Contents list available at CBIORE journal website

**Journal of Emerging Science and Engineering**

Journal homepage: https://journal.cbiore.id/index.php/jese/index

Research Article

# Analysis of the surface roughness of 3D-printed occlusal splints fabricated using biocompatible resins

Sumit Gahletia, Ashish Kaushik*, Ramesh Kumar Garg

*Department of Mechanical Engineering, DCRUST, Murthal, 131039, Sonipat, Haryana, India*

**Abstract**. Nowadays, in order to promote innovation and sustainable product design and manufacturing of occlusal splints, the dental profession requires significant upgrades in the form of novel materials and cutting-edge manufacturing technologies. Researchers and Industry frontrunners are constantly challenged to improve the properties of splint developed using three dimensional scanning and resin printing to meet consumer demand, as the ability of dental practitioners to take accurate impressions remains a major obstacle in dental laboratories. The proposed study outlines a digital manufacturing process for occlusal splints created with three-dimensional scanning and resin printing. The study also analysed the occlusal splints in terms of geometrical preciseness and surface roughness along with the costs involved during 3D printing a resin-based occlusal splint. Occlusal splints were created by scanning impressions made on a typodont model and then designing them in 3D modelling software. The splints were developed in MIMICS and 3D printed to a thickness of 10 microns using Rigid white methacryalate based resin material on a 3D systems DLP Figure IV standalone resin 3D printer to create a biocompatible occlusal splint. Splint tooth height was determined for geometric analysis. Surface roughness of splintwas measured using SURFCOM surface roughness tester. Resins used in 3D printing were proven to produce geometrically precise splints, the study showed. In conclusion, UV curable resin-based occlusal splints that have been 3D printed and cured are recommended for patient usage due to their increased accuracy and the ability to save processing time.

**Keywords:** Additive manufacturing, Digital workflow, 3D scanning, occlusal splint, resin printing, data acquisition


Received: 12th Feb 2024; Revised: 25th March 2024; Accepted: 4th April 2024; Available online: 8th April 2024

## 1. Introduction

In an era focused on enhancing technology, completely digital processes enable laboratories and practices to give better treatments and clinical results in an era focused on enhancing technology. However, they will only acquire widespread use when economically viable (Russo et al.,2019; Goujat et al.,2019). A rapid increase in global health expenditure, growing prevalence of temporomandibular disorders, rising patient awareness level, and increased awareness about oral health are the expected primary driving forces that fuel the market demand for occlusal splints. For decades, clinicians have prescribed and sold over-the-counter occlusal guards, splints, and occlusal splints with little change in manufacturing. However, with the increasing popularity of 3D intraoral scanners and 3D printing technologies in the dental industry, a new opportunity has created highly untapped opportunities to create fully digital equipment that offers multiple advantages over their conventional processes (Flugge et al.,2018; Muhlemann et al.,2018; Kattadiyil et al.,2017). Reports and Data, a market research and consultancy firm, projects a 10.6% CAGR for intraoral scanners worldwide between 2018 and 2026.1 In other words, digital impressions are replacing traditional impressions in the dental profession. Every patient is now routinely digitally scanned upon entering the practice, allowing for subsequent recall of impressions should the need arise. Dental appliances like clear aligners, occlusal guards, and periodontal trays can be custom-made from digital imprints and photos sent to a laboratory or company if a patient requires treatment. Patients must pay more money and wait longer for care when outsourcing. Dentists should expect to pay between $100 and $200 for an occlusal guard to be made in a lab[Bohner et al.,2019; Gallaardo et al.,2018; Jokubauskas et al.,2018; Salmi et al.,2013; Kishore et al.,2022). Occlusal splints have traditionally been fabricated in the dental laboratory using vacuum thermoforming,hand-forming acrylic articulated models, or a mix of these methods. Dental practitioners may directly fabricate the occlusal splints with enhanced durability using modern rapid prototyping processes and innovative biocompatible materials. Greater precision, less time spent on each unit, and a finished product with a proper fit are all the benefits of the digital workflow that culminates in 3D printing [Tahayeri et al.,2018; Singh et al.,2018; Kumar et al.,2019)

