Research, Society and Development, v. 11, n. 8, e9911830598, 2022
(CC BY 4.0) | ISSN 2525-3409 | DOI: http://dx.doi.org/10.33448/rsd-v11i8.30598

Digital workflow effectiveness: preliminary results

Efetividade do fluxo de trabalho digital: resultados preliminares

Eficacia del flujo de trabajo digital: resultados preliminaries

Received: 05/19/2022 | Reviewed: 06/06/2022 | Accept: 06/07/2022 | Published: 06/11/2022

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Abstract
Objective: The aim of this observational study was to evaluate the effectiveness of the complete digital workflow in the manufacture of implant-supported screw-retained prostheses regarding to their passive fitting. Materials and Methods: This study presents a preliminary result, part of the project approved by the Ethics Committee of Centro Universitário José Campos Andrade (UNIANDRADE) under number 3,367,320. The sample consisted of 9 patients who had partially edentulous areas with 2 to 3 healed implants, selected at clinic of Faculdade Ilapeo according to the inclusion criteria. All were rehabilitated with metal ceramics multiple implant-supported screw-retained partial dentures. The abutments were selected according to the characteristics of the peri-implant tissues. The frameworks were milled in cobalt-chrome and veneered. The passive fitting of infrastructure was used as a criterion for evaluating the effectiveness of the complete digital workflow through the Sheffield Test criteria. Printed models were used to apply the veneering ceramics. Results: This preliminary result presents 14 implant-supported screw-type fixed prostheses, installed in nine patients. All infrastructures showed a positive result according to the evaluation criteria. Conclusions: Based on the preliminary results presented, it seems fair to conclude that the complete digital workflow shows the necessary effectiveness for obtaining metal ceramic multiple implant-supported screw-retained partial dentures, as a prevalence of prostheses that presented passive sfitting was observed.
Keywords: Implant-fixed prosthesis; Intraoral scanner; CAD CAM.

Resumo
Objetivo: O objetivo deste estudo observacional foi avaliar a eficácia do fluxo de trabalho digital completo na fabricação de próteses parafusadas implanto-suportadas em relação ao seu assentamento passivo. Materiais e Métodos: Este estudo apresenta um resultado preliminar, parte do projeto aprovado pelo Comitê de Ética do Centro Universitário José Campos Andrade (UNIANDRADE) sob o número 3.367.320. A amostra foi composta por 9 pacientes que apresentavam áreas edêntulas parciais com 2 a 3 implantes cicatrizados, selecionados no ambulatório da Faculdade Ilapeo conforme os critérios de inclusão. Todos foram reabilitados com próteses parciais múltiplas parafusadas implanto suportadas. Os pilares foram selecionados de acordo com as características dos tecidos peri implantares. As infraestruturas foram fresadas em cobalto-cromo e revestidas com cerâmica. O assentamento passivo das infraestruturas foi utilizado como critério de avaliação da eficácia do fluxo de trabalho digital completo através dos critérios do Teste de Sheffield. Modelos impressos foram utilizados para aplicação das cerâmicas de revestimento. Resultados: Este resultado preliminar apresenta 14 próteses fixas implanto suportadas tipo parafuso, instaladas em nove pacientes. Todas as infraestruturas apresentaram resultado positivo de acordo com os critérios de avaliação. Conclusões: Com base nos resultados preliminares apresentados, parece justo concluir que o fluxo de trabalho digital completo mostra a eficácia necessária para a obtenção de próteses parciais múltiplas implanto suportadas do tipo parafusadas revestidas por cerâmica, pois foi observada uma prevalência de próteses que apresentaram assentamento passivo.
Palavras-chave: Prótese implanto-fixa; Scanner intraoral; CAD CAM.

