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Randomized controlled within-subject evaluation of digital and conventional workflows for the fabrication of lithium disilicate single crowns. Part II: CAD-CAM versus conventional laboratory procedures

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Abstract: STATEMENT OF PROBLEM Clinical studies are needed to evaluate the entire digital and conventional workflows in prosthetic dentistry. PURPOSE The purpose of the second part of this clinical study was to compare the laboratory production time for tooth-supported single crowns made with 4 different digital workflows and 1 conventional workflow and to compare these crowns clinically. MATERIAL AND METHODS For each of 10 participants, a monolithic crown was fabricated in lithium disilicate-reinforced glass ceramic (IPS e.max CAD). The computer-aided design and computer-aided manufacturing (CAD-CAM) systems were Lava C.O.S. CAD software and centralized CAM (group L), Cares CAD software and centralized CAM (group iT), Cerec Connect CAD software and lab side CAM (group CiL), and Cerec Connect CAD software with centralized CAM (group CiD). The conventional fabrication (group K) included a wax pattern of the crown and heat pressing according to the lost-wax technique (IPS e.max Press). The time for the fabrication of the casts and the crowns was recorded. Subsequently, the crowns were clinically evaluated and the corresponding treatment times were recorded. The Paired Wilcoxon test with the Bonferroni correction was applied to detect differences among treatment groups (=.05). RESULTS The total mean (±standard deviation) active working time for the dental technician was 88 ±6 minutes in group L, 74 ±12 minutes in group iT, 74 ±5 minutes in group CiL, 92 ±8 minutes in group CiD, and 148 ±11 minutes in group K. The dental technician spent significantly more working time for the conventional workflow than for the digital workflows (P<.001). No statistically significant differences were found between group L and group CiD or between group iT and group CiL. No statistical differences in time for the clinical evaluation were found among groups, indicating similar outcomes (P>.05). CONCLUSIONS Irrespective of the CAD-CAM system, the overall laboratory working time for a digital workflow was significantly shorter than for the conventional workflow, since the dental technician needed less active working time.

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ABSTRACT

Statement of problem: Clinical studies are needed to evaluate the entire digital and conventional workflows in prosthetic dentistry.

Purpose: The purpose of the second part of this clinical study was to compare the laboratory production time for tooth-supported single crowns made with 4 different digital workflows and 1 conventional workflow and to compare these crowns clinically.

Material and methods: For each of 10 participants, a monolithic crown was fabricated in lithium disilicate reinforced glass ceramic (IPS e.max CAD). The computer-aided design and computer-aided manufacturing (CAD-CAM) systems were Lava C.O.S. CAD software and centralized CAM (group L), Cares CAD software and centralized CAM (group iT), Cerec Connect CAD software and lab side CAM (group CiL), and Cerec Connect CAD software with centralized CAM (group CiD). The conventional fabrication (group K) included a wax pattern of the crown and heat pressing according to the lost-wax technique (IPS e.max Press). The time for the fabrication of the casts and the crowns was recorded. Subsequently, the crowns were clinically evaluated and the corresponding treatment times were recorded. The Paired Wilcoxon test with the Bonferroni correction was applied to detect differences among treatment groups (α=.05).

Results. The total mean (±standard deviation) active working time for the dental technician was 88 ±6 minutes in group L, 7 ±12 minutes in group iT, 74 ±5 minutes in group CiL, 92 ±8 minutes in group CiD, and 148 ±11 minutes in group K. The dental technician spent significantly more working time for the conventional workflow than for the digital workflows (*P*<.001). No statistically significant difference was found between group L and group CiD, or between group iT and group CiL. No statistical differences of time for the clinical evaluation were found among groups, indicating similar outcomes (*P*>.05).

Conclusions. Irrespective of the CAD-CAM system, the overall laboratory working time for a digital workflow was significantly shorter than for the conventional workflow, since the dental technician needed less active working time .

CLINICAL IMPLICATIONS

The fabrication of single crowns is more time efficient for the dental technician using CAD-CAM systems than a conventional workflow. The limiting time factor for CAD-CAM systems involving a centralized production is the time for delivery of the definitive cast and the crown.

