Abstract


**Aim** To assess the feasibility of creating a realistic model for hands-on training in dental traumatology using 3D printing technology, and then to investigate the added value of working with the website dental-traumaguide.org.

**Methodology** With the use of special software applications, a model was designed based on the CBCT of the maxilla of a real patient that imitated several traumatic dental injuries. The model was reproduced using a stereolithographic printer to use the specimens in a hands-on training course on dental traumatology for undergraduate students in their final year in the Department of Conservative Dentistry and Periodontology in Munich, Germany. During the course, half of the participants had access to dental-traumaguide.org, whereas the others did not. The students were then assessed according to their theoretical knowledge and practical performance in simulated treatment. These data were analysed by Kolmogorov–Smirnov test, unpaired t-test and Mann–Whitney U test. Subsequently, the participants were asked to evaluate the model.

**Results** The workflow for manufacturing a model of dental traumatology for training purposes was practical and relatively inexpensive. In the evaluation process, the model was considered to be highly realistic and useful during an instructive hands-on training course. There were significant differences between the two groups in favour of using the dentaltraumaguide.org website.

**Conclusions** 3D printing technology offers new possibilities for training specific dental treatments that are currently difficult to imitate. The online platform dentaltraumaguide.org assisted students in correctly managing traumatic dental injuries.

**Keywords:** 3D printing, dental traumatology, education, feasibility study.

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Introduction

In a pre-clinical setting, realistic, extensive and repetitive hands-on training is needed to prepare students for their first real-life patient. Unfortunately, at present, there exists no appropriate commercially available model offering the possibility of imitating diagnosis and treatment following dental trauma.

Even students in a clinical setting can only, to a small degree, participate in the treatment of a traumatized tooth since the nature of such an accident requires immediate care from an experienced professional. Consequently, dental traumatology is mostly taught in theoretical lectures and less in practical courses, making the selection of a correct treatment plan and clinical execution difficult for newly graduating dentists. This might explain the often-insufficient knowledge of general dentists about dental traumatology (Krastl *et al.* 2009). This is a problem because the treatment of most dental accidents is usually carried out by general dentists, and inadequate knowledge can seriously jeopardize the outcome (Hamilton *et al.* 1997).
Consequently, the aim of this study was to design a model for hands-on training in dental traumatology that was highly realistic and appropriate for the diagnosis and treatment of several simulated traumatic dental injuries. 3D printing technology seems to be the most feasible way to develop such a model and reproduce it in sufficient quantity. With the initial investment costs no longer being a real obstacle, this technology offers new possibilities, especially for dental clinics that are in need of new models for education purposes. Thus, the purpose of this study was to design a workflow that could be implemented within the technical limitations of an educational institution and therefore be transferrable to other dental clinics.

When treating a trauma, correct diagnosis and treatment planning, according to valid guidelines, are mandatory. Apart from textbooks, several software applications have been developed recently (Djemal & Singh 2016) that aimed to provide advice to dentists who have to address traumatic dental injuries. These applications allow the dentist rapid and clear access to information on how to manage a trauma case. A widely known online source is dentaltraumaguide.org, which is supported by the International Association of Dental Traumatology (IADT). It offers a large amount of information, instructions and visualizations of single treatment steps for each injury according to the latest guidelines of the IADT (Andersson et al. 2012, DiAngelis et al. 2012, Malmgren et al. 2012).

The second objective of the study was to compare the performance of dental students in a hands-on training course in which only half of them had access to the online platform dentaltraumaguide.org. At the end of the course, the participants were asked to fill in a questionnaire, the results of which were used to further improve the model as well as the training course.

Materials and methods

A three-dimensional radiograph of the maxilla of a patient facing orthodontic treatment was taken using a cone-beam CT (Kodak 950, 10 × 5×5 cm, 90 kV, 3.2 mA, 8 s, 311 mGy cm⁻²). The data generated were exported as single DICOM files and imported to Invesalius for Mac (Centre for Information Technology Renato Archer, Amarais, Brazil) to convert it into one STL-file. This file was subsequently imported to Meshmixer for Mac 11.0 (Autodesk, San Rafael, CA, USA) and trimmed to a region extending from the right first premolar to the left premolar. The right lateral incisor, the left first incisor as well as the left second incisor were cut out of the STL-mesh and exported as single STL-files. Using the function ‘Boolean difference’, these teeth were cut out, leaving imitation tooth sockets in their original position. Additionally, the right lateral incisor was positioned at a 30° angle towards the palatal from its original position, and again, the function ‘Boolean difference’ was used to imitate a lateral luxation of the tooth perforating the buccal bone (Fig. 1). The left lateral incisor was separated into two parts at its apical third imitating a horizontal root fracture. The extracted left incisor was not changed, imitating an avulsion. The mesial edge of the right incisor was removed, exposing the pulp chamber to imitate a complex crown fracture. The final model was ground on a base to leave a space for a connector to a mannequin’s head. The model, as well as the single teeth, was imported to PreForm for Mac (Formlabs, Sommerville, MA, USA) and was manufactured with a stereolithographic printer (Print 2, Formlabs) using the resin of the manufacturer (Grey Resin, Formlabs) mixed with barium sulphate powder for achieving adequate radio opacity. After the printing process, the model and the teeth were separated from the support structures, cleaned with alcohol in an ultra-sonic bath and post-cured for 10 min (LC 3DPrint Box, Nextdent, Soesterberg, Netherlands). The single teeth were inserted into the corresponding tooth sockets, and a gingiva mask was waxed up on the model. This gingiva mask was subsequently scanned (Activity 885 Mark 2, Smartoptics, Bochum, Germany), exported as a STL-file and
reproduced by 3D printing (Form 2 in Open Modus; Gingiva Mask, Nextdent, Soesterberg, Netherlands).