Resumen
Objetivo: El objetivo de este estudio observacional fue evaluar la efectividad del flujo de trabajo digital completo en la fabricación de prótesis implantosoportadas atornilladas con respecto a su ajuste pasivo. Materiales y Métodos: Este estudio presenta un resultado preliminar, parte del proyecto aprobado por el Comité de Ética del Centro Universitário José Campos Andrade (UNIANDRADE) bajo el número 3.367.320. La muestra estuvo compuesta por 9 pacientes que tenían áreas parcialmente edéntulas con 2 a 3 implantes cicatrizados, seleccionados en la clínica de la Faculdade Ilapeo de acuerdo con los criterios de inclusión. Todos fueron rehabilitados con prótesis parciales múltiples atornilladas sobre implantes metalocerámicas. Los pilares se seleccionaron de acuerdo con las características de los tejidos periimplantarios. Las estructuras se fresaron en cromo-cobalto y se recubrieron. El ajuste pasivo de la infraestructura se utilizó como criterio para evaluar la eficacia del flujo de trabajo digital completo a través de los criterios de la prueba de Sheffield. Se utilizaron modelos impresos para aplicar la cerámica de recubrimiento. Resultados: Este resultado preliminar presenta 14 prótesis fijas tipo tornillo implantosoportadas, instaladas en nueve pacientes. Todas las infraestructuras mostraron un resultado positivo según los criterios de evaluación. Conclusiones: Con base en los resultados preliminares presentados, parece justo concluir que el flujo de trabajo digital completo muestra la efectividad necesaria para la obtención de prótesis parciales atornilladas implantosoportadas múltiples metal cerámicas, ya que se observó un predominio de prótesis que presentaron ajuste pasivo.
Palabras clave: Prótesis fija sobre implantes; Escáner intraoral; CAD CAM.

1. Introduction

Traditionally, clinicians use a conventional workflow to rehabilitate oral function and/or aesthetics with prostheses. This approach consists of a conventional printing or impression technique, using specific material and a plaster model on which the planned prosthesis is created. However, patient demand for treatments with more predictable results and fewer consultations has driven the development of new technologies and dental materials that can be machined (Joda, Ferrari et al., 2017; Joda, Zarone et al., 2017; Yuzbasioglu et al., 2014).

The CAD/CAM technology (CAD: computer aided design – CAM: computer aided machine) has presented many advantages, but there are still some technical gaps to be filled. This technology can be divided into three stages: image acquisition, restoration design and the construction of the prosthesis (Kapos & Evans, 2014; Miyazaki et al., 2009; Samra et al., 2016; Siqueira et al., 2021; Strub et al., 2006). When combined with intraoral scanning it is called a complete digital workflow. This workflow dispenses the need for conventional impressions and plaster casts, (Aragón et al., 2016; Fluegge et al., 2017; Gjelvold et al., 2016; Mangano et al., 2017; Siqueira et al., 2021), saving time for the manufacture of implant-supported prostheses (Joda & Brägger, 2015; Sawase & Kuroshima, 2020). However, the printing of models will be necessary when the prosthesis were veneering.

Intraoral scanners were introduced in dentistry to improve the techniques of instant digital recording of occlusion (Aragón et al., 2016). These scanners allow the dentist to capture a three-dimensional image of the surface of teeth, of scan bodies of implants and soft tissues. This optical impression creates a virtual work model on which, using specific software (CAD), prosthetic structures can be planned and designed (Moreno et al., 2013; Russo et al., 2019; Rutkunas et al., 2020).

Optical impressions must make it easier to obtain accurate and truthful virtual models, which can be printed (Standardization IOf, 1994). This is the only way it is possible to manufacture a prosthetic structure with adequate passive fitness (Berejuk et al., 2014; Fontoura et al., 2018; Jemt, 1991; Jemt et al., 1999; Jemt & Lekholm, 1998; Rutkunas et al., 2020).

Passive fitness of the prosthetic structure is an important mechanical parameter and is one of the criteria that determine the longevity of prostheses on implants. Digital workflow is presented as a fully mastered reality with innumerable operational advantages with a large arsenal of materials available to obtain machined prostheses, so it is essential to conduct studies that evaluate if this technology makes it possible to obtain passive supported implant infrastructures (Abduo et al., 2010; Abduo et al., 2011; Berejuk et al., 2014; Oteiza-Galdón et al., 2020; Song et al., 2019; Taşın et al., 2019; Uribarri et al., 2019).

