Editorial

3D Imaging Advancements and New Technologies in Clinical and Scientific Dental and Orthodontic Fields

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The recent technological updates in medical field are irrevocably changing the clinical work-flow of dentists, from the diagnosis to the treatment plan approaches and decision-making activities. New available technologies permit the accomplishment of a comprehensive multidisciplinary approach to the rehabilitative treatments as well as enhance the effectiveness and efficiency of the therapy and streamline daily clinical workflow.

3D Imaging systems represent one of the pillars of this new era for dentistry and dental applications. In this regard, Cone-Beam Computed Tomography (CBCT) has represented a significant step forward in the diagnostic imaging protocols. 3D digital reproduction of maxillofacial anatomy from CBCT are used in the diagnosis and planning of therapy [1], surgery [2], dental implantology [3], and in the cranio-facial research field [4–12]. In addition, intra-oral scans and facial scans allow for reproduction, respectively, the dentoalveolar component and facial soft-tissue and to integrate these data with those obtained from CBCT, for a comprehensive “digitally-assisted” diagnosis and treatment plan [13–16].

The step further the usage of digital reconstruction of the anatomical structures is the possibility to edit and modify these files, following appropriate biological and anatomical principles and landmarks/references, in order to acquire useful information for the analysis of the morphology and for comparative pre- and post- treatment evaluation. This can be achieved by using software, borrowed from informatics engineering and based on sophisticated algorithms, that can perform the superimposition [17,18] of the anatomical digital files and the calculation of the surface distances. Such differences are visualized in a color-coded map which allows clinicians to distinguish area of disagreement between the two surfaces, representing the morphological differences or the changes induced by a specific therapy. Data differences can also be expressed in percentage of agreement between the two 3D rendered models. This technique is called deviation analysis and surface-to-surface matching [19,20].

Artificial Intelligence (AI) has been introduced with the aim to enhance diagnosis, therapy, prognosis, and patient monitoring [21]. Artificial intelligence (AI) is the capacity of a computer to accomplish tasks normally associated to humans. Hence, AI itself is a general term that defines the imitation of human intelligence. Computer vision is one of the most dominant types of AI which is already involved in digital technology used during our daily-life, sometimes without being aware of it [22]. Computer vision is based on replicating parts of the human visual system, allowing computers to identify and process entities in images and videos. Categorization, definition of areas, entity detection and identification represent the typical computer vision tasks of this system. The usage of computer vision is becoming widespread among clinicians to enhance diagnosis, monitoring the progression/regression of diseases, and set the appropriate treatment protocols [23]. To date, the most prevailing applications for computer vision in medical field are those related to radiology and imaging systems [24,25].

The latest innovations in 3D imaging and rapid prototyping (RP) procedures are significantly modifying the clinical workflow of dental and orthodontic specialists [26]. With the appropriate equipment, it is possible to improve the efficiency and the accuracy...
of dental manufactures production [27,28] such as dental models for fabricating dental aligners [29–32], occlusal and splints [33,34], bonding trays [35,36], positional guide for miniscrew insertion [37,38], on lays or veneers [15], etcetera. 3D printing is a manufacturing process involving stratification of materials to produce an object. It can be based on different material processing technologies, with the Vat-Polymerization system being the most popular for orthodontic and dental applications [39–41]. In the Vat-Polymerization system, the liquid resin is polymerized with exposure to a light source [6], and according to the light source employed, 3D printers are classified as stereolithography (SLA), digital light processing (DLP), and liquid crystal display based (LCD).

There are many options for dental 3D printers including cost-effective desktop models and industrial high throughput machines. The main advantages of 3D printing applications in dentistry are:

1. Better Fit to The Patient: 3D printers can create intricate structures and allow for greater geometric complexity without sacrificing production time. As 3D printed oral devices are more customizable, they are more accurate and better fit the patient without requiring extensive trimming and polishing.

2. Simplified Production Processes: Dentistry has long embraced digital manufacturing technologies to simplify production processes and workflows. Early developments with intraoral scanners allowed dentists to make and send oral impressions to a dental lab within minutes. Today’s 3D printers eliminate thermoforming. Clear aligners, retainers, nightguards, and other devices are directly 3D printed with minimal post-production. Dentists and lab technicians save time, labor, and material by eliminating models, thermoforming, and product trimming.

