PROJECT PROPOSAL

FOR CONSIDERATION UNDER

TECHNOLOGY DEVELOPMENT PROGRAMME (TDP)

Advancing Dental Scanning and Facial Structure Prediction using Machine Learning techniques for enhanced Orthodontic and Orthognathic Treatment

July 5, 2023

Contents

1 Detailed Proposal

1 Title of the project

"Advancing Dental Scanning and Facial Structure Prediction using Machine Learning techniques for enhanced Orthodontic and Orthognathic Treatment"

2 Principal Investigators

	PI	Co-PI 1	Co-PI 2
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Date of birth:	Cell 4	Cell 5	Cell 6

3 Nature of the Project

- Development of a technology of societal importance

4 Duration of the project

The project duration shall be between 24-36 months.

5 Names of participating Organizations with their addresses

- **Indian Institute of Technology, Goa :** Bhausaheb Bandodkar Technical Education Complex, Goa Engineering College Campus, Farmagudi, Ponda, Goa 403401
- **Dental college Name :** Address

6 Objectives of the Proposal

6.1 Overall Development Objectives

- **Abstract:** This project aims to enhance Orthodontic and Orthognathic treatment in India by addressing the limitations of expensive[1] facial prediction software currently available in the market. These software solutions often yield moderate accuracy and pose financial constraints for dental practitioners and patients. By prioritizing advancements in scanning techniques and enhancement methods rather than expensive[2] hardware

[1] refer to the appendix for analysis
[2] refer to the appendix

modifications, we intend to significantly reduce costs while improving the accuracy of facial prediction. Leveraging state-of-the-art machine learning algorithms, our affordable system will empower dentists to achieve precise facial structure predictions after Orthodontic and Orthognathic treatment, enabling better treatment planning and patient outcomes. Through this project, we seek to enhance the accessibility and affordability of Orthodontic and Orthognathic care in India, ultimately benefiting a larger population.

- **Statement of Need:** Affordable dental scanning and facial prediction software are urgently required in India to overcome current tools' high costs and limitations. The existing expensive software and hardware hinder accessibility and compromise accuracy in predicting facial structure after Orthodontic and Orthognathic treatment. There is a pressing need for cost-effective solutions that leverage advanced scanning techniques, reducing expenses while ensuring precise and reliable predictions. By focusing on enhancing scanning techniques rather than costly hardware modifications, we can achieve affordability without compromising quality. This will empower practitioners, improve treatment outcomes, and bridge the accessibility gap, ensuring equitable access to advanced Orthodontic and Orthognathic technologies in India. [1]

6.2 Intermediate Objectives

- **Stage I:** The primary objective of the first stage is to build a 3D scanner that gives us a 3D point cloud of a dental alginate impression. Subsequently, these acquired point clouds will undergo refinement[2, 3] utilizing elementary yet effective machine learning techniques. This pivotal stage will establish the cornerstone for all forthcoming phases of the project.

- **Stage II:** As the hardware is limited by the small and frequently incomplete 3D point clouds produced by the scanner, the main goal of the second phase is to implement cutting-edge machine learning algorithms to address the challenge of 3D point-cloud completion, which may prove to be effective for enhancing and improving the scans obtained. Applying the solutions for the 3D point cloud completion problem[4] could improve the point cloud of the dental scan. By leveraging these sophisticated methodologies, our aim is to obtain a clinically acceptable and meticulously accurate 3D representation of the dental impression. The algorithmic aspect takes center stage in this phase, wherein technologies such as Generative Adversarial Networks (GANs) may be employed[5], along with other recently proposed methodologies [6]. This stage also aims at improvising the hardware to obtain better scans.

- **Stage III:**

  The objective of this stage is to integrate methodologies for enhancing scans obtained through X-rays, CBCT, and 3D point clouds[7] in order

to improve the quality of dental alginate impressions. Building upon the techniques used in Stage II, this stage involves defining points and angles based on Steiner's analysis which will be used as parameters in Stage IV [8]. By utilizing these improved scans, we aim to simulate surgical cuts and procedures, leading to an altered point cloud reflecting the simulated cuts and procedures. This milestone signifies significant progress in the project, enabling more accurate surgical simulations and contributing to Orthodontic and/or Orthognathic treatment advancements.

- **Stage IV:** The primary objective of this stage is to target the problem of post-Orthodontic/Orthognathic facial predictions using GANs[9]and other advanced methodologies [10] [11], to predict and visualize facial features and changes after the simulated treatments. The major goals during this stage would be to reconstruct the facial features over the altered X-rays, CBCT, and 3D point clouds obtained from the earlier stage. This phase represents a critical step in the project, incorporating Machine Learning techniques to achieve our desired results. We also aim during this stage to create a dataset for facial prediction after Orthodontic and/or Orthognathic treatment.

7 Fulfillment of Technology Qualifiers' Criteria

The proposal is :

- Based on established R&D outcome/results
- Potentially useful, demand-driven, and required by other agencies and users.
- An application of advanced science and technology with a promise of giving competitive solutions.

8 Cost Benefit (C-B) Analysis)/ Cost-Economic Analysis Report

9 Role of Industry (If any)

No industries or industrial corporations are involved or are partnering as a part of this project.

10 Origin and Justification of the Proposal

There exists an urgent and pressing demand within dental institutions and clinics for an accessible and cost-effective software solution that can accurately predict post-Orthodontic and Orthognathic treatment facial outcomes. While existing software serves the purpose of simulating surgical incisions and subsequent post-surgical face predictions, its exorbitant cost and the disparities

between predicted and actual results present a compelling opportunity for improvement. It is within this context that this project aims to make its mark. The ultimate objective is to employ advanced machine learning techniques to forecast patients' facial appearance after undergoing surgical procedures. Recent Machine Learning research conducted by esteemed international institutions has yielded promising findings in the realm of facial generation methods following Orthodontic and Orthognathic treatment [5]. Notably, studies exploring deep learning algorithms and Generative Adversarial Networks (GANs), particularly StyleGAN, have shown considerable potential in achieving accurate facial predictions[9], [12]. Utilizing such innovative methods is anticipated to considerably increase the accuracy of our forecasts. Additionally, notable breakthroughs in addressing the challenge of 3D point cloud completion using GANs and other alternatives [13] [14], offer valuable insights that can be adapted to this project. Our approach entails harnessing the methodologies employed in solving the above-mentioned challenges. Specifically, we intend to apply the principles of 3D point cloud completion to acquire high-quality scans of dental alginate impressions. This innovative approach will enable us to work with more modest hardware for scanning purposes, allowing for greater investment in the refinement of machine learning techniques. Consequently, we can substitute the expensive scanning tools presently available in the market, accompanied by their device-specific specialized software, with a superior and more cost-effective alternative. Once we obtain the comprehensive point cloud data, we will then apply the facial prediction methods developed for post-Orthodontic and Orthognathic treatment, utilizing GANs and other methods, to generate the anticipated outcomes. By combining these sophisticated techniques and enhancing the scanning process, our project endeavors to achieve remarkable advancements in the field. The proposed solution not only offers improved accuracy in facial predictions but also provides an affordable alternative to current industry standards. Ultimately, this undertaking has the potential to enhance Orthodontics and Orthognathic surgery by equipping dental professionals with a powerful tool that optimizes treatment planning and enhances patient satisfaction, all while delivering clinically acceptable results.

