Received: 2 January 2019 | Revised: 9 April 2019 | Accepted: 9 April 2019

DOI: 10.1111/clr.13447



ORIGINAL RESEARCH

CLINICAL ORAL IMPLANTS RESEARCH WILEY

# Time efficiency and quality of outcomes in a model-free digital workflow using digital impression immediately after implant placement: A double-blind self-controlled clinical trial

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## Abstract

**Objective:** To assess the clinical and laboratory time efficiency and quality of outcomes for posterior single implant crowns by means of a model-free digital workflow using digital impressions immediately after implant placement.

**Methods:** Forty patients missing a single posterior tooth received implant therapy. For within-subject comparison, digital impressions were taken immediately after implant placement and conventional impressions after implant healing. Two monolithic zirconia crowns were fabricated using a laboratory-based CAD-CAM system. One crown was produced from the immediate digital impression and a model-free digital workflow (test group), and the second crown was produced from the conventional impression and a hybrid workflow (control group). Clinical and laboratory time was recorded. Quality of outcomes was evaluated double-blinded. A paired-sample *t* test was applied for statistical analysis.

**Results:** The total mean chairside time (impression and delivery) was 23.2 min (95%CI 22.2, 24.3) in the test group and 25.7 min (95%CI 24.4, 26.9) in the control group ($p = 0.013$). Significantly less laboratory time was needed in the model-free digital workflow (13.6 min, 95%CI 11.5, 15.6) as compared to the model-based hybrid workflow (29.9 min, 95%CI 25.7, 34.2) ($p < 0.05$). At crown delivery, 4/40 (test) and 12/40 (control) had no need of chairside adjustments, and 6/40 (test) and 5/40 (control) implant crowns were in need of additional laboratory interventions.

**Conclusion:** The fabrication of posterior single implant crowns using digital impressions taken immediately after implant placement and a model-free, laboratory-based digital workflow was more time efficient and resulted in similar quality of outcomes as a hybrid workflow using conventional impressions.

KEYWORDS

computer-aided design, computer-aided manufacturing, conventional workflow, digital workflow, implant crown, impression, intraoral scanner, quality of outcomes, time efficiency

Shaoxia Pan and Danni Guo are equally contributed as first authors

## 1 | INTRODUCTION

The traditional fabrication process for implant-supported crowns involves several working steps starting with a conventional impression by the dentist, casting/pressing procedures based on the lost-wax technique by the dental technician, and finally the delivery of the implant crown by the dentist. Generally, the final crown is fabricated after successful osseointegration of the implant (Benic, Mir-Mari, & Hammerle, 2014).

Recently, digital technologies offer alternative pathways for the fabrication of implant-supported crowns. The fabrication process may include intraoral scanning (IOS), laboratory scanning, computer-aided design (CAD), and computer-aided manufacturing (CAM) of models and reconstructions. A fully digital workflow involves both IOS and CAD-CAM, whereas the involvement of any digital technology in at least one working step was defined as hybrid workflow (Muhlemann, Kraus, Hammerle, & Thoma, 2018).

The impression taking by means of IOS is a contact-free procedure and may be applied immediately after implant placement. This would allow to start the fabrication process of the final implant crown before successful implant healing. Thereby, the impression taking appointment may be skipped, and patients could avoid time loss and potential financial loss from leave of work. This novel concept would allow to further improve overall time efficiency within an implant therapy.

Today, IOS systems from several manufacturers are available on the market (Zimmermann, Mehl, Mormann, & Reich, 2015). Only two clinical trials reported that IOS was more time efficient than the conventional impression technique (Joda & Bragger, Schepke, Meijer, Kerdijk; 2015, & Cune, 2015), while another demonstrated that IOS was more time consuming (Wismeijer, Mans, van Genuchten, & Reijers, 2014). One of the time-saving factors is specific to IOS, because unilateral impressions can be applied for single implant crowns, whereas a conventional impression technique generally involves a full-arch impression. A recent clinical trial showed, however, that a full-arch digital impression was significantly more time efficient compared to the conventional impression technique (Schepke et al., 2015).

In the dental laboratory, the involvement of digital technologies can significantly increase time efficiency (Muhlemann, Kraus, Hammerle, & Thoma 2018;Sailer, Benic, Fehmer, Hammerle, & Muhlemann, 2017). A digital workflow allows to omit the model fabrication (Joda & Bragger, 2014, 2016). The customization of the abutment and the veneering to the implant crown, however, reduced time efficiency in the dental laboratory (Joda & Bragger, 2016).

A systematic review showed that the quality of outcomes in fully digital workflows was highly effective (Muhlemann, Benic, Fehmer, Hammerle, & Sailer, 2018a). The current scientific evidence on the quality of outcomes of a fully digital workflow for posterior single implant crowns is limited to few clinical studies (Joda & Bragger, 2014, 2016; Joda, Ferrari, & Bragger, 2017). In all these studies, the same IOS (iTero) and the same CAD-CAM devices (CARES, Straumann) were used and resulted in implant crowns that had no need for chairside adjustments. The involvement of manual veneering to implant crowns generated from a hybrid workflow negatively influenced the quality of outcomes (Joda & Bragger, 2016).

