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VISUALIZING HEALTH: THE SIGNIFICANCE OF MEDICAL IMAGING AND HUMAN FACTORS

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Abstract This article delves into the dynamic interplay reshaping diagnostic precision, treatment efficacy, and patient-centered care through the integration of medical imaging, human factors, and additive technologies in healthcare. Beginning with a theoretical exploration of medical imaging modalities such as CT, MRI, and USG, it highlights their indispensable role in diagnosis and treatment planning, offering clinicians detailed anatomical insights and superior diagnostic accuracy. The article meticulously examines how human factors contribute to optimizing healthcare delivery, emphasizing the imperative of ergonomic designs and enhanced usability to ensure seamless integration of medical technologies into clinical practice. Transitioning from theory to practice, the article illustrates practical examples, particularly in dentistry, where additive technologies like digitalization and computer numerical control (CNC) enhance treatment modalities. By fabricating precise dental restorations and prosthetics, these technologies offer personalized solutions tailored to individual patient needs. Through interdisciplinary collaboration, clinicians, engineers, and researchers forge novel pathways, leveraging technological advancements to redefine standards of healthcare excellence. This convergence envisions a future where precision, efficiency, and patient-centricity elevate the quality of care and outcomes for patients worldwide.

Keywords: CT; CNC; digitalization; dentistry; healthcare; human factors; medical imaging.

1. INTRODUCTION

In the modern healthcare, the convergence of medical imaging, human factors, and additive technologies represents a special moment in reshaping diagnostic accuracy, treatment efficacy, and patient-centered care [1-16]. As these domains intersect, they present opportunities for innovation that promise to redefine the standards of healthcare delivery.

1.1. Computed Tomography (CT), Magnetic Resonance Imaging (MRI) and Ultrasound (USG)

At the core of this convergence lies medical imaging, an essential tool empowering healthcare professionals with unparalleled insights into the complexities of human anatomy. From the detailed images produced by Computed Tomography (CT) scans to the precise visualization provided by Magnetic Resonance Imaging (MRI) and the real-time monitoring enabled by Ultrasound (USG), medical imaging facilitates accurate diagnosis and targeted treatment strategies [17-22] In details:

- *Computed Tomography (CT):* Using X-ray technology and advanced computer algorithms, computed tomography (CT) scanners produce cross-sectional images of the body to aid in the diagnosis and management of a wide range of medical conditions in a variety of specialties. In dentistry, CT imaging plays a vital role in maxillofacial evaluations, providing comprehensive views of the jaw, teeth and surrounding tissues. CT enables precise planning for the placement of dental implants, assessment of bone density and identification of oral pathologies, improving

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treatment outcomes and patient care. In orthopaedics, CT scans provide invaluable information for assessing bone fractures, joint integrity and musculoskeletal abnormalities [23-25].

- *Magnetic Resonance Imaging (MRI):* MRI is a non-invasive and versatile imaging modality that is widely used across medical specialties for its ability to provide detailed anatomical and functional information. Using powerful magnetic fields and radiofrequency pulses, MRI scanners produce high-resolution images of soft tissues, organs and joints with exceptional contrast and clarity. In dentistry, MRI plays a limited but important role in the evaluation of temporomandibular joint (TMJ) disorders, providing valuable insight into joint morphology, disc displacement and surrounding soft tissues. In orthopaedics, MRI is used to assess musculoskeletal conditions, providing detailed visualisation of ligaments, tendons, cartilage and bone, facilitating accurate diagnosis and treatment [26-28].
- *Ultrasound (US):* US, commonly referred to as sonography, serves as a non-invasive imaging modality that is used across medical disciplines due to its versatility and safety profile. By emitting high-frequency sound waves and capturing their reflections, ultrasound machines produce real-time images of internal organs, tissues and structures to aid in diagnostic evaluation and treatment planning. In dentistry, although less commonly used than other modalities, ultrasound is used to assess soft tissue abnormalities, helping to diagnose conditions such as salivary gland disorders or cysts. In orthopaedics, ultrasound assists in the assessment of soft tissue injuries, tendon abnormalities and joint effusions, and provides real-time guidance during procedures such as injections or aspirations [29-31].

