Clin Oral Invest (2013) 17:1759–1764
DOI 10.1007/s00784-012-0864-4

ORIGINAL ARTICLE

Accuracy of digital and conventional impression techniques and workflow

Paul Seelbach · Cora Brueckel · Bernd Wöstmann

Received: 3 July 2012 / Accepted: 10 October 2012 / Published online: 21 October 2012

Abstract
Objectives Digital impression techniques are advertised as an alternative to conventional impressioning. The purpose of this in vitro study was to compare the accuracy of full ceramic crowns obtained from intraoral scans with Lava C.O.S. (3M ESPE), CEREC (Sirona), and iTero (Straumann) with conventional impression techniques.
Materials and methods A model of a simplified molar was fabricated. Ten 2-step and 10 single-step putty-wash impressions were taken using silicone impression material and poured with type IV plaster. For both techniques 10 crowns were made of two materials (Lava zirconia, Cera E cast crowns). Then, 10 digital impressions (Lava C.O.S.) were taken and Lava zirconia crowns manufactured, 10 full ceramic crowns were fabricated with CEREC (Empress CAD) and 10 full ceramic crowns were made with iTero (Copran Zr-i). The accessible marginal inaccuracy (AMI) and the internal fit (IF) were measured.
Results For AMI, the following results were obtained (mean±SD): overall groups, 44±26 μm; single-step putty-wash impression (Lava zirconia), 33±19 μm; single-step putty-wash impression (Cera-E), 38±25 μm; two-step putty-wash impression (Lava zirconia), 60±30 μm; two-step putty-wash impression (Cera-E), 68±29 μm; Lava C.O.S., 48±25 μm; CEREC, 30±17 μm; and iTero, 41±16 μm. With regard to IF, errors were assessed as follows (mean±SD): overall groups, 49±25 μm; single-step putty-wash impression (Lava zirconia), 36±5 μm; single-step putty-wash impression (Cera-E), 44±22 μm; two-step putty-wash impression (Lava zirconia), 35±7 μm; two-step putty-wash impression (Cera-E), 56±36 μm; Lava C.O.S., 29±7 μm; CEREC, 88±20 μm; and iTero, 50±2 μm.
Conclusions Within the limitations of this in vitro study, it can be stated that digital impression systems allow the fabrication of fixed prosthetic restorations with similar accuracy as conventional impression methods.
Clinical relevance Digital impression techniques can be regarded as a clinical alternative to conventional impressions for fixed dental restorations.

Keywords Digital impression · Intraoral scanning · CAD/CAM · Dental impression · CEREC · Lava

P. Seelbach (✉) · C. Brueckel · B. Wöstmann
Department of Prosthodontics, Justus-Liebig-University,
Schlangenzahl 14,
35392 Giessen, Germany
e-mail: paul.seelbach@dentist.med.uni-giessen.de

Introduction

Computer-aided design and manufacturing techniques are gaining more and more importance in the fabrication of dental restorations. However, most approaches are limited to the dental laboratory and start only with scans of a traditional gypsum cast based on a conventional impression technique. Despite all developments in impression techniques and materials, the results in clinical daily practice are, in many cases, still unsatisfactory and therefore in need of further improvement [1]. The reasons for that are manifold and cannot be projected on a single work step in the manufacturing process of prosthetic restorations. Though these problems can be reduced by standardization of work sequences in the workflow, they cannot be eliminated entirely. In this context, digital impressioning procedures may be an approach to improve the accuracy of dental restorations as by their nature these processes eliminate the error-prone conventional impression and gypsum model casting and warrant a high degree of standardization [2].

The information gathered by digital impressioning devices can be entered directly into the digital CAD/CAM production chain. From the viewpoint of information processing, the conventional impression can also be regarded as a means to transfer data from the patient to the dental laboratory. Hence, both procedures—digital impressioning and conventional impression taking—can be described as intraoral data acquisition. In order to minimize process errors deriving from impression taking and model fabrication, it is only logical to transfer the scanning process to the patient and directly scan the preparations in the patient's mouth [3]. This approach was first realized by the CEREC system which is already commercially available for more than 25 years; since then, it has been continuously improved. Meanwhile, the hardware is available in the fourth generation (CEREC Bluecam). However, this system mainly focuses on the chairside production of inlays and partial crowns [4]. This also applies to the E4D system (D4D Technologies, TX, USA) which is primarily available in the USA. However, both systems have never been established as a real alternative to traditional impression taking. In dental literature, there are many data available with regard to the CEREC system. However, little information could be identified regarding the E4D system. Overall, CEREC delivers acceptable results [5, 6] but the precision achieved does not outperform conventional impression techniques [6, 7].

