Stochastic analysis of multilevel artificial disc replacement and impact on spinal balance

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Abstract

Different opinions exist about the reasonability of total disc replacement in the human lumbar spine in the case that more than one natural disc should be replaced by an artificial one. Simulation of the biomechanical situations after surgery can help to estimate the reasonability of these procedures. The spinal shape during upright standing after surgery can be used to estimate clinical success. It is generally assumed that the body chooses such postures which require least energy, thus the spinal shape for standing after surgery can be determined by optimization, and judgments can be given as to how far multilevel disc replacement is sensible.

Keywords: Lumbar spine, Spinal balance, Artificial discs

1 Introduction

The spine is divided into different parts according to different anatomical conditions and consists of the cervical, the thoracic, the lumbar, the sacral, and the coccygeal region. Mobility is provided by elastic intervertebral discs connecting the relatively rigid vertebrae. The highest loaded part of the spine is the lumbar one which additionally allows large motions. Here most of the intervertebral disc problems occur.

For certain clinical indications surgeons recommend to replace the natural intervertebral discs by an artificial one (total disc replacement, TDR). TDR at a single level is well established and usually leads to surgical success. Different opinions, however, exist about as to how far multilevel TDR is reasonable. Here the success rates are reported inconsistently (Tropianio et al. (2005), Bertagnoli et al. (2005), Di Silvestre et al. (2009), Siepe et al. (2007)). The factors responsible for clinical success are not entirely known; especially it is unclear whether biomechanical or non-biomechanical factors play a dominant role.

The so called spinal balance is a set of geometrical measurements taken on lateral x-rays during standing to describe the spinal shape. If these measurements show large deviations from the normal values, there is a potential risk of developing diseases (Barrey et al. (2007)), especially on intervertebral discs. Due to TDR the balance may alter with potential risk of clinical failure. Knowledge about the resulting balance after certain constellations of TDR is thus valuable.

2 Methods

During the design of experiments the number of artificial discs as well as their surgical uncertain positioning in the intervertebral space was varied between zero (intact situation) and three between the levels L3 and S1 and between +3 mm and -3 mm in antero-posterior direction (Fig 1 top left). The artificial discs were inserted into an inverse static model of the standing human (Han et al., 2011). This model was analysed with the AnyBody Modelling System (AnyBody Technology A/S, Aalborg, Denmark) which is capable to calculate muscle forces when the posture of the body is given (Fig. 1, bottom left). Here the posture, especially the lumbar shape after TDR is, however, not known but is to be determined. Therefore the method was inversed by optimizing the posture following the well established objective that the body will take over such a posture which needs least energy, i. e. which requires least muscle activity (Fig. 1, top centre). This method allows determining the likely standing posture for all constellations of surgery. After optimizations were performed for all designs, the balance values are known (Fig. 1, right).

The number of artificial discs are the input parameters which were sampled (Latin Hypercube) by optiSLang (Dynardo GmbH, Weimar, Germany). The considered balance parameters after simulated surgery were the sacral slope, the lumbar lordosis and the horizontal sacro-cervical distance (S-C7-Distance). The

optimization to determine the resulting standing posture was performed with a gradient based algorithm implemented in optiSLang.
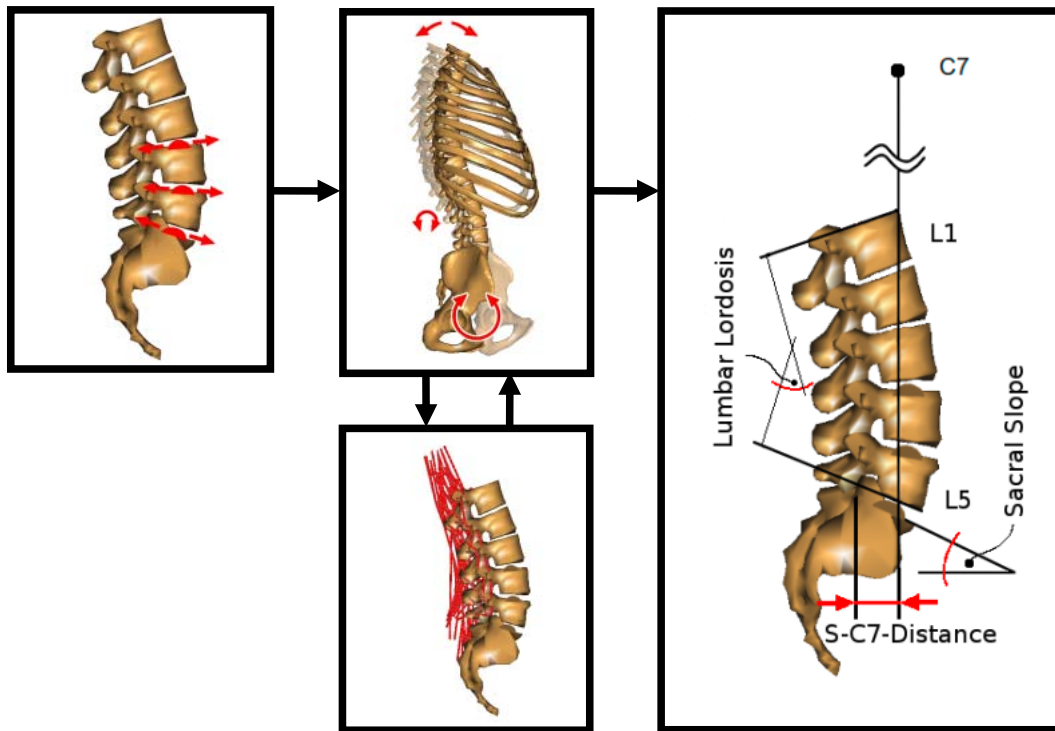