The objective of this clinical trial was to evaluate the clinical and laboratory time efficiency and quality of outcomes of a fully digital workflow using digital impressions taken immediately after implant placement and a model-free, laboratory-based CAD-CAM fabrication for posterior single implant crowns as compared to a hybrid workflow using conventional impressions after implant healing.

## 2 | MATERIAL AND METHODS

### 2.1 | Participants

This prospective, double-blind, self-controlled clinical trial was conducted in the Department of Prosthodontics, Peking University School and Hospital of Stomatology.

The study was independently reviewed and approved by the Institutional Review Board of Peking University School and Hospital of Stomatology (Ethical approval No: PKUSSIRB-201732002). The

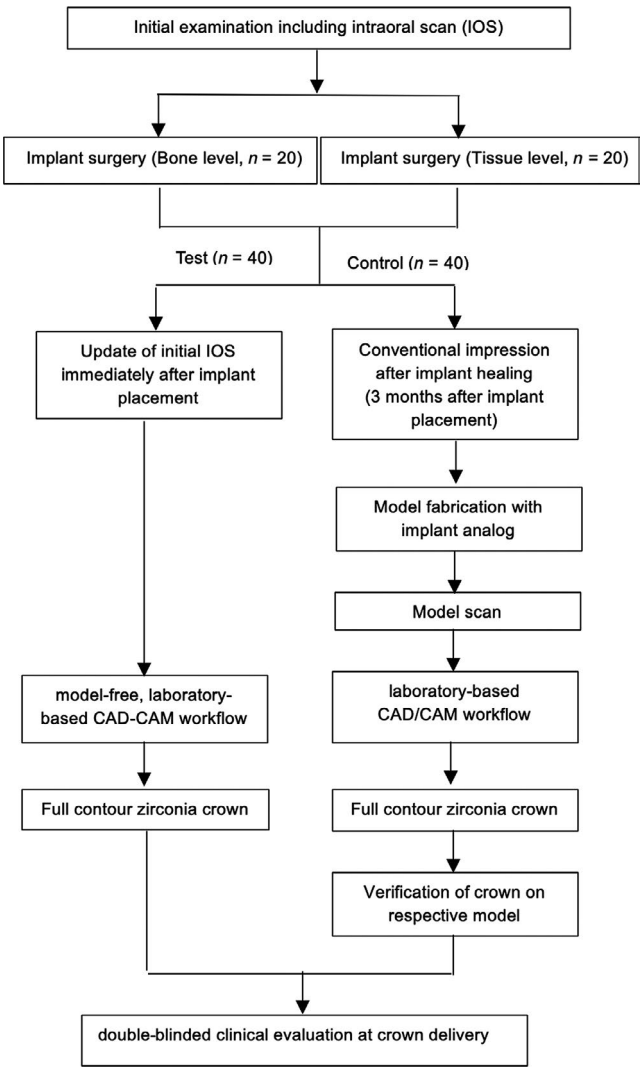


**FIGURE 1** Study flowchart

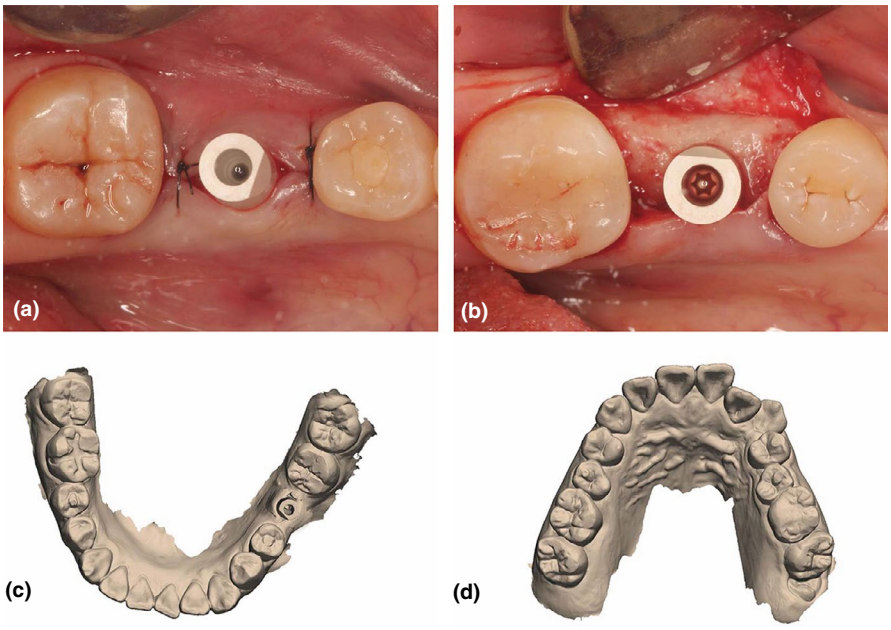


**FIGURE 2** Test group: Digital impression taken immediately after implant placement with implant-specific scan body (a), bone-level implant, (b), tissue-level implant. The initial IOS was updated for the implant site (c), jaw with implant, (d), opposing jaw

study had been registered in Chinese Clinical Trial Registry (ChiCTR) (ChiCTR No: INR-17014092). The Consolidated Standards of Reporting Trials (CONSORT) guidelines were used as the framework for this study.

