13.1 Thoracic wall deformities: 3-D scanning and computerized remodeling

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13.1.1 Background

The morphological estimation of complex anatomic body regions and of congenital or acquired defects is of great importance for an individualized surgical planning, the operative quality management and for long-term postoperative outcome control [11]. Especially congenital thoracic wall deformities frequently show substantial anterior thoracic wall affections, but only few and often deficient analyzing methods exist to objectively assess the complex three-dimensional (3-D) contour anomalies [19]. In particular, women show associated malformations of the breast soft tissue, which aggravates the 3-D evaluation of the female breast region.

In the last decades different evaluation methods have been presented to classify the severity of an anatomical distortion to enable a more objective quantification of an anterior chest wall depression [3]. Direct linear body surface measurements or radiologic distance measurements (chest X-ray, computed tomography (CT), nuclear magnetic resonance imaging (MRI)) provide specific anthropometric indices to quantify chest wall deformities and to compare the surgically induced contour changes [1, 5, 9, 10]. The generated indices only measure the present body deformity punctiform and along one body axis, they are difficult to standardize and show examiner-dependent measurement inaccuracies. Sometimes even invasive examinations are needed and thus inadequately assess the defect geometry [11]. Conventional documentation and assessment of body surface changes using two-dimensional (2-D) photography also neglect spatial dimensions of the chest wall deformity and because of perspective distortion, lack of metric and 3-D information are not suitable and limited by empiric and subjective examiner interpretation [12]. Modern imaging procedures such as CT and MRI enable reconstruction of the complete thorax with all anatomical structures and also the body surface in three dimensions to provide a more vivid visualization and interpretation of the entire complexity of thoracic wall deformities. Highly disadvantageous herein is the patient acquisition in supine or prone position with resulting soft tissue deformation of the whole breast region, time and cost intensive acquisition and the invasive character of these techniques which disallows a routine application for clinical follow-up examinations at close intervals [8, 18].

This lack of criteria oriented clinical assessment methods raises the necessity for supplement existing techniques with additional evaluation methods to guarantee fast, non-invasive, routine clinical follow-up examinations at close intervals and objective, patient specific 3-D assessment and quantification of the body geometry.

New optical measurement systems for the 3-D body surface assessment fulfill the above named relevant requirements and different clinical applications in the field of plastic, reconstructive and aesthetic breast surgery have been demonstrated [16, 17]. One particular advantage of 3-D surface imaging is the non-invasive patient acquisition which provides a risk-free, non-contact, non-deformable, high-resolution 3-D virtual colored model creation of different and specific body regions. 3-D surface imaging enable precise and accurate pre- and especially postoperative 3-D quantification of shape, volume, surface changes, symmetry, projection, swelling tendency, contour and deformation, close intervals postoperative follow-up examinations and therefore optimizes specific steps in the preoperative surgical planning [7]. Digitalized 3-D datasets allow a well-structured patient documentation and computer-aided analysis and evaluation without the necessity of the patients being physically present. The possibility to work with the stored 3-D data in absence of the patients avoids time consuming patient measurements and enables the surgeon to work with different data versions for different clinical questions in different software solutions and to access, revise and overwork the data at any time, in particular even during surgery [14, 16–18].

Optical systems are based on the measurement principle of triangulation and consist of a transmitter unit (light source) which projects a point upon the measured object and a receiver unit (camera) which detects the reflected
light. The geometric configuration and the measured angle between the transmitter and the receiver allow the calculation of the correct object point in space and the resulting surface geometry [2]. The measured surface is captured as an accumulation of different single points (point cloud). Every point is defined and computed on the basis of the respective x-, y-, and z-coordinates and provides mathematic precise visualization of the whole body surface [16, 17]. A wide range of optical systems for 3-D surface geometry acquisition exist and are based on different physical principles (stereo(-photo)grammetry, Moiré topographie, pattern/structured light, linear laser scanner, etc.). All optical surface imaging systems have in common that they detect the body surface in a short time without any deformable body contact to create a virtual digitalized 3-D model for later computer-aided analysis. In preliminary studies different body surface imaging systems were tested regarding their potential medical application and found the 3-D linear laser scanner most suitable for clinical applications [4].

By means of different patients with pectus excavatum deformities the vantages and existing limitations of current 3-D visualization techniques regarding objective 3-D quantification, computer-aided surgical planning and the development potential in the field of surgical correction of thoracic wall deformities are presented in the following.

13.1.2 3-D quantification of the body surface geometry

A common challenge in plastic and reconstructive surgery is the correction of congenital or acquired deformities. Precise detection and quantification would provide more security to surgeons during the intervention and would enable an objective quality assurance and thus would ease communication with the patient as well. The body surface geometry is quantifiable using 3-D surface imaging systems. The pre- and postoperative assessment of the breast and thorax region can be accomplished sufficiently precise and accurate using a 3-D linear laser scanner according to a standardized scanning protocol and can be presented as a virtual 3-D model for further computer-aided evaluation with appropriate software [16, 17].

On the one hand the accuracy of the existing scanning systems depends on the capturing speed; on the other hand accuracy depends on the capability to assess larger body regions in one or more steps. Current scanning systems vary enormously in fulfilling these require-