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Impact of 3d Printing Technologies on Designing and Executing Dental Implant Surgeries

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Abstract
Purpose –The aim of the study is to investigate the impact of 3D printing technologies on the process of designing and executing dental implant surgeries specifically within the context of Ghana. This includes examining how the integration of 3D printing affects the planning, precision, and outcomes of dental implant procedures in Ghanaian dental practices. Additionally, the study aims to explore the challenges, opportunities, and potential barriers associated with the adoption of 3D printing technologies in the Ghanaian dental industry. Through this investigation, the study seeks to provide insights that can inform strategies for optimizing the use of 3D printing in dental implant surgeries, ultimately aiming to improve patient care and outcomes in Ghana.

Design/methodology/approach -The research employed a quantitative approach, focusing on numerical data collection. Using a descriptive survey design, the study aimed to specify the nature of the phenomenon under investigation. The target population comprised surgeons at the Korle-Bu Teaching Hospital in Ghana, with purposive sampling used to select 100 respondents based on their knowledge of 3D printing and dental surgeries. Data was collected via a questionnaire due to its efficiency in gathering information from a large sample size.

Findings -In terms of impact, respondents widely agree on the benefits, including improved precision, efficiency with surgical guides, better outcomes with patient-specific implants, streamlined workflows, and the perceived value among dental professionals.Regarding opportunities, there's recognition of cost-saving potential and enhanced surgical accuracy, but mixed views on infrastructure support and regulatory frameworks. As for challenges, respondents identify barriers like limited access to equipment, insufficient training, high costs, concerns about product quality, and compatibility issues.

Research limitations/implications–The study's sample size of 100 respondents from the Korle-Bu Teaching Hospital in Ghana may not fully represent the diversity of perspectives within the Ghanaian dental industry. This could limit the generalizability of the findings to other dental practices or regions in Ghana.
Practical implementation-To address the identified challenges such as the lack of training and expertise among dental professionals, training programs and educational initiatives on 3D printing technologies can be developed and implemented. This will help to enhance the knowledge and skills of dental practitioners in utilizing 3D printing for dental implant surgeries.

I. INTRODUCTION

According to Nelson (2011), there are a number of mechanical and biological factors that determine the clinical outcome of implant dentistry. If we want our implants to last and stay in for a long period, we need to think about how their surface interacts with the tissues around them (Smeets, 2016). Furthermore, surface characteristics are thought to be crucial in enhancing osseointegration (Smeets, 2016). How well an implant stays put in the host bone depends on its surface qualities. Hence, to avoid implant failure, it is recommended to make superficial changes to promote early bone healing at the implant-bone contact. Grinding, blasting, and acid etching are common methods for altering surface roughness, which can increase implant osseointegration (Nelson, 2011). Cell adhesion and attachment, gene expression for angiogenic and osteogenic markers, and ECM deposition are all affected by these treatments' effects on cell behavior (Smeets et al., 2016). Also, according to Ryan (2006), porosity has a significant role in how well osseointegration works. The manufacture of a structure with a fully regulated external form design is not possible using the typical procedures employed to generate a rough surface (Ryan, 2006).

Dental implant surgeries have become increasingly prevalent in Ghana due to factors such as improved oral health awareness, lifestyle changes, and advancements in dental care services. However, the implementation of these procedures can be hindered by various challenges, including limited access to specialized equipment, trained professionals, and high costs associated with traditional implant fabrication techniques (Agyapong-Badu et al., 2019).Despite efforts to expand dental services across the country, disparities in access to advanced dental care persist, with rural areas often experiencing a shortage of skilled practitioners and inadequate infrastructure (Amuasi et al., 2019). Consequently, patients may face long wait times for treatment and travel long distances to access specialized care, leading to delays in receiving essential dental services, including implant surgeries.

Therefore, the aim of the study is to investigate the impact of 3D printing technologies on the process of designing and executing dental implant surgeries specifically within the context of Ghana. This includes examining how the integration of 3D printing affects the planning, precision, and outcomes of dental implant procedures in Ghanaian dental practices. Additionally, the study aims to explore the challenges, opportunities, and potential barriers associated with the adoption of 3D printing technologies in the Ghanaian dental industry. Through this investigation, the study seeks to provide insights that can inform strategies for optimizing the use of 3D printing in dental implant surgeries, ultimately aiming to improve patient care and outcomes in Ghana.

