J Orofac Orthop
DOI 10.1007/s00056-016-0048-y

ORIGINAL ARTICLE

Virtual setup: application in orthodontic practice
Virtuelles Setup: Anwendung in der kieferorthopädischen Praxis

Leonardo T. Camardella[1] · Eduardo Kant C. Rothier[1] · Oswaldo V. Vilella[1] · Edwin M. Ongkosuwito[2] · Karel Hero Breuning[2]

Received: 8 September 2015 / Accepted: 21 March 2016

Abstract
Background A plaster dental model is a patient's traditional three-dimensional (3D) record. If the dental crowns from a plaster model are separated and positioned in wax, this setup of the crowns can be used to simulate orthodontic treatment. The traditional way to make this dental setup requires significant time by the orthodontist and in the orthodontic lab. New developments in dentistry and orthodontics include the possibility of virtual setups.
Aim In this article, the differences between conventional setups with plaster models and virtual setups are discussed.
Methods A clinical patient is described for whom two different setups were made and compared by model superimposition with Geomagic Qualify software.
Results According to the literature and the results from this study, virtual setups and conventional setups with plaster models are equally accurate.
Conclusion Virtual setups present several advantages, e.g., digital storage, digital models cannot be damaged, the same model can undergo several treatment simulations, and communication between dental and surgical professionals and between dental professionals and patients is facilitated. Despite these advantages, considerable time and training are needed for dental professionals to master and adopt the general use of digital models and virtual setups in dentistry.

Keywords Orthodontics · Dental model · Diagnosis · Treatment outcome

Zusammenfassung
Hintergrund Ein Gipsmodell ist die traditionelle dreidimensionale Akte des Patienten. Die vom Gipsmodell getrennten und in Wachs eingebrachten Zahnkronen können dazu dienen, die kieferorthopädische Behandlung zu simulieren. Das traditionelle Verfahren für dieses Setup bedarf eines erheblichen Zeitaufwandes sowohl für den Kieferorthopäden als auch für den Zahntechniker. Zu den neuen Entwicklungen in der Zahnheilkunde und in der Kieferorthopädie zählt die Möglichkeit virtueller Setups.
Ziel Diskutiert wird der Unterschied zwischen konventionellen Setups mit Gipsmodellen und virtuellen Setups.
Methoden Für einen klinischen Patienten wurden 2 verschiedene Setups erstellt, die anhand der Überlagerung der Modelle unter Verwendung der Software Geomagic Qualify miteinander verglichen wurden.
Ergebnisse Der Literatur und den Ergebnissen der Studie zufolge ist die Genauigkeit virtueller Setups und konventioneller Setups mit Gipsmodellen gleich.
Schlussfolgerung Virtuelle Setups bieten eine Reihe von Vorteilen, u. a. lassen sie sich digital archivieren, digitale Modelle können nicht beschädigt werden, und dasselbe Modell kann für mehrere Behandlungssimulationen eingesetzt werden. Ferner erleichtern sie die Kommunikation zwischen Kieferorthopäden und Kieferchirurgen sowie zwischen Kieferorthopäden und Patienten. Trotz dieser Vorteile ist ein erhebliches Maß an Zeit- und Fortbildungsaufwand notwendig, um den Einsatz von digitalen

Dr. Leonardo Tavares Camardella.

✉ Leonardo T. Camardella
leocamardella@globo.com

[1] Department of Orthodontics, Dental School, Federal Fluminense University, Mário Santos Braga Street, 30, 2° Floor, Room 214, Niteroi, RJ 24020-140, Brazil

[2] Department of Orthodontics and Craniofacal Biology and Cleft Palate, Craniofacial Centre, Radboud University Medical Centre, Nijmegen, The Netherlands

Modellen und virtuellen Setups in der Zahnheilkunde zu erlernen und anzuwenden.

Schlüssewörter Kieferorthopädie · Zahnmodell · Diagnose · Behandlungsergebnis

Introduction

Diagnosis and treatment planning are essential steps for successful orthodontic treatment. Capturing the face (if possible in 3D), including the patient's dentition in photographs, radiographs, and dental models, is fundamental. Dental models provide a great deal of information on the mesiodistal dimensions of teeth, arch length discrepancies, dental asymmetries, and arch relationships in three dimensions. A dental model can also be used to produce a 3D simulation of a treatment plan called a dental "setup" [2]. Through these simulations, potential therapeutic objectives such as the need for tooth extractions or interproximal stripping can be evaluated. A setup is thus a valuable diagnostic tool that can be used to confirm, modify or reject a suggested treatment plan and can be particularly valuable in complex cases. An alternative to the traditional setup (using a plaster model) is "the virtual setup," which was introduced in the last decade. In this article, the advantages and disadvantages associated with the use of the conventional setup and virtual setup are discussed and these two setup methods for a clinical case are compared by model superimposition technique with Geomagic Qualify software (3D Systems®, Rock Hill, SC, USA).

Setup in orthodontics

Harold Kesling introduced the setup in orthodontics to manufacture a dental positioner for finishing orthodontic treatment. After the orthodontic bands were removed, the remaining spaces could be closed with the positioner. Shortly thereafter, Kesling realized the importance of this setup for orthodontic diagnosis and treatment planning [14].

The original technique to make a setup, using separated plaster crowns of the dentition fixed in dental wax, has been improved over time. One of these improvements was to position of the lower incisor in the setup according to the cephalometric planning (Fig. 1) [2]. After correcting the position of the lower incisors, the next step traditionally was to manufacture a setup maintaining the vertical dimension of the patient́s dentition by keeping the posterior teeth such as third and second molars, or placing wax or resin stops in the model's posterior region.

