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Time efficiency and efficacy of a centralized computer-aided-design/computer-aided-manufacturing workflow for implant crown fabrication: A prospective controlled clinical study

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ABSTRACT

Objective: To assess time efficiency and the efficacy of the prosthetic manufacturing for implant crown fabrication in a centralized workflow applying computer aided design and computer aided manufacturing (CAD-CAM).
Material and Methods: Fifty-nine patients with one posterior implant each, were randomly allocated to either a centralized digital workflow (c-DW, test) or a laboratory digital workflow (l-DW, control). Patients were excluded from efficiency and efficacy analyses, if any additional restoration than this single implant crown had to be fabricated. A customized titanium abutment and a monolithic zirconia crown were fabricated in the c-DW. In the l-DW, models were digitalized for CAD-CAM fabrication of a monolithic zirconia crown using a standardized titanium base abutment. Time for impression, laboratory operating and delivery time were recorded. The efficacy of the prosthetic manufacturing was evaluated at try-in and at delivery. Data was analyzed descriptively. Statistical analyses using student's unpaired t- and paired Wilcoxon were performed ($p < 0.05$).
Results: At impression taking, 12 patients (c-DW) and 19 patients (l-DW) were included. The impression time was 9.4±3.5 min (c-DW) and 15.1 ± 4.6 min (l-DW) ($p < 0.05$). The laboratory operating time was 130 ± 31 min (c-DW) and 218.0±8 min (l-DW) ($p < 0.05$). The delivery time was significantly longer in the c-DW (5.9 ± 3.5 1 days) as compared to the l-DW (0.5±0.05 days). At try-in and at delivery, efficacy of prosthetic manufacturing was similar high in both workflows.
Clinical relevance: The c-DW was more time efficient compared to the lab-DW and rendered a similar efficacy of prosthetic manufacturing.

1. Introduction

Digital technologies allow modifying the conventional treatment modalities in reconstructive implant dentistry. Intraoral scanners (IOS) enabled clinicians to take impressions immediately after implant installation [1], and represent the advantageous gateway to the digital workflow [2,3]. The subsequent processing of digital data by means of computer aided design/computer aided manufacturing (CAD-CAM) may offer the delivery of implant reconstructions within the same appointment [4]. Consequently, patients benefit from an increased time efficiency, as well as from a higher treatment comfort [5].

A systematic review demonstrated that the use of digital technologies had the greatest impact on time efficiency when applied during laboratory fabrication of implant reconstructions [6]. Time-consuming manual work steps may be delegated to digital devices upon availability or may be outsourced to centralized manufacturers. Thereby, a variety of different workflows become available for each of the fabrication processes and for each of the components of an implant reconstruction [7].

The outsourcing of any fabrication process allows dental technicians to omit investments in expensive and fast evolving digital technologies that are subjected to a high depreciation in value. Industrial manufacturing allows highly standardized processes by means of state-of-the-art CAM devices. Consequently, the operating time of a dental technician is limited to the CAD process. Clinical studies showed that a dental technician spent between 46.8 [8] and 68 min [8] for the virtual design of a monolithic implant crown. In a workflow outsourcing some parts of the fabrication chain, delivery times have to be considered and

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therefore may prevent a timely delivery of implant reconstructions [9,10].

The prosthetic outcomes rendered from a digital workflow have to fulfill standard clinical criteria to be delivered. So-called efficacy studies involving a centralized fabrication of the implant crown showed that quality of outcomes was high and all crowns could be delivered with no need for chairside adjustments [8,11,12]. In contrast, a clinical study using a digital workflow involving laboratory CAD-CAM technology showed that 16 out of 40 implant crowns needed chairside adjustments to be delivered [1]. The different outcomes between the clinical studies may be explained by the different IOS and CAD-CAM systems used within the crown fabrication process [13,14].

Today, also CAD processes may be delegated to an industrial manufacturer further increasing time efficiency of a dental technician. Generally, this CAD processes are remotely supervised and approved by the dental technician. Thereafter, finalization of the implant reconstructions may include manual veneering or staining as well as the assembly of the components. To the best of our knowledge, no clinical scientific evidence is available reporting on the time efficiency and the quality of outcomes for the fabrication of single implant crowns in a centralized digital workflow with remote supervision by a dental technician.

The primary aim of this clinical study was, therefore, to record the time needed by a dental technician for the fabrication of an implant crown in a centralized workflow compared to a laboratory workflow using in-house CAD-CAM technologies. The second aim was to assess the quality of outcomes of implant crowns resulting from a centralized digital workflow compared to a laboratory digital workflow. The null hypotheses were that there is no difference in time efficiency nor in the efficacy of the prosthetic manufacturing when applying a centralized compared to a laboratory workflow.