Thus, this clinical study presents a preliminary result and aims to begin to elucidate the effectiveness of the use of the complete digital workflow in the manufacture of multiple implants supported multi-layer screw-prostheses in the rehabilitation of partial edentulous spaces, through the assessment of the passive fitting of the infrastructures. Although there are monolithic materials to produce this type of prosthesis and they are always being tested when digital flow is mentioned, this study aims to evaluate the possibility of using metal-ceramics.

2. Materials e Methods

This observational clinical study, which presents a preliminary result, is part of a project approved by the Ethics Committee of ‘Centro Universitário José Campos Andrade’ (UNIANDRADE) under number 3,367,320. The sample consisted of patients at the clinic of Faculdade Ilapeo who met the inclusion criteria. These inclusions criteria were: presenting a uni or bilateral partially edentulous area, in the posterior or anterior region, which had already been treated surgically with a minimum of two osseointegrated implants (which had had adequate osseointegration time according to the type of implant surface, i.e., for hydrophilic surfaces, three months in the maxilla and two months in the mandible; for the other surfaces, six months in the maxilla and four months in the mandible. The implants could not present clinical mobility or signs of inflammation); having an occlusal pattern (contact with at least two posterior teeth) that guaranteed the maintenance of the vertical dimension of occlusion and did not show signs and symptoms of temporomandibular disorder; and agreeing to sign the informed consent form. Patients were not included if, despite having osseointegrated implants that were positioned according to the inclusion criteria, they presented wear facets not compatible with chronological age and/or need for complete occlusal rehabilitation, or if they needed occlusal adjustments in order to have dental prostheses in CRO (centric relation occlusion).

In all implants, mini-pillar or micro-pillar conical type abutments (Neodent, Curitiba, Brazil) were installed. The type and height of the abutments were selected according to the peri-implant tissues. All received the torque recommended by the manufacturer (32Ncm). Then, scan bodies were installed (Figure 1), which were positioned with manual torque until resistance and digital images were acquired using the Trios® S1P intraoral scanner (3Shape A/S, Copenhagen, Denmark). The capture of the images followed the sequence established by the scanner software and the occlusion pattern was recorded at maximum habitual intercuspation (MHI) according to the criteria established by this study.

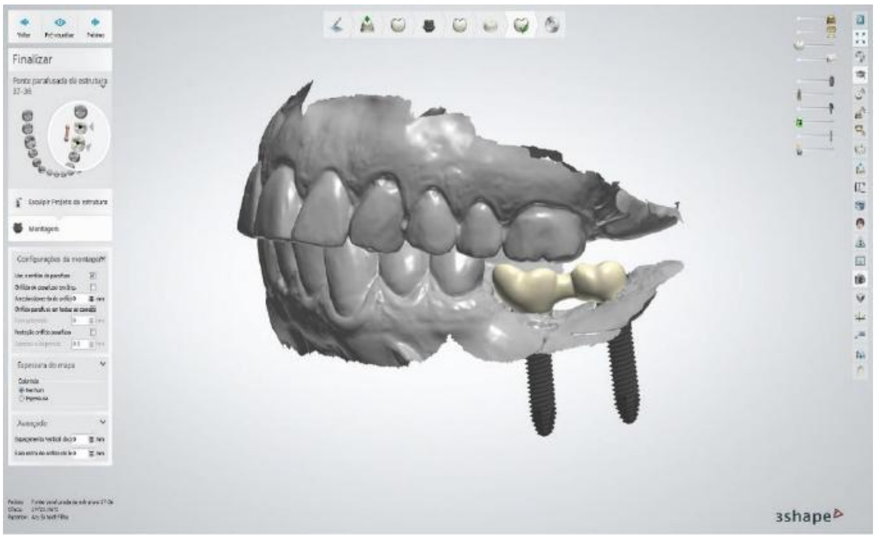
Figure 1. Positioned scan bodies.

Source: Authors (2022).

The images obtained were transferred as STL files (Standard Triangle Language or Standard Tessellation Language: the file type used to describe the layout of three-dimensional objects, used in open systems) to a single prosthetic laboratory (Laboratório Buche, in Curitiba, Brazil).