3. In-Office Printing: Dentists that integrate the 3D printing machines into their operations gain better control over workflow and minimize product turnaround time. Creating oral devices in-house saves money on lab fees and shipping costs while also enabling same-day patient services for specific devices.

Virtual reality is a interesting tool which to date has been under-utilized in dentistry. VR can be described as “a computer generated, three-dimensional world in which the user interacts with virtual objects” or characters [42,43], permitting the full combination of user’ cognitive, motor and mental functions. Virtual reality technology can be generally categorized into immersive virtual reality and non-immersive virtual reality. Both these two categories of VR can be applied in dentistry field, with immersive virtual reality being used as a distraction tool for patients during procedures, while non-immersive virtual reality being used for surgical or clinical procedure simulations [44].

Concerning patients’ experience, VR supports the children’s’ confidence and reiterates their ability to face complex or challenging situations. This would lead subjects experience to the next dental visit with less anxiety.

Concerning doctors’ experience, the aim of VR is to provide a consistent and secure platform for the analysis of different anatomical areas for diagnosis, planning and for the surgical training [45]. In this regard, Augmented Reality is the new frontier of “near reality” that integrate virtual reality with a 3D real environment specific for each patient. This occurs through sophisticated registration process which augments the virtual scene with the reality. The integrated image is superimposed on the real environment using semi-transparent glass [46]. This system is particularly interesting for surgical training since the 3D reconstruction of the several tissues provides a realistic platform to work with.

Pain management and patients’ clinical experience represents two other pillars of the new era of dentistry. In this regard, low-level laser therapy is a treatment with no adverse effects that has many functions in medicine and dental practice [47]. It is based on a low-powered laser light source within the red to near-infrared range (wavelengths from 632 to 1064 nm) to induce biological reactions. LLLT has been found to effective in favoring pain reduction after wound healing and during orthodontic treatment [45,47–49].

Another approach for pain management is Kinesio Taping (KT). This technique was conceived by Kenzo Kase in Japan in 2003 [50], and it is based on the administration of Kinesio
Tapes—thin, waterproof, adhesive, elastic tapes. The use of KT provokes the activation of mechanoreceptors, by pressuring and stretching the skin, and enhances blood and lymph circulation by pulling the subcutaneous tissue and skin from the muscles [50–58]. The effectiveness of KT remarkably reduces after 24 h. Kinesio Taping (KT) was found to moderate the gravity of complications after third molar extractions. Recent evidences would suggest that this method could reduce the pain after tooth extraction and trismus and could reduce the dimension of facial edema.

In general, technologies applied to dentistry are in a continuous updating process. Specific editorial initiatives, aiming to collect the best scientific evidence on this topic, are warmly encouraged to allow readers/clinicians to keep up with significant advancements in this topic.

