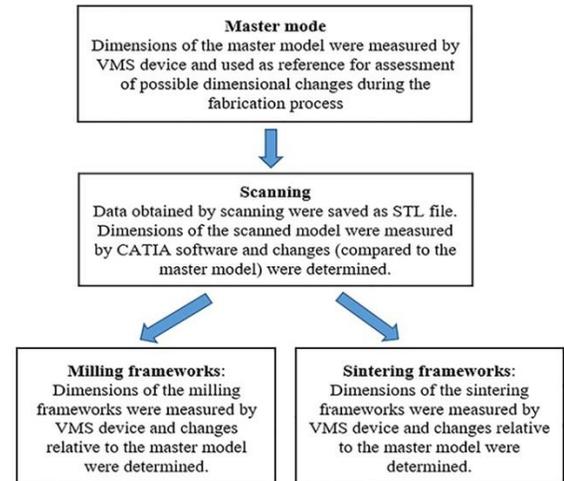


Fig. 3. Measurement of dimensional changes

Whenever the interaction effect of the factors on dimensional changes was significant, one factor was eliminated, and proper analysis was carried out. If all interaction effects were significant, the independent effect of each factor was evaluated. Paired t-test (the size of abutment) and repeated measures ANOVA (fabrication phase) were applied for attached data. Independent t-test was used for independent data (the type of CAD/CAM system). The level of significance was set at 0.05.

RESULTS

The results of the present study are summarized in Tables 2 to 6.

Intra-abutment dimensional changes:

In both systems and in all fabrication phases, changes in the height of premolar were greater than that of the canine abutment ($P < 0.05$); no other significant differences were noted between the two abutments ($P > 0.05$).

In the AG system, changes in the mesiodistal diameter of the canine abutment in the scanning phase were significantly lower than those in the other two phases but no other significant differences were noted between the phases. In the ZZ system, changes in all dimensions in the milling phase were greater than those in the other two phases; however, this difference was not statistically significant for the canine abutment height. In this

Table 2. Descriptive data of intra-abutment dimensional changes (μm) and comparison of the two Computer-Aided Design/Computer-Aided Manufacturing (CAD/CAM) systems

Intra-abutment dimension	Fabrication phase	Abutment	Amann-Girrbach (AG) Mean \pm SD	Zirkonzahn (ZZ) Mean \pm SD	MD (AG-ZZ)	SE	95% CI	P-value
Mesiodistal diameter	SC	Premolar	0.028 \pm 0.017	0.046 \pm 0.01	-0.02	0.006	-0.029 - -0.006	0.005
		Canine	0.013 \pm 0.013	0.027 \pm 0.013	-0.01	0.005	-0.025 - -0.003	0.012
	MI	Premolar	0.045 \pm 0.027	0.172 \pm 0.069	-0.13	0.021	-0.171 - -0.082	<0.001
		Canine	0.053 \pm 0.024	0.16 \pm 0.084	-0.11	0.025	-0.159 - -0.055	0.001
	SI	Premolar	0.04 \pm 0.026	0.024 \pm 0.015	0.02	0.009	-0.002 - 0.034	0.086
		Canine	0.056 \pm 0.033	0.027 \pm 0.016	0.03	0.010	0.008 - 0.051	0.013
Buccolingual diameter	SC	Premolar	0.066 \pm 0.039	0.04 \pm 0.039	0.03	0.016	-0.008 - 0.058	0.128
		Canine	0.06 \pm 0.038	0.028 \pm 0.014	0.03	0.012	0.008 - 0.057	0.015
	MI	Premolar	0.072 \pm 0.023	0.172 \pm 0.083	-0.1	0.025	-0.151 - -0.048	0.002
		Canine	0.064 \pm 0.035	0.153 \pm 0.072	-0.09	0.023	-0.137 - -0.042	0.001
	SI	Premolar	0.061 \pm 0.041	0.029 \pm 0.022	0.03	0.014	0.004 - 0.061	0.025
		Canine	0.048 \pm 0.036	0.024 \pm 0.017	0.02	0.011	0 - 0.048	0.053
Height	SC	Premolar	0.186 \pm 0.056	0.165 \pm 0.025	0.02	0.018	-0.016 - 0.058	0.249
		Canine	0.122 \pm 0.035	0.071 \pm 0.027	0.05	0.013	0.025 - 0.078	<0.001
	MI	Premolar	0.228 \pm 0.054	0.18 \pm 0.029	0.05	0.018	0.011 - 0.084	0.013
		Canine	0.084 \pm 0.046	0.077 \pm 0.049	0.01	0.019	-0.033 - 0.047	0.726
	SI	Premolar	0.193 \pm 0.052	0.103 \pm 0.027	0.09	0.017	0.055 - 0.125	<0.001
		Canine	0.093 \pm 0.051	0.05 \pm 0.033	0.04	0.018	0.007 - 0.079	0.023

