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A Comprehensive AI Framework for Superior Diagnosis, Cranial Reconstruction, and Implant Generation for Diverse Cranial Defects

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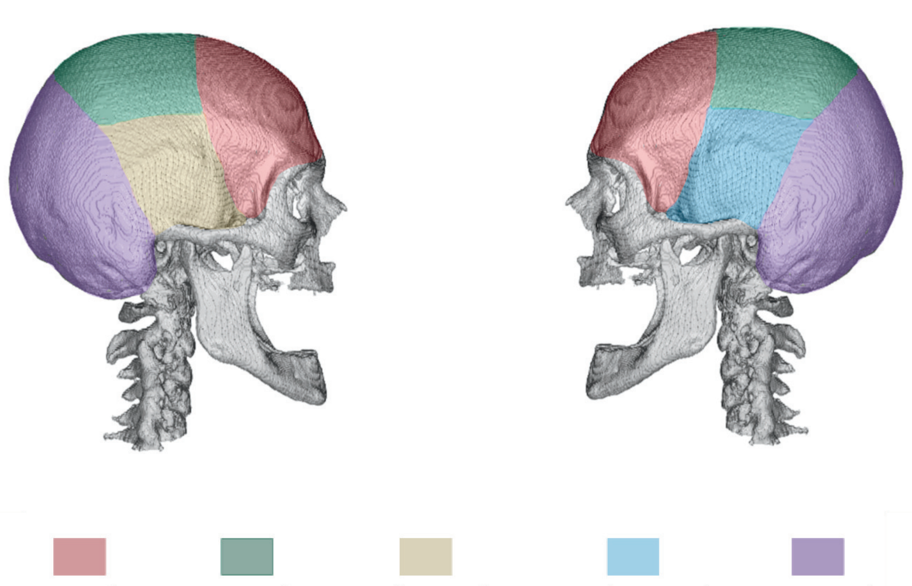

Figure 2. Regions for defect generation.

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Abstract: Cranioplasty enables the restoration of cranial defects caused by traumatic injuries, brain tumour excisions, or decompressive craniectomies. Conventional methods rely on Computer-Aided Design (CAD) for implant design, which requires significant resources and expertise. Recent advancements in Artificial Intelligence (AI) have improved Computer-Aided Diagnostic systems for accurate and faster cranial reconstruction and implant generation procedures. However, these face inherent limitations, including the limited availability of diverse datasets covering different defect shapes spanning various locations, absence of a comprehensive pipeline integrating the preprocessing of medical images, cranial reconstruction, and implant generation, along with mechanical testing and validation. The proposed framework incorporates a robust preprocessing pipeline for easier processing of Computed Tomography (CT) images through data conversion, denoising, Connected Component Analysis (CCA), and image alignment. At its core is CRIGNet (Cranial Reconstruction and Implant Generation Network), a novel deep learning model rigorously trained on a diverse dataset of 2160 images, which was prepared by simulating cylindrical, cubical, spherical, and triangular prism-shaped defects across five skull regions, ensuring robustness in diagnosing a wide variety of defect patterns. CRIGNet achieved an exceptional reconstruction accuracy with a Dice Similarity Coefficient (DSC) of 0.99, Jaccard Similarity Coefficient (JSC) of 0.98, and Hausdorff distance (HD) of 4.63 mm. The generated implants showed superior geometric accuracy, load-bearing capacity, and gap-free fitment in the defected skull compared to CAD-generated implants. Also, this framework reduced the implant generation processing time from 40–45 min (CAD) to 25–30 s, suggesting its application for a faster turnaround time, enabling decisive clinical support systems.

Keywords: artificial intelligence; cranial reconstruction; computer-aided diagnosis; deep learning; CT imaging; preprocessing; augmentation

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