1.2. Medical Imaging and Human Factors

Medical imaging, coupled with considerations of human factors, epitomizes a symbiotic relationship essential to modern healthcare delivery. Medical imaging technologies, such as Computed Tomography (CT), Magnetic Resonance Imaging (MRI), and Ultrasound (USG), harness X-ray, magnetic, and sound wave technologies, respectively, to provide detailed diagnostic insights across various medical specialties. These modalities enable precise diagnosis, treatment planning, and intervention. However, the integration of human factors, including ergonomic design and enhanced usability, ensures that medical imaging technologies seamlessly align with clinical workflows, optimizing efficiency, and reducing errors. The collaboration between healthcare professionals and engineers underscores the significance of ergonomics and usability in medical device design, fostering patient safety and enhancing the quality of care. In essence, the amalgamation of medical imaging and human factors embodies a holistic approach to healthcare, prioritizing patient-centricity and interdisciplinary collaboration in pursuit of optimal healthcare outcomes. Medical imaging and human factors collaborating with:

- *CT in dentistry*: In dentistry, CT imaging provides comprehensive views of the jaw, teeth and surrounding tissues. This capability allows dentists to assess the anatomy of the oral cavity in unparalleled detail, facilitating precise treatment planning and intervention. CT imaging is particularly useful in the placement of dental implants, allowing dentists to assess bone density and quality at potential implant sites. By visualising the jawbone in three dimensions, dentists can determine the optimal location and angle for implant placement, improving treatment outcomes and patient care. CT scans in dentistry help identify oral pathologies such as cysts, tumours and infections, enabling early diagnosis and appropriate management strategies. In terms of human factors and healthcare delivery, the integration of CT technology into dental practice underscores the importance of ergonomic design and enhanced usability. Dentists and healthcare professionals work together to ensure that CT scanners fit seamlessly into clinical workflows, optimising efficiency and minimising errors. As part of multidisciplinary care, CT imaging contributes to the

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holistic management of patients, providing valuable insights into oral health and facilitating interdisciplinary collaboration between dentists and other healthcare professionals [32-34].

- *CT in orthopedics:* In orthopedics, the integration of computed tomography (CT) imaging has been a significant advance, enabling precise assessment of bone fractures, joint integrity and musculoskeletal abnormalities. Using X-ray technology and sophisticated algorithms, CT technology provides detailed cross-sectional images that are essential for accurate diagnosis and treatment planning in orthopedic practice. Orthopedic surgeons rely on CT scans to assess the extent and location of bone fractures, facilitating tailored treatment strategies for optimal patient outcomes. CT imaging provides critical insight into joint integrity, helping to assess ligament and tendon injuries, cartilage defects and degenerative joint disease. Incorporating human factors into orthopedic CT imaging underscores the importance of ergonomic design and usability, ensuring seamless integration into clinical workflows and improving patient care. With collaboration between orthopedic specialists and healthcare professionals, CT technology optimises treatment efficacy and safety, reflecting a commitment to interdisciplinary care and excellence in orthopedic practice [35-37].
- *MRI in dentistry:* In dentistry, the combination of magnetic resonance imaging (MRI) and human factors is driving diagnostic precision and patient-centred care. MRI technology, which uses powerful magnetic fields and radiofrequency pulses, provides detailed anatomical and functional insights critical for comprehensive dental assessments. Dentists use MRI imaging to evaluate temporomandibular joint (TMJ) disorders, providing invaluable insight into joint morphology and soft tissue structures. MRI facilitates accurate diagnosis and treatment planning for TMJ disorders, guiding tailored interventions for optimal patient outcomes. In addition, MRI imaging assists in the evaluation of oral and maxillofacial pathology, enabling early detection and appropriate management strategies for conditions such as cysts, tumours and infections [38, 39].
- *MRI in orthopedics:* MRI technology, harnessing powerful magnetic fields and radiofrequency pulses, offers detailed anatomical and functional insights essential for orthopedic evaluations. Orthopedic surgeons leverage MRI imaging to assess musculoskeletal conditions, including ligament and tendon injuries, cartilage defects, and degenerative joint diseases. MRI imaging provides critical information regarding bone and soft tissue pathology, enabling early detection and appropriate management strategies. The integration of human factors into MRI technology underscores the importance of ergonomic design and usability, ensuring seamless integration into orthopedic workflows and enhancing patient safety [40, 41].
- *USG in dentistry:* USG technology provides real-time visualization of internal organs, tissues and structures critical to dental evaluations. Dentists use USG imaging to assess various oral conditions, including soft tissue abnormalities and structural anomalies, facilitating precise treatment planning and intervention. The integration of human factors into USG technology underscores the importance of ergonomic design and usability, ensuring seamless integration into the dental workflow while enhancing patient safety. In collaboration with dental and allied health professionals, USG technology supports diagnostic accuracy and promotes interdisciplinary collaboration, heralding advances in dentistry [42, 43].
- *USG in orthopedics:* By high-frequency sound waves and their reflections, USG technology provides real-time insights into internal musculoskeletal structures critical to orthopedic assessments. Orthopedic specialists use USG imaging to evaluate various conditions, including soft tissue injuries, tendon irregularities, and joint effusions, and to guide meticulous treatment planning and interventions. USG serves as a guide for orthopedic procedures such as injections and aspirations, improving procedural accuracy and patient outcomes. In addition, USG facilitates early detection of musculoskeletal pathologies, enabling timely intervention and strategic management. The infusion of human factors into USG technology underscores ensuring seamless integration into orthopedic workflows while enhancing patient safety [44, 45].