A major disadvantage of plaster models and setups in plaster is that superimposition is not possible. It is thus difficult to compare two plaster models made at different times [8]. To analyze tooth movement, dental models need to be superimposed on a stable structure [6, 31]. Nowadays, digital dental models can be made using a model scanner, a scanned impression, or an intraoral scanner [17, 23, 27, 28, 30, 32]. If digital models are available, they can be superimposed using specialized software. For upper model superimposition, the third rugae is suggested as a stable reference landmark [31]. However, the use of a specific palate volume when superimposing digital models seems to be more accurate [6]. Attempts to use stable bone structures on the mandible to superimpose cone beam computed tomography and digital models have been tested [22].

Versatility of a virtual setup

The use of digital models in orthodontics has several advantages. They eliminate the need for storage space [17, 21, 23, 25, 27, 28, 30, 32] as these models can be stored on hard drives, memory sticks, CDs and DVDs. If digital models are available, they can be used to obtain information for diagnosis and treatment planning [10, 29]; they facilitate the transfer of dental models [9, 12, 17, 25, 27, 28, 32] and can be used to make custom appliances based on a virtual setup [11, 20]. These models also allow visualization of orthodontic treatment plans [5, 7, 13, 15, 18].

The actual construction of a virtual setup takes less time than making a conventional setup in plaster. To make a virtual setup, no actual cutting of the plaster or positioning of the dental crowns in wax is needed. Setup accuracy can be improved when digital models are used, because any loss of tooth structure during the cutting process of the plaster is avoided during the digital dental crown separation procedure. The virtual teeth are cut from the model using virtual segmentation techniques, according to the software used. In Ortho Analyzer software (3Shape®, Copenhagen, Denmark) this segmentation process starts with marking mesial and distal points on each tooth. Then, the software draws a segmentation line along the gingival margin. This process is executed semi-automatically, but the suggested segmentation lines still need to be manually corrected. After that, the software separates the dental crowns from the virtual gingiva and defines the interproximal contacts. The time consuming process of laminating and polishing the dental wax needed to make conventional setups, is not needed for virtual setups. Plaster model duplication (as used for the traditional fabrication of a setup) is also not required [12].

In the conventional setup, the dental arch form is planned using a brass wire or pre-established wire shape diagrams available from different companies. In virtual

Fig. 1 The setup manufacturing process with plaster models. **a** Initial plaster model, **b** documenting the most protruded lower incisor position, **c** splitting the crowns and finishing, **d** positioning the teeth in wax and checking the lower incisor position, **e** finished conventional setup

Abb. 1 Herstellungsprozess beim Setup mit Gipsmodellen. **a** Initiales Gipsmodell, **b** Dokumentation der stärksten Protrusion im unteren Schneidezahnbereich, **c** Spleißen der Kronen und Finishing/Finieren, **d** Einbringen der Zähne in Wachs und Lagekontrolle der unteren Schneidezähne, **e** fertiges konventionelles Setup

setups, the arch form can be easily adjusted for each individual patient using software tools that can create an individual digital arch form. As an alternative, the orthodontist can select reference points on the digital dental arch and selects a digital template arch to choose the best arch form for the patient, for instance by using the WALA ridge.

References such as dental midlines, the position of upper and lower molars and the buccal surface of the most protruded lower incisor are needed for plaster setups [2]. For virtual setups, the original occlusal and vertical plane serves as a reference. The orthodontist can quantify and visualize the applied tooth movement in all directions during the actual virtual setup process and, when required, applied tooth movement can be easily reversed. The effect of gradual dental arch expansion, reduction of interdental tooth material ("stripping"), or the decision to extract teeth can be evaluated in a virtual setup for any patient. Although dental changes on a plaster setup can be compared with the original plaster model, in a virtual setup the differences between the original position of the dentition and the planned teeth movement can be visualized after superimposition of the digital models in different colors. With digital models it is even possible to make a simulation video demonstrating the planned movements of the teeth. This virtual setup facilitates efficient communication between the orthodontist, patients and dental professionals. If a proposed treatment plan is not accepted, an alternative plan can be made within minutes.

It is important to mention that tooth movements on computers are unlimited. Tooth alignment and levelling can be planned on the computer screen but this result may not be realistic for that specific patient. Obviously, tooth movement has its biological limitations. Therefore, too much expansion or compression of the dental arches as planned in virtual setups may result in unstable results and periodontal recessions [5]. In a setup of the custom orthodontic appliance system "Insignia" (Ormco®, Orange, CA, USA), the outline of the alveolar mandible bone at a distance of approximately 4 mm below the

Tab. 1 Summary of characteristics of conventional and virtual setups
Tab. 1 Zusammenfassung der charakteristischen Merkmale konventioneller und virtueller Setups

Conventional setup	Virtual setup
More time-consuming	Less time-consuming
Difficult to duplicate	Easy to duplicate
Dental arch form planned using a brass wire or diagrams	Dental arch form planned digitally
Need for dental and facial references	Digital references and quantification of the movements of all teeth
Physical comparison with initial dental model	Comparison with initial model via digital superimposition
Verbal communication requiring the presence of dental professionals and patient	Efficient digital communication between the orthodontist, patient and dental professionals
Potential of tooth fracture during separation	Effective digital segmentation of the teeth
Enables only one setup from each model	Enables different treatment plans on the same model
Conventional orthodontic analysis	Analysis facilitated by software programs
Need for storage space	Digital storage and a copy in the cloud
Deteriorates over time	Easy digital back-up maintaining the same quality
Difficulty of sharing diagnostic information with other professionals	Easy transfer and sharing of dental models and setups via the internet
Used only for treatment planning	Also used to design and make custom appliances (aligners, fixed appliances) and evaluation of treatment progress and result
Difficult to reproduce the same setup	Possibility to reproduce the same setup according to the pre-determined records of movements
CBCTs cannot be combined with plaster models	CBCTs can be combined the digital models to make a virtual head

CBCT cone beam computed tomography

gingival margin (the so-called "Mantrough") can be drawn; it reveals the limitations for moving the mandibular dentition in the virtual setup and during treatment [4]. After adapting the lower dentition to the mandibular alveolar bone's dimensions, the upper dentition can be adapted to the setup of the lower arch. In some software programs such as the Ortho Analyzer, the occlusion of the dentition in the setup can be simulated and visualized in a virtual articulator. Obviously, all setups should be based on biological principles, and their utility depends on the clinician's experience; so although a trained dental technician can make an initial virtual setup, the orthodontist should check each setup and make the corrections needed.