11 Summary Outline of the Project

This research attempts to overcome the shortcomings of current software which incur significant expenditures and displays discrepancies between anticipated and real results, in predicting post-Orthodontic and Orthognathic treatment face outcomes. The study aims to anticipate patients' facial appearance following surgery by using cutting-edge machine learning techniques. Recent studies by several organizations have shown encouraging results in the area of face-generation techniques after Orthodontic and Orthognathic treatment. Generative Adversarial Networks (GANs), StyleGAN, and deep learning algorithms have shown significant promise for making precise face predictions. Utilizing these innovative methods is anticipated to greatly improve forecast accuracy. Important developments in the construction of 3D point clouds using GANs are

also major factors for the improvements that might be gained in this project. The project's specific objective is to acquire high-quality scans of dental alginate imprints using 3D point cloud completion methods. This novel method makes it possible to use scanning technology that is more reasonably priced which might hold the potential to enhance the influx of customers seeking dental services by virtue of the reduced cost. Consequently, a better and more affordable solution may be used in place of expensive scanning instruments[3] now on the market and their device-specific specialized software. The facial prediction techniques created for post-Orthodontic and Orthognathic treatments, ideally utilizing GANs, will be utilized to generate predicted results after comprehensive point cloud data has been gathered. The research hopes to make significant breakthroughs in the industry by fusing these complex approaches and improving the scanning procedure. The proposed solution not only offers accuracy in facial predictions but also provides an affordable alternative to current industry standards. Ultimately, this undertaking has the potential to enhance Orthodontics and Orthognathic surgery by equipping dental professionals with a powerful tool that optimizes treatment planning, enhances patient satisfaction, and delivers exceptional results.

12 Expected Outcome in Physical Terms

a. New/ Upgraded Product: A new scanning hardware will be developed with minimal expenditure.

b. New/ Upscaled Process: The existing scanning processes will be enhanced and improvised using Machine Learning techniques which will be used for improving the current facial prediction software.

c. New/ Upgraded System: A new system for dental scanning and facial prediction post-orthodontic/orthognathic treatment will be developed.

d. Services (including Software): A new software will be developed to simulate surgical cuts and splints involved in orthodontic/orthognathic treatments and predict post-surgical facial structure using advanced Machine Learning Algorithms.

e. Feasibility Analysis: Assess the availability and compatibility of dental scanning technologies and machine learning algorithms required for the proposed project. Evaluate the availability of skilled personnel with expertise in dental scanning and machine learning techniques. Determine the time required for implementing and integrating the new technology into the orthodontic and orthognathic treatment workflow.

f. Any other: Evaluate the societal acceptance and ethical implications of using machine learning techniques for orthodontic and orthognathic treatment. Consider the impact on patient experience and satisfaction with enhanced treatment outcomes.

[3]refer to the appendix

13 Targeted Specifications of the Expected Outcome

- A cheaper alternative to currently used dental scanners could be developed equipped with better software to obtain high-quality dental scans using dental alginate imprints.
- A cheaper and more precise alternative to currently available options in the market for post-Orthodontic/Orthognathic facial predictions could be developed.

14 Deliverables of the Project

- Prototype of a scanner will be developed to obtain scans of the dental alginate impressions slightly improvised by a combination of noise removal techniques and point cloud completion techniques.
- Improvised scanner accompanied with software to obtain better scans of the dental alginate impressions which will be clinically acceptable.
- A software system for simulating the surgical cuts and splints over the 3D Point Cloud, CBCT, and the X-rays.
- A software system for predicting the changes in the facial appearance of the patient post-treatment from the simulated surgical cuts and splints.

15 Methodology

1. Scanning device: In order to obtain a 3D scan of the dental alginate impression, a 3D scanner will be built. The output of this scanner would be a 3D point cloud of the impression.
2. Enhancing the scans: The 3D point cloud of the dental alginate impression is then to be improvised using the approaches to the 3D point cloud completion problem along with making use of X-rays, CBCT for obtaining better scans. This enables filling the vacant 3D spaces and completes the 3D cloud that can be then rendered to obtain 3D scans. This procedure is also going to involve comparing the actual model and the enhanced scan repetitively enabling us to obtain a good scan by using the 3D Point Clouds, CBCT and X-rays.
3. Simulating the surgical procedures: The 3D Point Clouds, CBCT and X-rays from Stage II will be used to simulate the surgical cuts and splints resulting in an altered point cloud and X-ray images. This will be then used in the later stage for facial prediction.
4. Facial prediction: We utilize advanced techniques such as GANs, along with other methodologies, to forecast and visualize facial features after simulated treatments. Our primary focus involves reconstructing facial features based on modified X-rays, CBCT and 3D point clouds from the

simulation and the initial scanning of patients. The use of discriminative methods will help improve the accuracy and the facial points established before simulation will be used as reference while morphing the new point cloud over the facial structure.

16 Milestones with Dates, Work Elements for each and the Organisation responsible for each Work Element

S. No.	Milestone	Target Date	Work Elements	Responsib
1.	Project Initiation & Planning	3 Months	1. Objectives, scope, & deliverables 2. Formulate a detailed project plan 3. Identify key stakeholders	
2.	Data Collection & Preprocessing		1. Gather dental scanning data 2. Organize & preprocess 3. Annotate and label	
3.	Feature Extraction & Selection		1. Explore various ML methods 2.	
4.	Feature Extraction & Selection		1. Explore various ML methods 2.	

17 Work Plan

Stage I: Building the scanner

1. Purchasing the hardware for building a scanner.
2. Obtaining dental alginate impressions and their high-quality scans obtained by using the already existing scanners to compare the efficiency with the scan from our scanner.
3. Generating the 3D point cloud of the impressions from the scanner and improvising on them using noise-removal and other relevant techniques.

Stage II: Improvising the 3D Point Cloud

1. Literature Survey: There are currently many ways to approach the 3D Point Cloud Completion Problem. Publications and other relevant resources tackling this problem will be surveyed and analyzed.
2. Implementation: The methodology derived from the survey is to then be developed efficiently while considering the applications in the field of Orthodontics. This shall involve the development of an algorithm based on 3D Point Cloud Completion and other scanning improvement techniques based on Machine Learning, along with feasible hardware modifications to the scanners.