Occlusal splints are widely recommended for therapeutic and preventative purposes, but they are often under-prescribed or not even provided because of poor fits, high cost, and cumbersome workflow. Most commonly, occlusal splints are used to protect teeth against damage like chips and cracks, as well as wear and tear. Due to the preventative nature of occlusal guards, many dentists choose not to prescribe or encourage their use, and even when provided, patients are sometimes unwilling to spend hundreds of dollars on their future oral health[Singh et al.,2022). The use of a technologically advanced 3D-printed occlusal splint with an emphasis

*Corresponding author
Email: ashishkaushik6789@gmail.com (A. Kaushik))

https://doi.org/10.61435/jese.2024.e17
ISSN: p-ISSN: 3026-0817; e-ISSN: 3026-0183.The Author(s). Published by CBIORE

on clinical acceptability and patient safety serves as the possible solution to the aforementioned concern. The price requirements can be met, and a wider market can be opened through 3D printing for these appliances. Dentists can save time and money by making occlusal guards with the help of a 3D printer right in the office. Without the cost of outsourcing, a custom occlusal guard can run you between $400 and $800[Sharma et al.,2022). The price of a 3D printer and materials is typically around $6,000. For example, after printing occlusal guards, the investment in the printer will have paid for itself. Therefore 3D printing techniques are continuously changing the landscape of the dental split market by creating a positive shift in the demand curve. Figure 1(a) demonstrates the sequential steps involved in fabricating occlusal splints using traditional and digital workflow, respectively (Bahl et al.,2020; Kaushik et al.,2022).

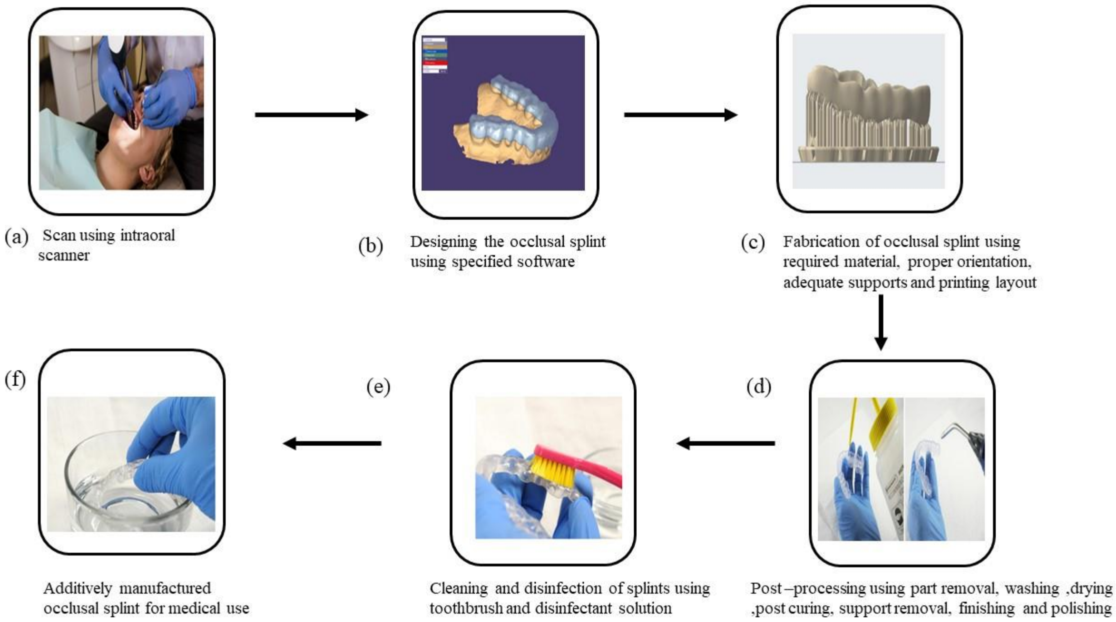



**Fig. 1** Sequential steps involved in digital fabrication of optimized occlusal splint

The proposed research aims to describe a complete digital workflow for an occlusal splint, including data acquisition, design, fabrication, and post-processing using extra-oral 3D scanning and resin printing. A dental cast model is scanned using a hand-held 3D scanner for recording the impressions. Metrology-based software further processes the captured scanned data for inspection and measurement. The digital impression files are imported into medical image processing software to design the occlusal splint. The designed occlusal splint is then fabricated using a resin 3D printer. The fabricated splint is checked for geometrical accuracy.