On the contrary, recently introduced digital impressioning systems such as the Lava C.O.S. (3M ESPE, MN, USA), the iTero system (Cadent, NJ, USA), and the TRIOS digital impressioning device (3Shape, Denmark) are more focused on general reproduction purposes of the teeth. Subsequently, the indication for the aforementioned devices has been broadened by their respective manufacturers. The marginal accuracy of a restoration is considered an important prerequisite for healthy periodontal conditions, whereas the internal fit is regarded relevant for the longevity of a ceramic restoration [8–10].

Hence, it was the purpose of this in vitro study to analyze the marginal and the internal accuracy of crowns obtained from three digital impressioning systems (Lava C.O.S., CEREC Bluecam, and iTero intraoral scanner) and two conventional impression techniques with their related workflow. The following null hypothesis was tested: There is no statistically significant difference ($p<0.05$) in the accessible marginal inaccuracy (a) and the internal fit (b) of crowns obtained from the different data acquisition modes and the subsequent workflow (digital and conventional impressions).

Methods

Measuring body

A stainless steel model of an upper jaw was fabricated. For this purpose, a training model was used as a template (KaVo Dental, Germany) (Fig. 1). Tooth 16 was replaced by a simplified tooth model with a circular chamfer preparation (chamfer radius, 1 mm), a circular parallel area (height, 2 mm), and a conical area on top (height, 2.5 mm; angle, 6°) (Fig. 2). To avoid reflections during scanning, the model had a sandblasted matt surface finish (sandblasting with glass pearls of type 212, grain size 40–70 µm), with a roughness similar to prepared teeth. The die was marked in 90° intervals for the assessment of the accessible marginal inaccuracy. Testing was performed under ambient laboratory conditions (23±1 °C at 50±5 % relative humidity).

Digital impressions

Ten digital impressions were taken with a Lava C.O.S. (software version: 2.0.1_p1), CEREC AC (software version 3.80), and iTero (software version 4.0.5.31), according to the manufacturer's recommendations. At this, the model was powdered with Lava C.O.S. powder for the Lava scans and with CEREC Optispray for the CEREC scans. Then, the Lava- and the iTero scans were sent to the respective manufacturers for optimization. Afterwards, iTero scans were exported to Dental Wings (3 Shape) for further processing. The final data sets were transferred to a dental laboratory for milling and manufacturing of 10 full ceramic frameworks each, according to the manufacturer's specifications (Lava Zirconia, 3M ESPE, USA for Lava C.O.S. and Copran Zr-i, White Peaks Dental Systems, Germany for iTero). The CEREC scans were directly transferred to a milling center for the production of 10 full ceramic crowns (IPS Empress CAD, Ivoclar Vivadent, milled on CEREC Inlab).

Conventional impressions

Putty-wash impressions (10 single-step, 10 two-step) were taken from the same model with a polyvinyl siloxane impression material (Express2 Penta Putty/Light Body Standard, 3M ESPE), stored for a minimum of 2 h, and poured

Fig. 1 A stainless steel model of an upper jaw

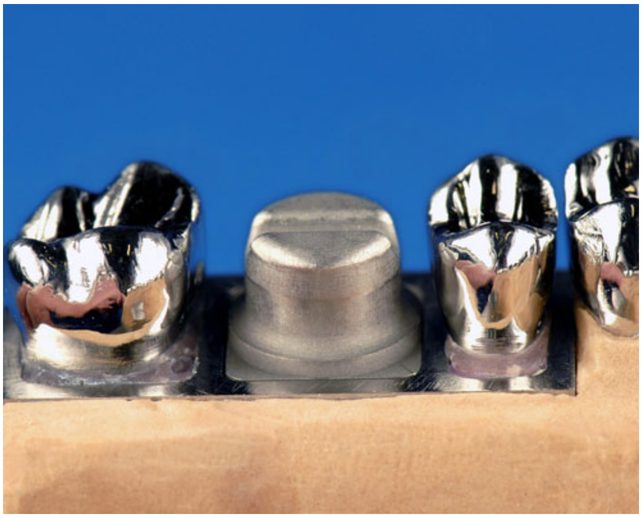


Fig. 2 A simplified tooth model with a circular chamfer preparation, a circular parallel area, and a conical area on top

with type IV plaster (pico-rock 280, Picodent). The resulting models were scanned using a dental laboratory scanner (Lava Scan ST). Based on the scans obtained, full ceramic zirconia frameworks made of Lava were designed, milled, and sintered according to the manufacturer's specifications.