Virtual setup applications in orthodontic treatment

There is ample evidence that digital models are as accurate and reliable as plaster models [17, 21, 23, 25, 27, 28, 30, 32]. With the introduction of digital models, virtual setups and arch wire bending robots, new individual (custom) orthodontic appliances have been developed. The virtual setup of a specific case can be used to gradually move the dentition into the planned position. A series of 3D printed dental models can be used to fabricate a series of aligners which move the teeth gradually into the planned position [19]. Digitally designed attachments can be bonded on the teeth to improve the efficiency of specific tooth movement with aligners.

A digital model can also be used to virtually position images of a scanned series of standard brackets. This virtual bracket positioning can be done on the virtual dentition before treatment or on a virtual treatment setup. This planned bracket position should be transferred to the dentition before treatment and printed dental models can be used to construct indirect bracket bonding trays [26]. Recent software programs can even be used to design a virtual indirect bracket transfer bonding tray which can be printed with 3D printers, without the need to actually print the dental models. A virtual setup can also be used to design individualized ("custom") brackets and custom wires for buccal and lingual fixed appliance therapy. These virtual custom brackets can be printed in wax and casted in a gold alloy using digital technology [11, 20]. A set of individual wires can be bent by a wire-bending robot to complete an individual tooth movement system such as Incognito.

Of course, the dental roots are not visible in a setup made from a plaster model or from an intraoral scan of the dentition. Root parallelism or bone dehiscence of the alveolar ridge cannot be evaluated on these models. If both cone beam computed tomography (CBCT) radiographs and digital models are available, these 3D images can be

Fig. 2 Initial extra-oral and intra-oral photos
Abb. 2 Extra- und intraorale Fotos zu Beginn

accurately superimposed [15, 18, 24]. Some current CBCT machines such as the Planmeca ProMax 3D (Planmeca Inc., Roselle, IL, USA) can make 2D and 3D radiographs and a 3D facial scan. The software available can be used for combined 3D information (a "virtual head"). Evaluation of the available alveolar bone and the effect of planned tooth movement on the soft tissues is now possible [15, 18, 24]. Some companies, such as SureSmile (Orametrix®, Richardson, TX, USA) use intraoral scans as well as CBCT images for treatment planning and evaluation. A major advantage of a virtual treatment plan using the 3D documentation of the head in a 1:1 ratio is that the orthodontist can evaluate and plan the dentition's correction and if needed, the jaws including correction of the dental roots. Progress intraoral scans and CBCTs allow a progress setup to be made, which can be used for the fabrication of finishing wires or finishing aligners. Studies have shown that the use of computer-bent custom wires as used in the SureSmile system can reduce orthodontic treatment time and improve treatment outcomes [1]. But according to Larson et al. [16] the effectiveness of orthodontic treatment using SureSmile technology to achieve predicted tooth position varies according to the tooth types and movements needed. Table 1 illustrates the advantages and disadvantages of the conventional and virtual setups.

Clinical case

A female patient aged 17 years and 11 months presented for consultation in the Orthodontic Clinic at the Federal Fluminense University (Niterói, Brazil). Her main complaint was her lip prominence. After the anamnesis and clinical examination, regular orthodontic documentation was planned. The diagnosis for this patient was a Class I malocclusion with an anterior open bite, mild anterior crowding, and lip protrusion (Fig. 2). Cephalometric analysis showed upper and lower incisor protrusion (Fig. 3).

Fig. 3 Initial lateral cephalogram showing the upper and lower incisor protrusion

Abb. 3 Initiales laterales Kephalogramm zur Darstellung der unteren und oberen Schneidezahnprotrusion

An initial plaster model was manufactured and copied to make the conventional setup (Figs. 4, 5). The initial plaster model was scanned with a desktop scanner (type R700, 3Shape®, Copenhagen, Denmark) in order to obtain a digital model (Fig. 6). On this digital model, a virtual setup was made with Ortho Analyzer software (Fig. 7). One orthodontist made the conventional setup on plaster model and another orthodontist made the virtual setup. The fabrication of the conventional setup took up to 5 h, while the virtual setup was made in 40 min.

After evaluation of the setups, the proposed final treatment (extraction of the first four premolars and fixed orthodontic appliances in the upper and lower arch) was presented to and accepted by the patient.

Orthodontic treatment started with extraction of the first four premolars and bonding of the upper and lower fixed appliance. The dentition was aligned and leveled using flexible wires. Then an 0.020″ stainless steel arch wire was used to retract the cuspids with elastic chain. Incisor retraction and space closure was achieved with a $0.019'' \times 0.025''$ stainless steel arch wire with a bubble loop. Steel wire bends and anterior and posterior intermaxillary elastics were used for finishing. An upper removable plate ("Hawley plate") was used for retention in the upper arch. A lower fixed retainer was bonded in the mandible (Fig. 8). Treatment of this patient resulted in