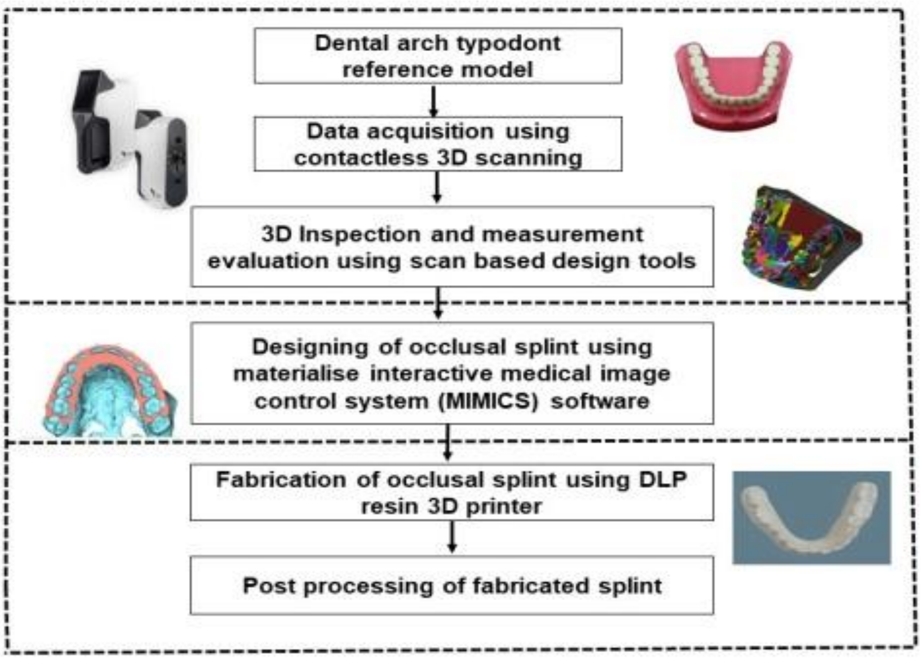



**Fig. 2** An adopted methodology for occlusal splint fabrication

## 2. Materials and Methods

### *2.1 3D Scanner*

A hand-held laser scanner is used to scan a dental cast typodont reference model, which typically has sixteen teeth, to practice dental procedures. The proposed research utilizes the Calbiri small 3D scanner to acquire data, specifically for collecting human anatomical parts and prototypes. The Calbiri tiny scanner has a print resolution of roughly 0.15mm. Its minimum field of view is 86*115mm, while its maximum field of view is 144*192mm. The hardware and software architecture of the 3D scanner employed for the present study is provided in Table 1. The approach employed for the proposed research is depicted in Figure 2.

### *2.2 3D Printer and Resin Material*

DLP Figure IV Standalone(represented in figure 3(a)) by 3D System is a commercial resin 3D printer used to fabricate designed occlusal splints with rigid white as the printing material. Figure 3(b) represents the working principle of the DLP resin 3d printer. Rigid White is an opaque white material designed for mass manufacturing; it features excellent oral stability and a bright white appearance that won't fade or yellow over time. Its smooth surface finish, longer durability, and biocompatible capability make it ideal for dental and other clinical applications. The thermoplasticity of rigid white material and necking upon break make it perfect for making occlusal appliances. It has a high elongation at break and can withstand heat up to 65 degrees Celsius without breaking. Moreover, its rapid printing and minimal post-print work allow for high output.