Stage III: A system for simulating the surgical procedures

The refined and enhanced 3D Point cloud, X-rays, and CBCT will then be altered depending on the surgical needs. A system will be developed to apply the surgical cuts and splints.

Stage IV: Facial Prediction after Orthodontic/Orthognathic treatment

1. Literature Survey: There have been many publications on the subject of Facial Prediction after Orthodontic/Orthognathic treatments. These resources will be surveyed.
2. Proposing Methodology: A constructive method/algorithm will be developed depending on the key findings from the survey.
3. The developed algorithm is then to be applied to the altered 3D Point Cloud and X-ray. Thereby, obtaining a prediction of the facial appearance post-treatment.

18 Bench Marks to be achieved (In quantitative terms):

19 Novelty/uniqueness of the proposal (not more than one page):

20 Gaps to be covered through proposed work with special reference to the proposal:

21 Critical Review of latest Status of the Technology (minimum 2 pages each & with complete references) :

21.1 National Status Review

21.2 International Status Review

Significant developments in the Automated systems for Orthodontic Treatment in Dentistry have involved machine learning. The recent models developed to tackle the problem of 3D Point Cloud Completion often complete the point clouds of objects from a pre-defined set of shapes involving popular data sets such as ShapeNet. A promising model which approaches this problem is PoinTr(Diverse Point Cloud Completion with Geometry-Aware Transformers). PoinTr[15] is a transformer-based model designed for point cloud completion tasks. It utilizes position embeddings to convert point clouds into sequences of point proxies and employs a transformer encoder-decoder architecture for a generation. Additionally, the research introduces ShapeNet-55/34 benchmarks, which feature more diverse and realistic incomplete point clouds, providing a valuable resource for further advancements in the field. In the field of tooth segmentation on 3D dental meshes, various deep learning techniques have been employed, including convolutional neural networks (CNNs) and graph neural

networks (GNNs). For instance, Xu et al. developed a CNN-based approach where hand-crafted features were extracted at the cell level to form 2D image-like inputs, allowing the CNN to predict the semantic label of each cell [16]. Zhang et al. proposed an approach where a 3D tooth model was mapped to a 2D "image" using harmonic attributes, and a CNN model was trained to predict the segmentation mask, which was then transferred back to the original 3D space. However, these CNN-based methods require converting 3D meshes or point clouds to regular "images" of hand-crafted features, leading to a loss of fine-grained geometric information in dental surfaces [17]. Zanjani et al. [18] introduced an approach that combines PointCNN [19] with an adversarial discriminator to assign tooth labels to individual points in intraoral scans. Considering the variation in the number of teeth among patients, they proposed Mask-MCNet [20], inspired by Mask-RCNN [21], for instance segmentation on intraoral scans. MeshSegNet [6], a graph neural network (GNN)-based approach, has demonstrated impressive segmentation accuracy but suffers from heavy computational requirements due to large adjacent matrices. Meanwhile, Kumer et al.[22] proposed specific methods to automatically identify dental features on digital dental meshes, while Zhang et al. focused on landmark digitization in medical images without considering complex structures like irregular dental meshes [23]. Another important development in the same direction was PointNet [24]. This research presents a groundbreaking deep learning architecture that directly processes unstructured point clouds, preserving their spatial information. PointNet consists of input transformation, feature extraction, and feature aggregation modules to efficiently capture local and global features. It achieves competitive performance in object classification and part segmentation, outperforming traditional methods. PointNet is robust against input transformations and scalable for varying numbers of points. Its success has inspired advancements in 3D scene understanding, robotics, and autonomous driving, making it a significant contribution to the field of 3D point cloud analysis. Numerous research endeavors focused on simulating surgical procedures have demonstrated encouraging outcomes, paving the way for advancements in surgical simulations. The research by Rosalia et al. proposes a hybrid approach based on Cellular Neural Networks (CNNs) for the automatic detection of landmarks [25]. The evaluation of the method's performance on scanned cephalograms showed promising results, although some landmarks exhibited larger errors compared to manual location. However, the study achieved an acceptable level of accuracy in automatic landmark detection by utilizing softcopy digital X-rays and improved algorithms integrated with the CNN technique.

Jeong-Hoon et al. introduced a novel framework for locating cephalometric landmarks with confidence regions using Bayesian Convolutional Neural Networks (BCNN) [26]. The unique aspect of this research is the incorporation of confidence regions, which sets it apart from previous studies. By providing these confidence regions, the improved models offer valuable assistance to inexperienced dentists in cephalometric tracing. This framework is an efficient and powerful tool that can enhance the accuracy and reliability of cephalometric analysis, benefiting dentists and patients.

There have been notable studies in the direction of machine learning based methods for identification and analysis of photometric points on 2D facial images in the field of orthodontics[27].This aims to automate the process of identifying key facial points relevant to orthodontic treatments. The proposed approach utilizes machine learning techniques to train models that can accurately locate and analyze these photometric points. The experiments conducted on a dataset demonstrate the effectiveness of the approach, providing valuable insights and potential applications in orthodontic diagnosis and treatment planning.

The current planning methods used in orthognathic surgery are clinically acceptable because most patients require relatively simple operations. However, it is well known that these methods are less than accurate. Traditional surgical planning methods, including the use of cephalometric tracing, acetate drawings, and plaster dental model surgery, are inadequate to solve the complex 3D problems involved in mandibular distraction. The best way to solve these complex problems is to use 3D CASS. The success of a planning process depends on the surgeon's ability to execute the plan at the time of surgery. Xia et al. developed a technique that enables the precise installation of the distractor in distraction osteogenesis surgery [28].

Assessing treatment outcomes in medical and dental fields involves analyzing various image types, including MRI, CT scans, radiographs, and 3D digital models. These analyses are typically time-consuming and require specialized expertise. Machine learning techniques have gained attention for their potential in assisting with image analysis, aiding in interpretation and reducing interpretation times [29], [30]. Cephalometric radiographs play a crucial role in orthodontic diagnosis and treatment planning. Lindner et al. developed a fully automatic landmark annotation (FALA) system to identify cephalometric landmarks and classify skeletal malformations [31]. The system utilized a machine learning approach, combining Random Forest regression voting for skull position, scale, and orientation detection, with the Constrained Local Model framework (RFRV-CLM) for landmark localization. The FALA system achieved efficient and accurate landmark identification, locating 19 landmarks in just 24 seconds. This approach eliminates the need for manual landmark identification, saving time and enhancing the efficiency of cephalometric analysis. Kunz et al. developed a customized CNN deep learning algorithm for automated cephalometric radiographic analysis. The algorithm demonstrated comparable precision to experienced human examiners and achieved results in a fraction of a second [32]. The limitations of standard 2D cephalometric radiographs, including overlapping structures and positional variations [33], have led to the increasing popularity of 3D cephalometric analyses using CT and CBCT images. However, developing an automated machine learning-based 3D cephalometric analysis framework is challenging due to the increased number of parameters, resource requirements, and computational complexity. Lee et al. proposed an automatic 3D cephalometric annotation system using a 2D image-based machine learning strategy, which allows learning with smaller data numbers and overcomes memory limitations. However, this approach only achieved localization of seven landmarks [34]. Digital 3D dental models have revolutionized dental