INTRODUCTION

The computer-aided design and computer-aided manufacturing (CAD-CAM) fabrication of dental restorations has become an inherent part of the daily work of dental technicians. Initially introduced for the processing of high-strength ceramics such as zirconia for fixed prosthesis frameworks, CAD-CAM technology now offers a wide range of materials and applications.[1]

CAD-CAM fabrication encompasses the virtual design and automated milling of restorations from prefabricated blanks.[2] Initially, CAD-CAM production led to problems with restoration accuracy.[3-5] Refinement of the CAD-CAM software and milling strategies and the adaptation of tooth preparation techniques to computerized technology have significantly improved these outcomes.[6] This has led to high acceptance of this computerized technology by dental technicians and clinicians. As with any innovative process, CAD-CAM technology is constantly improving.[7,8]

CAD-CAM restorations are generally made in the dental laboratory. The dentist makes a conventional impression, and the resulting cast is digitized in the laboratory for CAD-CAM processing,[9]. In most CAD-CAM systems, dental technicians use CAD software to design restorations in their laboratories; yet, the associated CAM process can be located in another dental laboratory or in an industrial production center.[10]

Chairside CAD-CAM systems, first introduced as the Cerec system, allow restoration design and fabrication in the dental office.[11-13] Both chairside and laboratory CAD-CAM manufacturing procedures may increase the efficiency of the fabrication of dental restorations.[14,15] Time-consuming manual fabrication steps, including waxing and casting or pressing, can now be delegated to the CAD-CAM software and machines.[2]

Nevertheless, CAD-CAM technology is associated with large financial investments. When judging the efficiency of new digital compared with conventional workflows, besides treatment time and material costs, dentists must also consider the amortization of the fabrication technology.[16,17] Studies comparing the entire conventional and digital procedures for the fabrication of tooth-supported restorations are scarce.[18] A majority of studies evaluated a single working step in the digital workflow, such as comparing the time efficiency of an intraoral scanner with a conventional impression technique.[19] A recent clinical study assessed the time efficiency of a digital compared with a conventional workflow for implant-supported crowns.[15]

Overall, including the clinical and laboratory steps, the digital workflow was 16% faster than the conventional workflow. However, the digital workflow was executed with only one CAD-CAM system. Therefore, the results may not be transferable to other CAD-CAM systems. In addition, it remains to be evaluated whether or not digital workflows are more efficient than the conventional workflow and whether or not a difference in efficiency exists between CAD/CAM systems.

The purpose of the present study, the second part of a randomized controlled clinical trial, was to compare the laboratory production time for tooth-supported single crowns made by 4 different digital workflows with a conventional workflow and to evaluate the treatment times needed to evaluate the clinical outcomes of the restorations.

MATERIAL AND METHODS

This study was the second part of a series of connected investigations that were performed to compare the complete digital and conventional workflows for the fabrication of monolithic single crowns. Part I of the investigations focused on the clinical efficiency of digital versus conventional impressions.[20] The present part II analyzed the time and effort of the corresponding technical workflows, whereas part III assessed the marginal and internal accuracy of the digitally and conventionally fabricated crowns with the replica technique.[21]

Ten participants in need of a single crown in the posterior region were included in the study. All participants were informed about the study protocol and written informed consent was obtained. The study protocol was approved by the local ethical committee of the University of Zurich, Switzerland (Ref. KEK-ZH_Nr. 2011-0102/5).

Four different digital workflows including a digital intraoral scanner and the corresponding CAD-CAM procedures were evaluated for the fabrication of a monolithic single crown from lithium disilicate reinforced glass ceramic (IPS e.max CAD; Ivoclar Vivadent AG). Test group L: Optical impression scanner: Lava C.O.S. 3M ESPE); CAD software: Lava C.O.S. Software (Version 3.0, 3M ESPE) and Cares Software (Cares Visual 6.2, Straumann); Centralized milling process (Straumann). Test group iT: Optical impression scanner: Cadent iTero (Align Technologies Inc.); CAD software: Cares software (Cares Visual 6.2; Straumann); Centralized milling process (Straumann). Test group CiL: Optical impression scanner: Cerec Bluecam (Sirona Dental Systems GmbH); CAD software: Cerec Connect software (v4.0.3; Sirona Dental Systems GmbH) and Cerec inLab 3D (v4.0.3; Sirona Dental Systems GmbH); Labside milling process: Cerec inLab MC XL milling unit (Sirona Dental Systems GmbH). Test group CiD: Optical impression scanner: Cerec Bluecam (Sirona Dental Systems GmbH); CAD software: Cerec Connect software (v4.0.3; Sirona Dental Systems GmbH) and Cerec inLab 3D (v4.0.3; Sirona Dental Systems GmbH); Centralized milling process: (infiniDent; Sirona Dental Systems GmbH).