This was undertaken with the understanding and written consent of each subject and according to the World Medical Association declaration of Helsinki (version, 2013).

The inclusion criteria were as follows:

- Age ≥ 18 years.
- Missing single posterior premolar or first molar for at least 3 months.
- Mesial and distal teeth / restorations present and intact.
- Sufficient bone height and width at implant site (vertical bone height ≥ 10 mm, buccal-lingual bone width ≥ 6 mm).
- Sufficient prosthetic space (Vertical height ≥ 5mm, mesial-distal distance ≥ 6mm).
- Willing to receive implant treatment.

The exclusion criteria were as follows:

- Local or systemic contraindication for implant therapy (i.e., uncontrolled diabetes, hemophilia, metabolic bone disorder, history of renal failure, radiation treatment to the head or neck region, current chemotherapy, and pregnancy).
- Smoking ≥ 10 cigarettes per day.

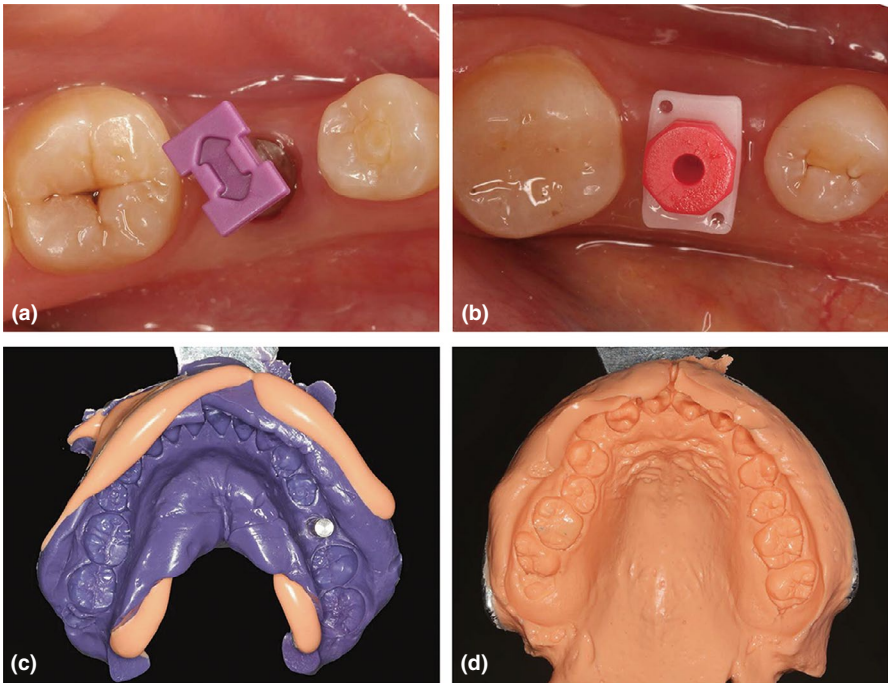


**FIGURE 3** Control group: Conventional impression with specific implant transfer post after 3 months of implant healing (a), bone-level implant, (b), tissue-level implant. For the jaw with the implant a polyether material (c) and for the opposing jaw alginate was used (d)

**TABLE 1** Time recording within the model-free fully digital workflow (test) and the model-based hybrid workflow (control)

| | Model-free fully digital workflow | | Model-based hybrid workflow | |
|---|---|---|---|---|
| IE | Clinical examination | | Clinical examination | |
| | CBCT | | CBCT | |
| | IOS | ⏲ | | |
| IS | Shade selection | | | |
| | Implant placement | | Implant placement | |
| | Connection of scan body | ⏲ | | |
| | Local scanning | ⏲ | | |
| | Healing abutment connection | ⏲ | Healing abutment connection | |
| SR | Suture removal | | Suture removal | |
| CI | | | Impression tray preparation | ⏲ |
| | | | Healing abutment removal | ⏲ |
| | | | Impression jaw with implant | ⏲ |
| | | | Impression opposing jaw | ⏲ |
| | | | Healing abutment connection | ⏲ |
| LF | Data transfer to CAD | ⏲ | Model fabrication | ⏲ |
| | CAD | ⏲ | Model scanning | ⏲ |
| | CAM | | Data transfer to CAD | ⏲ |
| | | | CAD | ⏲ |
| | | | CAM | |
| | | | Verification of crown on model | ⏲ |
| CD | Interproximal adjustments | ⏲ | Interproximal adjustments | ⏲ |
| | Occlusal adjustments | ⏲ | Occlusal adjustments | ⏲ |
| NOA | 4 | | 5 | |

Abbreviations: ⏲, time recording procedure; CD, crown delivery; CI, conventional impression; IE, initial examination; IS, implant surgery; LF, laboratory fabrication; NOA, number of appointments; SR, suture removal.