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**References**

1. Almaqrami, B.S.; Alhammadi, M.S.; Cao, B. Three-dimensional reliability analyses of currently used methods for assessment of sagittal jaw discrepancy. J. Clin Exp. Dent. 2018, 10, e352–e360. [CrossRef] [PubMed]
2. Pelo, S.; Correra, P.; Gasparini, G.; Marianetti, T.M.; Cervelli, D.; Grippaudo, C.; Boniello, R.; Azzuni, C.; Deli, R.; Moro, A. Three-dimensional analysis and treatment planning of hemimandibular hyperplasia. J. Craniofac. Surg. 2011, 22, 2227–2234. [CrossRef] [PubMed]
3. Fourie, Z.; Damstra, J.; Schepers, R.H.; Gerrits, P.O.; Ren, Y. Segmentation process significantly influences the accuracy of 3D surface models derived from cone beam computed tomography. Eur. J. Radiol. 2012, 81, e524–e530. [CrossRef]
4. Lagravere, M.O.; Hansen, L.; Harzer, W.; Major, P.W. Plane orientation for standardization in 3-dimensional cephalometric analysis with computerized tomography imaging. Am. J. Orthod. Dentofacial. Orthop. 2006, 129, 601–604. [CrossRef]
5. Leonardi, R.; Muraglie, S.; Lo Giudice, A.; Aboulazm, K.S.; Nucera, R. Evaluation of mandibular symmetry and morphology in adult patients with unilateral posterior crossbite: A CBCT study using a surface-to-surface matching technique. Eur. J. Orthod. 2020, 42, 650–657. [CrossRef]
6. Lo Giudice, A.; Rustico, L.; Caprioglio, A.; Migliorati, M.; Nucera, R. Evaluation of condylar cortical bone thickness in patient groups with different vertical facial dimensions using cone-beam computed tomography. Odontology 2020, 108, 669–675. [CrossRef] [PubMed]
7. Fischer, B.; Masucci, C.; Ruellas, A.; Cevidanes, L.; Giuntini, V.; Nieri, M.; Nardi, C.; Franchi, L.; McNamara, J.A., Jr.; Defraia, E. Three-dimensional evaluation of the maxillary effects of two orthopaedic protocols for the treatment of Class III malocclusion: A prospective study. Orthod. Craniofac. Res. 2018, 21, 248–257. [CrossRef]
8. Lo Giudice, A.; Caccianiga, G.; Crimi, S.; Cavallini, C.; Leonardi, R. Frequency and type of ponticulus posticus in a longitudinal sample of nonorthodontically treated patients: Relationship with gender, age, skeletal maturity, and skeletal malocclusion. Oral Surg. Oral Med. Oral Pathol. Oral Radiol. 2018, 126, 291–297. [CrossRef]
9. Leonardi, R.; Farella, M.; Cobourne, M.T. An association between sella turcica bridging and dental transposition. Eur. J. Orthod. 2011, 33, 461–465. [CrossRef] [PubMed]
10. Perillo, L.; Isola, G.; Esercizio, D.; Iovane, M.; Triolo, G.; Matarrese, G. Differences in craniofacial characteristics in Southern Italian children from Naples: A retrospective study by cephalometric analysis. Eur. J. Paediatr. Dent. 2013, 14, 195–198.
11. Leonardi, R.; Loreto, C.; Talic, N.; Caltabiano, R.; Musumeci, G. Immunolocalization of lubricin in the rat periodontal ligament during experimental tooth movement. Acta Histochim. 2012, 114, 700–704. [CrossRef]
12. Perillo, L.; Padrinelli, G.; Isola, G.; Femiano, F.; Chiodini, P.; Matarrese, G. Class II malocclusion division 1: A new classification method by cephalometric analysis. Eur. J. Paediatr. Dent. 2012, 13, 192–196. [PubMed]
13. Revilla-León, M.; Zandinejad, A.; Nair, M.K.; Barmak, B.A.; Feilzer, A.J.; Özcan, M. Accuracy of a patient 3-dimensional virtual representation obtained from the superimposition of facial and intraoral scans guided by extraoral and intraoral scan body systems. J. Prostheth. Dent. 2021, in press. [CrossRef] [PubMed]
14. Vandenberghhe, B. The digital patient—Imaging science in dentistry. J. Dent. 2018, 74 (Suppl. 1), S21–S26. [CrossRef]
15. Lo Giudice, A.; Ortensi, L.; Farronato, M.; Lucchese, A.; Lo Castro, E.; Isola, G. The step further smile virtual planning: Milled versus prototyped mock-ups for the evaluation of the designed smile characteristics. BMC Oral Health 2020, 20, 165. [CrossRef]
16. Lo Giudice, A.; Ronisville, V.; Lagravere, M.; Leonardi, R.; Martina, S.; Isola, G. Transverse dentoalveolar response of mandibular arch after rapid maxillary expansion (RME) with tooth-borne and bone-borne appliances: A CBCT retrospective study. Angle Orthod. 2020, 90, 680–687. [CrossRef] [PubMed]
17. Leonardi, R.; Aboulazm, K.; Lo Giudice, A.; Ronsivalle, V.; D’Antò, V.; Lagravère, M.; Isola, G. Evaluation of mandibular changes after rapid maxillary expansion: A CBCT study in youngsters with unilateral posterior crossbite using a surface-to-surface matching technique. Clin. Oral Investig. 2021, 25, 1775–1785. [CrossRef]