Figure 1: Procedure of the study and considered spinal balance values (right):
(1) Variation of number and location of artificial discs (top left)
(2) determination of optimal standing posture (top centre) including
(3) inverse static analyses for muscle force determination (bottom left).
Adapted from Zander et al. (submitted).

3   Findings

With increasing number of artificial discs, there are mainly two observations which could be discovered for all investigated balance values (Fig. 2):

1.) The possible range of deviations of the resulting from the desired balance values strongly increases, i. e. the resulting balance becomes less predictable. The maximum deviation of the S-C7-Distance, e. g., is less than 2 mm for one TDR while it is larger than 30 mm for three TDRs which corresponds to about 46% of the *in vivo* range of the *healthy* population.
2.) The median of the change of the balance values increases meaning that the resulting balance will – with a high probability – be the more different from the desired value the more discs were replaced.

The calculated ranges of the balance changes show however, that there is a small but existing probability that the desired balance is obtained.

The current finding are in accordance with clinical results which show that multilevel surgery might be successful, but generally the risk of failure increases.

Biomechanical factors might thus to a large portion be responsible for the clinical success of TDR. More detailed results can be found in Zander et al. (submitted). Further simulation studies could reveal the origin for undesired resulting balance values as well as how far muscle training or avoidance of certain iatrogenic factors might improve clinical results.
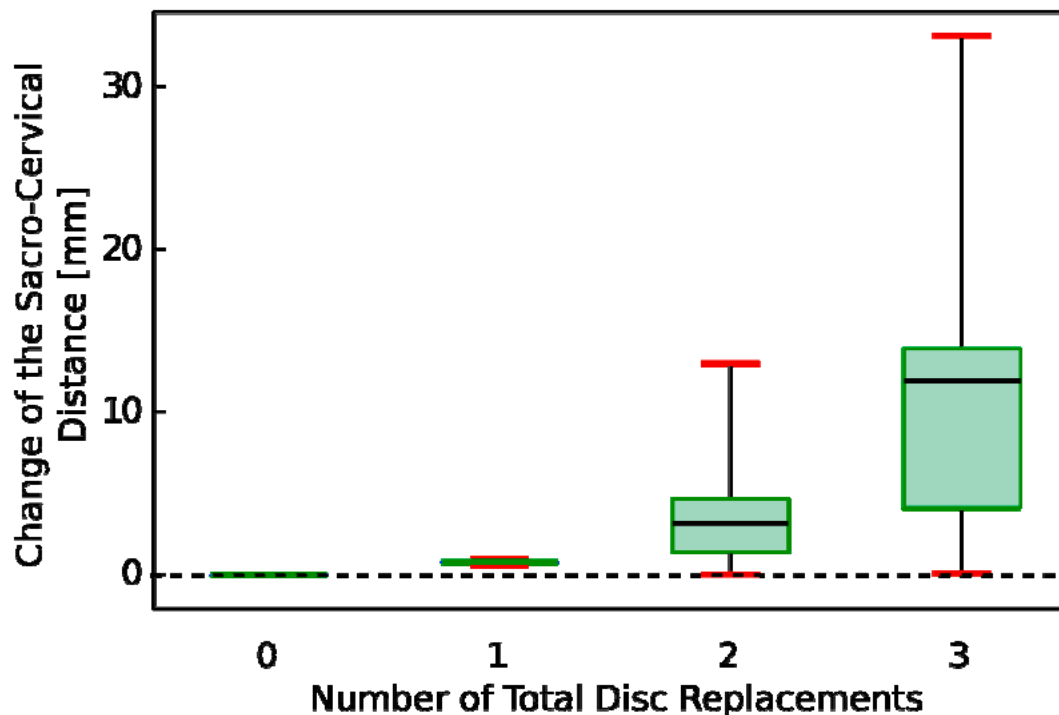

Figure 2: Boxplots (min-max) of the possible variations of the sacro-cervical distance after total disc replacement

Acknowledgements

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