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Development of a three-dimensional hand model using 3D stereophotogrammetry: Evaluation of landmark reproducibility

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Summary *BACKGROUND:* Using three-dimensional (3D) photography, exact images of the human body can be produced. Over the last few years, this technique is mainly being developed in the field of maxillofacial reconstructive surgery, creating fusion images with computed tomography (CT) data for accurate planning and prediction of treatment outcome. However, in hand surgery, 3D photography is not yet being used in clinical settings.
METHODS: The aim of this study was to develop a valid method for imaging the hand using 3D stereophotogrammetry. The reproducibility of 30 soft tissue landmarks was determined using 3D stereophotogrammetric images. Analysis was performed by two observers on 20 3D photographs. Reproducibility and reliability of the landmark identification were determined using statistical analysis.
RESULTS: The intra- and interobserver reproducibility of the landmarks were high. This study showed a high reliability coefficient for intraobserver (1.00) and interobserver reliability (0.99).
Identification of the landmarks on the palmar aspect of individual fingers was more precise than the identification of landmarks of the thumb.
CONCLUSIONS: This study shows that 3D photography can safely produce accurate and reproducible images of the hand, which makes the technique a reliable method for soft tissue analysis. 3D images can be a helpful tool in pre- and postoperative evaluation of reconstructive

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trauma surgery, in aesthetic surgery of the hand, and for educational purposes. The use in everyday practice of hand surgery and the concept of fusing 3D photography images with radiologic images of the interior hand structures needs to be further explored.

Introduction

Given the continuing technological progress in computer science and high demands from surgeons as well as patients on surgical capabilities, three-dimensional (3D) imaging techniques are being used more and more in clinical settings to image soft and bony tissues. For soft tissue analysis, multiple 3D imaging techniques have been introduced, such as Digital Imaging and Communications in Medicine (DICOM) files from computed tomography (CT) and cone-beam CT (CBCT) imaging,[1] surface laser scanning,[2,3] and 3D stereophotogrammetry.[4]

3D stereophotogrammetry is currently developing as a new, promising technique that is capturing the surgical field.[5–11] Within the broad field of reconstructive surgery, it has already found solid applications in maxillofacial surgery[9,12–14] and is upcoming in breast and free flap reconstructive surgery.[10,13,15–18] Within these clinical fields, 3D models based on 3D photographs are currently changing technically highly challenging operations into predictable and feasible procedures.[8]

However, 3D photography in hand and wrist surgery is still a field to be discovered, with a growing need for exact preoperative planning, real-life anatomic training models, and precise follow-up and evaluation methods in this complex anatomical field of surgery.

In order to perform soft tissue analysis on the collected data, predefined landmarks were required. In recent literature, no consistent description of soft tissue landmarks of the complete hand exists. A variety of landmarks on the palmar aspect of the hand are described in different anatomical studies,[19–21] with Kaplan's cardinal line being one of the more notable surface markers.[22–24]

The aim of this study was to evaluate the reproducibility and validity of newly defined soft tissue landmarks of the hand using 3D stereophotogrammetry.

Subjects and methods

Subjects

Twenty adult Caucasian individuals (three male, 17 female; mean age 38.7 years, range 20–64 years) without any preexistent hand deformities were randomly selected from our departments, and 3D photographs of both the left and right hand were taken. Written informed consent was given prior to inclusion.

Imaging methods

For all individuals, 3D photographs were captured with a 3D stereophotogrammetrical camera setup and the software program Modular System v1.0 (3dMDfaceTM System, 3dMD, Atlanta, GA, USA). The camera setup consisted of five pods, each equipped with three digital cameras and a flash. Prior to its use, the camera was calibrated to define a 3D coordinate system for the 3D photograph, which was referred to as the original 3D coordinate system.[25] The imaging method was validated in a previous pilot study by Hoevenaren et al. The 3D photographs were taken with each subject seated with flexion in the elbow joint and the hand kept in a predesigned template with the fingers in a fully abducted and extended position (Figure 1). In order to achieve accurate images of both the palmar and dorsal aspect of the hand, the template was removed by an assistant, less than 1 s before the photograph was taken. The patient was instructed to keep the hand absolutely still and not to move the hand to another position after removal of the template.

3D photograph-based reference frame

Based on experience using a reference frame in maxillofacial surgery,[12] this method was copied for setting up a reference frame for the 3D hand images and developed by

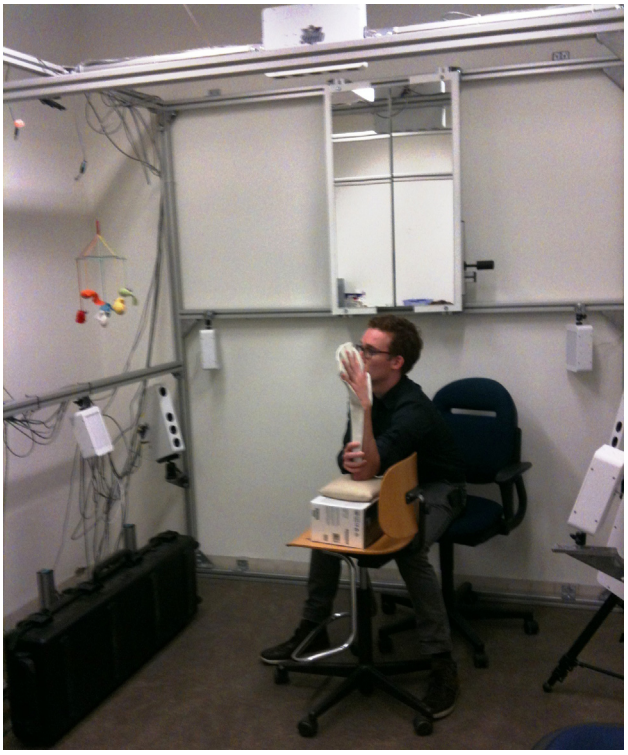

Figure 1 3D stereophotogrammetrical camera alignment. Legend: 3D stereophotogrammetrical camera alignment, with the hand positioned in the center and the template in place.