2. Material and methods

The present study is a sub-analysis of a randomized controlled clinical trial (RCT) with two parallel study groups. The study was approved by the local ethical committee and registered in the German Clinical Trials Register. After provision of informed consent, patients were treated in compliance with the study protocol, the current version of the Declaration of Helsinki, and the ISO EN 14155. The article follows the CONSORT Statement [15]. The authors report no financial interests related to any products involved in this study. Study materials such as implants, abutments (laboratory and centralized workflow) and crowns (centralized workflow) were provided by a grant from Dentsply Sirona Implants (I-AA-17-020).

The primary objective of the RCT was to compare the clinical performance of screw-retained monolithic zirconia crowns using a customized titanium abutment and applying a centralized digital workflow (c-DW) versus a standardized titanium base abutment and applying a laboratory digital workflow (l-DW) after five years. Time efficiency and quality of prosthetic outcomes of the fabrication process were secondary objectives of this RCT resulting in the present sub-analysis.

2.1. Study population

Patients were recruited according to the following inclusion criteria:

- Female/male patients >18 years of age
- Good general health
- Need for one implant in a healed posterior single missing tooth site (molar and premolar)
- Presence of antagonists

The presence of one of the following criteria led to exclusion of the participant:

- Women who are pregnant at time of implant placement
- Known or suspected non-compliance, drug or alcohol abuse
- Inability to follow the procedures of the study, e.g. due to language problems etc.
- Heavy smokers (>10 cigarettes per day)
- Poor oral hygiene after hygienic phase (Plaque Index above 30 %)
- Active periodontal disease

2.2. Clinical procedures

Implant placement (ASTRA TECH OsseoSpeed EV, Dentsply Sirona) was timed as type 3 or 4 [16] and carried out to enable a screw-retained implant crown. After successful osseointegration and before taking the implant impression, patients were randomly assigned to the c-DW or the l-DW of the RCT. An independent study monitor concealed the allocation to the study group using a computer-generated randomization list (www.sealedenvelope.com) and sealed envelopes. In case the impression was also used for the fabrication of restorations not related to the study, the patient was excluded from the present sub-analysis.

One of the two following randomly assigned prosthetic workflows was executed:

- Centralized digital worfklow (c-DW): An intraoral scan (TRIOS 3, Software 1.4.7.0, 3Shape) was initiated at the implant site capturing a hand-tightened scan body (Elos Accurate IO Scan body, Elos Medtech) including the mesial and distal contours of the neighboring dentition and extended to a full-arch scan. Thereafter, a full-arch scan of the opposing jaw and bite registration scans in maximal intercuspation (without the scan body) from both sides were added. The scan path was based on the manufacturer's instructions and no software updates were allowed during the entire duration of the study.
- Laboratory digital workflow (l-DW): A conventional impression was taken from the jaw with the implant using light and heavy body polyether impression material (Permadyne, 3M), a screw-retained impression post (Implant Pick-up EV, ASTRA TECH, Dentsply Sirona) and a perforated plastic stock impression tray (PRESIDENT Tray, Coltène Whaledent). Hydrocolloid (Cavex Alginate, Cavex) and a stock impression tray were used for the opposing jaw. Occlusal registration was captured using a silicone material (Preciform, Merz Dental).

2.3. Laboratory procedures

One experienced and calibrated dental technician (D.R.) performed all laboratory procedures in the dental laboratory. Prior to the beginning of the clinical study, a meeting was held in order to guarantee a standardized fabrication workflow for all implant crowns.

- In group c-DW, the digital scan data was downloaded from a cloud-based server (3Shape Communicate Portal) and uploaded to a centralized server (Atlantis WebOrder, Dentsply Sirona). Thereafter, the workflow included centralized CAD by the manufacturer (Virtual Atlantis Design, Dentsply Sirona) with remote validation by the dental technician and centralized CAM of the abutment by the manufacturer (Atlantis, CustomBase solution, Dentsply Sirona) as well as the monolithic zirconia crown (Atlantis Crown, Full-contour, Dentsply Sirona). The zirconia crown was shipped in a sintered stage including the customized titanium abutment as well as digital models (printer: Formlabs Form 3, printing material: Model v2, Formlabs).
- The l-DW was executed using a validated laboratory fabrication process involving a laboratory scan (Ceramill Map 400, Amann Girrbach) of the conventionally fabricated stone models followed by in-house CAD (ceramill mind, Amann Girrbach) of a monolithic crown on a titanium base abutment (TitaniumBase EV, Dentsyply

Sirona) and in-house CAM (ceramill motion 2, Amann Girrbach) of a monolithic zirconia crown (Ceramill Zolid HT + preshades, Amann Girrbach). Before sintering (Carmill Therm 3, Amann Girrbach) of the zirconia, the crown was adjusted on the respective abutment/model and internal staining (Ceramill Liquid CL, Amann Girrbach) was applied.