- Need for major guided bone regeneration (GBR)/submucosal healing.

The initial visit included a clinical examination, a cone beam computed tomography (CBCT NewTom VGi , NewTom), and a digital impression of the complete upper and lower jaws including bite registration by means of an intraoral scanner (3Shape Trios® Standard-P11, 3Shape A/S). The digital impression was permanently saved on the IOS. After treatment planning, the visits were scheduled according to the study flowchart (Figure 1).

## 2.2 | Surgical procedure and immediate digital impression

Forty patients were included in the study. The first twenty patients received a two-piece implant (Straumann Bone level, Institut Straumann AG), whereas the following 20 patients received a one-piece implant (Straumann Tissue level, Institut Straumann AG). A full-thickness flap was raised under local anesthesia (Primacaine adrenaline 1:100,000, Dentaires Pierre Rolland), and the implant was inserted with a minimum torque of 35 Ncm. Before suturing, the implant-specific scan body (Straumann, Institut Straumann AG) was manually screwed onto the implant. In case of a minor buccal dehiscence defect, a GBR procedure (Bio-Oss/Bio-Gide, Geistlich) was performed. After suturing, a partial digital impression of the scan body and the neighboring teeth was taken to update the scan data from the initial examination (Figure 2). Finally, the scan body was unscrewed, and a healing abutment was connected to the implant. Seven to ten days after surgery, sutures were removed.

## 2.3 | Conventional impression

Three months after implant placement, a conventional closed-tray implant impression was taken using an implant transfer post (Straumann, Institut Straumann AG) and a polyether material (Impregum Penta, 3M ESPE GmbH). A conventional impression of the opposing jaw was taken with alginate material (Alginoplast, Heraeus Kulzer GmbH) (Figure 3). Bite registration was performed with a silicon material (O-bite, DMG).

## 2.4 | Fabrication of implant crown

Screw-retained monolithic zirconia (Zenotec select hybrid, Wieland Dental) crowns were fabricated by one experienced dental

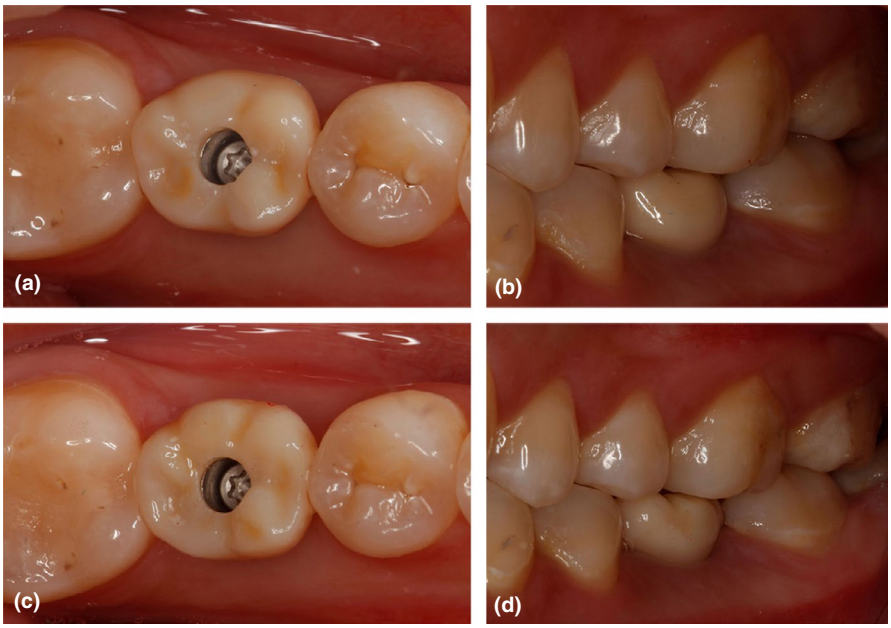


**FIGURE 4** Clinical evaluation (double blinded) of the implant crown from the test (a,b) and the control groups (c,d) within the same patient (tissue-level implant)

technician. In the model-free digital workflow, CAD-CAM crowns were produced based on the data from the immediate digital impression (test group). In the model-based hybrid workflow, CAD-CAM crowns were produced by digitizing the stone model with a laboratory scanner (control group).