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1.3. Additive and Advanced Technologies

Additive technologies further contribute to healthcare innovation, offering personalized solutions tailored to individual patient needs. From dental reconstruction using digitalization and computer numerical control (CNC) to regenerative medicine advancements through 3D printing and bioprinting, additive technologies drive advancements in patient care. Interdisciplinary collaboration is the optimal key to progress. Clinicians, engineers, and researchers unite to forge new pathways toward enhanced healthcare delivery. Together, they navigate the complexities of medical innovation, shaping a future where precision, efficiency, and patient-centric care are with high importance [46-51].

1.4. Significance of Medical Imaging and Human Factors in Academy and Science

The integration of medical imaging and human factors holds significant importance in academia and science, as evidenced by projects like the ErgoDesign initiative. This project, led by an international consortium including institutions such as Poznan University of Technology, Technical University of Varna, Óbuda University, National Technical University of Athens, Technická Univerzita v Košiciach, and ValueDo in Italy, highlights the crucial role of advanced technologies and anatomical understanding in inclusive healthcare [52-54]. With substantive partners including universities and organizations across Europe, the ErgoDesign project aims to enhance digital skills for ergonomics and bioengineering innovations, thereby improving healthcare accessibility and effectiveness. By fostering interdisciplinary collaboration and leveraging the insights from medical imaging and human factors, initiatives like ErgoDesign contribute to the advancement and dissemination of knowledge in the fields of ergonomics and healthcare innovation on a global scale.

2. IMPLEMENTATION OF MEDICAL IMAGING AND HUMAN FACTORS IN REAL PRACTICE (DENTISTRY EXAMPLE)

The implementation of medical imaging and human factors in real dental practice involves several sequential steps that seamlessly integrate advanced technology and precision craftsmanship (Figures 1-5 [55]). It begins with the acquisition of a CT scan of the patient's jaw, providing detailed three-dimensional images of the dental anatomy, including bones, teeth, and surrounding tissues. Subsequently, a 3D intraoral scanner captures precise digital impressions of the patient's teeth and gums, ensuring accurate representation of the intraoral environment. The digital data from the CT scan and intraoral scanner is then imported into specialized software for designing the construction of the 3D model, allowing dental professionals to plan the placement of dental implants and design custom restorations. Once the digital design is finalized, the data is transferred to a computer numerical control (CNC) machine, which precisely carves out the physical dentistry model from a block of material, such as resin or ceramic, based on the digital specifications. The individual components of the dental model, including the jaw, implants, and teeth, are then assembled to ensure proper fit and alignment, allowing for adjustments to be made before proceeding to the final stages of production. Hand painting may be employed to simulate natural tooth colors and textures, enhancing the model's realism and aesthetic appeal, followed by polishing with specialized pastes to smooth out any imperfections and achieve a glossy finish. Further refinement of the dental model is conducted to ensure precise contours and surface textures, enhancing its overall appearance and functionality. Thorough inspection is carried out to verify accuracy and quality, ensuring that the model meets the desired specifications and standards.