This laboratory used the 3Shape Dental system to process the received images and designed the infrastructures (Figure 2) for the posterior region that were obtained in CoCr and in Zr for the anterior region, at the Neodent Machining Center (Curitiba, Brazil).

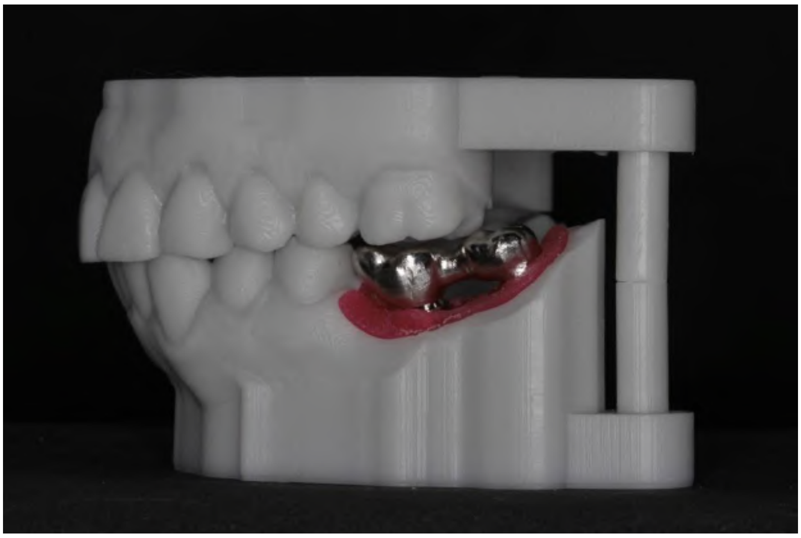
Figure 2. CAD.



Source: Authors (2022).

In addition to designing the infrastructures, this laboratory used the scans to print the 3D working models (Figure 3), using the Straumann® CARES® Pseries model P30 printer. Hybrid analogues corresponding to the prosthetic components installed in the mouth were positioned on these printed models.

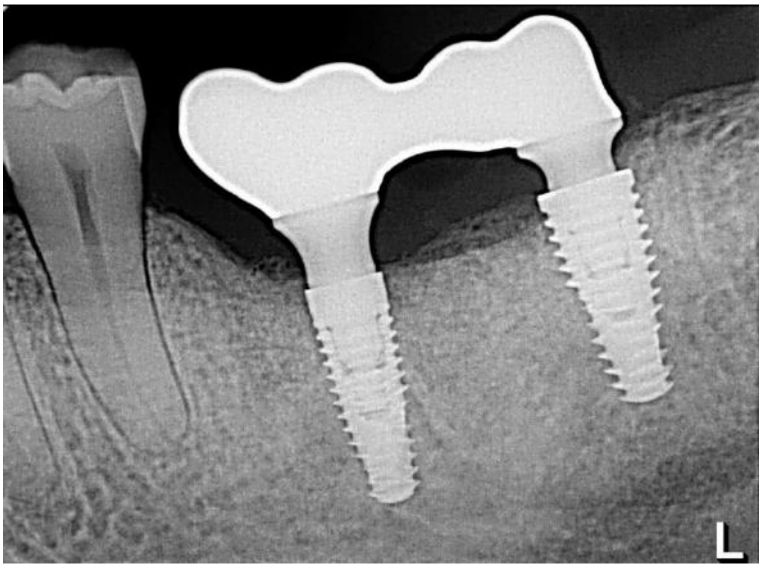
Figure 3. Printed model and infrastructure in CoCr.



Source: Authors (2022).

After machining, the infrastructures were delivered for assess clinical fitting together with the printed work models. Infrastructures were positioned in the mouth and their passive fitness was assessed through the Sheffield Test (Fontoura et al., 2018; Jemt & Lekholm, 1998), also called the One Screw Test. It consists of positioning the prosthetic structure on the prosthetic components of the implants and screwing only one of the screws that fixes the prosthesis. With the prosthesis retained by a single screw, a periapical radiography (Figure 4) was performed to observe the presence or absence of a vertical gap between the prosthetic component and the infrastructure, on the side where there was no screw. When no vertical gap was observed, passive fitting was considered adequate for that prosthesis. Therefore, the test offers a dichotomous result, being positive when there is passive fitting of the infrastructure and negative when it is not verified.