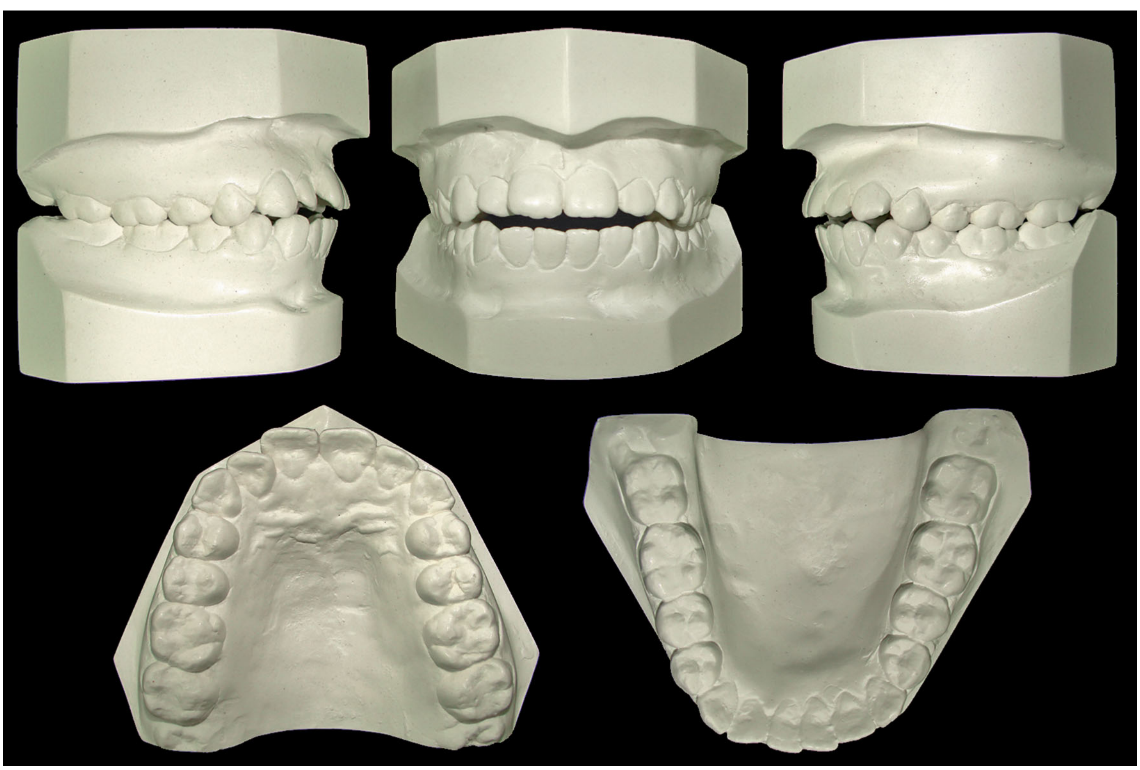

Fig. 4 Initial plaster model (views: *right side*, *front*, *left side*, *upper occlusal* and *lower occlusal*)

Abb. 4 Initiales Gipsmodell (Ansichten: rechte Seite, Front, linke Seite, Oberkieferaufsicht, Unterkieferaufsicht)

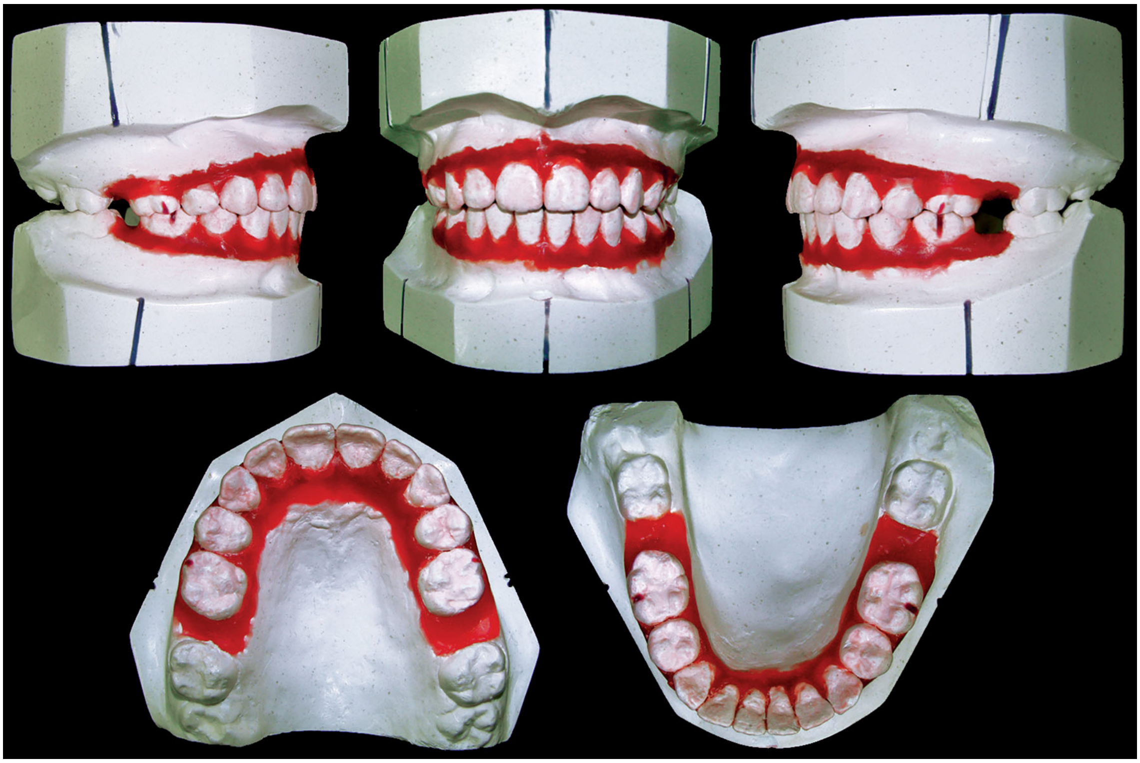

Fig. 5 Conventional plaster setup (views: *right side*, *front*, *left side*, *upper occlusal* and *lower occlusal*)
Abb. 5 Konventionelles Gips-Setup (Ansichten: rechte Seite, Front, linke Seite, Oberkieferaufsicht, Unterkieferaufsicht)