The implant crowns were prepared for a try-in by temporarily cementing (TempBond, Kerr) the monolithic zirconia crown onto the respective titanium abutment. After clinical evaluation and chairside adjustments, the implant crowns were finalized by the dental technician. If indicated, the anatomical crown contour was manually adapted. In order to increase color match to the neighboring dentition, external staining and glazing (IPS E.max Ceram, Ivoclar Vivadent) was applied by means of multiple firing cycles (Programat P500, Ivoclar Vivadent). Finally, the titanium abutments were air-borne particle abraded using 50 μm aluminium oxide (1 bar at 1 centimeter distance for 10 seconds; Rocatec Plus, 3M). Silane (Monobond Plus, Ivoclar Vivadent) was applied for 60 seconds before final cementation of the crown to the abutment using a chemically curing adhesive cement (Multilink Hybrid Abutment HO, Ivoclar Vivadent).

2.4. Outcome measures

2.4.1. Time efficiency

The clinical chairside time at impression taking was recorded. The time recording included all clinical working steps executed by the dentist:

- Healing abutment removal/fixation
- Impression post/scan body fixation/removal
- Impression/scan of complete arch with implant
- Impression/scan of complete opposing arch
- Bite registration

The boot-up of the intraoral scanner and the customization of the impression tray were not recorded, as these work steps were delegated to the dental assistant and executed before the appointment.

Also, all laboratory work steps executed by the dental technician were recorded including delivery times (Table 1).

2.4.2. Efficacy of prosthetic manufacturing

At try-in and at delivery of the implant crowns, the quality of fabrication outcomes was assessed (Table 2). All operators (S.M, L.S.) attended a calibration meeting to guarantee a standardized clinical assessment. In brief, proximal contacts were checked with dental floss, occlusal contacts in maximal intercuspidation and during articulation were evaluated using a double folded occlusion foil (Shimstock foil 8 μm, HANEL). The match of the anatomical form as well as of the crown color to the neighboring dentition were rated. In addition, the need for chairside adjustments at try-in was recorded. Finally, at delivery patient satisfaction was determined. In order to deliver the crown, at least a beta rating was needed for each of the outcomes evaluated.

2.5. Statistical analysis

The sample size calculation was based on the primary outcome of the RCT investigating the peri-implant marginal bone level changes between baseline (crown insertion) and 5 years and resulted in a total of 60 patients. In order to guarantee standardization at impression taking and during the fabrication workflow, patients were included in the present sub-analysis when the prosthetic phase was limited to the fabrication of the study implant crown. Therefore, the size of study groups was not controlled.

The sample size calculation was based on the results of a clinical study evaluating the time efficiency in the laboratory workflow [11].

Table 1
Overview of work steps and waiting times in the centralized digital workflow (c-DW) and laboratory digital workflow (l-DW).

c-DW (test)	l-DW (control)	c-DW (test)	l-DW (control)
Laboratory working steps until try-in		**Waiting/shipping time until try-in**	
Transfer and upload of IOS onto cloud-based platform (Atlantis web order)	Stone model fabrication (implant model, antagonist model)	Time from upload of IOS until email notification for CAD approval	Setting of dental stone model
Review, adaptation, and approval of CAD	Mounting of models in articulator	Time from email delivery until email notification	Setting of model mounting in articulator
Unboxing and assembling of abutment and crown for try-in	Laboratory scan of models	Time from final order until delivery of abutment and crown	CAM of zirconia crown
	CAD of implant crown		Sinter firing of zirconia crown
	Preparation for CAM (fixation of zirconia disc, nesting of crown)		
	Detaching of crown from zirconia disc and preparation for sintering including application of stains		
	Assembling of abutment and crown for try-in		
Laboratory working time until delivery		**Waiting time in the dental laboratory until delivery**	
Adaptation of abutment and crown		Stain firing cycles	
Application of staining/glazing (as much cycles as needed)		Glaze firing cycles	
Cementation of crown onto abutment		Setting time of cement	
Finish (polishing and cleaning) of implant crown			

For the sub-analysis primarily evaluating laboratory fabrication time, a minimum sample size of 4 in each group will have 80% power to detect a difference in means between control and of 10 min, assuming that the common standard deviation is 4.9 min using a Mann-Whitney-U with a 0.05 two-sided significance level.