Figure 4. Radiographic record of the Shefield Test.



Source: Authors (2022).

After the confirmation of the passive fitting, with the infrastructures positioned in the mouth, interocclusal registrations were made using a rapid polymerization red acrylic resin (Pattern Resin^{TM}/ GC American Inc./USA). After that, the restorations were again sent to the laboratory for the application of the feldspathic covering ceramic.

For the application of the covering ceramic, the infrastructures were positioned on the printed work models.

As in the conventional processes, the restorations received increments of the covering ceramic, Super Porcelain EX-3 (Noritake, Japan). Then, a clinical fitting of the finished prosthetic parts was carried out (Figure 5).

Figure 5 – Appearance of installed in the mouth.

Source: Authors (2022).

Proximal and occlusal adjustments followed conventional methods and when necessary, wear was carried out with ceramic finishing rubbers. With the prosthesis adjusted and the occlusion checked, the screws received the final torque recommended by the manufacturer (10Ncm) and the access hole for the screws was sealed with Teflon and composite resin (Filtek^{TM} Z350XT/ 3M ESPE). The patient then received guidelines on oral and prosthetic hygiene and follow-up consultations were booked.

3. Results

Two women and seven men, aged between 39 and 67 years participated in the study. They had a total of 30 implants (Neodent®, Curitiba, Brazil) that served as support for fourteen fixed partial prostheses in nine patients. The implant data are shown in Table 1. All implants received abutments, with the mini or conical micro-pillar (Neodent®, Curitiba, Brazil) selected according to the characteristics of the peri-implant tissues.

Table 1. Patient and implant data.

Patient Gender Age	Prosthesis	Position of implant	Implant	Diameter	Size
A ♀ **39**	1	14	Helix GM Acqua	3.5	11.5 mm
		15	Helix GM Acqua	3.75	11.5 mm
A ♀ **39**	2	36	Helix GM Acqua	3.75	10 mm
		37	Helix GM Acqua	3.75	10 mm
B ♂ **67**	3	36	Titamax CM Cortical	3.75	7 mm
		37	Titamax CM Cortical	3.75	7 mm
C ♂ **60**	4	35	Helix GM Acqua	3.5	11.5 mm
		36	Helix GM Acqua	3.75	11.5 mm
		37	Helix GM Acqua	4.3	10 mm
D ♂ **57**	5	36	Helix GM Acqua	3.5	10 mm
		37	Helix GM Acqua	4.3	10 mm
E ♂ **39**	6	15	Helix GM Acqua	3.75	11.5 mm
		16	Helix GM Acqua	4.3	8 mm
F ♂ **55**	7	36	Helix GM Acqua	4.0	10 mm
		37	Helix GM Acqua	4.3	8 mm
G ♂ **50**	8	46	Helix GM Acqua	3.75	10 mm
		47	Helix GM Acqua	4.0	11.5 mm
G ♂ **50**	9	36	Helix GM Acqua	4.0	10 mm
		37	Helix GM Acqua	3.75	10 mm
H ♂ **67**	10	26	Helix GM Acqua	4.0	11.5 mm
		27	Helix GM Acqua	4.0	11.5 mm
H ♂ **67**	11	36	Helix GM Acqua	4.3	11.5 mm
		37	Helix GM Acqua	4.3	11.5 mm
H ♂ **67**	12	46	Helix GM Acqua	3.75	11.5 mm
		47	Helix GM Acqua	3.75	11.5 mm
I ♀ **54**	13	36	Helix GM Acqua	4.0	10 mm
		37	Helix GM Acqua	4.3	8 mm
I ♀ **54**	14	45	Helix GM Acqua	3.5	10 mm
		46	Helix GM Acqua	3.75	10 mm
		47	Helix GM Acqua	3.75	8 mm

Source: Authors (2022).

The dental arch regions rehabilitated in each patient, the type of intermediary and the material used in the machining of the infrastructures are shown in Table 2.

Table 2. Type and position of the components and materials used for machining of infrastructures.