Two dental technicians in the dental technical laboratory of the Clinic of Fixed and Removable Prosthodontics and Dental Material Science, University of Zurich, performed all the laboratory steps for the fabrication of the monolithic crowns. The laboratory had several years of experience in fabricating restorations with the CAD-CAM systems tested, and both dental technicians were experienced in the use of each system, having used them on a daily to weekly basis.

The present part of the study (Part II) involved recording the time (in minutes) for each of the laboratory fabrication steps of the digital and conventional workflows and a subjective evaluation of the laboratory working steps by the dental technicians.

The following laboratory steps in the digital and conventional workflow were evaluated (Fig. 1 and 2):

Data transfer: The recorded time began with hitting the “send” button on the digital impression system and ended with the arrival of the data in the dental laboratory. In test groups L and iT, the intraoral scan data was transferred to the respective manufacturer of the impression system for optimization. Then, the optimized file was transmitted to the laboratory software for further processing by the dental technician. In test group CiD, the scan data were directly transferred to the laboratory software without further processing by the respective manufacturer.

Cast fabrication: After receiving the intraoral scan data, the dental technicians virtually designed the definitive cast with the respective software (cast design). The time needed for the cast design was recorded until the cast data were sent via the Internet to the respective manufacturer for centralized fabrication of the definitive cast. Similarly, the time until delivery of the cast to the dental laboratory was recorded. The digital workflow in test group CiL was conducted without a physical cast.

In the conventional workflow, the conventionally acquired impressions were poured with dental stone (Quadro-rock Plus; Picodent). Then, the definitive cast was trimmed and fixed in a small nonadjustable articulator (Artigator; Amann Girrbach). The time needed for fabrication of the cast was recorded (cast design). The waiting times for the setting of the dental stone were recorded (delivery of cast).

Crown fabrication: The respective CAD software of each digital workflow was used to design the complete anatomic-contour crown (crown design). The CAD software in test group L did not allow the virtual design of an anatomic-contour crown. As a result, the data set of the definitive cast needed to be exported to the same CAD software as in group iT. In group CiL, the same data set as in group CiD could be used for the crown design. Both the time needed for the crown design and the time until delivery of the crown to the dental laboratory, including the sintering procedure, were recorded. The CAD-CAM crowns were delivered in the pre-sintered stage to the dental laboratory. If necessary, the crowns were adjusted before final sintering on the corresponding digital cast. However, the internal surfaces of the crowns were not adjusted. Thus, the marginal and internal fit of the crowns could be evaluated with the replica technique during the in vitro evaluation (Part III of this study).

The conventional fabrication of the crowns included waxing (design), investing, heat pressing the lithium disilicate glass ceramic blank (IPS e.max Press; Ivoclar Vivadent AG), and de-vesting. The waiting time during heat pressing was recorded (delivery of crown).

The treatment times at the clinical evaluation appointment were recorded. The total treatment time included the time needed for clinical evaluation of the crown and the time required for chairside adjustments. Chairside adjustments were limited to 3 clinical procedures: internal fit (evaluated with a silicone material [Fit Checker Black; GC Europe]), interproximal contacts, and occlusal contacts. After clinical evaluation, the dental technicians characterized the crown by staining; this time was recorded.

Continuous treatment time values and clinical treatment times were analyzed with statistical software (IBM SPSS v20.0; IBM Corp). Descriptive statistics together with 95% confidence intervals for the true mean were calculated. The Kolmogorov-Smirnov test was used to validate the normality assumption of the data. The nonparametric paired Wilcoxon test together with an appropriate Bonferroni correction was applied to evaluate differences between treatment groups (α=.05).