Afterward, on each die, a wax pattern was fabricated, invested (Fujivest Super, GC Corp., Japan), cast and fitted (Cera E, Elephant Dental B.V., The Netherlands). Table 1 provides an overview of all materials and methods tested.

Measurement procedures

The biggest deviation from the dies original radius was used as a measure of the internal fit (IF). Measurements were performed with a 3D-coordinate measuring system (CNC Rapid, Thome Präzision GmbH, Germany). The deviation was assessed at 50 points per crown (3D measuring precision, 3 μm in this setup). Metrolog XG (Version 12.003 HF1, Metrologic Group S.A., France) was used as controlling software. Negative values denote crowns smaller than the original die.

After assessment of the internal fit, the specimen was fitted (fit checker, GC Corp.) by an experienced dentist according to standard clinical procedure prior to the assessment of the accessible marginal inaccuracy (AMI). A diamond bur (379 EF.314.018, Brasseler, Germany) with water cooling was used for fitting. Only the inner parallel surfaces of the crown were ground whereas the marginal areas were left untouched.

The AMI of the test specimen was determined using the original master at each of the four predefined marks with a traveling microscope with electronic data acquisition (Leitz M420, Leitz, Germany) and also with digital micrometer heads (Mitutoyo Digimatic, Mitutoyo Corp., Japan) according to the recommendations of Holmes et al. [11]. The reproducibility of a single measurement was ±5 μm. The measuring process was monitored by a technical assistant. The entire workflow is depicted in Fig. 3. All testing procedures were performed under ambient laboratory conditions (23±1 °C at 50±5 % relative humidity).

Statistical analysis

Both parameters (IF and AMI) were analyzed with the same statistical methods: The Kolmogorov–Smirnov test ($p<0.05$) was used to check for normal distribution, whereas the Levene test ($p<0.05$) served to investigate the homogeneity of variances. Following, ANOVA was used to reveal statistically significant differences between the different groups for both parameters ($p<0.05$). All statistical analyzes were carried out with SPSS for Windows (release 19, SPSS Inc., Chicago, USA).

Results

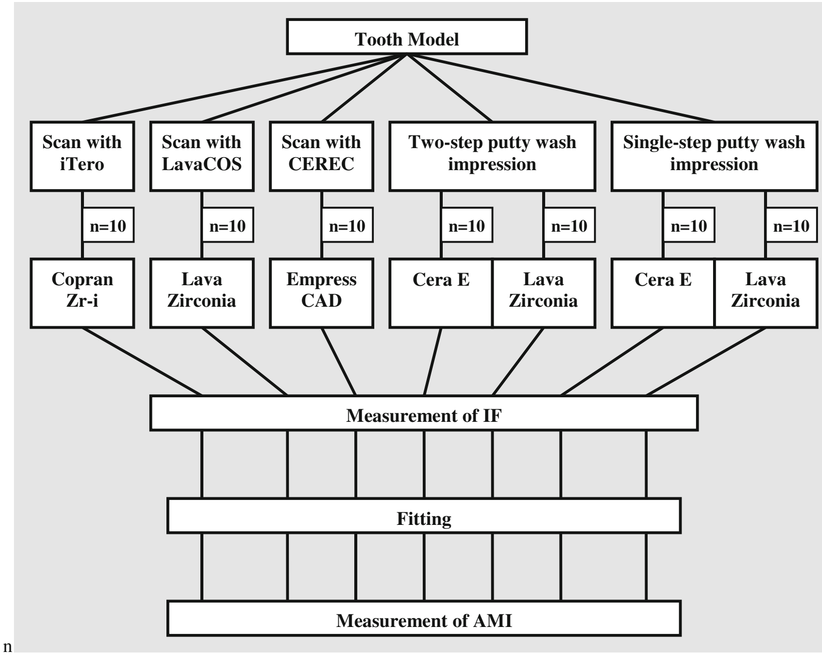
Internal fit

With regard to IF, errors with a mean of 49±25 μm in overall groups were measured (range, 22 to 121 μm). Hence, the best results were obtained for Lava zirconia restorations made on the basis of Lava C.O.S. scans (29±