Time efficiency (min) was described by means, standard deviation (SD), ranges and interquartile ranges. Discrete values were described by absolute frequencies. Differences between the two treatments were analyzed using Wilcoxon rank sum. Statistical analyses and box plots were performed in R [17] and the significance level was set to α=0.05.

3. Results

After screening a total of 59 patients in the randomized controlled clinical trial, a total of 31 patients were included in the present sub analysis. 12 patients were included in the c-DW and 19 patients in the l-DW (Fig. 1).

3.1. Time efficiency

The mean total impression time amounted to 9.5 ± 3.5 min using an intraoral scanner (c-DW) and 15.1 ± 4.6 min by means of the conventional impression technique (l-DW) ($p < 0.001$) (Fig. 2). In group c-DW, the mean time needed for the full-arch impression of the jaw with the implant was 5.7 ± 3.0 min, whereas the full-arch scan of the opposing jaw and the scan for bite registration accounted for a mean of 2.6 ± 0.8 min and 1.1 ± 0.6 min, respectively. In group l-DW, the open tray

Table 2
Prosthetic criteria used to evaluate the quality of outcomes.

Parameters	Rating	Criteria
Anatomical form	Alpha	Ideal anatomical form. Contour is continuous with the neighbouring dentition.
	Bravo	Slightly over- or under-contoured as compared to the neighbouring dentition.
	Charlie	Severely over- or under-contoured as compared to the neighbouring dentition.
	Delta	New crown is needed.
Proximal contact (mesial/distal)	Alpha	Tight proximal contact point.
	Bravo	Weak proximal contact point.
	Charlie	Open proximal contact point.
	Delta	-
Occlusal contact	Alpha	Occlusal contacts on the crown and the neighbouring dentition equal in strength.
	Bravo	Increased occlusal contacts on the crown. No occlusal contacts on neighbouring dentition.
	Charlie	No occlusal contact on the crown. Normal occlusal contacts on neighbouring dentition.
	Delta	-
Color match	Alpha	No deviation in color and translucency between crown and neighbouring dentition.
	Bravo	Slight deviation in color and translucency between crown and dentition. Deviation lies within natural range of dentition.
	Charlie	Major deviation in color and translucency between crown and dentition. Deviation lies outside natural range of dentition.
	Delta	-
Patient satisfaction	Alpha	Very satisfied. No complaints.
	Bravo	Critics regarding aesthetics, chewing, or comfort.
	Charlie	Unsatisfied.
	Delta	Completely unsatisfied. Unbearable complaints.

impression took a mean of 11.8 ± 3.4 min, the impression of the opposing jaw 2.2 ± 1.2 min, and the bite registration 1.2 ± 0.8 min.

The dental technician's total working time amounted to a mean of 130 ± 31 min in group c-DW and to 218 ± 31 min group l-DW ($p < 0.001$) (Fig. 3). In contrast, the mean total waiting time was significantly higher ($p < 0.001$) in group c-DW (8593 ± 4407 min) compared to group l-DW (764 ± 65 min).

The dental technician's total working time in group c-DW consisted of 18.8 ± 6.1 min for the transfer of data, 10.1 ± 5.0 min for the remote evaluation of the crown design, and 39.3 ± 23.38 min for the assembly of components to be ready for the try-in (total time 68.2 ± 28.1 min). In 50% of the cases, a second remote evaluation was needed before final approval of the order. After approval, the mean shipping time for the implant crown components was 5.9 ± 3.1 days.

The dental technician's operating time in the l-DW consisted of (i) model fabrication and mounting in an articulator (42.1 ± 3.0 min), (ii) digitalization of models (16.5 ± 3.9 min), (iii) CAD of implant crown (21.1 ± 4.2 min), (iv) preparation before and postprocessing after CAM (20.5 ± 2.4 min), and (v) assembly of components for try-in (42.9 ± 3.8 min). The total operating time was 143.0 ± 5.7 min before the implant crown was ready for try-in. The respective waiting time consisted of 50.8 ± 7.5 min during model fabrication/mounting, 29.1 ± 4.1 min during CAM (milling process), and 594.2 ± 57.3 min during sintering of the zirconia crown, totaling in a mean of 674.1 ± 61.0 min.