- Model-free digital workflow: Digital impression data were digitally transferred to the computer-aided design (CAD) software (3Shape Designer, 3Shape A/S). After generating a digital model, a full-contour crown was designed on top of the virtual titanium base.
- Model-based hybrid workflow: The impressions were disinfected in the Ozone and ultraviolet ray chamber (ZYW-170Z) for 1 hr. The implant analog was manually fixed to the implant transfer post. An implant model was poured using dental type V stone (Die-Stone, Heraeus Kulzer GmbH) and stored for 2 hr. The alginate impression was poured (Pemaco) and stored for 1 hr. A scan body (Straumann, Institut Straumann AG) was fixed onto the implant analog. Both models and bite registration were digitalized using a laboratory scanner (3Shape D2000, 3shape A/S). Thereafter, the scan data were imported to the CAD software (3Shape Designer, 3Shape A/S) and a full-contour crown was virtually designed on top of the virtual titanium base.

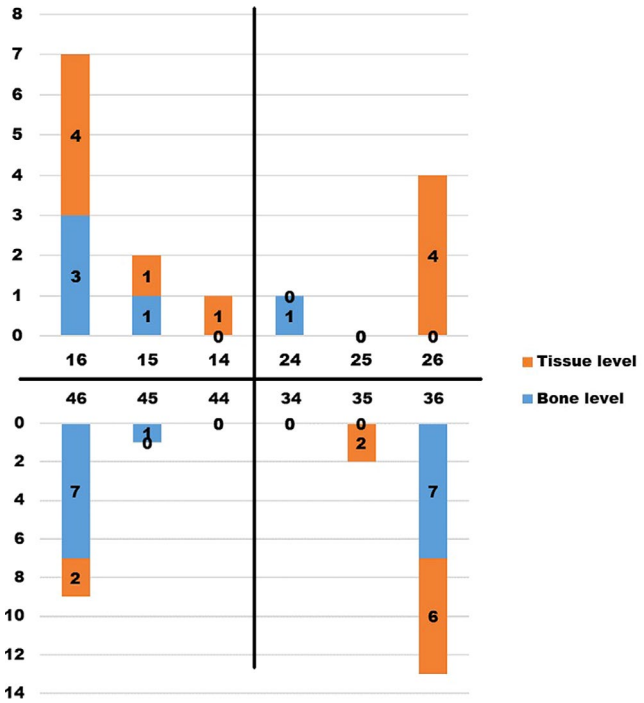


**FIGURE 5** Implant site distribution

In both workflows, the same settings in the CAD software were used for the design of the interproximal contact point (−18 μm) and the occlusal contact point (+20 μm). These settings were established before study initiation. A screw access hole was generated, and the occlusal anatomy was finalized to fulfill functional requirements. The crown data were automatically sent to CAM using a laboratory-based milling machine (Zenotec Select Hybrid, Wieland Dental). After milling and sintering of the zirconia crown, the dental technician was allowed to adjust the crown in the model-based hybrid workflow (control group). Then, both crowns were manually finalized by staining and glazing procedures (Vita Akzent, Vita Zahnfabrik; Programat P310, Ivoclar Vivadent). Before the delivery session, the crowns were adhesively fixed (Rely U200, 3M ESPE) on the titanium base (Variobase, Institut Straumann AG). The dental technician blinded the two implant crowns according to a computer-generated randomization list. Crowns were stored in two separate bags with two different numbers (1 and 2).

**TABLE 2** Mean (95% CI) clinical chairside time in minutes for different processes in the test and control groups

| | Test ($n$ = 40) [mean (95% CI)] | Control ($n$ = 40) [mean (95% CI)] | $p$-value ($t$, $df$) |
|---|---|---|---|
| Impression taking | 10.9 (10.4, 11.5) | 14.3 (13.4, 15.1) | <0.001* (–10.013, 39) |
| Crown delivery | 12.3 (11.4, 13.2) | 11.4 (10.6, 12.2) | 0.256 (1.097, 39) |
| Total | 23.2 (22.2, 24.3) | 25.7 (24.4, 26.9) | 0.013* (–2.643, 39) |

Abbreviations: *df*, degree of freedom; *t*, *t* value.
*$p$ < 0.05

## 2.5 | Time measurements

A regular stopwatch (LOEASE) was used to record clinical and laboratory work steps (Table 1). Time was recorded by an independent investigator who was informed about the study protocol before study initiation. Clinical time for impression taking (IOS during initial examination and update of IOS after implant placement vs. conventional impression) and for crown delivery (chairside adjustments of occlusal and interproximal contact points) were recorded. The mean time for impression taking in the twenty patients with a two-piece implant was reported separately in a recently published study (Guo et al., 2019) investigating patient preference of IOS. Laboratory working time included only the active working time of the dental technician (no waiting time, e.g., for milling/sintering processes).

