THE DIMENSIONAL ACCURACY OF PROVISIONAL DENTAL REPLACEMENTS MADE BY DIFFERENT TECHNOLOGIES

Miroslav Kohan[1], Viktória Rajťúková[1], Ľuboš Chromý[2], Tomáš Balint[1], Radovan Hudák[1]

[1]Department of Biomedical Engineering and Measurement, Faculty of Mechanical Engineering, Technical University of Košice, Košice, Slovakia

[2]Dental Engineering s.r.o., Košice, Slovakia

Abstract
The accuracy and quality of temporary dentures are important factors in dentistry, especially when bridging the time between tooth preparation and the placement of definitive dentures. The aim of this study is to determine the dimensional accuracy of temporary dental prostheses, specifically crowns and bridges, manufactured using different technologies. Three manufacturing methods were evaluated: stereolithography (SLA), digital light processing (DLP) and CNC milling. A total of 30 temporaries (n = 30) were fabricated, with an equal number fabricated using each technology. The fabricated samples were scanned with an S900 Arti 3D scanner (Zirkonzahn, Italy) and the scanned data was analyzed using GOM Inspect software (Zeiss, Germany) to detect deviations from the original model. The results showed that SLA technology showed the smallest deviations (0.025 ± 0.002 mm), indicating the highest accuracy among the tested technologies. DLP technology demonstrated medium accuracy (0.052 ± 0.011 mm), exceeding CNC milling, but not reaching SLA accuracy. Conversely, CNC milling showed the largest deviations (0.106 ± 0.009 mm) and the lowest accuracy in the production of temporary dentures. Based on the accuracy of the produced crowns and bridges, the SLA technology is therefore considered the most suitable for the creation of temporary dentures. These findings underscore the potential of SLA technology in achieving higher precision in dental applications, while offering a reliable method to produce quality temporary dental restorations.

Keywords
provisional dental replacement, 3D printing, CNC milling

Introduction

In dentistry, replacing damaged teeth is a common procedure that uses temporary restorations (crowns or bridges) to bridge the gap between extraction and installation of a permanent implant. Temporary crowns or bridges fulfill several functions: they provide an aesthetic solution, restore the function of the teeth and protect the repaired tooth from damage [1].

Different production technologies allow the creation of these replacements with different levels of accuracy and durability [2–5]. The traditional method is a direct production process (by hand) using conventional materials and procedures. These methods are traditionally based on castings and manual treatment of materials [6].

Another technology is CNC (Computer Numerical Control) milling. This technology is often used in dentistry to produce strong and durable restorations such as metal and ceramic implants and fixed bridges. CNC machines use milling tools to precisely carve the material, making it possible to create high-strength replacements. CNC milled products can be durable, which is suitable for applications where durability is important. Their disadvantage is that they have limitations in the creation of small and detailed structures, mainly due to the size of the milling tools. CNC milling is traditionally considered a very precise technology to produce fixed dental prostheses, but it has its limitations in the production of temporary prostheses, where fine detail is important [5].

In recent years, additive manufacturing technologies such as stereolithography (SLA) and digital light processing (DLP) have become increasingly popular in dental practice [7, 8].

Stereolithography is one of the additive manufacturing technologies, which is characterized by an approach to produce prototypes by gradually material addition layer by layer. SLA technology uses liquid photopolymers

Lekar a technika – Clinician and Technology 2024, vol. 54(4), pp. 128–133, DOI: 10.14311/CTJ.2024.4.03
ISSN 0301-5491 (Print), ISSN 2336-5552 (Online)

that are hardened using UV (ultraviolet) radiation. The laser beam illuminates the photopolymer on the surface of the liquid, thereby polymerizing the individual layers of the model. After one layer is cured, the working platform of the printer is moved by the selected layer thickness and the process is repeated until the entire prototype is completed. The advantage of SLA is the high precision and smoothness of the surface, which is crucial for dental applications [1, 8–11].

DLP is also an additive manufacturing method like SLA. It uses a digital projector instead of a laser to illuminate entire layers at once. In this process, the printer´s working platform moves upwards after each illumination, which means that every point in the layer is illuminated at the same time. DLP uses a projector to illuminate the photopolymer, allowing individual layers to cure faster as the entire layer is polymerized at once. DLP is a suitable choice in situations where fast production with high accuracy is required, but at the expense of fine detail compared to SLA. For temporary dentures where aesthetics and accuracy are important, DLP can still provide adequate results, especially for simpler crowns and bridges [12–14].