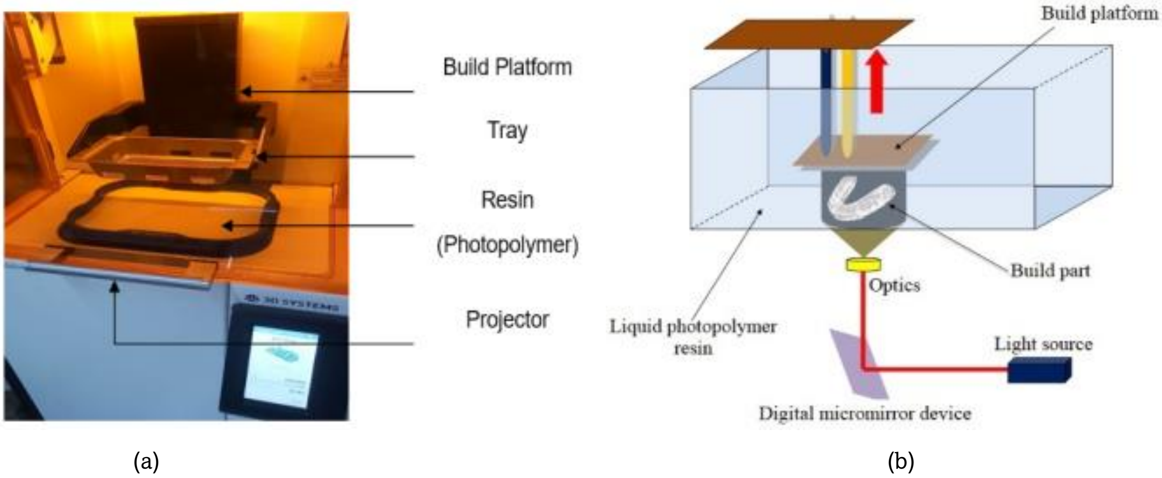



**Fig. 3** (a)DLP 3D printer, (b) working of resin 3D printer

## 3. Experimental Planning and Methods

### *3.1 Data Acquisition Using 3D Scanner*

To achieve the appropriate rotating motion, the typodont model is positioned on a swivel table while keeping the scanner steady. The suggested investigation encompasses a measurement field that spans from 100 mm to 400 mm. The measurement region of the 100 mm field of view is 120 mm in length, 100 mm in width, and 60 mm in height. The component is rotated on a swivel table to conduct individual scanning utilizing different sets of process parameters. The Calbri Nest program was utilized to replicate the surface following each scan.

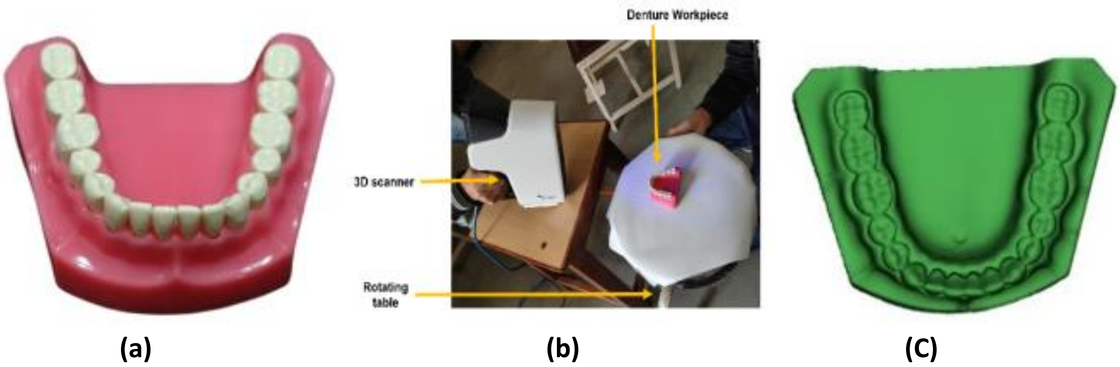
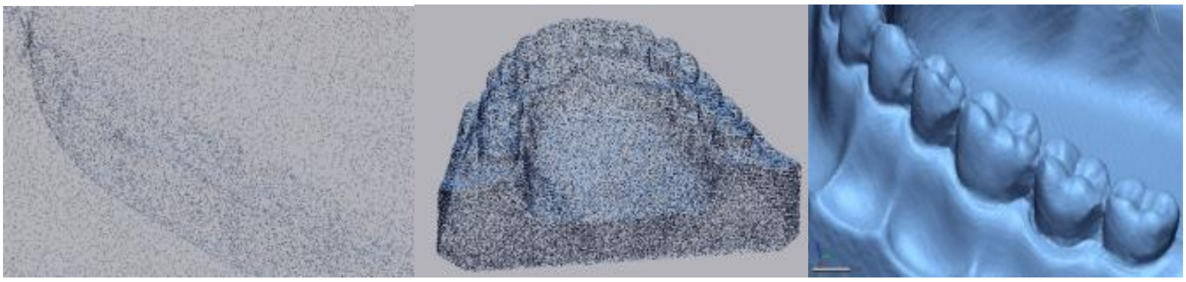