18. Pan, Y.; Wang, X.; Dai, F.; Chen, G.; Xu, T. Accuracy and reliability of maxillary digital model (MDM) superimposition in evaluating teeth movement in adults compared with CBCT maxillary superimposition. Sci. Rep. 2020, 9, 19384. [CrossRef]

19. Leonardi, R.; Muraglia, S.; Crimi, S.; Pirroni, M.; Musumeci, G.; Perrotta, R. Morphology of palatally displaced canines and adjacent teeth, a 3-D evaluation from cone-beam computed tomographic images. BMC Oral Health 2018, 18, 156. [CrossRef]

20. Lo Giudice, A.; Leonardi, R.; Ronsivalle, V.; Allegrini, S.; Lagravère, M.; Marzo, G.; Isola, G. Evaluation of pulp cavity/chamber changes after tooth-borne and bone-borne rapid maxillary expansion. A CBCT study using surface-based superimposition and deviation analysis. Clin. Oral Investig. 2020, 25, 2237–2247. [CrossRef]

21. Schwendicke, F.; Samek, W.; Krois, J. Artificial Intelligence in Dentistry: Chances and Challenges. J. Clin. Med. 2022, 11, 2200. [CrossRef]

22. D’Antoni, F.; Russo, F.; Ambrosio, L.; Vollero, L.; Vadala, G.; Merone, M.; Papalia, R.; Denaro, V. Artificial Intelligence and Computer Vision in Low Back Pain: A Systematic Review. Int. J. Environ. Res. Public Health 2021, 18, 10909. [CrossRef]

23. Leonardi, R.; Lo Giudice, A.; Farronato, M.; Ronsivalle, V.; Allegrini, S.; Musumeci, G.; Spampinato, C. Fully automatic segmentation of sinonasal cavity and pharyngeal airway based on convolutional neural networks. Am. J. Orthod. Dentofacial. Orthop. 2021, 159, 824–835.e1. [CrossRef] [PubMed]

24. Hosny, A.; Parmar, C.; Quackenbush, J.; Schwartz, L.H.; Aerts, H.J.W.L. Artificial intelligence in radiology. Nat. Rev. Cancer 2018, 18, 500–510. [CrossRef] [PubMed]

25. Lo Giudice, A.; Ronsivalle, V.; Spampinato, C.; Leonardi, R. Fully Automatic Segmentation Of The Mandible Based On Convolutional Neural Networks (CNNs). Orthod. Craniofac. Res. 2021, 24, 100–107. [CrossRef] [PubMed]

26. Wesemann, C.; Muallah, J.; Mah, J.; Bumann, A. Accuracy and efficiency of full-arch digitalization and 3D printing: A comparison between desktop model scanners, an intraoral scanner, a CBCT model scan, and stereolithographic 3D printing. Quintessence Int. 2017, 48, 41–50.

27. Stansbury, J.W.; Idacavage, M.J. 3D printing with polymers: Challenges among expanding options and opportunities. Dent. Mater. 2016, 32, 54–64. [CrossRef]

28. Moser, N.; Santander, P.; Quast, A. From 3D imaging to 3D printing in dentistry—A practical guide. Int. J. Comput. Dent. 2018, 21, 345–356.

29. De Felice, M.E.; Nucci, L.; Fiori, A.; Flore-Mir, C.; Perillo, L.; Grassia, V. Accuracy of interproximal enamel reduction during clear aligner treatment. Prog. Orthod. 2020, 21, 28. [CrossRef]

30. Jindal, P.; Juneja, M.; Siena, F.L.; Bajaj, D.; Breeden, P. Mechanical and geometric properties of thermoformed and 3D printed clear dental aligners. Am. J. Orthod. Dentofacial. Orthop. 2019, 156, 694–701. [CrossRef]

31. Caccianiga, G.; Crestale, C.; Cozzani, M.; Piras, A.; Mutinelli, S.; Lo Giudice, A.; Cordasco, G. Low-level laser therapy and invisible removal aligners. J. Biol. Regul. Homeost. Agents 2016, 30 (Suppl. 1), 107–113. [PubMed]