II. DEFINING CONCEPTS

2.1 3D Printing Technology

Stereolithography (SLA, SL): In stereolithography, an item is constructed layer by layer in a vat of light-cured photopolymer resin using a scanning laser. The liquid resin is laser-formed layer by layer; when the "build platform" lowers, another layer is wiped over the surface, and the process is repeated. In order to prevent the wiping action, support must first be created in CAD software, printed, and then deleted from the final product when fabrication is complete. After the product is complete, it needs to be post-processed by removing any extra resin and curing it in a UV oven (Tosto et al, 2022).

Photo-Polymer Jetting (PPJ): In photopolymer jetting technology, light-sensitive polymer is sprayed onto a build platform using an inkjet print head. The platform is raised incrementally to cure the polymer layer by layer. Rathee et al. (2022) state that this technique can be implemented using either a static platform with a moving print head or a moving platform with a still print head.

Powder Binder Printers (PBP): Layers of powder are printed layer by layer using liquid droplets in this system, which uses a modified inkjet head. The powder is usually printed onto using a colored liquid, the majority of which is water. No support material is needed because the model is produced in layers sequentially using un-filtrated powder. The printed model's strength and surface hardness can be enhanced through post-processing, according to Rathee et al. (2022).

Selective Laser Sintering (SLS): Availability of this technology dates back to the mid-1980s. Scanning lasers are used to fuse small material powder layer by layer in the construction industry. This process involves lowering a powder bed incrementally and evenly spreading a new layer of material over the surface. Polymers with high melting points and outstanding material characteristics are utilized in this procedure. There is no need for support material in this technology because it is also backed by surrounding powder. Stainless steel, titanium, cobalt chrome alloys, and metal combinations incorporating nylon are among the materials that are available (Tosto et al., 2022).

3D Printing Applications in Dentistry

Implants: The biocompatibility and mechanical characteristics of 3D-printed implants are comparable to those of natural teeth. According to Rathee et al. (2023), it is also possible to 3D print maxillofacial dental implants.

Crowns and bridges: Crowns and bridges for permanent and temporary fixed prostheses can be made to exacting specifications using 3D printers. Using the lost-wax method, printed burn-out resins can be used to create metal coping. After the object is scanned using an intraoral scanner, the Standard tessellation Language (STL) files are used to print the casting patterns.

Surgical Guides: To make surgical guides for cutting and drilling, dentists utilize 3D printers. Dental implant surgery and maxillofacial procedures both benefit from these recommendations.

Anatomical Models & Replicas: Using 3D printing technology, anatomical copies of a patient's jaw and mouth can be created. In order to better comprehend the patient's oral cavity architecture before treatment begins, this provides the dentist with a tangible representation (Rathee et al, 2022).

For almost ten years, surgeons have relied on 3D-printed surgical guides to accurately position implants. Predicting the 3D spatial placement of implants, reducing surgery time, and minimizing morbidity are some of the key advantages of this technology (Chen et al, 2015). Dental implant insertion precision is improved with the use of VSP and 3D-printed surgical guides, which allow minimal angular and linear variations (D'haese, et al, 2022). The use of 3D-printed surgical guides for implant placement has been demonstrated to significantly reduce the margin of error, as free-hand drilling frequently deviates from the treatment plan (Chen et al, 2015). In addition, guided implants offer a benefit through flapless operations, which result in less discomfort and less post-operative problems for patients, and they demonstrate similar or superior survival rates (Yeung, 2020).

The potential for producing dental implants is another emerging use of 3D printing technology. The materials used to make these implants can range from ceramics to titanium alloys (Lee et al., 2022). The variety of implant designs, lengths, diameters, and abutments that are now available on the market is limited. As a result, this technology can bridge the gap between generic designs and patients' unique requirements (Lee et al., 2022). Li et al. (2020) found that 3D-printed implants have a high proportion of bone-to-implant contact (BIC) and show great stability in biological and histological studies. Improving osseointegration is also possible, depending on the material chosen and the suggested surface alterations (Lee et al., 2022). Materials' biological and biomechanical reactions determine the technology's limitations. There is a current dearth of clinical evidence showing that 3D-printed dental implants have any benefit in the long run (Park et al., 2020).

2.2 THEORETICAL APPROACHES

The theoretical approaches to the study on the impact of 3D printing technologies on designing and executing dental implant surgeries in Ghana can encompass various perspectives. Such as:

Technological Innovation Theory:

Technological Innovation Theory, also known as the "Diffusion of Innovations" theory, provides a valuable framework for understanding the adoption and integration of new technologies into existing systems. Rogers (2003) defines technological innovation as "an idea, practice, or object perceived as new by an individual or other unit of adoption."This theory provides a comprehensive framework for understanding how new technologies are adopted and integrated into existing systems. It would be particularly useful for identifying the factors influencing the adoption of 3D printing technologies within Ghanaian dental practices, such as technological characteristics, organizational dynamics, and external influences. By applying technological innovation theory, researcher can analyze the barriers and facilitators to the adoption of 3D printing technologies and develop strategies to optimize their implementation in dental implant surgeries in Ghana.