## 2.6 | Clinical evaluation at crown delivery

Clinicians and patients were both blinded at the crown delivery. Crown evaluation was done by two independent and calibrated clinicians (Figure 4). Interproximal contact points were assessed for a strong contact using dental floss (Colgate Total Tartar Control, Colgate). Occlusal contact points were checked for light occlusal contacts without lateral occlusal disturbance (Arti-Fol shimstock foil, Dr. Jean Bausch GmbH & Co.). The decision for the crown was taken based on the clinical evaluation and the evaluation of patients' opinion. Patients' opinion was assessed by showing the intraorally seated crown to the patient with the help of a hand mirror and by asking for the patients' subjective comfort. The crown to be delivered had to fulfill all clinical criteria, and patients' opinion was considered when both crowns could be delivered.

## 2.7 | Statistical analysis

A power analysis was performed. The power analysis was based on a two-sample *t* test, and the standard deviation estimate is the one from the difference. The data originated from a clinical study assessing clinical time efficiency for the treatment with monolithic implant crowns (Joda & Bragger, 2016). A sample size of 20 in each group will have 90% power to detect a difference in means of 3.3 min to a conventional workflow with a mean of 24.1 min, assuming a standard deviation of 2.3 min.

Data were coded in Excel, and all statistical analyses were done with the statistical SPSS software (IBM SPSS Statistics v22; IBM Corp). Continuous variables were reported by using mean and 95% confidence interval (95%CI). Time differences between treatment groups were calculated using paired-sample *t* test. A *p*-value of <0.05 was considered statistically significant.

# 3 | RESULTS

A total of forty patients were included in this study with a mean age of 45.1 years and a gender distribution of 21 females and 19 males. Fifteen patients were missing an upper premolar/molar (4/11), whereas 25 patients missed a lower premolar/molar (3/22). The distribution of patients' according to the implant type is shown in Figure 5. Transcrestal sinus lift (five patients) and minor GBR (two patients) were performed.

The total clinical chairside time included the time for impression taking and for crown delivery. In the test group, significantly less time (23.2 min, 95%CI 22.2, 24.3) was needed than in the control group (25.7 min, 95%CI 24.4, 26.9) ($p$ = 0.013) (Table 2). The digital impression took significantly less time (10.9 min, 95%CI 10.4, 11.5) than the conventional impression (14.3 min, 95%CI 13.4, 15.1) ($p$ < 0.001) (Table 2). No significant difference was found in the mean clinical chairside time at crown delivery between test group (12.3 min, 95%CI 11.4, 13.2) and the control group (11.4 min, 95%CI 10.6, 12.2). Within both implant types (BL/TL), mean clinical chairside time was similar between the test and control groups (Table 3).

In the test group, significantly more clinical chairside time was needed at the delivery session in patients with a bone-level implant (13.8 min, 95%CI 12.8, 14.8) compared to patients with a tissue-level implant (10.8 min, 95%CI 9.7, 11.9) ($p$ = 0.002). In the control group, no significant difference was calculated ($p$ = 0.068) (Table 4).

In the dental laboratory, the model-free digital workflow took significantly less time (test group, 13.6 min, 95%CI 11.5, 15.6) than the model-based hybrid workflow (control group, 29.9 min, 95%CI 25.7, 34.2) (Table 5).

The clinical evaluation showed that in the test group 6 implant crowns (3 BL/3 TL) and in the control group 5 implant crowns (4 BL/1 TL) could not be delivered and would have needed laboratory intervention to be delivered (Table 6). The number of implant crowns without any need of chairside adjustments was 12 in the control group (7 BL /5 TL) and 4 in the test group (2 BL/2

**TABLE 3** Mean (95% CI) clinical chairside time in minutes at crown delivery between the model-free fully digital workflow (test group) and the model-based hybrid workflow (control group)

| | Bone-level implant | | | Tissue-level implant | | | Total | | |
|---|---|---|---|---|---|---|---|---|---|
| | Test ($n$ = 20) [mean (95%CI)] | Control ($n$ = 20) [mean (95%CI)] | $p$-value ($t$, $df$) | Test ($n$ = 20) [mean (95%CI)] | Control ($n$ = 20) [mean (95%CI)] | $p$-value ($t$, $df$) | Test ($n$ = 20) [mean (95%CI)] | Control ($n$ = 20) [mean (95%CI)] | $p$-value ($t$, $df$) |
| Inter-proximal | 4.5 (3.5,5.4) | 3.8 (3.0,4.6) | 0.306 (1.052, 19) | 3.3 (2.6,3.9) | 2.5 (1.9,3.0) | 0.064 (1.970, 19) | 3.9 (3.3-4.5) | 3.1 (2.6,3.6) | 0.058 (1.951, 39) |
| Occlusal | 9.3 (8.9,9.6) | 9.1 (7.9,10.3) | 0.715 (0.371, 19) | 7.6 (6.6,8.5) | 7.4 (5.5,9.3) | 0.906 (0.120, 19) | 8.4 (7.9-9.0) | 8.2 (7.1,9.3) | 0.773 (0.291, 39) |
| Total | 13.8 (12.8,14.8) | 12.9 (11.4,14.5) | 0.413 (0.838, 19) | 10.8 (9.7,11.9) | 9.9 (7.8,12.0) | 0.481 (0.718, 19) | 12.3 (11.4–13.2) | 11.4 (10.6,12.2) | 0.256 (1.097, 39) |

Abbreviations: *df*, degree of freedom; *t*, *t* value.