practices by enabling precise measurements, manipulation, and assessment of treatment outcomes. They are essential for CAD dental systems and virtual surgical planning. Manual segmentation of these models is time-consuming, prompting the need for automated processes. Xu et al. [35] proposed a deep CNN model for 3D dental mesh segmentation, achieving high accuracy and preserving teeth boundary information. Their approach significantly improved efficiency and showed promise for applications such as CAD dental restorations and customized orthodontic appliances. With the emergence of teledentistry and advancements in smartphone technology, orthodontic treatment monitoring has become more accessible. Dental Monitoring™ (DM™) is an advanced smartphone app that utilizes artificial intelligence and computer vision technology to remotely monitor patients' orthodontic progress. It calculates 3D tooth movements from intraoral photos and videos captured by patients using their smartphones. The app provides accurate results with claimed errors of less than 0.1 mm and 0.5 degrees for tip and torque measurements. The DM™ app consists of interconnected platforms, including a patient application, an artificial intelligence tracking algorithm, and an online Doctor Dashboard® for orthodontists to monitor treatment progress. It allows for real-time visualization of tooth movements, provides oral hygiene tracking, and can detect clinical situations such as broken brackets or wires. However, further research is necessary to validate the effectiveness of this technology [36, 37, 38, 39]

Facial reconstruction in orthognathic surgery plays a crucial role in addressing craniofacial deformities and reconstructing missing bony structures.Kiyak et al. believe that patients often express a strong desire to understand the potential changes in their postoperative facial appearance [1]. The maturation of generative adversarial network (GAN) technology, specifically StyleGAN, has provided effective technical support for post-orthodontic facial prediction. By leveraging AI algorithms, surgeons can generate faces with specific identities and utilize them for surgical planning and patient communication [40]. In orthodontics, machine learning algorithms have been employed to assess treatment outcomes and predict facial changes. Zarei et al. utilized a regression model to evaluate treatment effectiveness based on patient characteristics [41]. Lu et al. employed multiple linear regression to determine lip position using characteristic point distances on lateral cephalograms [42]. These studies highlight the potential of machine learning in predicting treatment outcomes. Zachow et al. presented a statistical 3D shape model of the human mandible, aiding in the surgical planning of complex cases [43]. Tian et al. proposed an Encoder-Decoder-based model in 2022, enabling the semantic transformation of StyleGAN latent space vectors to predict post-orthodontic facial appearance [44]. The integration of AI technologies, including GANs and machine learning algorithms, has shown promising results in facial reconstruction and prediction of post-orthodontic facial appearance.

22 Justification with reference to current status (in terms of technical/economic/societal aspects):

23 Summary of the Project

24 Deliverables

25 Methodology to be adopted

26 Milestones with Target Dates, Work Elements for each Milestone and the Organization(s) responsible for each

Sr. No.	**Milestone**	**Target Date**	**Work Elements to reach the respective milestones**	**Organization(s) responsible for each work element**
1.	Cell 2	Cell 3	cell 4	cell 5
2.	Cell 2	Cell 3	cell 4	cell 5

27 Budget for the Project

Sr. No.	**ITEM**	**DST Share**	**Other Agencies' Share**
Cell 1	Cell 2	Cell 3	cell 4
Cell 1	Cell 2	Cell 3	cell 4
Total	Cell 2	Cell 3	cell 4

28 List of Equipment with Cost. Requested from DST

29 List of the equipment available with the PI's Lab for utilization of the project activities

30 Techno-economic analysis of the project

31 Bar Chart /PERT-Chart

32 Items for Outsourcing

S. No.	Item	Justifications	Agency from which outsourcing to be made		
			First Year	Second Year	Third Year
1.	Cell 2	Cell 3	cell 4	Cell 5	Cell 6
2.	Cell 2	Cell 3	cell 4	Cell 5	Cell 6
3.	Cell 2	Cell 3	cell 4	Cell 5	Cell 6

33 Names and addresses of 10-15 subject Area Experts

34 Any other Information relevant to the Project Proposal and its Execution

35 Names and addresses of persons/institutions (10-15) interested in the outcome of the project

2 Bio-Data of the Principal Investigator/ Co-Principal Investigator

1. **Name:**
2. **Gender:**
3. **Date of Birth:**
4. **Designation & Affiliation**
5. **Postal Address**
6. **Phone Numbers**
7. **E-mail ID:**
8. **Qualifications**

S.No.	Degree	Institution	Year

9. **Employment Experience**

S.No.	Position and Organisation	Nature of Job	Period

10. **List of Publications**
    - 10.1. Journal Publications
    - 10.2. Conference Presentations
11. **Patents filed/granted with details**
12. **Books published /Chapters contributed**
13. **Sponsored Research Projects**

S. No	Title	Sponsoring Agency	Period	Amount *(Rupees in Lakhs)*	Achievements

14. Consultancy Projects

S. No	Title	Sponsoring Agency	Period	Amount *(Rupees in Lakhs)*

15. Sponsored Research/Consultancy Projects submitted for approval

S. No	Title	Agency to whom submitted	Duration	Date of Submission	Amount *(Rupees in Lakhs)*

16. Experience of Technology Development and Transfer (patent filed/granted), if any

3 Budget Estimates

	Item	1st Year		2nd Year		3rd Year		4th Year	
		DST	Partners	DST	Partners	DST	Partners	DST	Partners
1.	Manpower								
2.	Consumables								
3.	Contingency								
4.	Other Costs								
5.	Travel								
6.	Permanent Equipment								
7.	Overhead Charges								
	Total								

Total Project Budget =
Request for DST Grant=
Partners Contributions=

Research Manpower to be engaged in the project:

JRF (25,000+ HRA)	SRF (28,000+HRA)	RA-I (36,000+HRA)	RA-II (38,000+HRA)	RA-III (40,000+ HRA)

Norms for Manpower, Travel, Contingency & Overheads

Manpower

Nomenclature & Emoluments	Qualification
Junior Research Fellow (25,000 /- + HRA)	Post Graduate Degree in Basic Science with NET qualification or Graduate Degree in Professional course with NET qualification or Post Graduate Degree in Professional Course
Senior Research Fellow (28,000 /- + HRA)	Qualification prescribed for JRF with two years of research experience
Research Associate-I (36,000 /- + HRA)	Ph.D/ MD/ MS/ MDS or equivalent degree or having 3 years of research, teaching and design and development experience after MVSc/ M.Pharm/ ME/ M.Tech with at least one research paper in Science Citation lndexed (SCl) journal. The Research Associate Scale may be decided by the institute/ organization based on the experience of the candidate.
Research Associate-II (38,000 /- + HRA)	
Research Associate-III (40,000 /- + HRA)	

Travel & Contingency

50,000/- each per annum will be provided for Travel and Contingencies. Higher amount, based on the recommendations of the Expert Committee, to be provided where the research work involves field work or/and project has many investigators/institutions and larger manpower. The contingency amount may also be used for paying Registration Fees for attending international conferences.