Following the clinical try-in, the finalization of the implant crown in

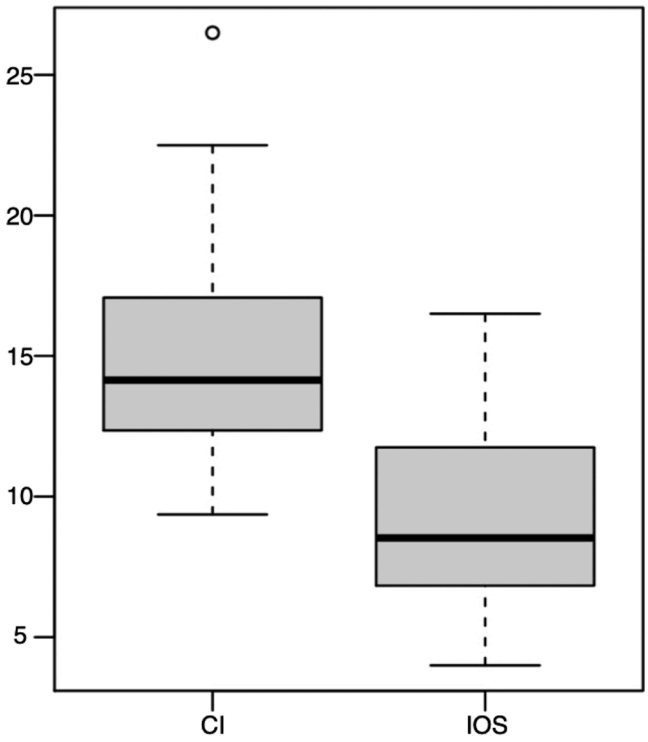

Fig. 2. Box plot of impression time (minutes); conventional impression (CI), intraoral scan (IOS).

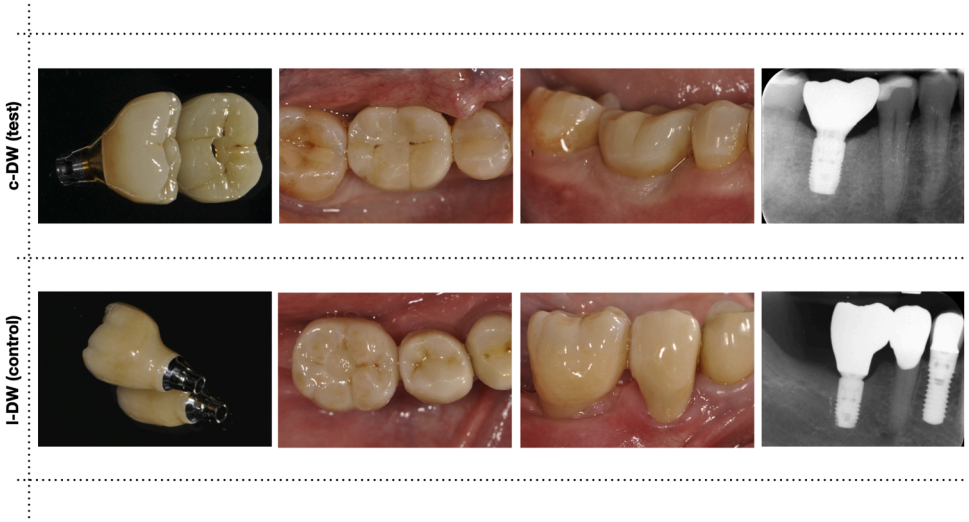

Fig. 1. Representative implant crowns of both workflows after crown delivery; centralized digital workflow (c-DW), laboratory digital workflow (l-DW).

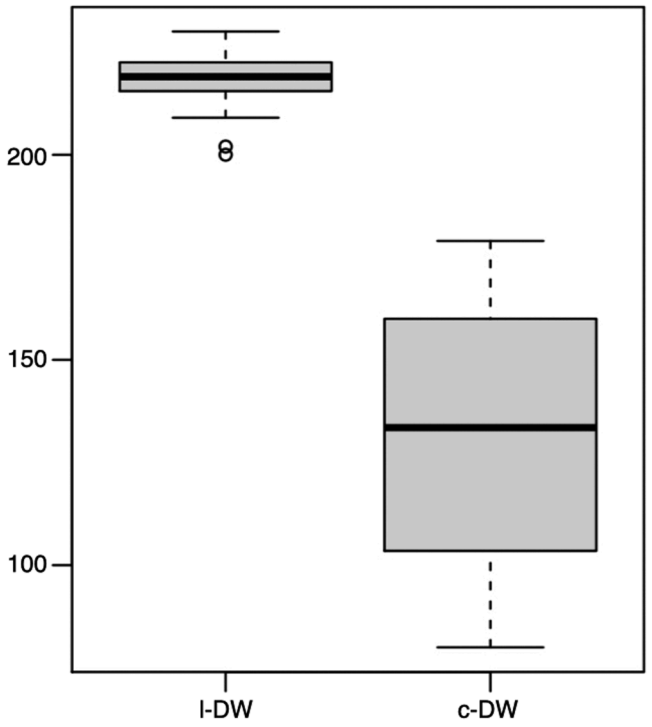

Fig. 3. Box plot of total working time (minutes) by the dental technician; centralized digital workflow (c-DW), laboratory digital workflow (l-DW).