Table 1 Test setup

Type of material and impression	Crown material	Number	Manufacturer
CEREC scan	Empress CAD	10	Ivoclar Vivadent, Liechtenstein
Lava C.O.S. scan	Lava zirconia	10	3M ESPE, USA
iTero scan	Copran Zr-i	10	White Peaks Dental Systems, Germany
Single-step putty-wash impression	Lava zirconia	10	3M ESPE, USA
	Cera E (silver palladium alloy)	10	Elephant Dental B.V., The Netherlands
Two-step putty-wash impression	Lava zirconia	10	3M ESPE, USA
	Cera E (silver palladium alloy)	10	Elephant Dental B.V., The Netherlands

Fig. 3 The entire workflow



n

7 μm). The biggest deviations were found for CEREC manufactured Empress CAD crowns (81±20 μm). Both differed statistically significantly from almost all other groups ($p<0.05$).

Accessible marginal inaccuracy

Overall groups, AMI with a mean of 44±26 μm were realized (range, 5 to 143 μm). At this, CEREC crowns neither differed statistically significantly from Lava C.O.S. crowns nor from crowns made on the basis of single-step putty-wash impressions ($p<0.05$). All results are displayed in Table 2.

Discussion

Methods

The intention of this in vitro study was to compare the influence of digital impressioning procedures and conventional impressions on the accuracy of the final restoration. An in vitro setup was selected to assess the full potential of digital impressioning for the fabrication of crowns under standardized conditions. Though a clinical setup would have been closer to reality, we abstained from this approach for different reasons: First, all measuring techniques for marginal inaccuracy and internal fit that can be used in patients—like replicas or measuring explorers—are less accurate than an in vitro assessment in the laboratory. Secondly, an in vivo situation cannot be standardized and patients willing to undergo several digital and conventional impressions are hard to find. Thirdly, the investigations primarily focused on the best possible accuracy that can be obtained under ideal conditions eliminating the influence of clinical error sources like bleeding, saliva, limited access, infragingival finishing lines, and different types of teeth. Furthermore, it has to be regarded that in this setup which used the final restoration as the measuring target, the influence of the impression method cannot be separated from other factors of the production chain like milling parameters, shrinking during the sintering process of the crown, or

Table 2 Results

Impression/scan	Material	AMI Mean (μm) ± SD	IF Mean (μm) ± SD
Cerec scan	Empress CAD	30 (±17) a	88 (±20)
Lava C.O.S. scan	Lava zirconia	48 (±25) a	29 (±7) a
iTero scan	Copran Zr-i	41 (±16) a	50 (±12) a
Single-step putty-wash impression	Lava zirconia	33 (±19) a	36 (±5) a
Single-step putty-wash impression	Cera E alloy	38 (±25) a	44 (±22) a
Two-step putty-wash impression	Lava zirconia	60 (±30) b	35 (±7) a
Two-step putty-wash impression	Cera E alloy	68 (±29) b	56 (±36) a

ANOVA ($p<0.05$); (a, b) same symbols denote same levels of statistical significance ($p<0.05$)

AMI accessible marginal inaccuracy, *IF* internal fit individual handling skills of the dental technician. To reduce the inevitable bias, similar production processes for the restorations were selected wherever possible.

For a precise analysis of the scanning device itself, it would have been more favorable to directly compare the data produced by the scanning devices [12] rather than choosing the detour via indirect assessment of the accuracy of the final crowns. As the Lava system was a closed system and denied access to data for investigation at the time when this in vitro study was conducted, there was no possibility of comparing the scan data mathematically to the geometry of the original master.

The precision of digital impressions depends on two different parameters. First, the resolution of the optical scanning system, and second, precision of the matching algorithm which may be decisive for the conduction of full arch scans. In order to minimize the effect of matching artifacts, only small parts of the dental arch in close vicinity of the tooth model were scanned. And following, with regard to the target variables investigated, we focused on those parameters that only characterize the accuracy of the die. Additionally, the flawless reproduction of the neighboring teeth as well as the occlusion is of high clinical relevance. However, as the latter parameters are much more influenced by the manual capability of the dental technician than AIM and IF, they are especially prone to an investigator-related bias. Furthermore, inaccuracies can be much better corrected in every day's clinical work than AMI and IF.

