Validation Methods for Soft Tissue Prediction in Maxillofacial Planning Environments

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1 Introduction

Before a maxillofacial surgical procedure, patients want mirror-like images of the probable outcome. Important research activities try to predict 3D soft tissue changes based on the skeletal changes. Major attention was paid on the biomechanical properties of soft tissues at a certain time instance. (Non-)linear mass-spring and FE models are developed [1-3]. But, what accuracy is obtained by a current soft tissue model? What improvements are needed? Some validation methods for soft tissue deformation prediction are investigated.

2 Methods

From preop CT imaging, a surface description of the face and the skeleton is obtained. With planning software [4-5], new positions of bone fragments, defining the boundary conditions for soft tissue simulation, are determined. Based on segmented CT images, a tetrahedral mesh of the soft tissues is automatically constructed. As a simplification, all facial soft tissues are assumed to be identical linear elastic isotropic materials. With FEM, the constitutive equations are solved [5]. From the deformed volumetric mesh, predictions of the new skin surface and the postop CT are derived. After surgery, three dimensional photography can be applied to acquire a surface description of the face of the patient. Or, from postop CT, the skin surface can easily be extracted. We compare postoperative outcome and preoperative prediction in two ways.

Surface based validation This validation method compares predicted and postop skin surfaces. After surface-to-surface registration (ICP, error is a combination of euclidean distance and differences between normals), color-coding visualises the distances between the surfaces. If the registration fails, matching based on user-indicated points is a fall-back option.

Volumetric validation This validation method compares predicted and postop CT volumes. If an unaltered region can be defined in the pre- and postop image data sets, rigid registration can be applied. The postop data set is resampled over the grid of the preop dataset (= same grid as predicted CT). The postop CT and predicted outcome are compared.

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3 Discussion and Conclusion

As a case study, a hemifacial microsomia patient treated with mandibular unilateral distraction osteogenesis is presented. After preop CT, the optimal surgical procedure is selected with our planning environment [4-5] and the soft tissue deformations were predicted. 64 days after removal of the distractor, the patient was CT-scanned.

Surface based validation (fig 1:a-b). Errors resulting from registration and from prediction can not be separated. A matching algorithm tries to minimise the distance between surfaces. Large soft tissue modelling errors at e.g. the chin can be reduced by the matching algorithm and may result in e.g. a shift of the tip of the nose. But, the same result can be explained as follows: the chin is well-predicted by the simulation, but there is an prediction error at the nose. The surface-based validation method comes up with an average error. Improving the soft tissue model based on these results is very hard.

Volumetric validation (fig 1:c-e). The accuracy of the registration is evaluated on the bony parts. With a good match of postop and planned skull, soft tissues should be the same. For this case, we notice accuracy differences at the left and right side of the patient. Whereas the fit at the left side of the patient is satisfactory, large errors are seen at the right side. With volumetric validation, sources of errors are localised and modelling failures are identified.

Conclusion Surface-based validation, gives a qualitative image of the average error. Localizing sources of error remains difficult. With volumetric validation, identifying sources of error can be done in more detail.

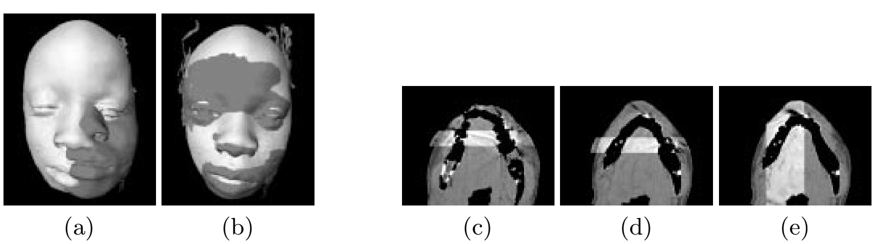

Fig. 1. (a-b) *Surface based validation.* The predicted (dark) and postop (bright) skin surfaces are depicted before (a) and after (b) surface based registration. (c-e) *Volumetric validation.* Slices (only soft tissues) from the predicted CT and parts of the registered postop CT in overlay windows (bright parts), are shown.

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