Overheads

Overhead amount is towards meeting the cost of academic expenses including infrastructural facilities at the host institutes, and is permissible as given below: :

a) For projects costing upto 1 crore, 10% of the total cost for educational institutions and NGOs and 8% for

b) For projects costing more than 1 crore and upto 5 crore, overheads of 15 lakh or 10% of total cost whichever is less;

c) For projects costing more than 5 crore and upto 20 crore, 20 lakh will be provided as overheads; and

d) For projects costing more than 20 crore, the quantum will be decided on a case to case basis laboratories and institutions under Central Government Departments/Agencies;

Itemised Budget

a. Manpower

i. Budget for Salaries - DST Grant

Designation	Qualification	Salary per month	Number of Persons	Amount (in Lakhs)	Role Description

ii. Budget for Salaries - Partner Contribution

Designation	Qualification	Salary per month	Number of Persons	Amount (in Lakhs)	Justification

b. Consumables

i. Budget for Consumable Materials - DST Grant (in lakhs)

1st year	2nd year	3rd year	Total

ii. Budget for Consumable Materials (Partners Contribution) (in lakhs)

1st year	2nd year	3rd year	Total

c. Contingencies

i. Budget for Contingencies- DST (in lakhs)

1st year	2nd year	3rd year	Total

ii. Budget for Contingencies (Partners Contribution) (in lakhs)

1st year	2nd year	3rd year	Total

d. Budget for Other Costs-DST Grant (in lakhs)

i. Budget for Contingencies- DST (in lakhs)

Item	1st year	2nd year	3rd year	Total
Outsourcing				
Fabrication				
Testing				
Others				

ii. Budget for Other costs- Partners Contribution (in lakhs)

Item	1st year	2nd year	3rd year	Total
Outsourcing				
Fabrication				
Testing				
Others				

e. Domestic Travel – from – DST Grant (in lakhs)

1st year	2nd year	3rd year	Total

f. Budget for Other Costs-DST Grant (in lakhs)

i. Budget for Permanent Equipment – (DST Grant)

Description of Equipment	Foreign/ Indigenous	Unit Landed Cost (CIF, Custom Duty etc.)	Number of Items	Total (in lakhs)

ii. Budget for Permanent Equipment - Partner Contribution

Description of Equipment	Foreign/ Indigenous	Unit Landed Cost (CIF, Custom Duty etc.)	Number of Items	Total (in lakhs)

4 Undertaking from the Principal Investigator

Project Title:"Advancing Dental Scanning and Facial Structure Prediction using Machine Learning for Enhanced Orthodontic and Orthognathic Treatment "

1. I have carefully read the terms and conditions of the Technology Development Programme and I agree to abide by them.
2. I have not submitted this or a similar Project Proposal elsewhere for financial support.
3. I shall ensure that no item/equipment shown available in the Project Proposal from my Organisation, shall be purchased under the Project.
4. I undertake that idle capacity of the permanent equipment procured under the Project will be made available to other users.
5. I have enclosed the following :
    a. First item
    b. Second item
    c. Third item

Principal Investigator: Name

Signature

Date:

Place:

5 Endorsement from Head of the Organization

Project Title:"Advancing Dental Scanning and Facial Structure Prediction using Machine Learning for Enhanced Orthodontic and Orthognathic Treatment "

1. Affirmed that the Organisation welcomes the participation of Dr/Mr/Ms .....as the PI and Dr/Mr/Ms..... as the Co-PI for the Project and that in the unforeseen and legitimate event of discontinuation by the PI, the Co-PI will assume full responsibility for completion of the Project. Information to this effect, endorsed by me, will be promptly sent to DST

2. Affirmed that the equipment and basic as well as other administrative facilities as per the terms and conditions of the award of the Project, will be made available to the Investigator(s) throughout the duration of the Project

3. The Organisation shall ensure that the financial and purchase procedures are followed as per the prevailing norms of the Organisation, within the allocated budget.

4. The Organisation shall provide timely the Statement of Expenditure and the Utilisation Certificate of the Funds under the Grant as required by DST in the prescribed format.

(Head of Organisation)
Seal/Stamp

Date:
Place:

6 Endorsement from Collaborating Industry/ Agency, if any.

I have gone through the Project Proposal entitled..... submitted by ..... (Name of PI) of ..... (Name of the Organisation) for DST funding and noted the obligations and responsibilities indicated in our name as stated below:
Kindly be specific vis-à-vis your collaboration with the PI in terms of:

- Contribution in financial terms (Rupees in Lakhs)
- Contribution in kind (List activities)

I hereby affirm that my Organization/Industry is committed to participate in the Project to the full extent as indicated in the Project Proposal including the financial liabilities accruing there from as detailed above. A summary profile of my Organization is given below:

- Name of Organization
- Nature of Business
- Number of Employees
- Annual Turn over

(Head of Industry/Agency)
Seal/Stamp

Date:
Place:

7 POLICY ON CONFLICT OF INTEREST

DEPARTMENT OF SCIENCE AND TECHNOLOGY

FOR REVIEWER & COMMITTEE MEMBER or APPLICANT or DST OFFICER ASSOCIATED/ DEALING WITH THE SCHEME/ PROGRAM OF DST:

Issues of Conflicts of Interest and ethics in scientific research and research management have assumed greater prominence, given the larger share of Government funding in the country's R & D scenario. The following policy pertaining to general aspects of Conflicts of Interest and code of ethics, are objective measures that is intended to protect the integrity of the decision making processes and minimize biasness. The policy aims to sustain transparency, increase accountability in funding mechanisms and provide assurance to the general public that processes followed in award of grants are fair and non-discriminatory. The Policy aims to avoid all forms of bias by following a system that is fair, transparent and free from all influence/ unprejudiced dealings, prior to, during and subsequent to the currency of the programme to be entered into with a view to enable public to abstain from bribing or any corrupt practice in order to secure the award by providing assurance to them that their competitors will also refrain from bribing and other corrupt practice and the decision makers will commit to prevent corruption, in any form, by their officials by following transparent procedures. This will also ensure a global acceptance of the decision making process adopted by DST.