As the die had a round cross section with a circular preparation in a single horizontal plan, it was decided to assess only four predefined measuring points in 90° distance per die in order to warrant independency of the measuring site. To standardize the setup as much as possible, it was abstained from a more anatomic design with lingual and particularly buccal longer axial walls.

Digital impressions

The AMI obtained from the different digital impressioning systems is in good accordance with literature. In 2010, Syrek et al. also reported, with reference to Lava zirconia deriving from intraoral Lava C.O.S. scans, a mean marginal accuracy of 49 μm compared to 71 μm for conventional crowns based on a two-step putty-wash impression [3]. These data can be compared to our results particularly as Syrek used the same approach suggested by Holmes [11] for assessment of the AMI.

In relation to the CEREC system, most investigators assessed inlay and onlay restorations, whereas information about the AMI of crowns is rare. In 1999, Bindl et al. reported a marginal width of computer-machined CEREC 2 crowns of 59.9±5.6 μm [13]. In 2008, Lee reported a mean marginal discrepancy of CEREC 3D crowns of 94.4±11.6 μm [5], whereas up to 111 μm was recorded for onlays manufactured with CEREC 3D [14].

Additionally, most data are based on the predecessor models of the CEREC Bluecam (CEREC 1–3). Data obtained from these systems cannot be directly compared to the actual system as the manufacturer improved the hardware decisively by employing a different light source (blue LED light). In all objectivity, only very few publications regarding Bluecam could be identified [2, 5, 14, 15]. According to the investigations of Mehl et al., the accuracy of the CEREC Bluecam comes up to 19 μm for single tooth images and 35 μm for quadrant images [2].

Ender et al. conducted an in vitro study to compare the accuracy of full arch scans with the CEREC Bluecam and the Lava C.O.S. Hence, the CEREC system showed deviations of 49±14.2 μm and the Lava C.O.S. showed deviations of 40.3±14.1 μm. In comparison, deviations of 55±21.8 μm were measured for a conventional impression technique [15].

The different accuracy with regard to the variables assessed here in-between the Lava and CEREC system may be due to their respective resolution: The manufacturer's state a voxel size of less than 10 μm for Lava and a resolution of approximately 19 μm for the Bluecam which actually would make a difference in 3D resolution of approximately 1:7 to 1:8. Besides differences in accuracy in-between, the milling machines (CEREC vs. Lava) may be also responsible for the difference.

For the iTero scanner, information is rare; however, our data are in good accordance with the few data available in this regard [16, 17]. Furthermore, it is known that the system composes the 3D information from different images with a distance in *z*-direction of about 50 μm [18], whereas no information could be found for the *x*–*y* resolution within each image. Thus, it is hypothesized that the accuracy obtained for the restorations based on iTero scans already represents the physical limit of the device.

In contrast to conventional impressions, a partial correction of the scans is possible by erasing and scanning certain areas of the preparation which were not recorded properly at the first attempt. Though still difficult, this feature can be used for the correct display of infragingival finishing lines which are, despite all efforts, often covered with blood and saliva. In this regard, further software improvements could be helpful to reach the full potential of digital scanning devices. Furthermore and in contrast to any kind of conventional impression material, digital impressions can be archived indefinitely; a fact that may suit for different dental purposes in a patient's future period of life. More clinical investigations are necessary to better understand and analyze these clinical parameters and their influence on the transfer accuracy.

Conventional impressions

With regard to the conventional impressions, results were as anticipated. In a laboratory setup, two-step putty-wash impressions mostly show higher errors than single-step impression techniques. This can be deliberately explained by the distortion of the primary impression during the second impression step. After removal of the mouth, the distorted primary materials reset resulting in a deviation from the original dimension [19]. However in clinical daily practice, this technique shows advantages with regard to the reproduction of infragingival finishing lines [3, 20] and therefore it is often used for crowns.

Conclusions

The AMI and IF of crowns made on the basis of digital impressions are comparable to those of conventionally fabricated crowns. The digital impressioning devices investigated deliver results comparable to conventional impression techniques and meet the accuracy requirements for the process of information transfer from the patient's mouth to the dental laboratory. At this, the null hypothesis cannot be rejected.