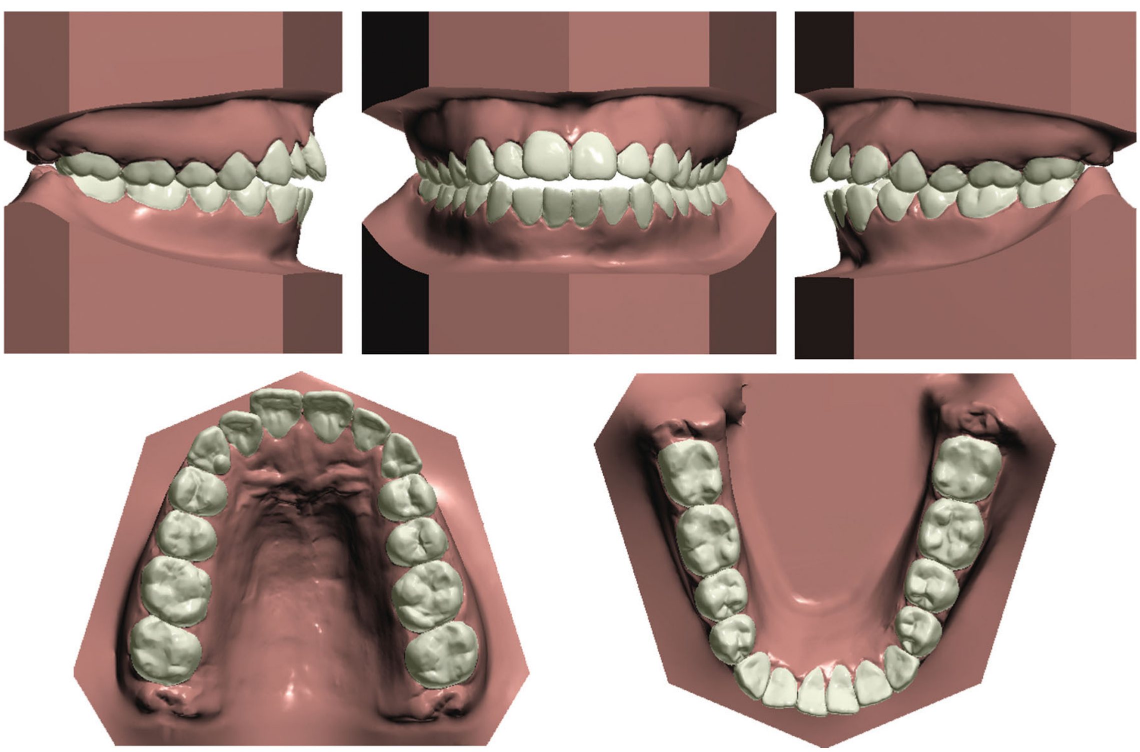

Fig. 6 Initial digital model (views: *right side*, *front*, *left side*, *upper occlusal* and *lower occlusal*)
Abb. 6 Initiales digitales Modell (Ansichten: rechte Seite, Front, linke Seite, Oberkieferaufsicht, Unterkieferaufsicht)

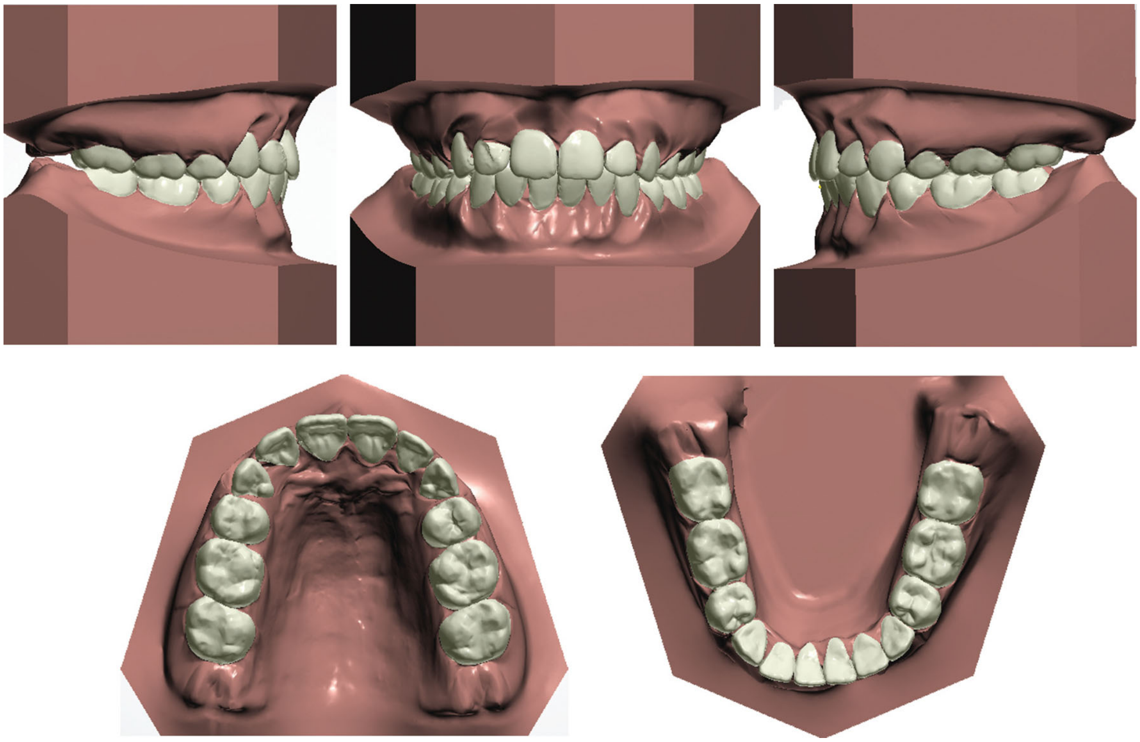

Fig. 7 Virtual setup (views: *right side*, *front*, *left side*, *upper occlusal* and *lower occlusal*)
Abb. 7 Virtuelles Setup (Ansichten: rechte Seite, Front, linke Seite, Oberkieferaufsicht, Unterkieferaufsicht)

upper and lower incisor retraction and an improvement in her profile (Fig. 9).