RESULTS

A total of 40 posterior CAD-CAM crowns and 10 conventional crowns from 5 different manufacturing processes were fabricated. Eight participants received a molar crown, and 2 a premolar crown.

The mean (± standard deviation) waiting time for the dental technician to receive the digital file was 87 ±66 minutes in group L, 2455 ±2150 minutes in group iT, and 68 ±123 minutes in group CiD. The data transfer in group iT was the longest of all digital groups (P=.005).

The time for the virtual cast design ranged between 1 ±0.5 minutes (group iT) and 8 ±1 minutes (group L) (Table 1). The cast design in group L took significantly more time than in group iT and group CiD (P<.001). The subsequent time for delivery of the CAD-CAM cast from the manufacturer to the dental laboratory ranged between 3.5 days (group L) and 3.9 days (group iT) (P>.05) (Table 1). Because no transit was involved, the actual fabrication time for the conventional cast was significantly shorter as compared with all CAD-CAM casts (P<.001).

The time for the virtual design of the crowns ranged from 10 ±1 minutes (group iT) to 14 ±2 minutes (group CiL) (Table 1). Virtual crown design took more time in groups L and CiD than in groups iT and CiL (P<.001). Conventional crown design (waxing) took significantly more time than all virtual designs (P<.001). The subsequent delivery of the crowns was the fastest in group CiL, followed by the conventional group K (P<.001). The delivery took significantly more time for all outsourced CAD-CAM crowns (*P*<.001), and ranged between 3.4 days (group L) and 4 days (group iT) (Figs. 1-3, Table 1).

At the clinical evaluation appointment, the mean treatment times ranged between 4.6 ±0.8 minutes (L) and 8.5 ±1.9 minutes (CiL) (Table 2). The times needed for chair-side adjustments ranged between 1.9 minutes (group L) and 366 minutes (group CiL) (Table 2). No statistically significant differences of mean treatment times were found for the chair-side adjustments, and total treatment times during the first clinical evaluation (*P*>.05).

The time to adjust and finalize the crowns in the laboratory ranged between 50 ±3 minutes (group K) and 76 ±5 minutes (group CiL) (Table 1). It took significantly less time to finalize the conventionally fabricated crowns than for most CAD-CAM crowns (group K vs. groups L, CiL, CiD; p<.05). The finalization of the crowns took significantly more time in group CiD than in any other group (*P*<.001).

Taking every crown fabrication step into account, the total active working time for the dental technician ranged between 74 ±5 minutes (group CiL) and 92 ±8 minutes (group CiL) for the digital workflows. At 148 ±11 minutes, the conventional workflow was associated with the longest active working time for the technicians (*P*<.001) (Fig. 3, Table 1).

DISCUSSION

The present study showed significant differences in the laboratory working time for the fabrication of single crowns with CAD-CAM as compared with conventional manual procedures. The total time to delivery of the restoration was shorter for the conventional fabrication of the crowns, because waiting times in the workflow were limited to the setting of materials or other corresponding technical fabrication procedures. For the CAD-CAM crowns several days elapsed before the delivery of the centrally produced definitive cast and crown. However, taking the effective active working times into consideration, the digital workflows were more time efficient for the technicians independent of the CAD-CAM system. The active working time for the dental technicians in the digital workflows was limited to the virtual design of the cast and the restoration and to finalizing the crown after delivery. While waiting for the delivery by the centralized production facility, the technician could work on another task. With the conventional workflow, the technicians had to do spend more effective working time preparing and fabricating the cast and crown.