the dental laboratory amounted to 62.1±8.7 min (c-DW) and to 75.0 ±5.4 min (l-DW) ($p < 0.05$).

3.2. Efficacy of prosthetic manufacturing

The frequency distribution of the prosthetic outcomes is presented in Table 3. In Fig. 4 representative crowns for the parameter anatomical form at try-in are presented. At try-in, chairside adjustments were performed in 3 out of 12 crowns in group c-DW (2 contour adjustments, 1 adjustment of a strong mesial approximal contact point) and 3 out of 19 crowns from the l-DW (3 occlusal contact adjustments). In group c-DW, one crown had to be redone (insufficient anatomical form as well as a missing mesial proximal contact). In both groups, a substantial improvement between try-in and crown delivery was observed for the parameter *anatomical form* (alpha rating at try-in 33% c-DW and 47% l-DW versus at crown delivery 92% c-DW and 89% l-DW) (representative crowns shown in Fig and for *color match* (alpha rating at try-in 0% c-DW and 5% l-DW versus at crown delivery 42% c-DW and 53% l-DW). At delivery, all crowns were delivered and patient satisfaction was rated highest (alpha rating) by 10/12 (c-DW) and 18/19 (l-DW) patients.

4. Discussion

The present sub-analysis of a randomized controlled clinical trial showed that a centralized digital workflow outsourcing CAD and CAM for the fabrication of an implant crown was significantly more time efficient as compared to a laboratory digital workflow using an in-house CAD-CAM technology. Therefore, the null hypothesis had to be rejected. These results, however depend on the applied technologies and therefore, may not be valid for all available laboratory or centralized digital workflows. Also, evolution of digital workflows is very fast and the present results are based on the software/hardware versions at the time of study execution.

Importantly, the prosthetic outcomes of implant crowns were similar for both workflows and therefore, the second null hypothesis was accepted. A refinement by the dental technician was needed in order

Table 3
Quality of prosthetic outcome ratings at try-in and at crown delivery; centralized digital workflow (c-DW), laboratory digital workflow (l-DW).

Parameter		Try-in		Crown delivery	
		c-DW	l-DW	C-DW	l-DW
Anatomical form	**n**	**12**	**19**	**12**	**19**
	A	4 (33%)	9 (47%)	11 (92%)	17 (89%)
	B	5 (42%)	10 (53%)	1 (8%)	2 (11%)
	C	2 (17%)	0	0	0
	D	1 (8%)	0	0	0
Proximal contact mesial	**n**	**12**	**19**	**12**	**19**
	A	11 (92%)	16 (84%)	11 (92%)	18 (95%)
	B	0	3 (16%)	1 (8%)	1 (5%)
	C	1 (8%)	0	0	0
	D	-	-	-	-
Proximal contact distal	**n**	**7**	**14**	**7**	**14**
	A	6 (86%)	13 (93%)	5 (71%)	13 (93%)
	B	1 (14%)	1 (7%)	2 (19%)	1 (7%)
	C	0	0	0	0
	D	-	-	-	-
Occlusal contact	**n**	**12**	**19**	**12**	**19**
	A	4 (33%)	6 (32%)	12 (100%)	17 (89%)
	B	8 (77%)	10 (53%)	0	2 (11%)
	C	0	3 (20%)	0	0
	D	-	-	-	-
Color match	**n**	**12**	**19**	**12**	**19**
	A	0	1 (5%)	5 (42%)	10 (53%)
	B	7 (58%)	13 (68%)	7 (58%)	9 (47%)
	C	5 (42%)	5 (26%)	0	0
	D	-	-	-	-
Patient satisfaction	**n**			**12**	**19**
	A			10 (83%)	18 (95%)
	B			2 (17%)	1 (5%)
	C			0	0
	D			-	-

that implant crowns of both groups fulfilled the standard of prosthetic care applied in the department at delivery. One limitation of this sub-analysis, however, is that the number of patients included were not evenly distributed between the two groups due to the secondary exclusion criterion and thereby, resulted in a limited number of patients.