**Fig. 4** (a)Typodont dental arch reference model,(b) 3D scanning arrangement,(c) 3D Scan model of the dental arch

Figure 4 (a) shows the typodont model that was used as a workpiece in the study. Figures 4 (b) and 4 (c) show the layout of the 3D scanning process and the resulting 3D scan model of the arch of the dental tooth, respectively. The typodont model is positioned on a rotating swivel table and slowly rotated, while the scanner is adjusted to different angles to ensure optimal capturing. The ambient light intensity during the experiment was measured to be 20 W/m^2. The scanning proximity to the scanner was subject to variation according to the instructions provided in the scanner's operating manual. Figure 5(a) and Figure 5(b) show a close-up view of the point clouds that comprise the typodont model, whereas Figure 5(c) displays the 3D mesh of the scanned denture

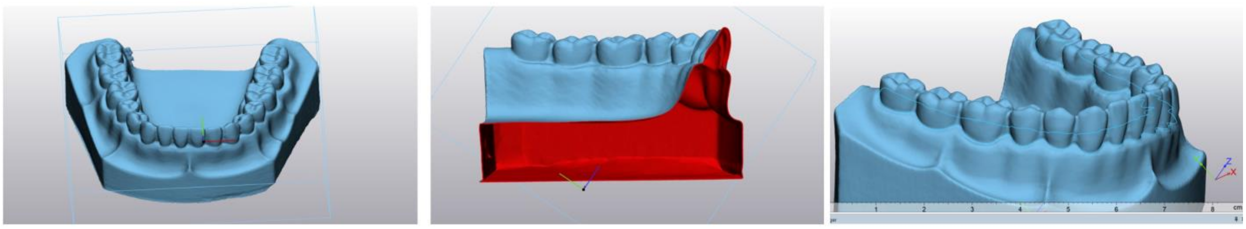


(a) (b) (C)

**Fig. 5** Zoomed view of point clouds in (a) & (b) typodont model, (c) 3D mesh of denture

*3.2 Designing of occlusal splint*

The occlusal splint is designed using Mimics software to detail. The scan data is imported into the software, and a 3D model of the denture is created using a segmentation tool. The CAD module is then used to produce a virtual model of the occlusal splint, tailoring it to the patient's demands in terms of splint thickness and occlusal force distribution. The gap width of 0.1 mm and the smallest detail of 1mm are used to design the splint for the proposed research. The design has to be thick enough to cover the patient's teeth but thin enough to distribute occlusal stresses evenly. Mimics software's measurement capabilities are used to examine the design's thickness and symmetry, and adjustments are made to provide a uniform distribution of occlusal forces. Last but not least, the splint must be adjusted so that it fits over the patient's teeth without causing any discomfort. Overall, it takes specialized expertise and training in dental design to use Mimics software to create an occlusal splint that is functional and tailored to the patient's demands. Figure 6 (a-c) demonstrates the design of the occlusal splint.