Clinical studies comparing digitally and conventionally fabricated crowns and evaluating the complete restorative workflows with respect to time efficiency and treatment outcomes are scarce. Some studies tested one particular step of the digital workflow.[19] Others only measured the times needed.[15] The present clinical study series tested the entire clinical and laboratory workflow for the fabrication of single crowns, from impression to insertion of the reconstruction. Part I focused on the time efficiency of digital and conventional partial unilateral impressions.[20] Interestingly, different results were found for the impression system with no need for powdering, as compared with those with a need for powdering. Optical impressions including powdering took significantly more time than the conventional impression, yet, no differences in the times were found when optical impressions without powdering were compared with conventional impressions.[20] Another part of the present series compared the accuracy of the resulting crowns.[21] No differences in the accuracy of CAD-CAM and conventional crowns was found.[21]

The present study part demonstrated that laboratory procedures most affect the complete workflow with regard to time efficiency. In the laboratory-side digital workflows, the active working time for the dental technician was significantly reduced compared with the conventional workflow. The present result is in line with the findings of other investigations. In 2 clinical studies evaluating the digital workflow for the fabrication of an implant crown, the laboratory work time was significantly shorter than the conventional workflow.[15,18]

Nevertheless, the centralized manufacturing procedures for the definitive casts and/or the crowns resulted in a significantly increased waiting time. This time-limiting factor in the digital workflow may explain the successful development of in-office CAD-CAM systems,[13] reducing treatment time.

As with any computerized technology, the CAD-CAM technology is constantly improving.[7, 17] The results of the present study are limited to the software version used. Similar clinical studies will be necessary in the future to evaluate the digital workflow in restorative dentistry and to assess the advances in digital technologies.

CONCLUSIONS

Within the limitations of the present clinical study, the following conclusions were drawn:

1. Independent of the CAD-CAM system, the overall active laboratory working time in a digital workflow is significantly shorter than in a conventional workflow.
2. CAD-CAM systems including a centralized production need significantly more time until delivery than conventional workflows or CAD-CAM systems with an in-house or laboratory-based manufacturing process.
3. The quality of the crowns after the fabrication did not differ between CAD-CAM and manually made crowns, as assessed by the times needed for the try-in of the tested reconstructions.

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TABLES

Table 1.

Time evaluation (minutes) of the 5 tested workflows

	Cast fabrication		Crown fabrication				Total working time
			Before evaluation		After evaluation		
n=10	cast design	cast delivery	crown design	crown delivery	finalization	waiting time	
	mean ±SD (95% CI)						
group L	8 ±1 *^{c} (7-9)	5085 ±387 *^{b} (4800-5370)	16 ±1*^{b} (15-17)	4854 ±247 *^{be} (4678-5031)	64 ±6*^{c} (60-68)	45 (standardized)	88 ±6*^{bd} (83-92)
group iT	1 ±0.5 *^{b} (1-2)	5605 ±251 *^{b} (5425-5785)	10 ±1 *^{c} (9-11)	5794 ±420 *^{bd} (5493-6094)	63 ±11*^{ac} (55-71)		74 ±12^{cd} (65-82)
group CiL	2 ±0.3*^{b} (1.5-2.1)	no pysical cast	11 ±2 *^{c} (9-12)	16 ±1 *^{c} (15-16)	62 ±5*^{c} (58-65)		74 ±5^{c} (71-78)
group CiD		5356 ±415 *^{b} (5059-5653)	14 ±2 *^{b} (12-16)	5296 ±606 *^{b} (4862-5729)	76 ±5*^{b} (72-80)		92 ±8*^{bd} (88-96)
group K	26 ±3 *^{a} (25-28)	120*^{a} (standardized)	71 ±11*^{a} (64-79)	149 ±2 *^{a} (148-151)	50.3 ±3*^{a} (48-52)		148 ±11*^{a} (140-156)

Different letters (a, b, c, d, e) per column represent statistically significant differences (P<.05) between treatment groups (paired Wilcoxon test together with appropriate Bonferroni correction)

Table 2. Clinical evaluation time (minutes) of the crowns

	group L		group iT		group CiL		group CiD		group K	
Clinical evaluation										
	Mean ±SD	95% CI	Mean ±SD	95% CI	Mean ±SD	95% CI	Mean ±SD	95% CI	Mean ±SD	95% CI
chairside adjustments (min)	1.9 ±0.7	0.3 – 3.4	3.6 ±1.6	0 – 7.1	6.1 ±1.9	1.8 – 10.4	3.1 ±1	4.6 – 0.1	4.6 ±0.8	2.9 – 6.3
treatment time (min)	4.6 ±0.8	0.4 – 6.4	5.8 ±1.6	2.2 – 9.3	8.6 ±1.9	4.2 – 12.8	5.5 ±1.2	0.05 – 0.1	7.6 ±1.2	4.7 – 10.4