The conventional setup was scanned (R700 scanner), which allowed a digital superimposition of both setups using Geomagic Qualify software. For this model superimposition, only the dentition's outline was used because the superimposition of the gingival area results in distortion. On the conventional setup, the wax does not accurately represent the gingiva. On the virtual setup, distortions of the virtual gingiva caused by virtual dental movements cause inaccurate representation of the gingival region. With this software, the superimposition of the dentition was achieved using the "best fit alignment method" (the software calculates the best alignment of a thousand identical points between the dentition of two setup models).

Superimposition of the setups reveals differences between the two setups. Average positive discrepancies of 0.39 mm and average negative discrepancies of 0.46 mm in the upper models, and average positive discrepancies of 0.53 mm and average negative discrepancies of 0.51 mm in the lower models can be seen in a color-coded scale of the superimposition (Fig. 10). The largest differences in dimensions of the upper arch were located in the first molars transversal dimensions and in the lateral incisors' vertical relationship. In the lower arch, the greatest differences were seen in the vertical relationship of the second premolars and in the transversal dimensions of the first molars. The superimposition on this model set shows similar dimensions in the canine-to-canine region.

Discussion

In many cases, a dental setup to simulate orthodontic treatment helps the orthodontist to decide which treatment option is the best for a specific patient. This setup can also be considered a powerful communication tool to explain possible treatment options to the patient and the referring dentist or a specialist such as a maxillofacial surgeon. It is not advisable to suggest that the orthodontic treatment outcome will be exactly as presented in the setup because during each orthodontic treatment, complications and side effects such as individual responses to treatment mechanics, periodontal restrictions, lack of cooperation in the use of extra oral appliances or elastics can affect the treatment outcome.

When conventional and virtual setups such as those presented in this case are compared, differences between treatment planning and actual outcome become apparent. Such differences are unavoidable because of the side effects already mentioned and inaccuracies in the setup

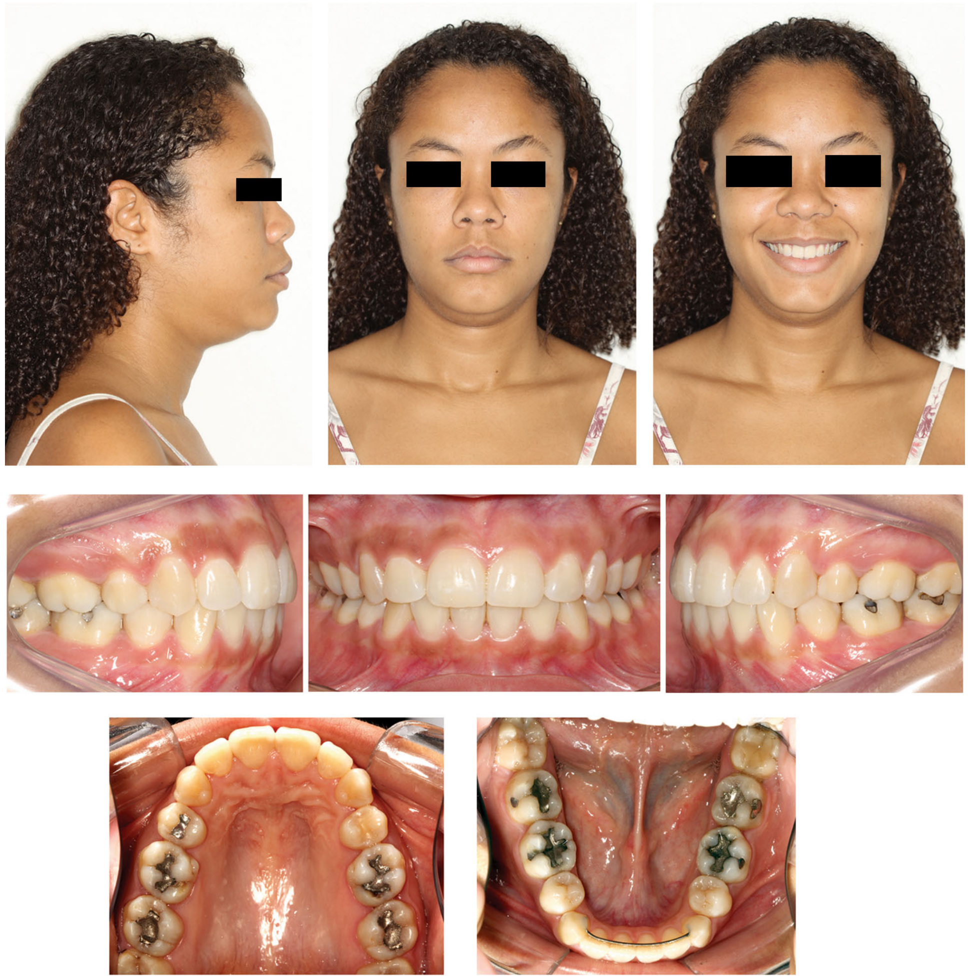

Fig. 8 Extra-oral and intra-oral photos after treatment
Abb. 8 Extra- und intraorale Fotos nach Behandlung

manufacturing process [7, 13]. Nevertheless, virtual setups are at least as effective and accurate as conventional setups and are an effective tool for diagnosis and orthodontic treatment planning, appliance fabrication, and treatment assessments [3].