A case of a traumatic accident suffered by a 16-year-old boy was presented to the 32 undergraduate students participating in a hands-on training course on dental traumatology. They received a manuscript with information regarding the case and further instructions. They were asked to note all their responses in the manuscript. Half of the participants had access to the online platform dentaltraumaguide.org, whereas the others did not. All participants were allowed to use textbooks on dental traumatology or corresponding online applications as support.

Initially, the dental students had to simulate a phone call with the mother of the injured teenager asking for more details about the accident and giving advice for post-traumatic behaviour. Subsequently, they were given the 3D-printed model with additional information about pulp sensibility, percussion and mobility of every single tooth as well as access to the radiographs of the model (Figs 2 and 3). Using this information, the students were then asked to make a diagnosis, develop a treatment plan, a recall regime and a prognosis of each injured tooth before starting the actual treatment. The manuscripts containing the students’ answers were collected and compared to the ideal solution (Andersson et al. 2012, DiAngelis et al. 2012).

For the assessment of the students’ performance, the manuscript was subdivided into five categories: pre-treatment (instructions given to the mother in the phone call, knowledge about potential storage media), therapy (diagnosis, treatment planning), post-treatment (informing the patient about the adequate behaviour after the accident), recall (knowledge about the recall regime for each injury) and complications (knowledge about potential complications). The form of the students’ answers consisted of free text to allow the participants to develop and describe their treatment strategy. Each accordance between the student’s answer and the ideal solution received one point. The points were summed and divided by the total amount of available points, and the resulting data were analysed using SPSS version 24.0 (IBM, Armonk, New York, USA). The level of statistical significance was set to \( P < 0.05 \). The Kolmogorov–Smirnov test was used to examine the normal distribution. The unpaired \( t \) test as well as the Mann–Whitney \( U \) test was applied to assess differences between the groups.

Finally, at the end of the training course, the participating students were asked to fill in a questionnaire evaluating the course as a whole as well as the model.

Figure 2 Radiograph of the right lateral incisor with a luxation injury and the right incisor with a complex crown fracture.

Figure 3 Radiograph of the empty tooth socket of the left incisor and the left lateral incisor with a horizontal root fracture.
Results

The presented workflow allowed the manufacturing of a radiopaque model that imitated a luxation injury, a complicated crown fracture, an avulsion and a horizontal root fracture in a realistic way (Fig. 4). The workflow was designed to be transferable to other dental schools that owned a CBCT and a stereolithographic printer, with the necessary software solutions being available free of charge. The extracted teeth could be relocated into the prefabricated tooth sockets, allowing the simulation of different traumatic dental injuries. Furthermore, the right lateral incisor could be set in a luxated location and repositioned in its original position. The resin for the model could be used in all treatment steps, for example, in the preparation of teeth with diamond burs, the placement of MTA or the application of a titan-trauma-splint.

The Kolmogorov–Smirnov test indicated that the data of the categories ‘therapy’ and ‘recall’ were not normally distributed. The unpaired t test and the Mann–Whitney U test revealed significant differences between the group that had access to dentaltraumaguide.org and the group without access regarding the assessment of the entire manuscript (P < 0.02) as well as of the categories ‘post-treatment’ (P < 0.00), ‘complications’ (P < 0.04) and ‘recall’ (P < 0.015). Descriptive statistics are shown in Tables 1, 2 and Fig. 5.

The 32 participants who filled in the questionnaire to evaluate the model reported that it was ‘very realistic’ (57%) and ‘rather realistic’ (43%). The single injuries were judged ‘very realistic’ by the participants ranging from 38% for the horizontal crown fracture to 68% for the complex crown fracture. The diagnosis of the lateral luxation was evaluated to be the most difficult of all injuries, whereas the avulsion was seen as the easiest injury to diagnose. Concerning treatment planning, the horizontal root fracture was rated as being the most difficult injury. When listing possible complications, the students had serious problems with the horizontal root fracture. An evaluation of the difficulty of each injury is listed in Table 3. All participants reported to have gained new knowledge on dental traumatology, and 97% felt better prepared for treating traumatic dental injuries in the future.