Prosthesis	**Correspondent component**	**Infrastructure material**	**Extension of the prosthesis (quantity of elements)**
1	14 GM MICRO CONICAL ABUTMENT 15 GM MINI CONICAL ABUTMENT	CoCr	2
2	36 GM MICRO CONICAL ABUTMENT 37 GM MINI CONICAL ABUTMENT	CoCr	2
3	36 CM MICRO CONICAL ABUTMENT 37 CM MINI CONICAL ABUTMENT	CoCr	2
4	35 GM MICRO CONICAL ABUTMENT 36 GM MINI CONICAL ABUTMENT 37 GM MINI CONICAL ABUTMENT	CoCr	3
5	36 GM MINI CONICAL ABUTMENT 37 GM MINI CONICAL ABUTMENT	CoCr	2
6	15 GM MICRO CONICAL ABUTMENT 16 GM MINI CONICAL ABUTMENT	CoCr	2
7	36 GM MINI CONICAL ABUTMENT 37 GM MINI CONICAL ABUTMENT	CoCr	2
8	46 GM MICRO CONICAL ABUTMENT 47 GM MINI CONICAL ABUTMENT	CoCr	2
9	36 GM MINI CONICAL ABUTMENT 37 GM MINI CONICAL ABUTMENT	CoCr	2
10	26 GM MICRO CONICAL ABUTMENT 27 GM MINI CONICAL ABUTMENT	CoCr	2
11	36 GM MICRO CONICAL ABUTMENT 37 GM MINI CONICAL ABUTMENT	CoCr	2
12	46 GM MICRO CONICAL ABUTMENT 47 GM MINI CONICAL ABUTMENT	CoCr	2
13	36 GM MINI CONICAL ABUTMENT 37 GM MINI CONICAL ABUTMENT	CoCr	2
14	45 GM MINI CONICAL ABUTMENT 46 GM MINI CONICAL ABUTMENT 47 GM MINI CONICAL ABUTMENT	CoCr	3

Source: Authors (2022).

All the infrastructures had a positive result according to the Sheffield test, thus confirming the passive fitting of these pieces (Table 3). All of them were covered with feldspathic ceramic.

Table 3. Results of evaluation of passive fitness of infrastructure (Sheffield Test).

Structure material	Number of structures	Positive Sheffield Test	Negative Sheffield Test
CoCr	14	14	0

Source: Authors (2022).

After the covering ceramic was applied (Super Porcelain EX-3 – Noritake, Japan), a clinical fitting, adjustment and installation took place. Occlusal adjustments were carried out with the same care recommended for analogue or conventional workflow prostheses.

4. Discussion

This observational study aimed to evaluate screw supported implant infrastructures obtained by fully digital workflow in relation to passive fitness. All fourteen CoCr (cobalt-chromium) infrastructures were considered passive by the Sheffield Test. This preliminary result supports the use of fully digital flow in the manufacture of screwed supported implant prostheses, corroborating other studies that have considered this technology reliable (Abduo, 2014; Berejuk et al., 2014; Jemt et al., 1999; Russo et al., 2019).

The evaluation method used in this study, the Sheffield test, is a previously described method (Berejuk et al., 2014; Sartori et al., 2004). The test assesses the passive fitness of the prostheses, without the use of tension reading devices (Abduo & Swain, 2012; Rodrigues et al., 2014; Tonin et al., 2021), which are difficult to use in a clinical setting. This test is considered an efficient clinical test for the assessment of passive fitness of multiple implant-supported screw-retained prostheses. The test consists of screwing only one side of the prosthetic structure and verifying whether there is any vertical gap on the opposite side, where no screw is placed. Periapical radiographs are used as an aid and to record the seating characteristics. Gap-free structures are considered adequate (Abduo et al., 2010). All prostheses made in this study showed acceptable passivity.