This study addresses the production of temporary dentures made using CNC milling, SLA, and DLP additive manufacturing technologies. Temporary crowns and bridges were produced as part of the research.

The aim of this work is to present results concerning the accuracy of the specified technologies for temporary denture manufacturing. The accuracy of production was assessed on crowns and a 6-unit bridge. It is assumed that greater deviations in accuracy with the selected technologies will be evident in the 6-unit bridge, as it is a larger model compared to the crown.

Material and methodology

Production of temporary dentures

Scans of modeled crowns and bridges in the dental software 3Shape Dental System (3Shape, Denmark) were utilized for this work. The completed 3D models, in the form of crowns and bridges, were generated in STL (Standard Triangle Language) format. The total number of manufactured crowns and bridges was n = 30 (Table 1). The generated STL models were then imported into the appropriate software.

Each 3D printer has its own software where the samples are positioned on the build plate and the support structure is designed. Ceramill Motion (Amann Girbach, Austria) prepares models for milling using Ceramill software (Fig. 1a), Formlabs 3B (Formlabs, USA) uses Preform software (Fig. 1b), and Prefactory Vida (EnvisioTEC, Germany) prepares models using Prefactory software (Fig. 1c). The software for the specified 3D printers is listed in Table 1.

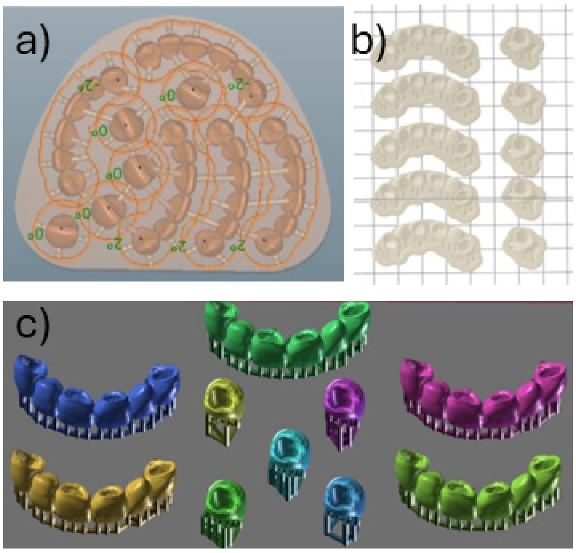

Fig. 1: Preparation of 3D models in CNC milling (a) and 3D printing (b, c) software.

The samples were produced using the Ceramill Motion 2 milling machine (Fig. 2a), a Formlabs 3B 3D printer employing SLA technology (Fig. 2b), and the Perfactory Vida 3D printer utilizing DLP technology (Fig. 2c).

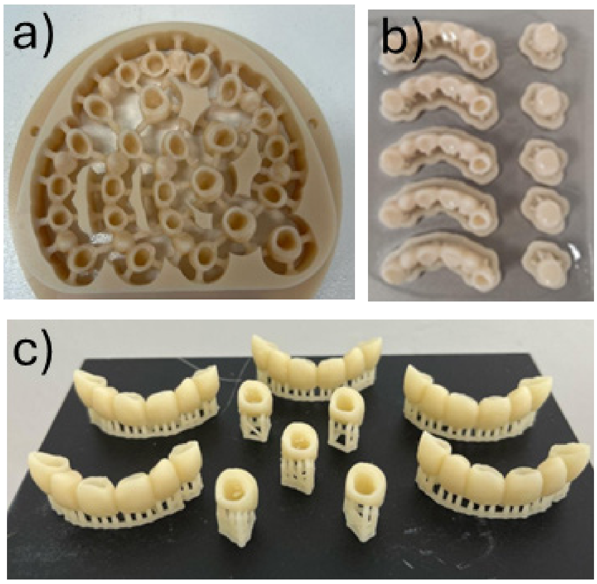

Fig. 2: Manufactured samples produced by CNC milling (a) and 3D printing (b, c).

Table 1 provides a more detailed distribution of manufactured crowns and bridges, as well as the production technologies used.

The post-processing work process followed after the production of crowns and bridges. The temporary dental prostheses made using additive technology with resin input material were soaked in isopropyl alcohol (≥99%). After drying, they were placed under a polymerization lamp for curing. Once cured with UV radiation, the supporting structures were removed using a cutting disc.