32. Lo Giudice, A.; Ronsivalle, V.; Rustico, L.; Aboulazm, K.; Isola, G.; Palazzo, G. Evaluation of the accuracy of orthodontic models prototyped with entry-level LCD-based 3D printers: A study using surface-based superimposition and deviation analysis. Clin. Oral Investig. 2022, 26, 303–312. [CrossRef]

33. Marcel, R.; Reinhard, H.; Andreas, K. Accuracy of CAD/CAM-fabricated bite splints: Milling vs 3D printing. Clin. Oral Investig. 2020, 24, 4607–4615. [CrossRef] [PubMed]

34. Caminetti, M.; Lou, T. Clear Aligner Orthognathic Splints. J. Oral Maxillofac. Surg. 2019, 77, 1071.e1–1071.e8. [CrossRef] [PubMed]

35. Ciuffolo, F.; Epifania, E.; Duranti, G.; De Luca, V.; Raviglia, D.; Rezza, S.; Festa, F. Rapid prototyping: A new method of preparing trays for indirect bonding. Am. J. Orthod. Dentofacial. Orthop. 2006, 129, 75–77. [CrossRef]

36. Lo Giudice, G.; Lo Giudice, A.; Isola, G.; Fabiano, F.; Artemisia, A.; Fabiano, V.; Nucera, R.; Matarese, G. Evaluation of bond strength and detachment interface distribution of different bracket base designs. Acta Med. Mediterr. 2015, 31, 585.

37. Lo Giudice, A.; Quinzi, V.; Ronsivalle, V.; Martina, S.; Bennici, O.; Isola, G. Description of a Digital Work-Flow for CBCT-Guided Construction of Micro-Implant Supported Maxillary Skeletal Expander. Materials 2020, 12, 1815. [CrossRef]

38. Suzuki, E.H.; Suzuki, B. Accuracy of miniscrew implant placement with a 3-dimensional surgical guide. J. Oral Maxillofac. Surg. 2008, 66, 1245–1252. [CrossRef] [PubMed]

39. Favero, C.S.; English, D.; Cozad, B.E.; Wirthlin, J.O.; Short, M.M.; Kasper, F.K. Effect of print layer height and printer type on the accuracy of 3-dimensional printed orthodontic models. Am. J. Orthod. Dentofacial. Orthop. 2017, 152, 557–565. [CrossRef]

40. Zhang, Z.C.; Li, P.L.; Chu, F.T.; Shen, G. Influence of the three-dimensional printing technique and printing layer thickness on model accuracy. J. Orofac. Orthop. 2019, 80, 194–204. [CrossRef]

41. Lo Giudice, A.; Ronsivalle, V.; Grippaudo, C.; Lucchese, A.; Muraglia, S.; Lagravère, M.O.; Isola, G. One Step before 3D Printing-Evaluation of Imaging Software Accuracy for 3-Dimensional Analysis of the Mandible: A Comparative Study Using a Surface-to-Surface Matching Technique. Materials 2020, 13, 2798. [CrossRef] [PubMed]

42. Ayoub, A.; Pulijala, Y. The application of virtual reality and augmented reality in Oral & Maxillofacial Surgery. BMC Oral Health 2019, 19, 238.

43. Kim, Y.; Kim, H.; Kim, Y.O. Virtual reality and augmented reality in plastic surgery: A review. Arch. Plast. Surg. 2017, 44, 179–187. [CrossRef] [PubMed]
44. Serrano, C.M.; Wesselink, P.M.; Vervoorn, J.M. First experiences with patient-centered training in virtual reality. *J. Dent. Educ.* 2020, *84*, 607–614. [CrossRef]

45. Leonardi, R.; Ronisvalli, V.; Lagravere, M.O.; Barbato, E.; Isola, G.; Lo Giudice, A. Three-dimensional assessment of the sphenocipital synchondrosis and clivus after tooth-borne and bone-borne rapid maxillary expansion. *Angle Orthod.* 2021, *91*, 822–829. [CrossRef] [PubMed]

46. Bartella, A.K.; Kamal, M.; Scholl, I.; Steegmann, J.; Ketelsen, D.; Holzle, F.; Lethaus, B. Virtual reality in preoperative imaging in maxillofacial surgery: Implementation of “the next level”. *Br. J. Oral Maxillofac. Surg.* 2019, *57*, 644–648. [CrossRef]