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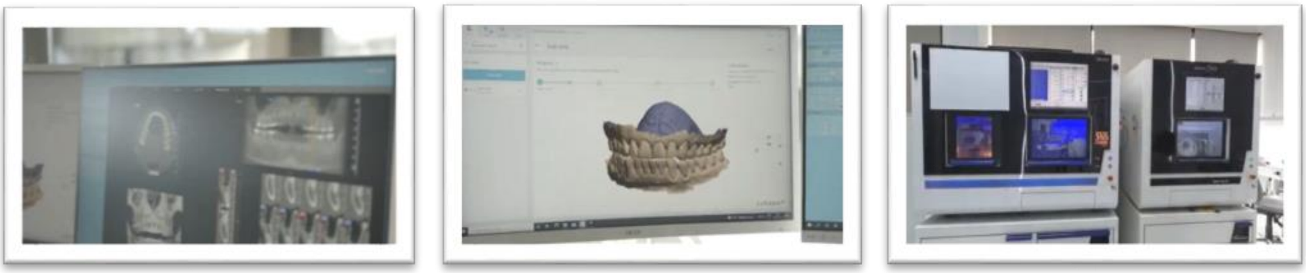
2.1. Creating Dentistry Example Model: Applications and Advancements

Creating a dental model involves a multi-step process that integrates state-of-the-art software and additive technologies. It begins with medical imaging, using CT scans to capture detailed anatomical data of the jaw (Figure 1a). Then, in the 3D Digital Modeling stage, the scanned jaw data is meticulously manipulated and refined in a software environment, allowing precise adjustments and enhancements to be made to the model (Figure 1b). Finally, in the 3D physical modeling phase, computer numerical control (CNC) technology is used to translate the digital design into a tangible physical model with unparalleled accuracy and detail (Figure 1c).



(a) (b) (c)

Figure 1. Dentistry example model: Working with software and additive technologies (a) Medical Imaging: CT; (b) 3D Digital modeling: scanned data of jaw in software environment; (c) 3D physical modeling: CNC.

2.2. Testing Construction

Testing construction of the dentistry example model involves meticulous handwork and assembly to ensure precision and functionality. Beginning with the lower jaw bone and implants, each component is carefully positioned and secured to create a stable foundation (Figure 2a). Subsequently, the process advances to incorporate teeth, meticulously aligning them with the implants to achieve optimal aesthetics and functionality (Figure 2b). Finally, fixing components are added to the assembly, ensuring stability and durability for long-term use (Figure 2c). Through this iterative process of testing construction, dental professionals meticulously evaluate the fit, alignment, and functionality of the model, ensuring that it accurately reflects real-world dental scenarios and meets the highest standards of quality and precision in patient care.

(a) (b) (c)

Figure 2. Testing construciton of dentistry example model: Hand work (a): Lower jaw bone and implants; (b) Lower jaw bone, implants and teeths; (c) Lower jaw bone, implants, teeths and fixing components.

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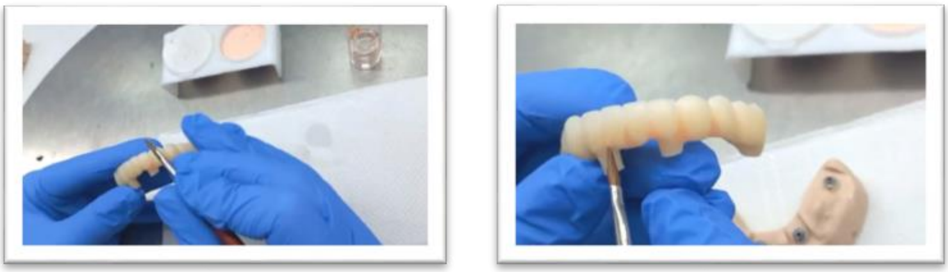
2.3. Hand Painting

Hand painting of the dentistry example model involves meticulous attention to detail and precision to achieve lifelike realism and aesthetic appeal. With skilled craftsmanship, dental professionals carefully apply paint to the model's surfaces, meticulously blending colors and textures to mimic natural tooth enamel (Figure 3a and b). Additionally, coloring teeth involves intricate shading and highlighting techniques to replicate the nuances of natural dentition, ensuring a realistic and visually appealing outcome. Through this meticulous process of hand painting, the dental model is transformed into a lifelike representation of oral anatomy, facilitating enhanced patient communication, treatment planning, and also for educational purposes in dental practice.