SD: Standard Deviation, MD: Mean Difference; SE: Standard Error; CI: Confidence Interval, SC: Scanning, MI: Milling, SI: Sintering

system, changes in the mesiodistal diameter and the height of the premolar abutment in the sintering phase were lower than those in the scanning phase but no other significant differences were noted between the phases. In the scanning phase, changes in the mesiodistal diameter were greater in the ZZ system but changes in the buccolingual diameter (canine) and the height (canine) in the AG system were significantly greater than

those in the ZZ system.

In the milling phase, changes in the mesiodistal and buccolingual diameters were greater in the ZZ system but changes in the height (premolar) were significantly greater in the AG system. In the sintering phase, changes in the mesiodistal and buccolingual diameters (premolar) and the height in the AG system were significantly greater than those in the ZZ system.

Table 3. Comparison of premolar and canine abutments in terms of the effect on dimensional changes (μm)

Intra-abutment dimension	CAD/CAM system	Fabrication phase	Mean difference (Premolar-Canine)	Standard error	95% CI	P-value
Mesiodistal diameter	AmannGirrbach	SC	0.02	0.007	-0.001 - 0.032	0.060
		MI	-0.01	0.012	-0.034 - 0.018	0.525
		SI	-0.02	0.010	-0.037 - 0.005	0.124
	Zirkonzahn	SC	0.02	0.006	-0.007 - 0.031	0.006
		MI	0.01	0.013	-0.017 - 0.04	0.387
		SI	-0.002	0.005	-0.014 - 0.01	0.686
Buccolingual diameter	AmannGirrbach	SC	0.01	0.013	-0.023 - 0.033	0.696
		MI	0.01	0.008	-0.008 - 0.026	0.268
		SI	0.01	0.017	-0.024 - 0.05	0.455
	Zirkonzahn	SC	0.01	0.009	-0.007 - 0.033	0.184
		MI	0.02	0.011	-0.005 - 0.043	0.114
		SI	0.01	0.007	-0.01 - 0.019	0.502
Height	AmannGirrbach	SC	0.06	0.016	0.028 - 0.099	0.002
		MI	0.14	0.021	0.097 - 0.189	<0.001
		SI	0.1	0.017	0.062 - 0.138	<0.001
	Zirkonzahn	SC	0.09	0.009	0.074 - 0.114	<0.001
		MI	0.1	0.017	0.065 - 0.14	<0.001
		SI	0.05	0.009	0.033 - 0.073	<0.001

CAD/CAM: Computer-Aided Design/Computer-Aided Manufacturing; CI: Confidence Interval; SC: Scanning; MI: Milling; SI: Sintering

Inter-abutment dimensional changes:

In both systems, changes in the external distance in the scanning phase were significantly less than those in the other two phases. In the ZZ system, these changes in the milling phase were greater than those in the sintering phase ($P < 0.05$). Regarding internal-internal changes in the AG system, no significant difference was noted between the manufacturing phases ($P > 0.05$) but in the ZZ system, changes in the milling phase were significantly greater than those in the other two phases ($P < 0.05$). It should be noted that

in the AG system, changes in both distances in the sintering phase were greater than those in the milling phase but these differences were not statistically significant ($P > 0.05$). In the scanning phase, no significant difference was noted between the two systems ($P > 0.05$). In the milling phase, changes in both distances in the ZZ system were significantly greater than those in the AG system ($P < 0.05$) but in the sintering phase, changes in the external-external distance in the AG system were significantly greater than those in the ZZ system ($P = 0.003$).