47. Sousa, M.V.; Pinzan, A.; Consolaro, A.; Henriques, J.F.; de Freitas, M.R. Systematic literature review: Influence of low-level laser on orthodontic movement and pain control in humans. *Photomed. Laser Surg.* 2014, *32*, 592–599. [CrossRef] [PubMed]

48. Bartella, A.K.; Kamal, M.; Scholl, I.; Steegmann, J.; Ketelsen, D.; Holzle, F.; Lethaus, B. Virtual reality in preoperative imaging in maxillofacial surgery: Implementation of “the next level”. *Br. J. Oral Maxillofac. Surg.* 2019, *57*, 644–648. [CrossRef]

49. Lo Giudice, A.; Galletti, C.; Gay-Escoda, C.; Leonardi, R. CBCT assessment of radicular volume loss after rapid maxillary expansion: A systematic review. *Lasers Med. Sci.* 2017, *32*, 953–963. [CrossRef]

50. Caccianiga, G.; Pausco, A.; Perillo, L.; Nucera, R.; Pinsino, A.; Maddalone, M.; Cordasco, G.; Lo Giudice, A. Does low-level laser therapy enhance the efficiency of orthodontic dental alignment? Results from a randomized pilot study. *Photomed. Laser Surg.* 2017, *35*, 421–426. [CrossRef]

51. Lietz-Kijak, D.; Kopacz, L.; Ardan, R.; Grzegocka, M.; Kijak, E. Assessment of the Short-Term Effectiveness of Kinesiotaping and Trigger Points Release Used in Functional Disorders of the Masticatory Muscles. *Pain Res. Manag.* 2018, *10*, 546985. [CrossRef] [PubMed]

52. Lo Giudice, A.; Galletti, C.; Gay-Escoda, C.; Leonardi, R. CBCT assessment of radicular volume loss after rapid maxillary expansion: A systematic review. *J. Clin. Exp. Dent.* 2018, *10*, e484–e494. [CrossRef]

53. Cutroneo, G.; Piancino, M.G.; Ramieri, G.; Bracco, P.; Vita, G.; Isola, G.; Vermiglio, G.; Favaloro, A.; Anastasi, G.; Trimarchi, F. Expression of muscle-specific integrins in masseter muscle fibers during malocclusion disease. *Int. J. Mol. Med.* 2012, *30*, 235–242. [CrossRef] [PubMed]

54. Lo Giudice, A.; Brewer, I.; Leonardi, R.; Roberts, N.; Bagnato, G. Pain threshold and temporomandibular function in systemic sclerosis: Comparison with psoriatic arthritis. *Clin. Rheumatol.* 2018, *37*, 1861–1867. [CrossRef] [PubMed]

55. Leonardi, R.; Lo Muzio, L.; Bernasconi, G.; Caltabiano, C.; Piacentini, C.; Caltabiano, M. Expression of vascular endothelial growth factor in human dysfunctional temporomandibular joint disc. *Arch. Oral Biol.* 2003, *48*, 185–192. [CrossRef]

56. Isola, G.; Ramaglia, L.; Cordasco, G.; Lucchesi, A.; Fiorillo, L.; Matarese, G. The effect of a functional appliance in the management of temporomandibular joint disorders in patients with juvenile idiopathic arthritis. *Minerva Stomatol.* 2017, *66*, 1–8. [CrossRef]

57. Leonardi, R.; Almeida, L.E.; Trevilatto, P.C.; Loreto, C. Occurrence and regional distribution of TRAIL and DR5 on temporomandibular joint discs: Comparison of disc derangement with and without reduction. *Oral Surg. Oral Med. Oral Pathol. Oral Radiol. Endodontol.* 2010, *109*, 244–251. [CrossRef]

58. Marra, P.; Nucci, L.; Abdolreza, J.; Perillo, L.; Itro, A.; Grassia, V. Odontoma in a young and anxious patient associated with unerupted permanent mandibular cuspid: A case report. *J. Int. Oral Health* 2020, *12*, 182–186. [CrossRef]