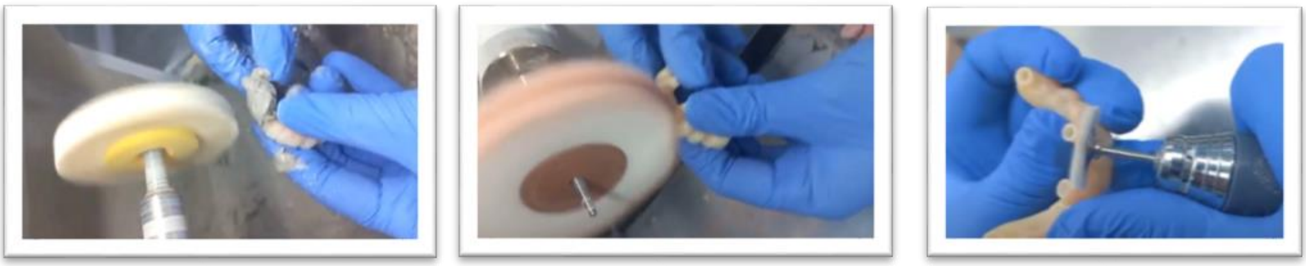


(a) **(b)**

Figure 3. Painting of dentistry example model: Hand work (a): and (b) coloring teeth.

2.4. Polishing With Paste

Polishing with paste in the dentistry example model involves the meticulous refinement and enhancement of surface texture and shine to achieve a professional finish. Dental professionals apply polishing paste to the teeth surfaces using specialized tools and techniques (Figures 4a and 4b), meticulously buffing and smoothing the surfaces to remove imperfections and create a glossy appearance. Precision polishing, depicted in Figure 4c, involves intricate detailing and careful contouring to ensure uniformity and natural aesthetics across the entire dental model. Through this meticulous process, the dental model attains a smooth, lustrous finish, enhancing its realism.



(a) (b) (c)

Figure 4. Polishing with paste the dentistry example model (PMMA): Hand work (a) and (b): teeth; (c) Precision polishing the teeths.

2.5. Completing the Dentistry Example Model

Completing the dentistry example model involves the meticulous assembly of its components to achieve the final ready result. This process, depicted in Figure 5, begins with the careful

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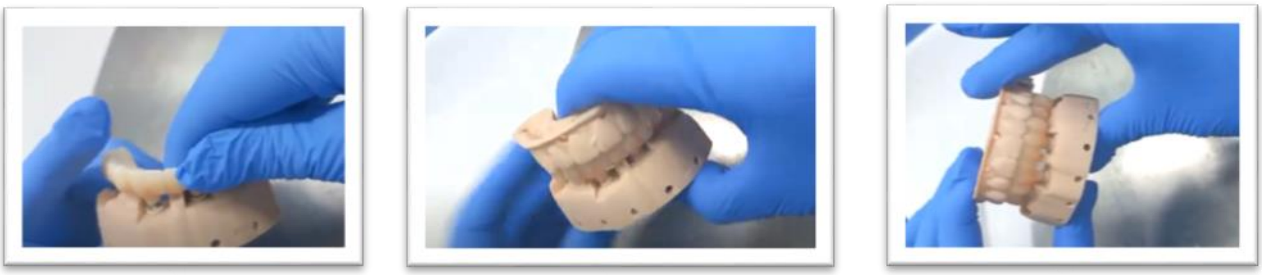
arrangement and alignment of the lower jaw component (Figure 5a), followed by the integration of all dental implants, teeth, and fixing components (Fig. 5b). Each element is meticulously positioned and secured to ensure structural integrity and functional coherence within the model. The final stage culminates in the presentation of the fully assembled dental model (Fig. 5c), showcasing the seamless integration of advanced technologies, precision craftsmanship, and clinical expertise.



(a) (b) (c)

Figure 5. Completing the dentistry example model: Assembling (a) lower jaw; (b) all components; (c) final ready result.

3. CONCLUSIONS

This article thoroughly explores the importance of medical imaging in healthcare, complemented by the significance of human factors and additive technologies. The theoretical part delves into the intricate details of Computed Tomography (CT), Magnetic Resonance Imaging (MRI), and Ultrasound (US), underscoring their pivotal role in diagnostic accuracy. Transitioning to implementation, real-world experiences are highlighted, particularly in the creation of dental constructions, showcasing the synergy between CT scanning and CNC technology. This practical example not only emphasizes the seamless integration of automated production processes but also underscores the indispensability of human intervention, particularly in ensuring the meticulous detail and precision required by human perception. The convergence of automated techniques and human craftsmanship underscores the symbiotic relationship between technological advancement and human ingenuity in shaping modern healthcare.

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