1 Definition of Conflict of Interest:

Conflict of Interest means "any interest which could significantly prejudice an individual's objectivity in the decision making process, thereby creating an unfair competitive advantage for the individual or to the organization which he/she represents". The Conflict of Interest also encompasses situations where an individual, in contravention to the accepted norms and ethics, could exploit his/her obligatory duties for personal benefits.

1.1 Coverage of the Policy:

- The provisions of the policy shall be followed by persons applying for and receiving funding from DST, Reviewers of the proposal and Members of Expert Committees and Programme Advisory Committees. The provisions of the policy will also be applicable on all individuals including Officers of DST connected directly or indirectly or through intermediaries and Committees involved in evaluation of proposals and subsequent decision making process.

- This policy aims to minimize aspects that may constitute actual Conflict of Interests, apparent Conflict of Interests and potential Conflict of Interests

in the funding mechanisms that are presently being operated by DST. The policy also aims to cover, although not limited to, Conflict of interests that are Financial (gains from the outcomes of the proposal or award), Personal (association of relative / Family members) and Institutional (Colleagues, Collaborators, Employer, persons associated in a professional career of an individual such as Ph.D. supervisor etc.)

1.2 Specifications as to what constitutes Conflict of Interest

Any of the following specifications (non-exhaustive list) imply Conflict of Interest if,

1. Due to any reason by which the Reviewer/Committee Member cannot deliver fair and objective assessment of the proposal.
2. The applicant is a directly relative# or family member (including but not limited to spouse, child, sibling, parent) or personal friend of the individual involved in the decision making process or alternatively, if any relative of an Officer directly involved in any decision making process / has influenced interest/ stake in the applicant's form etc.
3. The applicant for the grant/award is an employee or employer of an individual involved in the process as a Reviewer or Committee Member; or if the applicant to the grant/award has had an employer-employee relationship in the past three years with that individual.
4. The applicant to the grant/award belongs to the same Department as that of the Reviewer/Committee Member.
5. The Reviewer/Committee Member is a Head of an Organization from where the applicant is employed.
6. The Reviewer /Committee Member is or was, associated in the professional career of the applicant (such as Ph.D. supervisor, Mentor, present Collaborator etc.)
7. The Reviewer/Committee Member is involved in the preparation of the research proposal submitted by the applicant.
8. The applicant has joint research publications with the Reviewer/Committee Member in the last three years
9. The applicant/Reviewer/Committee Member, in contravention to the accepted norms and ethics followed in scientific research has a direct/indirect financial interest in the outcomes of the proposal.
10. The Reviewer/Committee Member stands to gain personally should the submitted proposal be accepted or rejected.

1.3 Regulation:

The DST shall strive to avoid conflict of interest in its funding mechanisms to the maximum extent possible. Self-regulatory mode is however recommended for stake holders involved in scientific research and research management, on issues pertaining to Conflict of Interest and Scientific Ethics. Any disclosure pertaining to the same must be made voluntarily by the applicant/Reviewer/Committee Member.

1.4 Confidentiality:

The Reviewers and the Members of the Committee shall safeguard the confidentiality of all discussions and decisions taken during the process and shall refrain from discussing the same with any applicant or a third party, unless the Committee recommends otherwise and records for doing so.

1.5 Code of Conduct

To be followed by Reviewers/Committee Members:

1. All reviewers shall submit a conflict of interest statement, declaring the presence or absence of any form of conflict of interest.
2. The reviewers shall refrain from evaluating the proposals if the conflict of interest is established or if it is apparent.
3. All discussions and decisions pertaining to conflict of interest shall be recorded in the minutes of the meeting.
4. The Chairman of the Committee shall decide on all aspects pertaining to conflict of interests.
5. The Chairman of the Committee shall request that all members disclose if they have any conflict of interest in the items of the agenda scheduled for discussion
6. The Committee Members shall refrain from participating in the decision making process and leave the room with respect to the specific item where the conflict of interest is established or is apparent.
7. If the Chairman himself/herself has conflict of interest, the Committee may choose a Chairman from among the remaining members, and the decision shall be made in consultation with Member Secretary of the Committee.
8. It is expected that a Committee member including the Chair-person will not seek funding from a Committee in which he/she is a member. If any member applies for grant, such proposals will be evaluated separately outside the Committee in which he/she is a member.

To be followed by the Applicant to the Grant/Award:

1. The applicant must refrain from suggesting referees with potential Conflict of Interest that may arise due to the factors mentioned in the specifications described above in Point No. 2.

2. The applicant may mention the names of individuals to whom the submitted proposal should not be sent for refereeing, clearly indicating the reasons for the same.

To be followed by the Officers dealing with Programs in DST: While it is mandatory for the program officers to maintain confidentiality as detailed in point no. 6 above, they should declare, in advance, if they are dealing with grant applications of a relative or family member (including but not limited to spouse, child, sibling, parent) or thesis/ post-doctoral mentor or stands to benefit financially if the applicant proposal is funded. In such cases, DST will allot the grant applications to the other program officer.

1.6 Sanction for violation

For Reviewers / Committee Members and Applicant
Any breach of the code of conduct will invite action as decided by the Committee.
For Officers dealing with Program in DST
Any breach of the code of conduct will invite action under present provision of CCS (conduct Rules), 1964.

1.7 Final Appellate authority:

Secretary, DST shall be the appellate authority in issues pertaining to conflict of interest and issues concerning the decision making process. The decision of Secretary, DST in these issues shall be final and binding.

1.8 Declaration

I have read the above "Policy on Conflict of Interest" of the DST applicable to the Reviewer/ Committee Member/ Applicant/ DST Scheme or Program Officer # and agree to abide by provisions thereof.
I hereby declare that I have no conflict of interest of any form pertaining to the proposed grant * I hereby declare that I have conflict of interest of any form pertaining to the proposed grant *

* & # (Tick whichever is applicable)
Name of the Reviewer/ Committee Member or Applicant or DST Officer

(Signature with Date)

8 Summary Sheet

SUMMARY

File No :	
Project Title:	
Principal Investigator Name & Address:	
Principal Investigator Name & Address:	Name: Designation: Address: Telephone No: E-mail : Date of Birth:
Collaborator /Participating Industry	
Project Budget:	
Duration:	
Project Manpower:	
Project Equipment: DST Share	
Innovative Element	• first • second • third
Objectives:	• first • second • third
Deliverables	• first • second • third

A Current Scenario

1 Financial Constraints

3D dental scanner price in India ranges between ₹12 lakh to ₹40 lakh or more, depending on the specifications and the brand [45].