Diffusion of Innovations Theory:

The Diffusion of Innovations Theory, proposed by Rogers (2003), offers insights into how new technologies, ideas, or practices spread within a social system. According to Rogers, the diffusion process involves several stages including knowledge, persuasion, decision, implementation, and confirmation. This theory emphasizes the role of various factors such as the perceived attributes of the innovation, communication channels, social networks, and the characteristics of adopters in influencing the adoption and dissemination of innovations.This framework would be valuable for examining the process by which 3D printing technologies are disseminated among dental professionals in Ghana and understanding the factors that influence their adoption and utilization.

By applying diffusion of innovations theory, researcher can identify key stakeholders, communication channels, and strategies for promoting the adoption of 3D printing technologies in dental implant surgeries in Ghana.

2.3 IMPACT OF 3D PRINTING TECHNOLOGIES ON DENTAL IMPLANT SURGERIES

3D printing has far-reaching and complex effects on dental implant procedures. Improving pre-surgical planning and design perfection is a key component. 3D printing allows dentists and oral surgeons to use digital scans of patients to make models and surgical guidelines that are unique to each patient (Flugge et al., 2013). Using these guides as exact templates during surgery helps surgeons place implants more precisely and with less risk of problems (Lee et al., 2016). The use of 3D printing has improved collaboration and communication between oral surgeons, prosthodontists, and dental technicians by making it possible to create precise anatomical models and simulations (Revilla-León et al., 2018).

In addition, dental implants can now be personalized using 3D printing to fit each patient's specific anatomy. According to Van Noort (2012), this customized method improves the fit and functionality of the implants, which in turn leads to better long-term results and patient satisfaction. With advantages including shorter prototyping timeframes and more leeway for design tweaks, 3D printing has also become an attractive choice for dental offices due to its efficiency and low cost (Alharbi et al., 2017).More biocompatible and visually beautiful materials are now accessible for dental prosthesis and implants thanks to 3D printing. According to Plugge et al. (2013), 3D printing allows for the exact fabrication of advanced materials like bioceramics and biocompatible polymers. This allows patients to receive implants that closely resemble the natural characteristics of teeth and bone. Both the aesthetic and functional results of dental implant surgeries are improved, and the patient is also more comfortable and satisfied as a result.

III. METHODOLOGY

Research Approach

Denzin (2010) argues that the paradigm (qualitative, quantitative, or mixed) is defined by the study purpose. The researcher used a quantitative technique in this investigation.

Research Design

The research design is crucial to the success of any study. As a whole, the design dictates the research approach. According to Malhotra and Birks (2003), research designs are like a road map for a study; they outline the steps to take and provide a framework for analyzing the results. The research goals and objectives were investigated using a descriptive survey design in this study. By identifying and documenting the current state of affairs, descriptive surveys help researchers define the characteristics of a certain phenomenon.

Target Population

According to Babbie (2005), the target population is all the things from which a sample is actually drawn. On the other hand, according to Castillo (2009), the study population is the totality of the people or things that researchers want to draw conclusions about. Participants in this research were general surgeons working out of Ghana's Korle-Bu Teaching Hospital.

Sampling Technique and Sample Size

To estimate or predict the prevalence of an unknown piece of information, scenario, or outcome regarding the wider group, sampling is chosen by selecting a few (a sample) from a broader group (the sampling population), according to Kumar (2011). Given the study's objectives, purposive sampling—in which researchers actively seek out participants with relevant background knowledge on 3D printing and dental surgeries—was the most acceptable sampling approach to use. The study's sample size is one hundred. This led to one hundred participants taking part in the research.

Data Collection Instruments

The study used questionnaires as its data gathering instrument. Staff members were asked to provide quantitative data through the use of a questionnaire. Because questionnaires are useful for gathering a variety of data from many people, this study opted to use them instead of other research tools. Because of the size of the study's sample, a questionnaire was necessary to collect data with statistical significance.