Table 4. Comparison of fabrication phases in terms of the effect on dimensional changes (µm) of abutments

Intra-abutment dimension	CAD/CAM system	Comparison of phases		Abutment	MD	SE	95% CI	P value	
Mesiodistal diameter	AmannGirrbach	SC	MI	Premolar	-0.02	0.008	-0.039 - 0.006	0.179	
				Canine	-0.04	0.007	-0.061 - -0.019	<0.001	
		SC	SI	Premolar	-0.01	0.01	-0.041 - 0.017	0.834	
				Canine	-0.04	0.01	-0.072 - -0.014	0.004	
		MI	SI	Premolar	0.01	0.01	-0.022 - 0.032	1	
				Canine	-0.003	0.009	-0.029 - 0.023	1	
	Zirkonzahn	SC	MI	Premolar	-0.13	0.021	-0.183 - -0.068	<0.001	
				Canine	-0.13	0.025	-0.202 - -0.063	<0.001	
		SC	SI	Premolar	0.02	0.005	0.007 - 0.037	0.005	
				Canine	0.001	0.007	-0.018 - 0.019	1	
		MI	SI	Premolar	0.15	0.02	0.092 - 0.203	<0.001	
				Canine	0.13	0.023	0.068 - 0.198	<0.001	
	Buccolingual diameter	AmannGirrbach	SC	MI	Premolar	-0.01	0.013	-0.043 - 0.029	1
					Canine	-0.003	0.015	-0.044 - 0.038	1
SC			SI	Premolar	0.01	0.014	-0.035 - 0.044	1	
				Canine	0.01	0.017	-0.037 - 0.061	1	
MI			SI	Premolar	0.01	0.013	-0.025 - 0.048	1	
				Canine	0.02	0.015	-0.026 - 0.058	0.944	
Zirkonzahn		SC	MI	Premolar	-0.13	0.022	-0.194 - -0.069	<0.001	
				Canine	-0.13	0.02	-0.182 - -0.069	<0.001	
		SC	SI	Premolar	0.01	0.014	-0.028 - 0.052	1	
				Canine	0.004	0.008	-0.018 - 0.025	1	
		MI	SI	Premolar	0.14	0.024	0.075 - 0.211	<0.001	
				Canine	0.13	0.02	0.071 - 0.187	<0.001	
Height		AmannGirrbach	SC	MI	Premolar	-0.04	0.023	-0.108 - 0.024	0.309
					Canine	0.04	0.015	-0.005 - 0.082	0.092
	SC		SI	Premolar	-0.01	0.014	-0.046 - 0.032	1	
				Canine	0.03	0.02	-0.028 - 0.086	0.529	
	MI		SI	Premolar	0.03	0.023	-0.03 - 0.099	0.490	
				Canine	-0.01	0.024	-0.077 - 0.059	1	
	Zirkonzahn	SC	MI	Premolar	-0.02	0.006	-0.031 - 0.001	0.069	
				Canine	-0.01	0.017	-0.054 - 0.041	1	
		SC	SI	Premolar	0.06	0.012	0.027 - 0.096	0.001	
				Canine	0.02	0.007	0 - 0.041	0.054	
		MI	SI	Premolar	0.08	0.013	0.04 - 0.113	<0.001	
				Canine	0.03	0.019	-0.026 - 0.079	0.531	

SI: Sintering; SC: Scanning; MI: Milling; CAD/CAM: Computer-Aided Design/Computer-Aided Manufacturing; MD: Mean Difference; SE: Standard Error; CI: Confidence Interval

Table 5. Descriptive statistics of inter-abutment dimensional changes (μm) and comparison of Computer-Aided Design/Computer-Aided Manufacturing (CAD/CAM) systems