Brånemark (1983) defined that for a structure to be accepted as passively fit, the vertical gap between the prosthesis and the intermediate should be 10 µm or less. However, a definition of passive fitness from a biomechanical perspective is still lacking (Abduo et al., 2010; 2011). Some studies reported no biomechanical problems in prostheses that had up to 150 µm of vertical gap (Jemt, 1991; Jemt et al., 1999; Jemt & Lekholm, 1998; Jemt & Lie, 1995) and others consider that a poorly adjusted prosthesis structure can generate biomechanical complications that can even compromise osseointegration (Moreno et al., 2013; Schwarz, 2000; Skalak, 1983). Faced with this issue, it seems crucial to seek the best possible fit and choose a clinical method that can be trusted in the analysis.

The superiority of cobalt-chromium machined infrastructures when compared with conventional infrastructures obtained has already been described in an in vitro study (Berejuk et al., 2014) the same study also found that machined zirconia presented microgaps of intermediate magnitude among the tested manufacturing methods. The data obtained in this study (Abduo & Swain, 2012; Brånemark, 1983) corroborate those findings, since all the parts obtained by machining showed acceptable fitness. Furthermore, the magnitude of peri-implant stresses is affected by the structure's fitting, and not by the manufacturing material in computer-controlled machining.

The advantage of milling prosthetic structures on implants using computer numerically controlled methods (CNC), the CAD/CAM systems, is the ability to skip several manufacturing steps, including waxing, casting and polishing. Such processes and their materials produce inaccuracies that are exacerbated for larger multiple structures (Abduo, 2014; Abduo et al., 2011; Prasad & Monaco Jr, 2009; Spazzin et al., 2016; Yilmaz et al., 2018). In addition, this method avoids the need for cutting and welding, which are considered weak links and potential failure zones in conventional prostheses (Abduo et al., 2011; Zervas et al., 1999).

The accuracy of CAD/CAM restorations is limited by the accuracy of the working model. However, intraoral optical impressions provide suitable working models for multiple implant-supported prostheses in a fully digital workflow method (Mangano et al., 2017; Tian et al., 2021). In addition, an *in vitro* study (Karl et al., 2012) concluded that the clinician can ensure that current intraoral scanning systems have the same accuracy as conventional impression techniques for manufacturing supported implant restorations. The results obtained in this study corroborate that finding, since intraoral scanning was used and the fitness outcome was considered excellent, although they had been manufactured from a monoblock.

Furthermore, patients' satisfaction regarding comfort during the collection of images of these clinical cases with the use of intraoral scanning was notable. This finding is in agreement with the results obtained in a randomized clinical study that compared digital impression techniques with conventional impression techniques. They demonstrated that digital techniques are more efficient and convenient than conventional techniques (Gjelvold et al., 2016).

The present study also showed that the final occlusal adjustments, made in the covering ceramic, were quite similar to the adjustments made in a conventional workflow prosthesis with the same materials. Studies suggest that monolithic materials, cubic zirconia (Stawarczyk; et al., 2016; Stawarczyk; et al., 2017a; 2017b; Spitznagel et al., 2018), developed for the use of the CAD/CAM system have interesting advantages over multilayer prostheses, which have structures covered with ceramic. Also, they have lower requirements for human participation in the manufacturing process, fewer adjustments, present adequate physical and optical properties, and eliminate some of the problems associated with the materials of multilayer prostheses (Cesar et al., 2018; Souza, 2017; Spitznagel; Boldt & Gierthmuehlen, 2018; Tonin et al., 2021).

The evolution of materials has been very rapid. Monolithic materials enable the manufacture of monoblock partial implant-supported screwed prostheses, without the need for application of aesthetic material. Thus, future studies using screw-type implant-supported partial prostheses in a fully digital workflow using currently available monolithic materials are encouraged. These may be even more time efficient compared with the rehabilitation described here, since they will also remove the need for manual application of feldspathic ceramics (Tonin et al., 2021).

Due to the difficulties faced in the development of this work, specially faced with the veneering process, we intend to carry out more cases and compare them with other materials that are being used for making monolithic prostheses in the complete digital workflow that can potentially demonstrate the effectiveness in obtaining this type of prosthesis with passive fitting corroborating the results obtained so far.

5. Conclusion

Based on the preliminary results presented in this observational study, it seems fair to conclude that the complete digital workflow shows the effectiveness for obtaining multiple implant-supported multi-layer screw-retained prostheses, as it was observed a prevalence of prostheses that presented passive fitting.

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