FIGURES

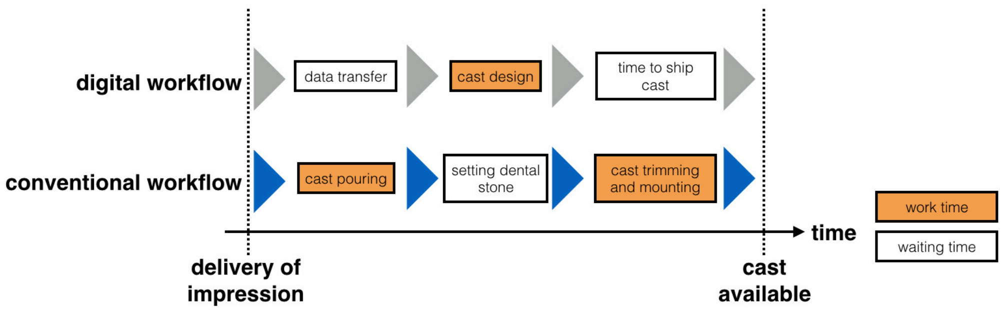

Figure 1. Evaluation of time for cast fabrication.

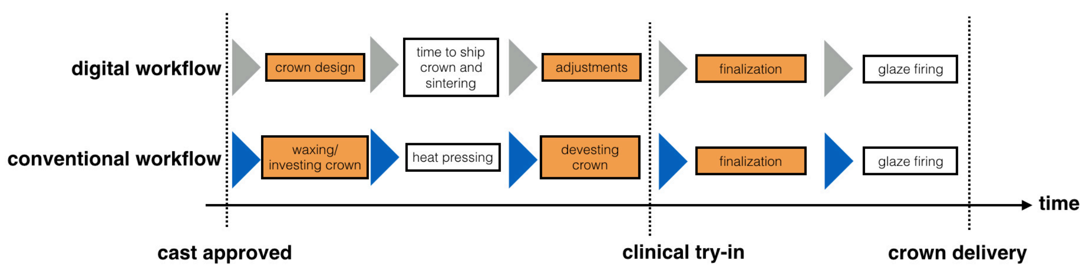

Figure 2. Evaluation of time for crown fabrication.

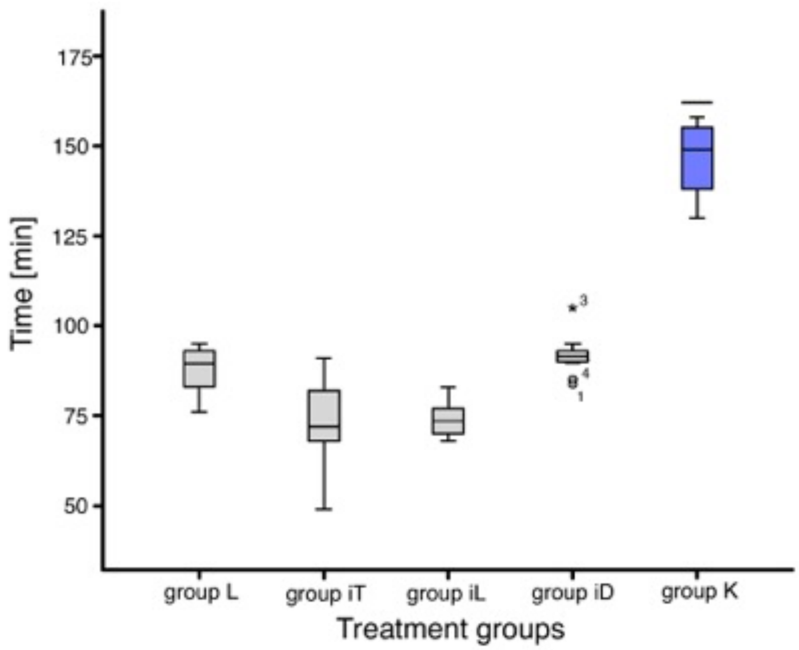

Figure 3. Total dental technician working time.