(a) (b) (C)

**Fig. 6** (a-c) Designing of occlusal splint

*3.3 Fabrication of occlusal splint using resin 3D printing*

The occlusal splint is fabricated using a digital light processing resin 3D printer using rigid white resin material. A thickness of approximately 30 microns is used to achieve enhanced accuracy for fabricated splints. The print orientation of printed splints is kept such that intaglio surfaces are positioned in an upward-facing direction, and the print platform and the occlusal plane are considered to be at an angle of 20 to 30 degrees. Additionally, the design's anterior portion should be nearer to the print platform than its posterior to achieve better results. Adequate supports are added to the design once the proper alignment has been attained, as represented in Figure 7(a). To prevent defects in the finished product, the splint is printed using all available supports. Utilizing supports simply in the anterior region could result in a poor fit. The resin material is stirred for approximately thirty minutes to facilitate proper mixing of the resin material. The resin is now poured into the tank within the maximum and minimum levels. After the completion of the model, with the platform lifted, the drip-off period of roughly fifteen minutes was employed to remove additional material from the casts after the production process, as demonstrated in Figure 7(b). Figure 7(c) represents the additively manufactured occlusal splint and post-processing using a curing unit. Following a fifteen-minute soak in isopropyl alcohol for cleaning, post-light curing was carried out with a DLP device equipped with a UV laser source for better accuracy, stability and enhanced mechanical properties.Figure 7(d) depicts the fabricated occlusal splint after post-processing.

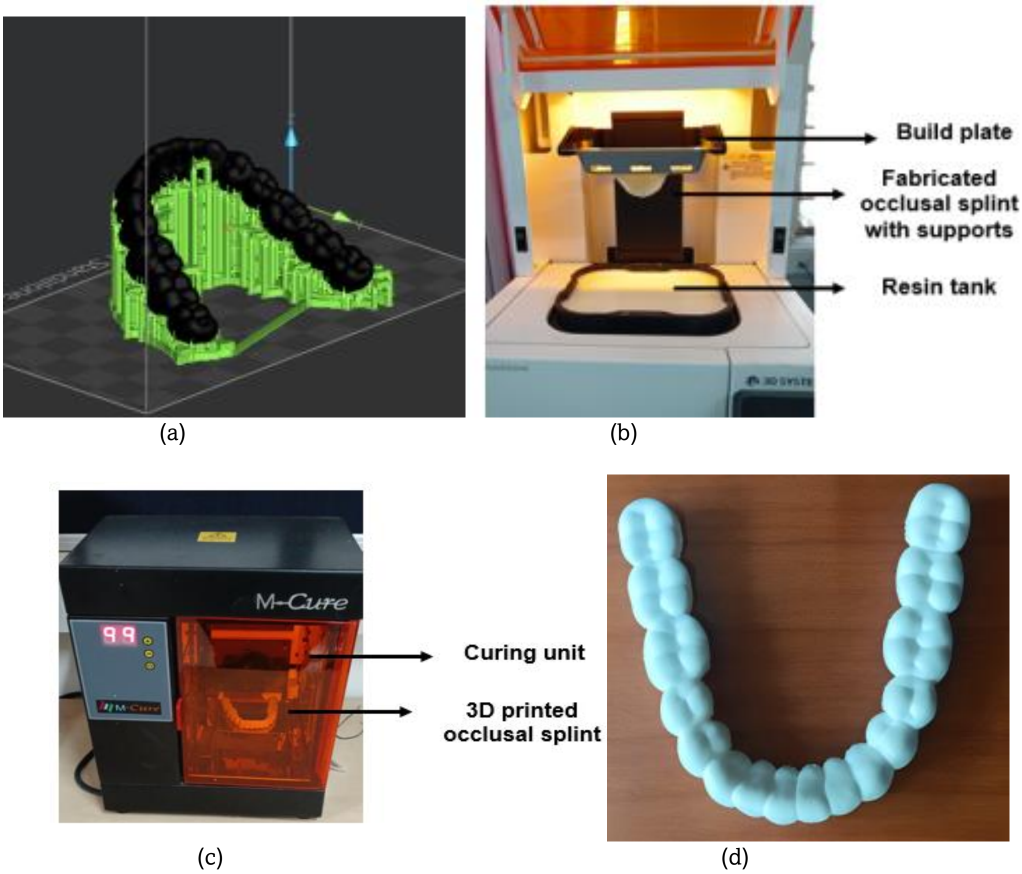



**Fig. 7** (a) print settings and configurations,(b) DLP resin 3D printer,(c) additively manufactured splint,(d) post-processing of fabricated splint,(e) fabricated splint after post-processing

*3.4 Test Setup for Surface Roughness*

Figure 3 provides an illustration of the tool used to measure surface roughness. Combination of a genuine 50 mm tracer from the S130A model. To achieve the highest straightness accuracy in the 3 m/50 mm class, waviness data are provided for the tiny tracing driver.