Lekar a technika – Clinician and Technology 2024, vol. 54(4), pp. 128–133, DOI: 10.14311/CTJ.2024.4.03
ISSN 0301-5491 (Print), ISSN 2336-5552 (Online)

Table 1: Distribution of samples for each selected technology used to produce provisional dental prostheses.

	Additive technology SLA	Additive technology DLP	CNC milling
Device	Formlabs 3B	Perfactory Vida	Ceramill Motion 2
SW	PreForm	Perfactory	Ceramill
Material	Temporary CB (Resin)	E-Dent 400 (Resin)	Ceramill A-Temp A2 (PMMA)
Sample	C 5, B 5	C 5, B 5	C 5, B 5

SW—software, C—crown, B—bridge

Methodology for comparison of dimensional characteristics in the production of temporary dentures

One method to accelerate computing is the use of automated 3D scanning systems, which include both hardware and software automation. The S900 Arti (Zirkonzahn, Italy), 3D scanner was used to obtain the 3D models of manufactured models. The scanning accuracy of the used scanner is 0.01 mm, as specified by the manufacturer.

The comparison of dimensional characteristics of fabricated dental prostheses was conducted between the nominal models of crowns C1–C5 (Fig. 3) and bridges B1–B5 (Fig. 4), as well as the 3D models of provisional dentures. The accuracy of the manufactured dentures was evaluated using GOM Inspect software (ZEISS, Germany).

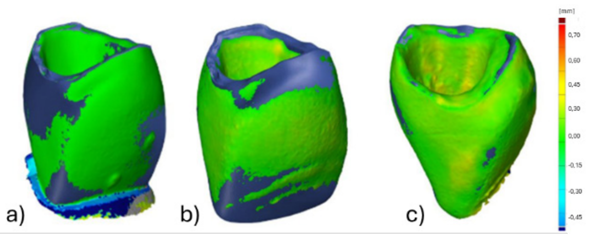

Fig. 3: Actual-to-nominal surface comparison of crown 3D models: Formlabs (a), Perfactory Vida (b), and Ceramill Motion 2 (c).

In this process, one of the crucial parameters for selecting the appropriate technique is accuracy. Table 2 provides a description of the accuracy associated with the manufacturing and scanning technologies.

The obtained values represent the arithmetic mean of deviations calculated on the models in GOM Inspect software, with the crowns and bridges models in STL format serving as the reference models. The resulting deviation values for individual groups were averaged and presented as mean ± standard deviation (x ± SD).

In this study, the alpha level was set at 0.05. This means that the results are considered statistically significant if the p-value (probability that the difference occurred by chance) is less than 0.05. This statistical significance threshold was used in the proposed research for T-tests to compare mean deviations between groups (crowns vs. bridges) and between technologies (SLA, DLP, CNC milling).

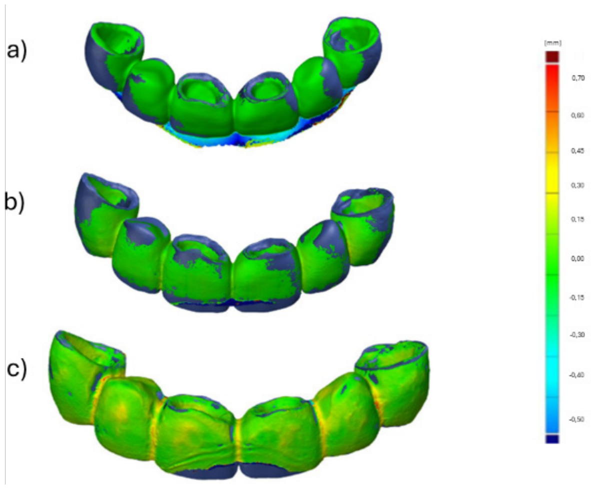

Fig. 4: Actual-to-nominal surface comparison of bridge 3D models: Formlabs (a), Perfactory Vida (b), and Ceramill Motion 2 (c).

Table 2: Accuracy of manufacturing and scanning technology.

Accuracy of the equipment	
Formlabs 3B (SLA 3D printer)	up to 0.05 mm
Perfactory Vida (DLP 3D printer)	0.04 mm
Ceramill Motion 2 (CNC milling)	0.005–0.02 mm
S900 Arti (3D scanner)	up to 0.01 mm

Results

The results of the dimensional comparison between the nominal model and the actual 3D scanned model of a temporary dental prosthesis in the form of a crown indicate smaller deviations.