2 Scanning Instruments

In India, dental professionals have access to a variety of scanning instruments such as 3Shape TRIOS, Planmeca Emerald, iTero Element, and Medit i500, etc. which are utilized for diverse purposes including digital impression taking, orthodontic analysis, prosthetic design, and more.

3 Dental patients in India

In India, about 85% to 90% of adults have dental cavities, along with about 60 to 80% of children. Also, around 30% of children have misaligned jaws and teeth [46]. For patients in India, the cost is a significant factor as dental treatments can be expensive. There is a prevalent fear and anxiety associated with dental visits due to past painful experiences or misconceptions about treatment discomfort. Additionally, the availability of dental facilities also plays an important role.

References

[1] H A Kiyak, T Hohl, R A West, and R W McNeill. Psychologic changes in orthognathic surgery patients: a 24-month follow up. *J. Oral Maxillofac. Surg.*, 42(8):506–512, August 1984. 5, 14

[2] Katja Wolff, Changil Kim, Henning Zimmer, Christopher Schroers, Mario Botsch, Olga Sorkine-Hornung, and Alexander Sorkine-Hornung. Point cloud noise and outlier removal for image-based 3D reconstruction. In *Proceedings of International Conference on 3D Vision (3DV)*, pages 118–127, 2016. 5

[3] Marie-Julie Rakotosaona, Vittorio La Barbera, Paul Guerrero, Niloy J. Mitra, and Maks Ovsjanikov. Pointcleannet: Learning to denoise and remove outliers from dense point clouds, 2019. 5

[4] Krishnendu Ghosh, Aupendu Kar, Saumik Bhattacharya, Debashis Sen, and Prabir Kumar Biswas. Multi-latent gan inversion for unsupervised 3d shape completion. In *2022 IEEE International Conference on Image Processing (ICIP)*, pages 3460–3464, 2022. 5

[5] Ben Fei, Weidong Yang, Wen-Ming Chen, Zhijun Li, Yikang Li, Tao Ma, Xing Hu, and Lipeng Ma. Comprehensive review of deep learning-based 3d point cloud completion processing and analysis. *IEEE Transactions on Intelligent Transportation Systems*, 23(12):22862–22883, dec 2022. 5, 7

[6] Chunfeng Lian, Li Wang, Tai-Hsien Wu, Fan Wang, Pew-Thian Yap, Ching-Chang Ko, and Dinggang Shen. Deep multi-scale mesh feature learning for automated labeling of raw dental surfaces from 3d intraoral scanners. *IEEE Transactions on Medical Imaging*, 39(7):2440–2450, July 2020. 5, 12

[7] Joanneke M Plooij, Thomas JJ Maal, Piet Haers, Wilfred A Borstlap, Anne Marie Kuijpers-Jagtman, and Stefaan J Bergé. Digital three-dimensional image fusion processes for planning and evaluating orthodontics and orthognathic surgery. a systematic review. *International journal of oral and maxillofacial surgery*, 40(4):341–352, 2011. 5

[8] Juan José Reyes Salgado. Design of open code software to downs and steiner lateral cephalometric analysis with tracing landmarks. *Digital*, 2(2):120–142, 2022. 6

[9] Jia–Liang Tian, Qin–Yan Zhang, Hai–Zhen Li, Qing Wang, Yi Lei, Lin Zang, Xue–Mei Gao, and Ji–Jiang Yang. Study of facial generation methods after orthodontic treatment. In *2022 IEEE 46th Annual Computers, Software, and Applications Conference (COMPSAC)*, pages 1006–1011, 2022. 6, 7

[10] Chihiro Tanikawa and Takashi Yamashiro. Development of novel artificial intelligence systems to predict facial morphology after orthognathic

surgery and orthodontic treatment in japanese patients. *Scientific Reports*, 11(1):15853, Aug 2021. 6

[11] Rutger Ter Horst, Hanneke van Weert, Tom Loonen, Stefaan Bergé, Shank Vinayahalingam, Frank Baan, Thomas Maal, Guido de Jong, and Tong Xi. Three-dimensional virtual planning in mandibular advancement surgery: Soft tissue prediction based on deep learning. *J. Craniomaxillofac. Surg.*, 49(9):775–782, September 2021. 6

[12] Xin Wang, Xiaoke Zhao, Guangying Song, Jianwei Niu, and Tianmin Xu. Machine learning-based evaluation on craniodentofacial morphological harmony of patients after orthodontic treatment. *Front. Physiol.*, 13:862847, May 2022. 7

[13] Ximing Yang, Yuan Wu, Kaiyi Zhang, and Cheng Jin. Cpcgan: A controllable 3d point cloud generative adversarial network with semantic label generating. *Proceedings of the AAAI Conference on Artificial Intelligence*, 35(4):3154–3162, May 2021. 7

[14] Junzhe Zhang, Xinyi Chen, Zhongang Cai, Liang Pan, Haiyu Zhao, Shuai Yi, Chai Kiat Yeo, Bo Dai, and Chen Change Loy. Unsupervised 3d shape completion through gan inversion, 2021. 7

[15] Xumin Yu, Yongming Rao, Ziyi Wang, Zuyan Liu, Jiwen Lu, and Jie Zhou. Pointr: Diverse point cloud completion with geometry-aware transformers, 2021. 11

[16] Xiaojie Xu, Chang Liu, and Youyi Zheng. 3D tooth segmentation and labeling using deep convolutional neural networks. *IEEE Trans. Vis. Comput. Graph.*, 25(7):2336–2348, July 2019. 12

[17] Jianda Zhang, Chunpeng Li, Qiang Song, Lin Gao, and Yu-Kun Lai. Automatic 3d tooth segmentation using convolutional neural networks in harmonic parameter space. *Graphical Models*, 109:101071, 2020. 12

[18] Farhad Ghazvinian Zanjani, David Anssari Moin, Bas Verheij, Frank Claessen, Teo Cherici, Tao Tan, and Peter H. N. de With. Deep learning approach to semantic segmentation in 3d point cloud intra-oral scans of teeth. In M. Jorge Cardoso, Aasa Feragen, Ben Glocker, Ender Konukoglu, Ipek Oguz, Gozde Unal, and Tom Vercauteren, editors, *Proceedings of The 2nd International Conference on Medical Imaging with Deep Learning*, volume 102 of *Proceedings of Machine Learning Research*, pages 557–571. PMLR, 08–10 Jul 2019. 12

[19] Yangyan Li, Rui Bu, Mingchao Sun, Wei Wu, Xinhan Di, and Baoquan Chen. Pointcnn: Convolution on $\mathcal{X}$-transformed points, 2018. 12

[20] Farhad Ghazvinian Zanjani, David Anssari Moin, Frank Claessen, Teo Cherici, Sarah Parinussa, Arash Pourtaherian, Svitlana Zinger, and Peter