Inter-abutment dimension	Fabrication phase	AmannGirrbach Mean \pm SD	Zirkonzahn Mean \pm SD	MD (AG-ZZ)	SE	95% CI	P-value
External	SC	0.036 \pm 0.017	0.028 \pm 0.017	0.01	0.007	-0.006 - 0.023	0.232
	MI	0.104 \pm 0.037	0.164 \pm 0.078	-0.06	0.025	-0.112 - -0.008	0.03
	SI	0.123 \pm 0.048	0.069 \pm 0.015	0.05	0.015	0.024 - 0.084	0.003
Internal	SC	0.022 \pm 0.012	0.035 \pm 0.027	-0.01	0.009	-0.032 - 0.004	0.125
	MI	0.019 \pm 0.015	0.144 \pm 0.073	-0.13	0.021	-0.17 - -0.081	<0.001
	SI	0.04 \pm 0.03	0.02 \pm 0.016	0.02	0.01	0 - 0.04	0.057

MD: Mean Difference; SE: Standard Error; SD: Standard Deviation; SC: Scanning, MI: Milling, SI: Sintering, CI: Confidence Interval,

Table 6. Comparison of fabrication phases in terms of the effect on inter-abutment dimensional changes (μm)

Inter-abutment dimension	CAD/CAM dystem	Comparison of phases		MD	SE	95% CI	P-value
External	AmannGirrbach	SC	MI	-0.07	0.013	-0.104 - -0.031	<0.001
		SC	SI	-0.09	0.013	-0.122 - -0.052	<0.001
		MI	SI	-0.02	0.017	-0.068 - 0.03	0.877
	Zirkonzahn	SC	MI	-0.14	0.025	-0.207 - -0.065	<0.001
		SC	SI	-0.04	0.006	-0.059 - -0.024	<0.001
		MI	SI	0.1	0.022	0.033 - 0.156	0.004
Internal	AmannGirrbach	SC	MI	0.003	0.006	-0.013 - 0.019	1
		SC	SI	-0.02	0.009	-0.045 - 0.008	0.215
		MI	SI	-0.02	0.009	-0.046 - 0.003	0.093
	Zirkonzahn	SC	MI	-0.11	0.02	-0.165 - -0.052	<0.001
		SC	SI	0.02	0.008	-0.007 - 0.037	0.235
		MI	SI	0.12	0.021	0.064 - 0.184	<0.001

CAD/CAM: Computer-Aided Design/Computer-Aided Manufacturing; MD: Mean Difference; SE: Standard Error; CI: Confidence Interval; SC: Scanning; MI: Milling; SI: Sintering

DISCUSSION

This study assessed the effect of three factors of abutment size, fabrication phase, and type of CAD/CAM system on dimensional changes of zirconia frameworks. The results showed that all three factors affected the dimensional changes in the frameworks. The null hypothesis, that the dimensional change of implant-supported zirconia frameworks is not influenced by abutment size, fabrication phase or type of CAD/CAM system, was rejected.

Many previous studies have assessed the final precision and fit of zirconia frameworks fabricated by different CAD/CAM systems. However, previous studies did not evaluate errors related to each fabrication phase

(scanning, milling, and sintering) separately and did not report that which phase has the highest rate of errors in the fabrication process. A number of previous studies, however, compared internal fit and marginal gap of frameworks milled out of fully sintered or semi-sintered zirconia frameworks [12,16,17,21,23,24]. These studies compared frameworks milled in actual size from a fully sintered block with frameworks milled in a larger size out of semi-sintered zirconia as well as the conduction of sintering process. Since milling of fully sintered zirconia is difficult due to high strength and is different from the milling of semi-sintered zirconia, the former may not be suitable for simulation of milling of semi-sintered zirconia. Therefore,

we milled semi-sintered zirconia in actual dimensions in this study to assess procedural errors related to the milling phase (independent of errors due to sintering shrinkage). Dimensional changes in the scanning phase were also measured.

Several methods have been used in previous studies to assess the fit of frameworks, such as using a silicon replica, sectioning of the frame after cementation, triple scanning, and micro-computed tomography [17,20,25-28]. Strain gauge has also been used in some previous studies to assess the fit of implant frameworks [5,29,30]. With regard to full arch implant-supported frameworks, most dimensional changes of the framework compared to the original model have been evaluated in the x, y, and z axes [31-35]. Since the aim of this study was to assess dimensional changes of frameworks during manufacturing, dimensions of the master model and each framework were measured in the three axes using a VMS device. Also, scanning data were measured three-dimensionally to determine changes in dimensions relative to the master model during the fabrication process.