When utilizing additive manufacturing technology, specifically SLA technology, the maximum deviations observed were at 0.071 mm for model C4, while the smallest differences in accuracy were recorded for model C3 at 0.022 mm. The average deviation with SLA technology was calculated to be 0.025 mm.

With the second type of production technology (DLP), the maximum deviation recorded was 0.065 mm for model C3. Conversely, the smallest recorded difference in accuracy was observed at 0.040 mm for model C4. The calculated average deviation for crowns produced using DLP technology was 0.052 mm.

The largest differences were observed when evaluating the accuracy of crowns produced using CNC

Lekar a technika – Clinician and Technology 2024, vol. 54(4), pp. 128–133, DOI: 10.14311/CTJ.2024.4.03
ISSN 0301-5491 (Print), ISSN 2336-5552 (Online)

milling. The greatest difference in accuracy was found in model C5, measuring 0.113 mm, while the smallest difference was measured at 0.085 mm for model C3. The average accuracy of the crowns produced by CNC milling was determined to be 0.099 mm. A comparison of the deviations in crown production using different technologies is presented in Fig. 5.

Comparing the nominal models with 3D scans of bridges produced using SLA technology yielded an average deviation of 0.049 mm. The maximum deviation recorded with SLA technology was 0.057 mm for model B2, while the highest accuracy was observed in model B5 at 0.044 mm.

In the case of DLP technology, the largest deviation was recorded at 0.063 mm for model B3, whereas the smallest deviation was noted at 0.046 mm for model B2. The calculated average deviation for DLP technology was 0.054 mm.

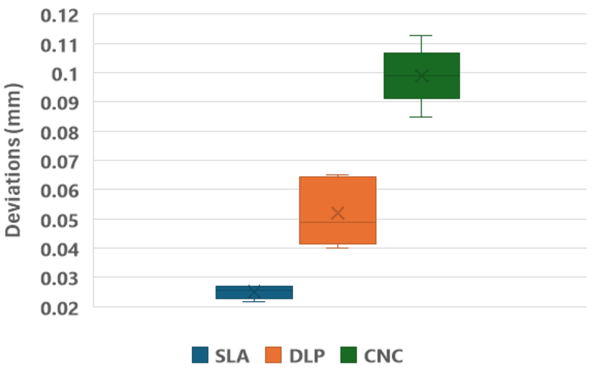

Fig. 5: Comparison of different technologies to produce temporary crowns.

The surface accuracy in CNC milling technology reveals the highest deviations from the nominal bridge model. The maximum recorded deviation was 0.118 mm for model B3, while the lowest was 0.098 mm for model B5. The average deviation for the manufactured bridges was 0.106 mm, which is the largest among all measured averages. A comparison of deviations in the production of crowns using different technologies is illustrated in Fig. 6.

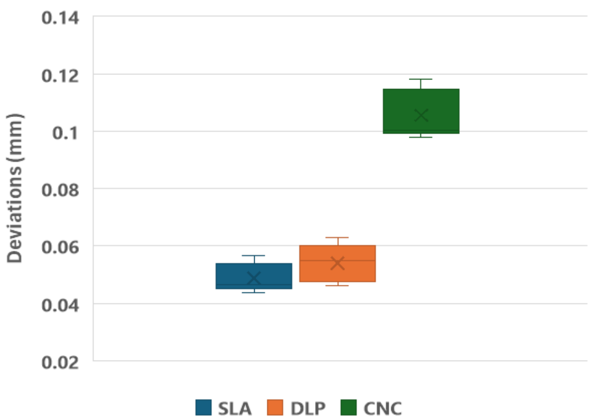

Fig. 6: Comparison of various technologies the production of temporary bridges.

A comparison of fabricated crowns and bridges indicates that SLA technology exhibits the highest deviations between the two. Conversely, the smallest deviations were recorded with DLP technology.

Table 3 presents the average values and standard deviations for crowns and bridges across all manufacturing technologies.

Table 3: Comparison of deviations between crowns and bridges.

	Crowns (mm)	Bridges (mm)	p-value
SLA	0.025 ± 0.002	0.049 ± 0.005	0.001
DLP	0.052 ± 0.011	0.054 ± 0.006	0.302
CNC milling	0.099 ± 0.010	0.106 ± 0.009	0.231

The comparison of deviations between the manufacturing technologies is described in Table 4. The differences between additive manufacturing technologies (SLA and DLP) and CNC milling were statistically significant.

Table 4: Comparison of statistical significance between different type of technology (Base on deviations of manufactured crowns and bridges).