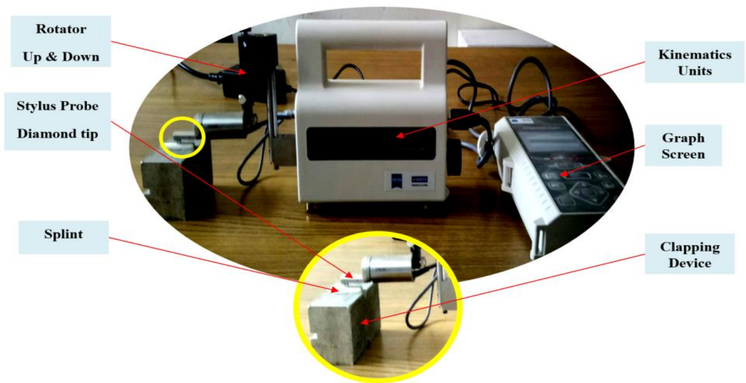



**Fig. 8** Surface roughness apparatus

## 4. Result and Discussion

A comprehensive investigation of the surface roughness of occlusal splints produced using biocompatible resins was conducted using a surface roughness tester. The study conducted a thorough analysis of various teeth to see how the final surface quality of the occlusal splints varies. Surface roughness research showed significant variability among the occlusal splints made from biocompatible resins. The variations in surface roughness can be ascribed to multiple factors, such as the composition of the resin, the parameters used in printing, and the procedures employed in post-processing. The resin formulation is vital in defining the ultimate surface quality, as specific additives or fillers can affect the flow behavior and curing properties of the resin during the printing process. Moreover, deviations in printer configurations such as the thickness of each layer, the speed at which the printing is done, and the strength of the curing process might impact the level of detail and accuracy of the printed layers, thus affecting the roughness of the surface of the produced occlusal splints. In addition, the surface roughness of the printed occlusal splints can be affected by post-processing techniques such as polishing or sanding. Although these procedures have the potential to enhance the surface polish, they can also bring additional variability based on the operator's skill level and consistency.

This work emphasizes the significance of choosing suitable resin materials and fine-tuning printing parameters to attain the desired surface quality in 3D-printed occlusal splints. Through a comprehensive understanding of the variables that impact surface roughness, dental professionals and researchers may make well-informed choices about the selection of materials and printing procedures, to achieve the best possible clinical results and assure patient contentment. Moreover, additional investigation is necessary to examine sophisticated post-processing methods and novel resin compositions to improve the surface quality of 3D-printed dental prostheses.

## 5. Conclusion

In conclusion, the use of intraoral scanners and resin 3D printing for occlusal guard fabrication has several advantages over traditional methods. It is more comfortable for patients, more accurate, and faster. While there are challenges to adopting this technology, the future looks promising as the technology becomes more widespread and standardized. Dental practices should carefully consider the potential cost savings and patient benefits when deciding whether or not to adopt this technology.

### Acknowledgments

Authors sincerely acknowledge DCRUST for providing 3D scanning and printing facilities.

**Author Contributions**: Ramesh Kumar Garg: Conceptualization, methodology, formal analysis, writing—original draft, Sumit Gahletia.; supervision, resources, project administration, Ashish Kaushik.; writing—review and editing, project administration, validation writing—review and editing, project administration, validation. All authors have read and agreed to the published version of the manuscript.

**Funding:** The author(s) received no financial support for the research, authorship, and/or publication of this article.