According to the literature, significant differences in the Original American Board of Orthodontics Objective Grading System (ABO-OGS) scores between two virtual setups of the same original models made by a single clinician were reported [7]. Virtual setups of the same original model made by different clinicians differed also [7]. Such differences also occur if conventional setups with plaster models are made, because dental setups depend on a practitioner's subjective decisions. In this article, two different orthodontists made the conventional and virtual setups. The differences between these setups, especially those in the transversal posterior relationship, are influenced by how the planned arch form had been selected (brass wire for the conventional setup versus a virtual arch form for the virtual setup). However, the advantage of a virtual setup is that a report with a script of all movements performed during the setup fabrication can be generated; thus, an identical setup can be made.

For each setup, references to the original dental position are needed. In the conventional setup, the second molar position was maintained to preserve the vertical occlusion dimension. In the virtual setup, all posterior teeth were moved but the original occlusal and transversal plane were used as a reference. Tooth movement limitations (constrained movement) can be selected in the planning software to prevent very large and clinically impossible tooth movements.

As progress in digital imaging techniques and tools to plan medical treatments accelerates, the use of virtual setups in orthodontics before and during treatment will become the "main stream" in orthodontics. If intra-oral color scanners are used, traditional intra-oral photographs

Fig. 9 Cephalogram after treatment showing the correction of the inclination of upper and lower incisors

Abb. 9 Kephalogramm nach der Behandlung: Darstellung der korrigierten Inklination von oberen und unteren Inzisiven

are no longer needed. If facial scanners are used, those scans can replace traditional extra-oral photographs. A potential obstacle for the transition into virtual treatment planning and appliance design may be that these techniques are more expensive and the orthodontic lab and orthodontist should buy the hardware and software needed for making virtual setups. Another problem is the adequate training of the orthodontic technician, the dentist and/or orthodontist to use this new technology. However, because of the growing demand for well-planned efficient orthodontic treatment, the use of digital models and virtual treatment planning will increase. The progress documented during treatment will help to correct side effects of orthodontic mechanics with orthodontic appliances. Progress scans after active orthodontic treatment can be used to design and fabricate custom orthodontic retention devices. These new developments will make orthodontic therapy more efficient and predictable.

Conclusion

Simulating orthodontic treatment outcomes before the actual treatment has started is desirable and now actually possible. There is a genuine demand for customized orthodontic appliances to achieve planned orthodontic treatment results in an efficient and predictable way. Despite the fact that virtual setups have many advantages, the high cost of the hardware and software as well as the lack of training (in making the dental virtual setup and using the software to design and manufacture custom

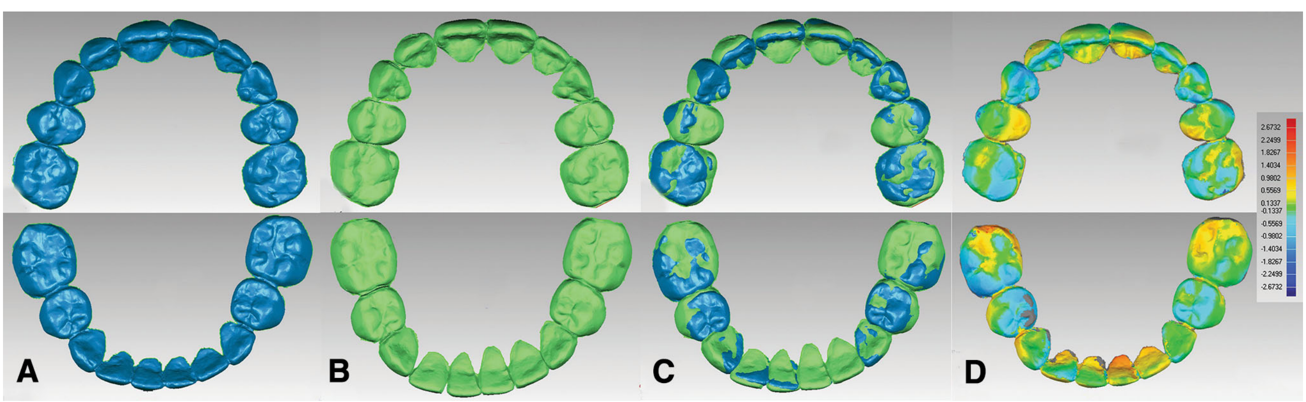

Fig. 10 Superimposition of conventional and virtual setups. **a** Digital model from the conventional setup. **b** Digital model from the virtual setup. **c** Superimposition of the scanned conventional setup and virtual setup using the "best fit alignment" method. **d** *Color code* representing differences between the setup models

Abb. 10 Überlagerung konventioneller und virtueller Setups. **a** Digitales Modell vom konventionellen Setup. **b** Digitales Modell vom virtuellen Setup. **c** Überlagerung des gescannten konventionellen Setups und des virtuellen Setup unter Verwendung der Methode "best fit alignment". **d** Farbkodierung zur Darstellung der Unterschiede zwischen den Setup-Modellen orthodontic appliances) currently limit the use of this technology in orthodontics.

Compliance with ethical guidelines

Conflict of interest L. T. Camardella, E. K. C. Rothier, O. V. Vilella, E. M. Ongkosuwito, and K. H. Breuning declare that they have no competing interests.

All procedures performed in studies involving human participants were in accordance with the ethical standards of the institutional and/or national research committee and with the 1964 Helsinki declaration and its later amendments or comparable ethical standards. Informed consent was obtained from all individual participants included in the study. Additional informed consent was obtained from all individual participants from whom identifying information is included in this article.

