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CT image segmentation methods for bone used in medical additive manufacturing

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ABSTRACT

Aim of the study: The accuracy of additive manufactured medical constructs is limited by errors introduced during image segmentation. The aim of this study was to review the existing literature on different image segmentation methods used in medical additive manufacturing.
Methods: Thirty-two publications that reported on the accuracy of bone segmentation based on computed tomography images were identified using PubMed, ScienceDirect, Scopus, and Google Scholar. The advantages and disadvantages of the different segmentation methods used in these studies were evaluated and reported accuracies were compared.
Results: The spread between the reported accuracies was large (0.04 mm – 1.9 mm). Global thresholding was the most commonly used segmentation method with accuracies under 0.6 mm. The disadvantage of this method is the extensive manual post-processing required. Advanced thresholding methods could improve the accuracy to under 0.38 mm. However, such methods are currently not included in commercial software packages. Statistical shape model methods resulted in accuracies from 0.25 mm to 1.9 mm but are only suitable for anatomical structures with moderate anatomical variations.
Conclusions: Thresholding remains the most widely used segmentation method in medical additive manufacturing. To improve the accuracy and reduce the costs of patient-specific additive manufactured constructs, more advanced segmentation methods are required.

1. Introduction

Additive manufacturing (AM), also referred to as three-dimensional (3D) printing, is becoming increasingly popular in medicine [1] since it offers the possibility to personalize patient care [2]. The use of AM anatomical models results in more precise treatment planning, better communication [3,4], and improved training and education [5,6]. Furthermore, AM can be used for the fabrication of drill guides [7], saw guides [8], and patient-specific implants [9]. To date, medical AM is most commonly used in branches of surgery involving the musculoskeletal system, such as oral and maxillofacial surgery, traumatology, and orthopaedic surgery. However, it must be noted that the overall accuracy and repeatability of medical AM constructs used for bone reconstruction still need to be improved [10]. In this context, a recent systematic review by Martelli et al. identified 34 studies (21.5%) that reported on the unsatisfactory accuracy of medical AM constructs [11].

The current medical AM process used for the reconstruction of the musculoskeletal system can be divided into four basic steps: imaging (1); image processing (2), optionally followed by computer-aided design (3); and additive manufacturing (4) [12]. Each of these steps can introduce geometric deviations that can cause distortions in the resulting medical AM constructs [13]. Recent studies, however, suggest that the majority of the inaccuracies are introduced during imaging (Fig. 1: step 1) and image processing (Fig. 1: step 2), rather than during the manufacturing, i.e., the 3D printing process, which is generally considered to be precise [11,14,15].

Step 1: Imaging

CT scanners are best suited for imaging bony structures due to their superior hard tissue contrast and spatial resolution [16]. Today, a plethora of different CT technologies are available, ranging from single, helical CT to 128-slice dual-source CT configurations. Cone-beam computed tomography (CBCT) scanners are becoming increasingly popular in orthopaedic [17] and maxillofacial surgery [18] due to their lower radiation dose and costs. Raw CT data

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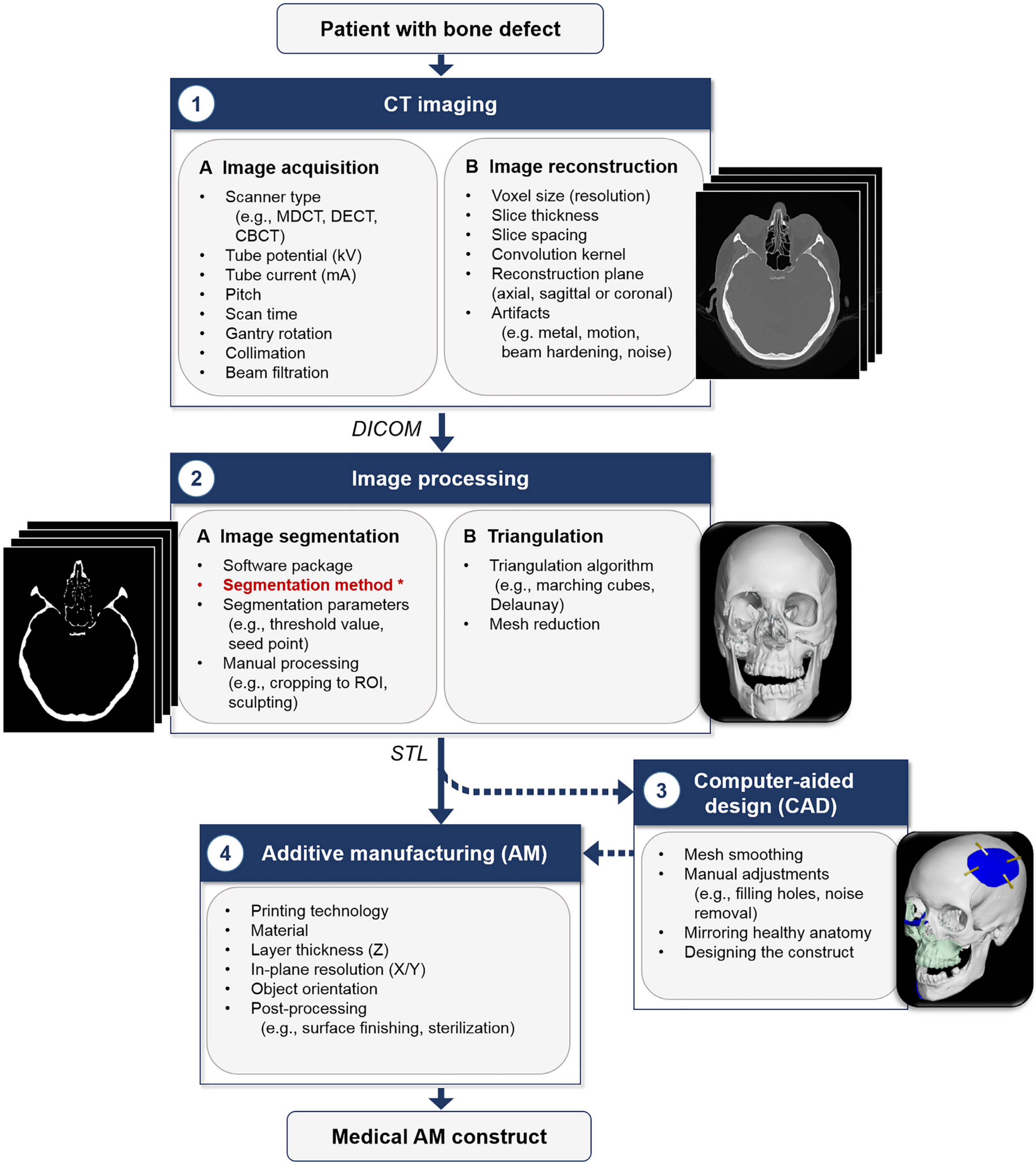

Fig. 1. Overview of the parameters that can influence the accuracy of medical AM constructs. * This review focuses on the different CT image segmentation methods used in medical AM.

acquired during image acquisition is commonly reconstructed as a Digital Imaging and Communications in Medicine (DICOM) file.

One major challenge faced in medical AM is the large variety of different CT image acquisition and reconstruction parameters currently available (see Fig. 1; step 1 A and B). To date, to the best of our knowledge, there are no standardized protocols available for medical AM. Image slice thickness and slice interval have been identified as the primary limiting factors for the overall accuracy of medical AM constructs [19], especially when reconstructing thin bony structures from axial plane images, such as the orbital floor [20], or where the imaging plane is nearly parallel to the bone surface to be reconstructed, such as in the tibial plateau. Moreover,