Effect of abutment size on dimensional changes:

Based on the results, changes in the diameter were not affected by the abutment size but changes in the height were greater for the premolar abutment compared to the canine abutment. The change in the height (depth) of the framework may be compared to the occlusal gap (lack of internal fit in the occlusal surface) in future studies. In this study, this error was greater in shorter and thicker (premolar) abutments; this finding was in agreement with the results reported by Anunmana et al [36], Grenade et al [37], and Moldovan et al [27]. In these studies, the occlusal gap of premolar and molar abutments was compared, and a higher error rate was noted in the molar abutment (which was shorter and thicker than the other abutment).

Effect of fabrication phase on dimensional changes:

In the AG system, changes in the mesiodistal

diameter and the external-external distance in the milling and sintering phases were greater than those in the scanning phase but no other significant differences were noted among the manufacturing phases in other dimensions. The changes in the distance between the abutments were slightly greater in the sintering phase compared to the milling phase but the differences did not reach statistical significance. In the ZZ system, dimensional changes in the milling phase were greater than those in the other two phases, and the least change in the mesiodistal diameter and height was noted in the sintering phase. In general, in this system, the highest error rate was related to the milling and the lowest (except for the external-external distance) to the sintering phase. It appears that in the ZZ system, some of the errors related to previous phases (even the scanning phase) were compensated after sintering. Bindl and Mormann [16] compared the internal fit of frameworks milled out of semi-sintered and fully sintered zirconia and noticed that milling of zirconia frameworks in actual dimensions (from a fully sintered block) caused greater errors and internal misfit. Our findings regarding the changes in the ZZ system were in line with theirs because, in the ZZ system, changes in framework dimensions in the milling phase were greater than those in the sintering phase. The accuracy of the milling process highly depends on the size and the quality of milling burs, and details smaller than the diameter of milling burs cannot be created [38,39]. Thus, milling of frameworks in actual dimensions requires higher precision than milling them in larger dimensions (taking into account 20% to 25% sintering shrinkage) and has a higher risk of errors as well. This issue depends on the accuracy of milling by each CAD/CAM system, and thus, the results of each system may be different from those of another system such that in the AG system, no significant difference was noted in errors of milling and sintering phases, and the data even supported fewer errors in the milling phase compared to the sintering phase. Therefore, it appears that the accuracy of the

AG system is suitable for framework milling in actual (small) dimensions, and the slight increase in errors is attributed to shrinkage.

Effect of type of CAD/CAM system on dimensional changes:

In the scanning phase, changes in the buccolingual diameter and height in the AG system were greater than those in the ZZ system but changes in the mesiodistal diameter were greater in the ZZ system. In the milling phase, dimensional changes (except for the external-external distance and height) in the ZZ system were greater than those in the AG system but in the sintering phase, dimensional changes were greater in the AG system.

In general, it appears that in case of milling of frameworks in actual dimensions, the precision of the AG system is greater than that of the ZZ system. However, in case of milling of enlarged frameworks followed by their sintering, the final precision of the ZZ system frameworks would be higher than that of the AG system. Similarly, our results showed that in the AG system, errors slightly increased in the sintering phase but in the ZZ system, if frameworks are milled in slightly larger dimensions (to compensate for shrinkage) and are then subjected to sintering, some of the scanning phase errors may be compensated for.

Within the limitations of this study, it appears that manufacturing phases, abutment size, and type of CAD/CAM system can affect dimensional changes of zirconia frameworks. This consideration in the treatment of patients with implant-supported prostheses can result in zirconia frameworks with better fitting.

CONCLUSION

Within the limitations of the present study, it appears that the manufacturing phase and the size of abutments affected dimensional changes of zirconia frameworks. These changes also depend on the CAD/CAM system used. In the milling phase, dimensional changes in the ZZ system were greater than those in the AG system; the results were reversed in the sintering phase. It can be

concluded that each CAD/CAM system has its own strengths and weaknesses.

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CONFLICT OF INTEREST STATEMENT

None declared.

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