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Project

Title: Automated Generation of Digital Twins of Fractured Tibial Plateaus for Personalized Surgical Planning in Trauma Surgery

1– SCIENTIFIC CONTEXT

Tibial plateau fractures remain a major challenge in trauma surgery, affecting approximately 10.3 individuals per 100,000 inhabitants each year [1]. They represent a significant public health issue due to the high costs associated with dependency and disability. Surgical management of these fractures is complex, often due to their comminuted nature, intra-articular involvement, and proximity to critical anatomical structures. Accurate preoperative planning is essential to restore anatomical surfaces and prevent surgery-related complications (such as infection, skin necrosis, or neurovascular injury), which currently relies solely on the surgeon's expertise [2].

Unlike scheduled orthopedic procedures, trauma surgery has seen little integration of artificial intelligence in preoperative planning. Currently, identifying bone fragments and determining the reduction needed to restore anatomy is based on radiographic and CT scan analysis. Manual segmentation can be performed, but the process is time-consuming and subject to significant inter-expert variability [3]. Automating fracture line identification would allow for more detailed and reproducible analysis of fracture patterns [4]. To date, models described in the literature are semi-automated and apply only to healthy knee bone structures in the context of elective orthopedic surgery [5, 6]. Moreover, many of these models are developed by private companies for implant placement, limiting accessibility for the broader scientific and surgical communities.

2 – CONCEPT AND OBJECTIVE

The objective of this doctoral thesis, building upon previous Master's research, is to develop a digital solution for preoperative planning of both simple and complex tibial plateau fractures, based on the internationally recognized Schatzker and AO classifications.

The completion of this project requires the design, development, and training of an artificial intelligence algorithm capable of automatically segmenting the bony structures of both healthy and fractured tibial plateaus. This will serve three main purposes: 1) Enable automated recognition of fractures; 2) Identify the displacement of these fractures; 3) Generate a reliable digital twin model of the fractured tibial plateau to assist the surgeon in diagnosis, decision-making, and intraoperative planning.

3 – EXPECTED RESULTS

Different steps are necessary for the completion of this thesis work:

i) The creation of a structured database, including CT scans of healthy and fractured knees extracted from the PACS. The selected pathological cases will include simple and complex tibial plateau fractures (Schatzker classification I to VI), with the analysis of uni- and bi-tuberosity fracture lines, metaphyseal-diaphyseal extensions, the presence of intra-articular depression, and any possible fracture displacements. The inclusion of approximately 300 scans is planned to allow the model to be trained. Access to this imaging has already been anticipated through the Health Data Warehouse (AAP Entrepôt de Données de Santé EDS 2023) via the "FraCTures" project, allowing for industrialized data collection while respecting regulatory frameworks.

ii) The scans will then be manually annotated by experts (surgeons/radiologists) to constitute a reference ground truth. These annotations include the segmentation of fragments, the differentiation of adjacent anatomical structures (tibia and fibula), and the characterization of fracture lines. This dataset will enable the training of specialized deep learning models (neural network or transformer) for automated segmentation of tibial plateau fractures.

iii) The algorithm must then be trained to allow it to learn the morphologies of bone structures. The algorithm will then be validated on real pathological cases, respecting anatomical constraints and comparing the results to a group of experts in the field considered as the gold standard.

iv) The model's performance will then be evaluated using classical segmentation metrics (Dice and Hausdorff distance), enabling functional evaluation under preclinical conditions.

At the end of this thesis work, the expected results involve applications in fracture analysis, virtual fracture reduction, and osteosynthesis planning. The practical interest of this tool will allow intraoperative assistance using augmented reality and, ultimately, the design of personalized implants through 3D printing to enable personalized trauma surgery adapted to each case while respecting the specific constraints of emergency situations.

Required Skills and Candidate Profile

The project is intended for a candidate with:

- ➢ Skills in medical image processing and deep learning adapted to clinical applications.
- ➢ A good knowledge of Python, TensorFlow, PyTorch environments, and segmentation software such as 3D Slicer is expected.
- ➢ Skills in knee anatomy, CT imaging, as well as an interest in traumatic pathologies are strongly recommended.
- ➢ A Master's degree in Health Engineering is recommended.
- ➢ Proficiency in English is recommended.

The desired profile combines scientific rigor, the ability to work independently, and team spirit within a multidisciplinary environment.

Keywords

- Tibial plateau fracture
- Automatic segmentation
- Deep learning (AI)
- Surgical planning
- Orthopedic traumatology

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