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AUTOMATIC CEPHALOMETRIC LANDMARKING OF CRANIOMAXILLOFACIAL COMPUTED TOMOGRAPHY SCANS USING A COARSE-TO-FINE DEEP LEARNING APPROACH

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Summary: Computer-aided orthognathic surgery planning must often deal with complex craniofacial deformities and would benefit from a standardized cephalometric analysis performed on three-dimensional (3D) craniomaxillofacial computed tomography (CT) scans. Such cephalometric analysis currently relies on manual localization of 3D landmarks on CT scans, requiring around 15 minutes for a trained and experienced clinician. In order to reduce the clinicians' burden, recent studies proposed deep learning-based models for automatic 3D cephalometric landmarking. The robustness and clinical usefulness of these results has still to be demonstrated, as most of these studies lacked a hold-out test dataset, localized a limited number of landmarks and/or did not clearly describe the database they used. The objective of this work was then to propose an automatic method for localization of multiple cephalometric landmarks on presurgical CT scans using a coarse-to-fine deep learning approach. High-resolution CT scans acquired before orthognathic surgery were randomly distributed among a training set (n = 128), a validation set (n = 32) and a test set (n = 38). The ground truth data consisted in 33 landmarks manually localized on each CT scan by trained and experienced operators: manual annotations of a single operator (n = 178) or means of the six annotations of three operators (n = 20, test set only). Six 3D Spatial Configuration Net networks were trained, either on full scans with a lowered resolution or on selected regions of interest (ROIs) with a full resolution. Inference was performed once on our test set following a 2-stage method. At stage 1, the full-scan network predicted the "coarse" localization of the landmarks, used to extract the 5 ROIs. At stage 2, the 5 other networks predicted the "fine" localization of the landmarks in the selected ROIs. To evaluate the overall localization performance of the proposed method, we computed mean radial errors (MRE) - Euclidian distance between the ground-truth and the predicted landmarks - and success detection rates (SDR) - proportion of landmarks located within a precision limit. Inference required around a minute per CT scan. On our test set, MRE for all landmarks was 1.14 mm (SD 2.09 mm) and SDRs for all landmarks were 89.64%, 92.85% and 94.62% using 2mm, 2.5mm and 3mm precision ranges, respectively. Eight landmarks (24.2%) showed an SDR at 2 mm of 100%; 22 landmarks (66.7%) showed an SDR at 2mm over 90%, and 5 landmarks (15.2%) showed an SDR at 2mm under 80%. These 5 least accurate landmarks are known to be the least reproducible in manual landmarking, being localized on anatomical curves. Outliers over 10mm were found in a single CT scan, from a patient exhibiting a syndromic deformity (cleidocranial dysplasia).The proposed coarse-to-fine approach is a promising method for the automatization of cephalometric landmarking of craniomaxillofacial CT scans. Its evaluation on a challenging test set from clinical practice showed that most of the landmarks were localized within a limit of 2mm and that error-prone landmarks were the same for manual and automatic landmarking.