Since this is an in vitro study, scans and impressions were conducted under ideal laboratory conditions and did not consider clinical difficulties like scanning of infragingival preparation margins, contamination with blood and saliva, or patients reactions to scanning procedures. However, within the limitations of this in vitro study, it is safe to say that within the same workflow for fixed restorations, the examined scanning systems can be considered as an alternative to conventional impression techniques in clinical daily practice. Yet, further in vivo investigations are necessary to assess whether or not the results obtained in this in vitro study also reflect the clinical situation.

Conflict of interest The authors declare that there is no conflict of interest.

References

1. Samet N, Shohat M, Livny A, Weiss EI (2005) A clinical evaluation of fixed partial denture impressions. J Prosthet Dent 94(2):112–117
2. Mehl A, Ender A, Mormann W, Attin T (2009) Accuracy testing of a new intraoral 3D camera. Int J Comput Dent 12(1):11–28
3. Syrek A, Reich G, Ranftl D, Klein C, Cerny B, Brodesser J (2010) Clinical evaluation of all-ceramic crowns fabricated from intraoral digital impressions based on the principle of active wavefront sampling. J Dent 38(7):553–559
4. Mormann WH, Brandestini M, Lutz F (1987) The Cerec system: computer-assisted preparation of direct ceramic inlays in 1 setting. Quintessenz 38(3):457–470
5. Lee KB, Park CW, Kim KH, Kwon TY (2008) Marginal and internal fit of all-ceramic crowns fabricated with two different CAD/CAM systems. Dent Mater J 27(3):422–426
6. Tinschert J, Natt G, Spiekermann H, Anusavice K (2001) Marginal fit of alumina- and zirconia-based fixed partial dentures produced by a CAD/CAM system. Oper Dent 26(4):367–374
7. Suarez MJ, Gonzalez de Villaumbrosia P, Pradies G, Lozano JF (2003) Comparison of the marginal fit of Procera AllCeram crowns with two finish lines. Int J Prosthodont 16(3):229–232
8. Bindl A, Mormann WH (2005) Marginal and internal fit of all-ceramic CAD/CAM crown-copings on chamfer preparations. J Oral Rehabil 32(6):441–447
9. Schaefer O, Watts DC, Sigusch BW, Kuepper H, Guentsch A (2012) Marginal and internal fit of pressed lithium disilicate partial crowns in vitro: a three-dimensional analysis of accuracy and reproducibility. Dent Mater 28(3):320–326
10. Grasso JE, Nalbandian J, Sanford C, Bailit H (1985) Effect of restoration quality on periodontal health. J Prosthet Dent 53(1):14–19
11. Holmes JR, Bayne SC, Holland GA, Sulik WD (1989) Considerations in measurement of marginal fit. J Prosthet Dent 62(4):405–408
12. Luthardt RG, Loos R, Quaas S (2005) Accuracy of intraoral data acquisition in comparison to the conventional impression. Int J Comput Dent 8(4):283–294
13. Bindl A, Windisch S, Mormann WH (1999) Full-ceramic CAD/CIM anterior crowns and copings. Int J Comput Dent 2(2):97–111
14. da Costa JB (2010) Evaluation of different methods of optical impression making on the marginal gap of onlays created with CEREC 3D. Oper Dent 35(3):324–329
15. Ender A, Mehl A (2011) Full arch scans: conventional versus digital impressions—an in vitro study. Int J Comput Dent 14 (1):11–21
16. Phark J, Oliveira AL (2012) Marginal fit of all-ceramic crowns using conventional and digital impressions. J Dent Res 91 (Spec Iss A):991. http://iadr.confex.com/iadr/2012tampa/webprogram/Paper158085.html
17. Kim M, Song H, Heo S (2012) Accuracy of an intraoral digital impression using parallel confocal imaging. J Dent Res 91 (Spec Iss B):995. http://iadr.confex.com/iadr/2012rio/webprogram/Paper160149.html
18. Kachalia PR, Geissberger MJ (2010) Dentistry a la carte: in-office CAD/CAM technology. J Calif Dent Assoc 38(5):323–330
19. Idris B, Houston F, Claffey N (1995) Comparison of the dimensional accuracy of one- and two-step techniques with the use of putty/wash addition silicone impression materials. J Prosthet Dent 74(5):535–541
20. Wostmann B, Blosser T, Gouentenoudis M, Balkenhol M, Ferger P (2005) Influence of margin design on the fit of high-precious alloy restorations in patients. J Dent 33(7):611–618