The present study recorded the time for data acquisition. Earlier studies demonstrated an improvement in time efficiency by means of IOS compared to conventional impression methods, because IOS allowed a partial impression limited to the area of interest as opposed to the conventional technique requiring full-arch impressions of both jaws [18,19]). In recent studies, however, even a full-arch IOS was more time efficient as a conventional full-arch impression for a single tooth implant [1,20]). The present results confirmed a superior time efficiency for the use of IOS at impression taking compared to a conventional technique. Therefore, the centralized workflow would ideally be initiated with a digital impression similar to the laboratory-based workflow. Importantly, clinical studies demonstrated that time efficiency of IOS depended on the respective manufacturer [5,21].

Until recently, outsourcing of certain work steps of the digital workflow was limited to the CAM process, whereas the CAD of the restoration remained in the hands of the dental technician. Earlier studies reported that the CAD of a monolithic implant crown took 10 min [22]), 12.6 min [1], or 22.3 min [11]. In the present study, the CAD of the monolithic crown accounted for 21.1 min. Time differences compared to previous studies may be attributed to the CAD software systems applied or the various study designs. In addition, the present study further evaluated laboratory work steps that are needed before

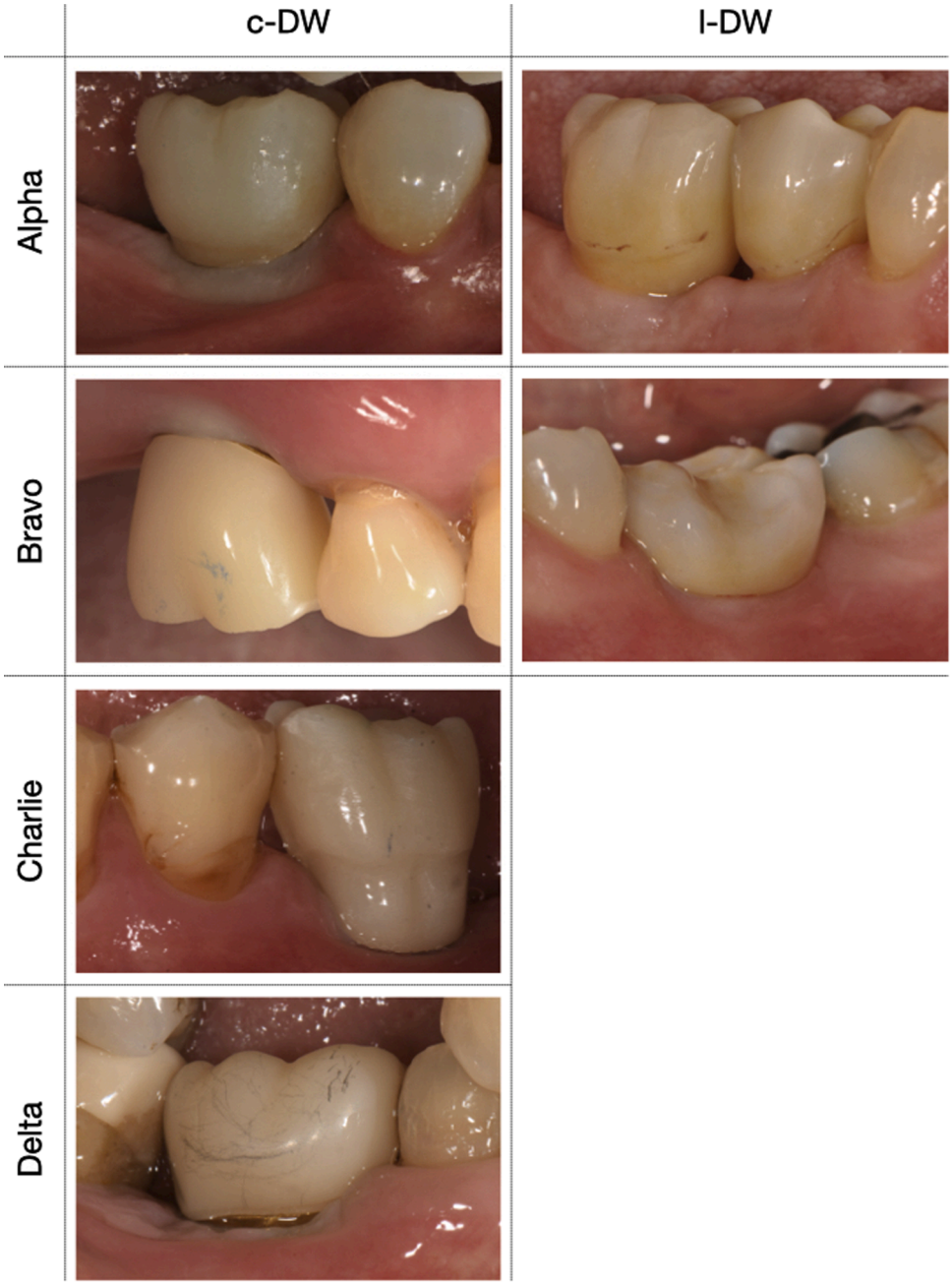

Fig. 4. Ratings of representative implant crowns of both workflows at try-in for the prosthetic outcome anatomical form.

operating the CAD software.

The laboratory CAM of a zirconia implant crown is a time-consuming process. The manufacturing time is not limited to the milling of the monolithic zirconia crown (29.1 min) only. Earlier studies reported similar milling time between 25 min and 28.9 min [22,23]. The milling time, however, accounted for only 4% of the total time needed in the CAM process. CAM inevitably includes operating time of the CAM device and the CAM software (nesting), as well as the post-processing of the CAM product involving the detachment of the crown and the application of stain liquids before sintering. Within the CAM workflow, sintering is the most time-consuming process [22]. For the centralized workflow, no detailed data of the respective fabrication steps were available.

The total working time of the dental technician was significantly shorter in the centralized digital workflow as compared to the laboratory workflow. This result is mostly attributed to the two very different fabrication workflows. Still, in the centralized workflow more than one hour of operating time was needed from the transfer of the digital data to the centralized manufacturer until the final approval of the order. The advantage of using a centralized workflow, however, is that dental laboratories do not need to invest in expensive CAD-CAM technologies while still guaranteeing highest industrial production standards at low prices [22]. The disadvantage, on the other hand, is the delayed availability of the products because of the shipping time. Earlier studies showed that the time of delivery depended on the location of the CAM device, whether it was chairside, laboratory-based or centralized [9,10]. Also, the technical costs may be higher in the centralized workflow, because of the need of an individualized abutment instead of using a prefabricated abutment (laboratory workflow). A clinical study demonstrated that technical costs depend on the type of digital workflow applied [24,25].