Discussion

Traumatic dental injuries represent a worldwide public health problem (Glendor 2008). Immediate care according to current guidelines is mandatory for preventing later complications that could restrict the patient’s aesthetic and functional well-being.
Nonetheless, the knowledge of general dentists on the correct treatment for a traumatized tooth is limited (Hu et al. 2006, Krastl et al. 2009, Traebert et al. 2009, Baginska & Wilczynska-Borawska 2013). Dental schools already carry a heavy burden in teaching the theoretical basics of dental traumatology, but it is almost impossible for them to provide practical experience on dental trauma cases to undergraduate students. Consequently, training models are necessary to imitate the diagnosis and treatment of traumatic dental injuries. To this effect, a model based upon the anterior segment of a sheep mandible has been presented previously (Marriot-Smith et al. 2016). It offers a very realistic way to train for avulsion or luxation injuries with the following application of a splint. Students may thus practice with biological tissue resembling that of humans. However, the limitations of this kind of model lie in its restricted availability and the regulations that apply when working with animal cadavers in a clinic. Consequently, an artificial replica that is as realistic as possible and that can be used for the simulation of several different traumatic dental injuries would be the preferred choice for a hands-on course for students. Unfortunately, this kind of model is not yet available.

Looking for a solution to this problem, the aim of this study was to develop the workflow for manufacturing a suitable training model. Since the model is based on a CBCT of a real patient, a highly realistic scenario was simulated. With the help of a computer-aided design (CAD) software application, the original CBCT scan was altered and manipulated to simulate various injuries. Furthermore, it is possible to manufacture the model with a low-cost desktop stereolithographic printer in the desired quantities. By mixing barium sulphate powder into the resin, radiopacity was achieved, thus making diagnostic and control radiographs possible.

As a result, the model was considered highly realistic and the hands-on course offered additional

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**Figure 5** Results of students’ answers (%) for each category; * indicates groups with significant differences.

**Table 3** Students’ evaluations of difficulty in diagnosis, treatment planning, therapy and knowledge about complications for each injury

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<th>Luxation</th>
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<td>Easy (%)</td>
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<td>Diagnosis</td>
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<td>47</td>
<td>73</td>
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<td>Treatment planning</td>
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<td>Therapy</td>
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<td>Complications</td>
<td>34</td>
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knowledge about dental traumatology to all participants. Hence, it is safe to conclude that practical training using a realistic model is capable of expanding the expertise for treating traumatic dental injuries much more than with a theoretical lecture. As an additional benefit, this model could be used to reach a broader audience, for example, general dentists; they could increase their knowledge of traumatic injuries to the teeth with hands-on training and gain additional experience in this specific field.

Despite the high prevalence of traumatic dental injuries, their occurrence in general dental practice is not that common. For dentists who are faced with such an incident, the situation can be stressful and challenging. Although there are currently a wide range of possibilities to access information about the treatment of a traumatic dental injury, a quick and feasible overview is of vital importance for proper treatment. Modern solutions, such as smartphone applications, have come to complement the traditional textbooks and manuals. In this context, the online platform dentaltraumaguide.org presents a knowledge base offering pictorial treatment steps for each injury. In addition, the platform offers highly useful information on possible complications and prognoses for each injury (Andreasen et al. 2012).

In the present study, dental undergraduate students participating in a hands-on training course on dental traumatology who had access to dentaltraumaguide.org performed considerably better than those students who were denied access to the site. Thus, dentaltraumaguide.org offers treatment information about traumatic dental injuries in a more rapid and clearer way than other applications. Especially the pictorial diagram called ‘Trauma pathfinder’, which avoids extensive text is efficient and clearly leads the user to the correct information. The single treatment steps are well described, and a video is available for each injury. Since it is online, changes in the current guidelines of the IADT can be immediately implemented, thus keeping the information up to date. In addition, dentaltraumaguide.org provides assistance in estimating the prognosis of an injured tooth by sharing its follow-up data on the corresponding injury with the user.

Students seem to focus especially on the diagnosis and treatment of traumatic injuries to teeth when dealing with dental traumatology. This is logical because these steps are of outmost importance for immediate care when confronted with a trauma case. Fortunately, both groups of students in the present study achieved their best results in these fields. The group without access to dentaltraumaguide.org, however, had only poor results when faced with developing a recall regime and knowing about possible complications. This might be explained by the fact that recall dates and splinting times for the many different injuries were rather confusing for the students as they well may be for general dentists who do not treat traumatic dental injuries routinely. As knowledge of these topics can have a decisive impact on the outcome of a dental trauma, the use of adequate assistance is highly recommended.

Conclusion

3D printing technology offers dental schools new possibilities for creating highly realistic training models covering treatment steps that have been difficult to imitate. The online platform dentaltraumaguide.org can assist recently graduated dentists in correctly handling traumatic injuries to the teeth.

Conflict of interest

The authors have stated explicitly that there are no conflicts of interest in connection with this article.

References