IV. ANALYSIS AND DISCUSSION

Exploring the impact of 3D printing technologies on designing and executing dental implant surgeries

No.	Quantitative	Strongly Disagree	Disagree	Neutral	Agree	Strongly Agree
1.	3D printing technologies significantly improve the precision and accuracy of dental implant surgeries.	5%	10%	20%	40%	25%
2.	The use of 3D printed surgical guides enhances the efficiency and effectiveness of dental implant procedures.	3%	8%	15%	45%	29%
3.	Patient-specific dental implants created with 3D printing technologies result in better clinical outcomes compared to traditional implants.	7%	12%	18%	35%	28%
4.	3D printing technologies streamline the workflow of dental implant surgeries and reduce the overall treatment time for patients.	10%	15%	25%	30%	20%
5.	Dental professionals perceive 3D printing technologies as valuable tools for optimizing the design and execution of dental implant surgeries.	2%	5%	10%	40%	43%

The data suggests widespread agreement among respondents regarding the positive impact of 3D printing technologies on the precision and accuracy of dental implant surgeries. With only 5% strongly disagreeing and 10% disagreeing, and a substantial proportion of 40% agreeing and 25% strongly agreeing, there is strong consensus regarding the beneficial effects of 3D printing in enhancing surgical precision and accuracy. Furthermore, 20% remain neutral, suggesting potential areas for further investigation or confirmation of these benefits.Moreover, the responses highlight a prevailing belief among respondents that the use of 3D printed surgical guides enhances the efficiency and effectiveness of dental implant procedures. With only 3% strongly disagreeing and 8% disagreeing, and a significant proportion of 45% agreeing and 29% strongly agreeing, there is strong support for the notion that 3D printing technologies contribute to improved procedural outcomes. Additionally, 15% remain neutral, indicating a need for further exploration or validation of these assertions.

Furthermore, the data reveals a widespread perception that patient-specific dental implants created with 3D printing technologies result in better clinical outcomes compared to traditional implants. With 7% strongly disagreeing and 12% disagreeing, and a notable proportion of 35% agreeing and 28% strongly agreeing, there is strong consensus regarding the clinical benefits of patient-specific implants. Moreover, 18% remain neutral, suggesting potential areas for further research or evaluation of these outcomes.Additionally, the responses indicate that 3D printing technologies streamline the workflow of dental implant surgeries and reduce the overall treatment time for patients. With only 10% strongly disagreeing and 15% disagreeing, and a significant proportion of 30% agreeing and 20% strongly agreeing, there is widespread recognition of the efficiency gains associated with 3D printing technologies. Furthermore, 25% remain neutral, indicating potential areas for further investigation or validation of these efficiency claims.Lastly, the data suggests a strong perception among dental professionals that 3D printing technologies are valuable tools for optimizing the design and execution of dental implant surgeries. With only 2% strongly disagreeing and 5% disagreeing, and a notable proportion of 40% agreeing and 43% strongly agreeing, there is overwhelming support for the notion that 3D printing technologies play a crucial role in enhancing surgical outcomes. Additionally, 10% remain neutral, highlighting potential areas for further education or awareness-building among dental professionals regarding the value of 3D printing technologies.

Exploring opportunities associated with the adoption of 3D printing technologies in the Ghanaian dental industry

No.	Question	Strongly Disagree	Disagree	Neutral	Agree	Strongly Agree
1.	3D printing technologies offer cost-saving opportunities for dental practices in Ghana.	8%	15%	20%	35%	22%
2.	The adoption of 3D printing technologies can improve the accuracy and precision of dental implant surgeries in Ghana.	5%	10%	18%	40%	27%
3.	There is adequate infrastructure and technical support available in Ghana to facilitate the adoption of 3D printing technologies in dental practices.	12%	5%	15%	45%	23%
4.	Dental professionals in Ghana perceive 3D printing technologies as valuable tools for enhancing patient care and outcomes.	3%	8%	15%	45%	29%
5.	The regulatory framework in Ghana supports the safe and effective use of 3D printing technologies in dental procedures.	10%	18%	22%	30%	20%

The data suggests that a significant proportion of respondents, comprising 8% who strongly disagree and 15% who disagree, do not perceive 3D printing technologies as offering cost-saving opportunities for dental practices in Ghana. However, 35% agree and 22% strongly agree, indicating that a majority of respondents recognize the potential for cost savings with the adoption of 3D printing technologies. Moreover, 20% remain neutral, suggesting a need for further evaluation or clarification of the cost-saving benefits.Furthermore, the responses highlight a widespread belief among respondents that the adoption of 3D printing technologies can improve the accuracy and precision of dental implant surgeries in Ghana. With only 5% strongly disagreeing and 10% disagreeing, and a substantial proportion of 40% agreeing and 27% strongly agreeing, there is strong consensus regarding the potential benefits of 3D printing in enhancing surgical outcomes. Additionally, 18% remain neutral, suggesting room for further exploration or validation of these benefits.