Most importantly, the outsourcing of the CAD-CAM fabrication resulted in similar quality outcomes compared to the laboratory CAD-

CAM fabrication. Earlier studies reported on the need and time for chairside adjustments as a measure of quality of outcome. A systematic review revealed that monolithic CAD-CAM implant crowns were most effective [6]. The present study applied a detailed prosthetic score to validate the quality of outcomes. The outsourcing of the entire CAD-CAM process had no negative effect on the fabrication outcomes. Still, the design of the virtual implant crown was performed by an employee of the manufacturer with a high level of CAD experience. In the near future, the integration of artificial intelligence in the CAD process may further decrease the time and the need of human intelligence [26]. Therefore, it may be hypothesized that the CAD process remains in the dental laboratory and will not be transferred to centralized manufacturer. Also, centralized manufacturing may become less important when using prefabricate titanium base abutments.

A clinical study showed that monolithic zirconia crowns resulting from centralized CAM showed lower ratings for color match of monolithic zirconia implant crowns to the neighboring dentition compared to porcelain-fused-to-metal implant crowns [27]. In the present study, the laboratory workflow allowed an individual color infiltration of the zirconia crown before sintering. This possible advantage, however, did not result in a better color match of laboratory-made crowns compared to centrally manufactured crowns at try-in. In both workflows the improvement of color match to the neighboring dentition was achieved by means of external staining with no time differences. The ratings for color as well as anatomical form, however, depend on the examiner and may therefore present a limitation of the study.

5. Conclusions

Outsourcing of the CAD-CAM fabrication of single implant crowns in the posterior zone results in less operating time by the dental technician and similar prosthetic outcomes compared to a laboratory-based CAD-CAM workflow. However, shipping times and technical costs have to be considered in a centralized fabrication. Also, a substantial refinement by an experienced dental technician is needed independently of the type of CAD-CAM workflow.

CRediT authorship contribution statement

S. Mühlemann: Conceptualization, Data curation, Formal analysis, Writing – original draft. **S.T. Lamperti:** Formal analysis, Writing – original draft. **L. Stucki:** Data curation. **C.H.F. Hämmerle:** Conceptualization. **D.S. Thoma:** Conceptualization, Writing – original draft.

Declaration of Competing Interest

The authors declare the following financial interests/personal relationships which may be considered as potential competing interests:

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