**Conflicts of Interest:** The authors declare no conflict of interest.

### References

Bahl, S., Nagar, H., Singh, I., & Sehgal, S. (2020). Smart materials types, properties and applications: A review. Materials Today: Proceedings, 28, 1302-1306.
Bohner, L., Gamba, D. D., Hanisch, M., Marcio, B. S., Neto, P. T., Laganá, D. C., & Sesma, N. (2019). Accuracy of digital technologies for the scanning of facial, skeletal, and intraoral tissues: A systematic review. The Journal of prosthetic dentistry, 121(2), 246-251.
Flügge, T., van der Meer, W. J., Gonzalez, B. G., Vach, K., Wismeijer, D., & Wang, P. (2018). The accuracy of different dental impression techniques for implant-supported dental prostheses: A systematic review and meta-analysis. Clinical oral implants research, 29, 374-392.
Gallardo, Y. R., Bohner, L., Tortamano, P., Pigozzo, M. N., Lagana, D. C., & Sesma, N. (2018). Patient outcomes and procedure working time for digital versus conventional impressions: A systematic review. The Journal of prosthetic dentistry, 119(2), 214-219.
Goujat, A., Abouelleil, H., Colon, P., Jeannin, C., Pradelle, N., Seux, D., & Grosgogeat, B. (2019). Marginal and internal fit of CAD-CAM inlay/onlay restorations: A systematic review of in vitro studies. The Journal of prosthetic dentistry, 121(4), 590-597.
Jokubauskas, L., Baltrušaitytė, A., & Pileičikienė, G. (2018). Oral appliances for managing sleep bruxism in adults: a systematic review from 2007 to 2017. Journal of oral rehabilitation, 45(1), 81-95.
Kattadiyil, M. T., AlHelal, A., & Goodacre, B. J. (2017). Clinical complications and quality assessments with computer-engineered complete dentures: A systematic review. The Journal of prosthetic dentistry, 117(6), 721-728.
Kaushik, A., Gahletia, S., Garg, R. K., Sharma, P., Chhabra, D., & Yadav, M. (2022, December). Advanced 3D body scanning techniques and its clinical applications. In 2022 International Conference on Computational Modelling, Simulation and Optimization (ICCMSO) (pp. 352-358). IEEE.
Kishore, K., Varshney, R., Singh, P., & Sinha, M. K. (2022). Materials for 3D Printing in Medicine: Metals, Polymers, Ceramics, Hydrogels. In Additive Manufacturing with Medical Applications (pp. 73-95). CRC Press.
Kumar, M., Kumar, R., Kumar, S., & Prakash, C. (2019). Biomechanical properties of orthopedic and dental implants: a comprehensive review. Handbook of research on green engineering techniques for modern manufacturing, 1-13.

Mühlemann, S., Kraus, R. D., Hämmerle, C. H., & Thoma, D. S. (2018). Is the use of digital technologies for the fabrication of implant-supported reconstructions more efficient and/or more effective than conventional techniques: A systematic review. Clinical Oral Implants Research, 29, 184-195.

Russo, L. L., Caradonna, G., Biancardino, M., De Lillo, A., Troiano, G., & Guida, L. (2019). Digital versus conventional workflow for the fabrication of multiunit fixed prostheses: A systematic review and meta-analysis of vertical marginal fit in controlled in vitro studies. The Journal of prosthetic dentistry, 122(5), 435-440.

Salmi, M., Paloheimo, K. S., Tuomi, J., Ingman, T., & Mäkitie, A. (2013). A digital process for additive manufacturing of occlusal splints: a clinical pilot study. Journal of the Royal Society Interface, 10(84), 20130203.

Sharma, S. K., Saxena, K. K., Dixit, A. K., Singh, R., & Mohammed, K. A. (2022). Role of additive manufacturing and various reinforcements in MMCs related to biomedical applications. Advances in Materials and Processing Technologies, 1-18.

Singh, H., Singh, S., & Prakash, C. (2019). Current trends in biomaterials and bio-manufacturing. Biomanufacturing, 1-34.

Singh, R., Saxena, K. K., & Singhal, P. (2022). Role of additive manufacturing in dental applications using ceramics: A review. Materials Today: Proceedings, 56, 2359-2364.

Tahayeri, A., Morgan, M., Fugolin, A. P., Bompolaki, D., Athirasala, A., Pfeifer, C. S., ... & Bertassoni, L. E. (2018). 3D printed versus conventionally cured provisional crown and bridge dental materials. Dental materials, 34(2), 192-200.