References

1. Alford TJ, Roberts WE, Hartsfield JK et al (2011) Clinical outcomes for patients finished with the SureSmile method compared with conventional fixed orthodontic therapy. Angle Orthod 81:383–388
2. Araujo TM, Fonseca LM, Caldus LD et al (2012) Preparation and evaluation of orthodontic setup. Dental Press J Orthod 17:146–165
3. Barreto MS, Faber J, Vogel CJ et al (2016) Reliability of digital orthodontic setups. Angle Orthod 86:255–259
4. Breuning KH (2011) Efficient tooth movement with new technologies for customized treatment. J Clin Orthod 45:257–262 **(quiz 87)**
5. Chen S, Xu TM (2013) Treatment of a severe transverse dental arch discrepancy assisted by 3-dimensional planning. Am J Orthod Dentofac Orthop 143:105–115
6. Choi DS, Jeong YM, Jang I et al (2010) Accuracy and reliability of palatal superimposition of three-dimensional digital models. Angle Orthod 80:497–503
7. Fabels LN, Nijkamp PG (2014) Interexaminer and intraexaminer reliabilities of 3-dimensional orthodontic virtual setups. Am J Orthod Dentofac Orthop 146:806–811
8. Flugge TV, Schlager S, Nelson K et al (2013) Precision of intraoral digital dental impressions with iTero and extraoral digitization with the iTero and a model scanner. Am J Orthod Dentofac Orthop 144:471–478
9. Goonewardene RW, Goonewardene MS, Razza JM et al (2008) Accuracy and validity of space analysis and irregularity index measurements using digital models. Aust Orthod J 24:83–90
10. Gracco A, Buranello M, Cozzani M et al (2007) Digital and plaster models: a comparison of measurements and times. Prog Orthod 8:252–259
11. Grauer D, Proffit WR (2011) Accuracy in tooth positioning with a fully customized lingual orthodontic appliance. Am J Orthod Dentofac Orthop 140:433–443
12. Horton HM, Miller JR, Gaillard PR et al (2010) Technique comparison for efficient orthodontic tooth measurements using digital models. Angle Orthod 80:254–261
13. Im J, Cha JY, Lee KJ et al (2014) Comparison of virtual and manual tooth setups with digital and plaster models in extraction cases. Am J Orthod Dentofac Orthop 145:434–442
14. Kesling H (1956) The diagnostic setup with consideration of the third dimension. Am J Orthod 42:740–748
15. Kihara T, Tanimoto K, Michida M et al (2012) Construction of orthodontic setup models on a computer. Am J Orthod Dentofac Orthop 141:806–813
16. Larson BE, Vaubel CJ, Grunheid T (2013) Effectiveness of computer-assisted orthodontic treatment technology to achieve predicted outcomes. Angle Orthod 83:557–562
17. Leifert MF, Leifert MM, Efstratiadis SS et al (2009) Comparison of space analysis evaluations with digital models and plaster dental casts. Am J Orthod Dentofacial Orthop 136:16e1–16e4 **(discussion)**
18. Macchi A, Carrafiello G, Cacciafesta V et al (2006) Three-dimensional digital modeling and setup. Am J Orthod Dentofac Orthop 129:605–610
19. Miller RJ, Derakhshan M (2004) Three-dimensional technology improves the range of orthodontic treatment with esthetic and removable aligners. World J Orthod 5:242–249
20. Mujagic M, Fauquet C, Galletti C et al (2005) Digital design and manufacturing of the Lingualcare bracket system. J Clin Orthod 39:375–382 **(quiz 0)**
21. Mullen SR, Martin CA, Ngan P et al (2007) Accuracy of space analysis with emodels and plaster models. Am J Orthod Dentofac Orthop 132:346–352
22. Park TJ, Lee SH, Lee KS (2012) A method for mandibular dental arch superimposition using 3D cone beam CT and orthodontic 3D digital model. Korean J Orthod 42:169–181
23. Quimby ML, Vig KW, Rashid RG et al (2004) The accuracy and reliability of measurements made on computer-based digital models. Angle Orthod 74:298–303
24. Rangel FA, Maal TJ, Bronkhorst EM et al (2013) Accuracy and reliability of a novel method for fusion of digital dental casts and Cone Beam Computed Tomography scans. PLoS ONE 8:e59130
25. Rheude B, Sadowsky PL, Ferriera A et al (2005) An evaluation of the use of digital study models in orthodontic diagnosis and treatment planning. Angle Orthod 75:300–304
26. Sachdeva RC (2001) SureSmile technology in a patient–centered orthodontic practice. J Clin Orthod 35:245–253
27. Sousa MV, Vasconcelos EC, Janson G et al (2012) Accuracy and reproducibility of 3-dimensional digital model measurements. Am J Orthod Dentofac Orthop 142:269–273
28. Stevens DR, Flores-Mir C, Nebbe B et al (2006) Validity, reliability, and reproducibility of plaster vs digital study models: comparison of peer assessment rating and Bolton analysis and their constituent measurements. Am J Orthod Dentofac Orthop 129:794–803
29. Tomassetti JJ, Taloumis LJ, Denny JM et al (2001) A comparison of 3 computerized Bolton tooth-size analyses with a commonly used method. Angle Orthod 71:351–357
30. Torassian G, Kau CH, English JD et al (2010) Digital models vs plaster models using alginate and alginate substitute materials. Angle Orthod 80:474–481
31. van der Linden FP (1978) Changes in the position of posterior teeth in relation to ruga points. Am J Orthod 74:142–161
32. Wiranto MG, Engelbrecht WP, Nolthenius HET et al (2013) Validity, reliability, and reproducibility of linear measurements on digital models obtained from intraoral and cone-beam computed tomography scans of alginate impressions. Am J Orthod Dentofac Orthop 143:140–147