Moreover, the data reveals varying perceptions regarding the availability of infrastructure and technical support for the adoption of 3D printing technologies in dental practices in Ghana. While 12% strongly disagree and 5% disagree, indicating skepticism or concerns, a significant proportion of 45% agree and 23% strongly agree, reflecting confidence in the existing support systems. Furthermore, 15% remain neutral, suggesting a need for further assessment or improvement of infrastructure and technical support mechanisms.Additionally, the responses indicate that dental professionals in Ghana perceive 3D printing technologies as valuable tools for enhancing patient care and outcomes. With only 3% strongly disagreeing and 8% disagreeing, and a notable proportion of 45% agreeing and 29% strongly agreeing, there is widespread recognition of the value of 3D printing technologies in dental practice. Moreover, 15% remain neutral, suggesting potential areas for further education or awareness-building among dental professionals.Lastly, the data suggests mixed perceptions regarding the regulatory framework supporting the use of 3D printing technologies in dental procedures in Ghana. While 10% strongly disagree and 18% disagree, indicating concerns or dissatisfaction, a substantial proportion of 30% agree and 20% strongly agree with the effectiveness of the regulatory framework. Furthermore, 22% remain neutral, highlighting the need for ongoing evaluation and refinement of regulatory policies to ensure safe and effective use of 3D printing technologies in dental procedures.

Exploring challenges associated with the adoption of 3D printing technologies in the Ghanaian dental industry

No.	Question	Strongly	Disagree	Neutral	Agree	Strongly

		Disagree				Agree
1.	Limited access to reliable 3D printing equipment and software in Ghana poses challenges to the widespread adoption of these technologies in dental practices.	10%	20%	25%	30%	15%
2.	There is a lack of training and expertise among dental professionals in Ghana to effectively utilize 3D printing technologies.	8%	15%	20%	40%	17%
3.	The high cost of 3D printing materials and consumables in Ghana is a major barrier preventing dental practices from embracing this technology.	15%	25%	30%	20%	10%
4.	Concerns about the reliability and quality of 3D printed dental prosthetics and implants hinder the adoption of these technologies in Ghana.	12%	20%	25%	30%	13%
5.	3D printing technologies are not be compatible with existing infrastructure and workflows in dental practices in Ghana, leading to operational challenges.	8%	15%	20%	30%	27%

The data reveals that a significant proportion of respondents, comprising 10% who strongly disagree and 20% who disagree, perceive limited access to reliable 3D printing equipment and software as a notable challenge. Moreover, 30% agree and 15% strongly agree that this limitation poses obstacles to widespread adoption. However, it is noteworthy that 25% remain neutral, suggesting a degree of uncertainty or variability in perceptions regarding this issue. Also, the responses highlight concerns about the level of training and expertise among dental professionals in Ghana, with 8% strongly disagreeing and 15% disagreeing. Additionally, a substantial proportion of 40% agree and 17% strongly agree that there is indeed a lack of training and expertise. Furthermore, 20% remain neutral, indicating a need for further investigation or assessment of the current training landscape.

Furthermore, the data illustrates that the high cost of 3D printing materials and consumables is perceived as a significant barrier by a notable proportion of respondents, with 15% strongly disagreeing and 25% disagreeing. Moreover, 20% agree and 10% strongly agree with this statement. However, it is interesting to note that 30% remain neutral, suggesting a divergence of opinion or uncertainty regarding the extent of the cost barrier.The responses indicate that concerns about the reliability and quality of 3D printed dental prosthetics and implants are prevalent among respondents, with 12% strongly disagreeing and 20% disagreeing. Additionally, 30% agree and 13% strongly agree with these concerns. Moreover, 25% remain neutral, suggesting a need for further evaluation or assurance regarding the reliability and quality of 3D printed dental products. Lastly, the data reveals that while some respondents express concerns about the compatibility of 3D printing technologies with existing infrastructure and workflows, with 8% strongly disagreeing and 15% disagreeing, a significant proportion of 30% agree and 27% strongly agree that such compatibility challenges exist. Furthermore, 20% remain neutral, indicating the need for further exploration or adaptation of 3D printing technologies to align with existing dental practice frameworks.

V. CONCLUSION

3D printing technology is having a massive effect on the dental industry, according to a number of research and clinical evaluations. Thanks to recent technological advancements, not only is it now feasible to mass customise products at reduced cost, but it is also considerably easier and faster to create an accurate 3D model of an object. Dental prosthodontics (both temporary and permanent restorations), orthodontics (both braces and permanent), maxillofacial and implant surgery (surgical guidance), and other areas of dentistry are already making extensive use of this technology. Even if 3D printers are getting cheaper, there are still a lot of factors to think about, such as the materials cost, the requirement for competent operators, and the necessity for post-processing.

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