	Crowns	Bridges
SLA vs DLP	$p = 0.006$	$p = 0.147$
SLA vs CNC	$p = 0.001$	$p = 0.001$
DLP vs CNC	$p = 0.002$	$p = 0.001$

A comparison of SLA and DLP technologies showed statistically significant differences in the production of crowns ($p = 0.006$). On the contrary, no statistically significant difference between these technologies was detected in the production of bridges ($p = 0.147$).

A comparison of SLA and CNC milling technology showed statistically significant differences for both types of products, i.e. for crowns ($p = 0.001$) and bridges ($p = 0.001$). These results indicate that CNC milling shows different results compared to SLA.

When comparing DLP and CNC milling technologies, statistically significant differences were found for crowns ($p = 0.002$) and bridges ($p = 0.001$), which indicates a significant difference between these technologies in both categories.

Statistical significance was shown when comparing SLA and CNC technology, where there were significant differences ($p < 0.05$), which implies that these technologies provide results with different levels of accuracy. Similarly, statistically significant differences were also identified between DLP and CNC milling in the production of crowns and bridges, with SLA and DLP showing no significant differences in the production of bridges ($p = 0.147$), which may indicate their similar level of accuracy in larger models.

Lekar a technika – Clinician and Technology 2024, vol. 54(4), pp. 128–133, DOI: 10.14311/CTJ.2024.4.03
ISSN 0301-5491 (Print), ISSN 2336-5552 (Online)

Discussion

This study analyzed the surface accuracy of temporary dentures made using three technologies: SLA, DLP and CNC milling. Based on the results, it can be interpreted that SLA technology has demonstrated the highest dimensional accuracy, which makes it ideal for the production of temporary crowns and bridges. The high accuracy of SLA technology, which reached an average deviation of 0.025 mm, is mainly a consequence of the fine layering of photopolymers, which enables the creation of detailed and finely structured surfaces. Similar findings are reported by other studies, which identify SLA technology as one of the most reliable methods for the production of precise and aesthetic dental restorations [1]. The significance of our results lies in the fact that SLA technology can support not only the functionality, but also the aesthetic comfort of patients during the temporary period of treatment.

DLP technology, although it shows slightly higher deviations (0.052 mm on average), offers a certain compromise between production speed and accuracy, which can make it a suitable alternative for lower aesthetic demands or in time-sensitive cases. In the literature [14], it is reported that DLP technology, due to the use of a digital projector, can produce dentures faster, but with limited accuracy, which is in line with our findings.

CNC milling achieved the largest deviations with an average value of 0.106 mm, which may be due to limitations in the size of the milling tools and their ability to reproduce fine details. Although CNC milling is widely used in dentistry, its limitations in the production of temporary dentures can limit its use, especially where precision is critical. This finding is also supported by studies suggesting that CNC technology, although reliable, may be less accurate for temporary restorations [5, 10].

The main limitations of this study include the relatively small number of samples (n = 30), which may limit the general validity of the results. In addition, the measurement of deviations was carried out using only one type of 3D scanner (S900 Arti), which may affect the reliability of the results depending on the accuracy of the equipment used. Another limitation is the investigation of only one type of temporary material for each technology, whereas different materials could affect the surface accuracy of the output models.

For future research, it would be appropriate to include a wider spectrum of materials and technologies that are used for the production of temporary replacements. It would also be beneficial to analyze the long-term stability and durability of these temporary prostheses, as accuracy is not the only factor affecting their functionality. Furthermore, it would be beneficial to expand the research with a larger number of samples and different scanning methods to verify the reliability of the results.

Conclusion

This study contributed to the understanding of the differences in the accuracy of different technologies to produce temporary dentures. SLA technology was found to have the highest accuracy in the production of crowns and bridges, while CNC milling showed the largest deviations. These findings point to the potential of SLA technology as the most suitable solution for the creation of accurate and aesthetically pleasing temporary dental prostheses. The findings may be beneficial for clinical practice in choosing the optimal manufacturing technology to ensure the quality and functionality of temporary dental restorations.

Acknowledgement

This work was developed with the support of the project KEGA 050TUKE-4/2022 Additive manufacturing in medicine—creation of multimedia material and aids to support teaching in biomedical engineering. This work was supported by the Research and Development Support Agency based on Contract no. SK-CZ-RD-21-0056. This publication is result of the project implementation CEMBAM – Center of for Medical Bioadditive Research and Production, ITMS2014+:313011V358 supported by the Operational Program Infrastructure funded by the European Regional Development Fund.