H. N. de With. Mask-mcnet: Instance segmentation in 3d point cloud of intra-oral scans. In *International Conference on Medical Image Computing and Computer-Assisted Intervention*, 2019. 12

[21] Kaiming He, Georgia Gkioxari, Piotr Dollár, and Ross Girshick. Mask r-cnn, 2018. 12

[22] Yokesh Kumar, Ravi Janardan, and Brent Larson. Automatic feature identification in dental meshes. *Computer-Aided Design and Applications*, 9:747–769, 08 2013. 12

[23] Jun Zhang, Mingxia Liu, Li Wang, Si Chen, Peng Yuan, Jianfu Li, Steve Guo-Fang Shen, Zhen Tang, Ken-Chung Chen, James J. Xia, and Dinggang Shen. Context-guided fully convolutional networks for joint craniomaxillofacial bone segmentation and landmark digitization. *Medical Image Analysis*, 60:101621, 2020. 12

[24] Charles R. Qi, Hao Su, Kaichun Mo, and Leonidas J. Guibas. Pointnet: Deep learning on point sets for 3d classification and segmentation, 2017. 12

[25] Rosalia Maria Leonardi, Daniela Giordano, and Francesco Maiorana. An evaluation of cellular neural networks for the automatic identification of cephalometric landmarks on digital images. *Journal of Biomedicine and Biotechnology*, 2009, 2009. 12

[26] Jeong-Hoon Lee, Heejin Yu, Min ji Kim, Jin-Woo Kim, and Jongeun Choi. Automated cephalometric landmark detection with confidence regions using bayesian convolutional neural networks. *BMC Oral Health*, 20, 2020. 12

[27] Gururajaprasad K L Rao, Arvind Srinivasa, Yulita P Iskandar, and N. Mokhtar. Identification and analysis of photometric points on 2d facial images: a machine learning approach in orthodontics. *Health and Technology*, 9:1–10, 03 2019. 13

[28] James J Xia, Jaime Gateno, and John F Teichgraeber. Three-dimensional computer-aided surgical simulation for maxillofacial surgery. *Atlas Oral Maxillofac. Surg. Clin. North Am.*, 13(1):25–39, March 2005. 13

[29] Geoff Currie. Intelligent imaging: Anatomy of machine learning and deep learning. *Journal of Nuclear Medicine Technology*, 47(4):273–281, 2019. 13

[30] Jung-Gi Lee, Sanghee Jun, Young-Wook Cho, Hyunna Lee, Guk Bae Kim, Joon Beom Seo, and Namkug Kim. Deep learning in medical imaging: General overview. *Korean Journal of Radiology*, 18(4):570–584, Jul 2017. 13

[31] Claudia Lindner, Cheng-Wei Wang, Chien-Ting Huang, and et al. Fully automatic system for accurate localisation and analysis of cephalometric landmarks in lateral cephalograms. *Scientific Reports*, 6:33581, 2016. 13

[32] Fabian Kunz, Angelika Stellzig-Eisenhauer, Florian Zeman, and et al. Artificial intelligence in orthodontics. *Journal of Orofacial Orthopedics*, 81(1):52–68, 2020. 13

[33] Sheldon Baumrind and Roger C Frantz. The reliability of head film measurements. 1. landmark identification. *American Journal of Orthodontics*, 60(2):111–127, Aug 1971. 13

[34] Seung Min Lee, Hyung Pyo Kim, Kyuho Jeon, Sang Hyuk Lee, and Jin Keun Seo. Automatic 3d cephalometric annotation system using shadowed 2d image-based machine learning. *Physics in Medicine & Biology*, 64(5):055002, Feb 2019. 13

[35] Zhonghao Xu, Xinyu Tang, Hao Liu, Jun Han, Jianlong Fu, and Yizhou Yu. 3d dental mesh segmentation using deep cnn model. *Computer Methods in Biomechanics and Biomedical Engineering: Imaging & Visualization*, 7(6):634–642, 2019. 14

[36] John W Chen, Martin H Hobdell, Kim Dunn, Kim A Johnson, and Jian Zhang. Teledentistry and its use in dental education. *Journal of the American Dental Association*, 134(3):342–346, Mar 2003. 14

[37] Shahid R Aziz and Vincent B Ziccardi. Telemedicine using smartphones for oral and maxillofacial surgery consultation, communication, and treatment planning. *Journal of Oral and Maxillofacial Surgery*, 67(11):2505–2509, Nov 2009. 14

[38] Neal D Kravitz, Benjamin Burris, David Butler, and Charles W Dabney. Teledentistry, do-it-yourself orthodontics, and remote treatment monitoring. *Journal of Clinical Orthodontics*, 50(12):718–726, Dec 2016. 14

[39] R. Shane Morris, Lara N. Hoye, M. Hassan Elnagar, Phimon Atsawasuwan, Maria Therese Galang-Boquiren, Justin Caplin, Grace C. Viana, Ales Obrez, and Budi Kusnoto. Accuracy of dental monitoring 3d digital dental models using photograph and video mode. *American Journal of Orthodontics and Dentofacial Orthopedics*, 156(3):420–428, Sep 2019. 14

[40] Tero Karras, Samuli Laine, and Timo Aila. A style-based generator architecture for generative adversarial networks, 2019. 14

[41] Anahita Zarei, Mohamed A. El-Sharkawi, Michael Hairfield, and Gregory King. An intelligent system for prediction of orthodontic treatment outcome. *The 2006 IEEE International Joint Conference on Neural Network Proceedings*, pages 2702–2706, 2006. 14

[42] Wenhsuan Lu, Guangying Song, Qiannan Sun, Liying Peng, Yunfan Zhang, Yan Wei, Bing Han, and Jiuxiang Lin. Analysis of facial features and prediction of lip position in skeletal class III malocclusion adult patients undergoing surgical-orthodontic treatment. *Clin. Oral Investig.*, 25(9):5227–5238, September 2021. 14

[43] Stefan Zachow, Hans Lamecker, Barbara Elsholtz, and Michael Stiller. Reconstruction of mandibular dysplasia using a statistical 3d shape model. *International Congress Series*, 1281:1238–1243, 2005. CARS 2005: Computer Assisted Radiology and Surgery. 14

[44] Jia–Liang Tian, Qin–Yan Zhang, Hai–Zhen Li, Qing Wang, Yi Lei, Lin Zang, Xue–Mei Gao, and Ji–Jiang Yang. Study of facial generation methods after orthodontic treatment. In *2022 IEEE 46th Annual Computers, Software, and Applications Conference (COMPSAC)*, pages 1006–1011, 2022. 14

[45] Dental scanner. https://www.hospitalsstore.com/dental-scanner-price/. 31

[46] Issues of dental heath in india. https://borgenproject.org/issues-of-dental-health-in-india/. 31