TL). Occlusal adjustments were performed in 34 (18 BL/16 TL) of the test implant crowns and in 27 (13 BL/14 TL) of the control implant crowns. Interproximal adjustments were needed in 28 (16 BL/12 TL) of the test implant crowns and in 15 (8 BL/7 TL) of the control implant crowns. Finally, the number of crowns delivered to the patients was similarly distributed between the test group ($n$ = 19; BL = 9, TL = 10) and the control group ($n$ = 21; BL = 11, TL = 10).

## 4 | DISCUSSION

The present study showed that clinical and laboratory time efficiency was significantly improved in a model-free fully digital workflow with immediate digital impression compared to a model-based hybrid workflow with conventional impressions. The quality of outcomes for the posterior implant crowns was similar for both workflows.

The present study is the first of its kind to introduce a fully digital workflow using digital impressions taken immediately after implant placement. The main advantage is that no separate appointment is needed for impression taking after implant healing. This novel concept provides significant benefits. For the patient, commuting time and possible financial loss due to absence from work can be avoided. For the dentist, the financial benefit is increased because the same treatment can be executed without a separate appointment for impression taking.

In the present study, the impression time using an IOS was significantly shorter as compared to the conventional impression technique. The clinical relevance, however, may be questionable based on the small time difference of 3.4 min. In this study, a complete-arch IOS was taken for the fabrication of a single implant crown. The mean time was 10.9 min, which was longer than reported in an earlier clinical study (Schepke et al., 2015) with a mean of 6.65 min. In the present study, the impression time included the IOS at the initial examination as well as the update of the same IOS immediately after implant placement. Generally, for the fabrication of a single implant crown in the posterior area, a unilateral IOS may provide sufficient information (Joda & Bragger, 2015). The mean impression time for a unilateral IOS was reported to range between 14.6 min (Joda & Bragger, 2015) and 20 min (Mangano & Veronesi, 2018), which was longer than the one reported for the complete-arch IOS in the present study. The time differences may be explained by the different IOS systems investigated. Also, digital technologies are constantly updated and the reported data are only valid for the software version at the time the investigation was performed.

The laboratory time efficiency was significantly improved in the model-free digital workflow as compared to the hybrid workflow with conventional impressions. The fabrication of the model and its digitalization could be omitted. The mean working time in the fully digital workflow was 13.6 min. In two randomized controlled clinical trials, the mean working time ranged from 25 min (Mangano &

**TABLE 4** Mean (95% CI) chairside time in minutes for clinical fitting and adjustment between different implant types

| | Test ($n$ = 40) | | | Control ($n$ = 40) | | |
|---|---|---|---|---|---|---|
| | BL ($n$ = 20) [mean (95%CI)] | TL ($n$ = 20) [mean(95%CI)] | $p$-value ($t$, $df$) | BL ($n$ = 20) [mean (95%CI)] | TL ($n$ = 20) [mean (95%CI)] | $p$-value ($t$, $df$) |
| Interproximal | 4.5 (3.5,5.4) | 3.3 (2.6,3.9) | 0.063 (2.237, 38) | 3.8 (3.0,4.6) | 2.5 (1.9,3.0) | 0.053 (2.843, 32.611) |
| Occlusal | 9.3 (8.9,9.6) | 7.6 (6.6,8.5) | 0.003* (3.506, 23.860) | 9.1 (7.9,10.3) | 7.4 (5.5,9.3) | 0.256 (1.531, 32.369) |
| Total | 13.8 (12.8,14.8) | 10.8 (9.7,11.9) | 0.002* (4.151, 38) | 12.9 (11.4,14.5) | 9.9 (7.8,12.0) | 0.068 (2.456, 38) |

Abbreviations: BL, bone-level implant; *df*, degree of freedom; *t*, *t* value; TL, tissue-level implant.
*$p < 0.05$

**TABLE 5** Mean (95% CI) laboratory active working time by the dental technician in minutes for different processes in the test and control groups

| Laboratory work steps | Test ($n$ = 40) [mean (95%CI)] | Control ($n$ = 40) [mean (95%CI)] | $p$-value ($t$, $df$) |
|---|---|---|---|
| Model fabrication | na | 4.0 (3.8,4.3) | / |
| Model scan | na | 7.6 (6.7,8.4) | / |
| Data transfer | 1.0 (0.9,1.1) | 1.0 (0.9,1.1) | / |
| CAD | 12.6 (10.5,14.6) | 12.0 (9.6,14.5) | / |
| Try-in on model | na | 5.3 (4.2,6.6) | / |
| Total | 13.6 (11.5,15.6) | 29.9 (25.7,34.2) | <0.001*a (−13.090, 39) |

Abbreviations: *df*, degree of freedom; *t*, *t* value. a* $p < 0.05$

Veronesi, 2018) to 54.5 min (Joda & Bragger, 2016) for the same working steps. One limitation of the present study was, however, that the time for finalization of the crown (bonding to abutment, glazing, polishing) was not included in the time recording. These finishing procedures were reported to take a mean of 20.4 min (Joda & Bragger, 2016).