References

[1] Dikova T. Production of high-quality temporary crowns and bridges by stereolithography. Scripta Scientifica Medicinae Dentalis. 2019 Jul 22;5(1):33–8. DOI: 10.14748/ssmd.v5i1.5863

[2] Thalji G, Jia-mahasap W. CAD/CAM Removable Dental Prostheses: a Review of Digital Impression Techniques for Edentulous Arches and Advancements on Design and Manufacturing Systems. Current Oral Health Reports. 2017 Apr 17;4(2):151–7. DOI: 10.1007/s40496-017-0137-z

[3] Sun Y, Lü P, Wang Y. Study on CAD&RP for removable complete denture. Computer Methods and Programs in Biomedicine. 2009 Mar;93(3):266–72. DOI: 10.1016/j.cmpb.2008.10.003

[4] Canciglieri MB, Leite AF, Szejka AL, Canciglieri Júnior O. An approach for dental prosthesis design and manufacturing through Rapid Manufacturing Technologies. International Journal of Computer Integrated Manufacturing. 2019 Jun 30;32(9):832–47. DOI: 10.1080/0951192x.2019.1636410

[5] Chang CC, Lee MY, Wang SH. Digital denture manufacturing-an integrated technologies of abrasive computer tomography, CNC machining and Rapid Prototyping. The International Journal of Advanced Manufacturing Technology. 2006 Apr 11;31(1–2):41–9. DOI: 10.1007/s00170-005-0181-z

[6] Hubálková, H., Krňoulová, J. Materiály a technologie v protetickém zubním lékařství. Zubní lékařství. Praha: Galén, c2009. ISBN 978-80-7262-581-9.

[7] Liu Q, Leu MC, Schmitt SM. Rapid prototyping in dentistry: Technology and application. The International Journal of Advanced Manufacturing Technology. 2006 Jun;29(3–4):317–35. DOI: 10.1007/s00170-005-2523-2

[8] Dawood A, Marti BM, Sauret-Jackson V, Darwood A. 3D printing in Dentistry. British Dental Journal. 2015 Dec 11;219(11):521–9. DOI: 10.1038/sj.bdj.2015.914

[9] Ozyilmaz ED, Turan A, Comoglu T. An overview on the advantages and limitations of 3D printing of Microneedles. Pharmaceutical Development and Technology. 2021 Aug 17;26(9):923–33. DOI: 10.1080/10837450.2021.1965163

[10] Methani MM, Cesar PF, de Paula Miranda RB, Morimoto S, Özcan M, Revilla-León M. Additive manufacturing in dentistry: Current Technologies, Clinical Applications, and limitations. Current Oral Health Reports. 2020 Nov 3;7(4):327–34. DOI: 10.1007/s40496-020-00288-w

[11] Pucci JU, Christophe BR, Sisti JA, Connolly ES. Three-dimensional printing: Technologies, applications, and limitations in Neurosurgery. Biotechnology Advances. 2017 Sept;35(5):521–9. DOI: 10.1016/j.biotechadv.2017.05.007

[12] Quan H, Zhang T, Xu H, Luo S, Nie J, Zhu X. Photo-curing 3D printing technique and its challenges. Bioactive Materials. 2020 Mar;5(1):110–5. DOI: 10.1016/j.bioactmat.2019.12.003

[13] Liu J, Tang J, Dai C. Design of DLP 3D Printer Control System Based on Arduino. 2020 3rd World Conference on Mechanical Engineering and Intelligent Manufacturing (WCMEIM); 2020 Dec 4–6; Shanghai, China. IEEE; 2020. DOI: 10.1109/wcmeim52463.2020.00110

[14] Barone S, Neri P, Paoli A, Razionale AV, Tamburrino F. Development of a DLP 3D printer for Orthodontic Applications. Procedia Manufacturing. 2019;38:1017–25. DOI: 10.1016/j.promfg.2020.01.187

Ing. Miroslav Kohan, Ph.D.
Department of Biomedical Engineering and Measurement
Faculty of Mechanical Engineering
Technical University of Košice
Letná 1/9, 042 00 Košice

E-mail: miroslav.kohan@tuke.sk
Phone: +421 917 950 809

Lekar a technika – Clinician and Technology 2024, vol. 54(4), pp. 128–133, DOI: 10.14311/CTJ.2024.4.03
ISSN 0301-5491 (Print), ISSN 2336-5552 (Online)