One advantage of the model-free digital workflow investigated was that the fabrication of the monolithic crown was performed by means of a laboratory-based CAM. Thereby, waiting time until delivery of the reconstruction from an industrial manufacturer could be avoided (Muhlemann, Benic, Fehmer, Hammerle, & Sailer, 2018b; Sailer et al., 2017). Even though the time for milling and sintering procedures is standardized for the specific CAM device and restorative material used, the resulting waiting time should have been included for a proper time analysis.

Three previous clinical studies proved that the model-free digital workflow for the fabrication of posterior single implant crowns is a feasible procedure without compromising the clinical outcome (Joda & Bragger, 2014, 2016; Joda, Ferrari, et al., 2017). The results, however, are only valid for the specific implant system (Straumann tissue-level implant) and the specific centralized manufacturing process investigated (Straumann CARES). Moreover, the positive results may be related to the skills and experience of the operators (Joda, Lenherr, et al., 2017).

In the present study, the chairside time at the delivery was similar in both workflows. Most of the implant crowns needed chairside adjustments (interproximal and / or occlusal contacts). These results were different from previous studies in which none of the model-free monolithic CAD-CAM crowns needed adjustments of interproximal nor occlusal contacts (Joda & Bragger, 2014, 2016; Joda, Ferrari, et al., 2017). The difference in reported quality of outcomes may be explained by the different CAD-CAM devices involved in the fully digital workflow. Also, in the fully digital workflow the time between the acquisition of the IOS and the delivery of the crown was greater than in the hybrid workflow and could have influenced the quality of outcomes. A recent systematic review showed that the quality

**TABLE 6** Clinical evaluation of crown quality before adjustments

| | Test ($n$ = 40) | | | Control ($n$ = 40) | | |
|---|---|---|---|---|---|---|
| | | Missing interproximal contact point | | | Missing interproximal contact point | |
| | No occlusal contact point | Mesial | Distal | No occlusal contact point | Mesial | Distal |
| BL | 0/20 | 0/20 | 3/20 | 2/20 | 2/20 | 0/20 |
| TL | 1/20 | 2/20 | 0/20 | 1/20 | 0/20 | 0/20 |

Abbreviations: BL, bone-level; TL, tissue-level.

of outcomes may be negatively influenced over time (Papageorgiou, Eliades, & Hammerle, 2018).

The mean clinical chairside time at tissue-level implants was shorter independently of the workflow. The increased delivery time at bone-level implants could be explained by a possible interference with the peri-implant tissues. At soft tissue-level implants, the implant neck is usually located 0.5 to 1 mm below the mucosal margin or even at the same level, and this can eliminate the interference with the peri-implant soft tissue.

The limitation of the present study is that the results are only valid for the specific workflow investigated including the digital systems applied and the operators involved. More studies are needed to measure time efficiency and quality of outcomes in a model-free digital workflow using immediate digital impressions with different implant systems or digital technologies involved.

## 5 | CONCLUSION

The fabrication of posterior single implant crowns using digital impressions taken immediately after implant placement and a model-free, laboratory-based digital workflow was more time efficient than a hybrid workflow using conventional impressions. The quality of outcomes was similar in both workflows.

## ACKNOWLEDGEMENTS

The authors express their gratitude to Dai Tong (Clinical professor, Department of Prosthodontics, Peking University School and Hospital of Stomatology), Bing Wang, Pengfei Wang, and Wenhui Gao (Dental Technicians, Laboratory Center, Peking University School and Hospital of Stomatology) for the fabrication of the implant crowns.

## CONFLICT OF INTEREST

The authors declare no conflict of interest.

## AUTHOR CONTRIBUTION

S.P., S.M., R.J., and Y.Z. conceived the ideas; S.P. and D.G. collected the data; S.P., D.G., and S.M. analyzed the data; and S.P., S.M., and C.H. led the writing.

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## SUPPORTING INFORMATION

Additional supporting information may be found online in the Supporting Information section at the end of the article.

**How to cite this article:** Pan S, Guo D, Zhou Y, Jung RE, Hämmerle CHF, Mühlemann S. Time efficiency and quality of outcomes in a model-free digital workflow using digital impression immediately after implant placement: A double-blind self-controlled clinical trial. *Clin Oral Impl Res*. 2019;30:617–626. https://doi.org/10.1111/clr.13447