AN APPROACH TOWARDS THE OPTIMIZATION OF DESIGN PARAMETERS FOR MONOLIMB USING TAGUCHI METHOD AND FINITE ELEMENT ANALYSIS

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INTRODUCTION

Monolimb refers to a trans-tibial prosthesis having the socket and the shank molded into one piece of thermoplastics. It has a characteristic that the shank could deflect during walking stimulating motions at ankle joints. Positive feedbacks were gained including improved gait efficiency and comfort from patients using prostheses with deformable shanks. Comfort and gait could be further improved by properly raising the shank flexibility. However, structural integrity should be remained which resists buckling of the prosthesis. Till now there is no guideline for the shank design of monolimb.

Currently, the structural test specifications of lower limb prostheses are specified in ISO10328. To optimize the design of the shank, monolimbs with different shank designs have to be subjected to tests according to the ISO standards. Performing such test experimentally is expensive and time demanding. Two approaches help ease the problem. A statistical approach developed by Taguchi using orthogonal arrays allows the design of an experiment involved a few well chosen tests but contains all main factor effects. Finite element (FE) analysis allows parametric analyses to be done efficiently.

In this work, FE analysis and Taguchi method were used to predict possible failure under structural test and identify which parameter is most sensitive to the overall performance. This promotes further optimization of the shank design of monolimbs.

METHODS

A plaster cast was taken on a male amputee subject which was digitized using BioSculptor system and exported to ShapeMaker 4.3. Shanks of different parameters (Table 1 and 2) were added to the socket. The monolimb was sent to SolidWorks 2001. The proximal part of the socket was filled. Foot block, extension rod and block were added so that loading can be added as instructed in ISO10328 (Fig. 1a). The whole model was sent to ABAQUS 6.4 for FE analysis. The monolimb was assigned with Young's modulus of 1500MPa and Poisson's ratio 0.3 resembling the polypropylene homopolymer (PP). Foot block, extension rod and block were assumed to be rigid. The bottom load application point was fixed and loadings were added at the top load application point according to ISO10328 A80 level. Peak von Mises stress, and deformation defined as the distance traveled by the top load application point were studied in the FE model.

PRELIMINARY RESULTS AND DISCUSSIONS

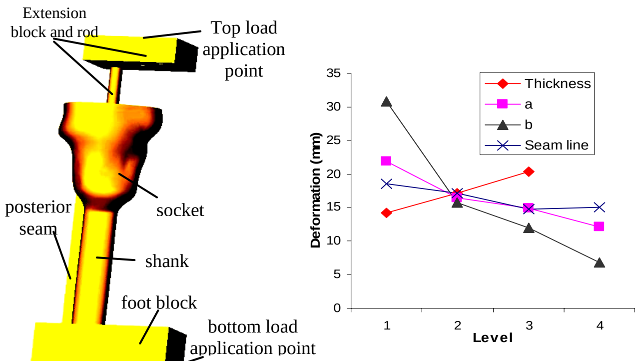
Table 1 shows that the sum of squares due to factor b (anteroposterior dimension of the shank) was the highest indicating the deflection and peak stress of monolimbs were most sensitive to the changes this factor. Reducing the values of the four parameters used in this study led to increases in prosthetic deflection (Figure 1b) and peak VM stress. As the peak VM stress was lower than the yield stress of the material (35MPa), no failure is predicted in the monolimbs used in this study. In the future, gait analysis will be performed to obtain the degree of flexibility of the monolimb which can bring about better gait performance. Design parameters of the shank will be altered according to this study and the gait analysis. Experiment will be performed according to ISO10328 to validate the FE model.

Table 1. Design variables and their levels: a, b refer to medial-lateral and antero-posterior dimension of the shank. Sum of squares of von Mises stress (stress) and deformation (deform).

Variables/ Level	Level 1	Level 2	Level 3	Level 4	Sum of squares (stress)	Sum of squares (deform)
Thickness (mm)	6	5	4		80.3	109.4
a (mm)	25	35	40	45	274.2	203.0
b (mm)	25	35	40	45	721.8	1274.8
Posterior Seam (mm)	0	5	10	15	42.6	39.6

Table 2. Orthogonal array table

Trial number	Thick-ness	a	b	Posterior Seam depth	Peak VM stress (MPa)	Deformation (mm)
1	1	1	1	1	35.0	35.4
2	1	2	2	2	16.4	12.5
3	1	3	3	3	9.9	5.5
4	1	4	4	4	6.8	3.5
5	2	1	2	3	30.8	24.9
6	2	2	1	4	30	29
7	2	3	4	1	10.9	6.4
8	2	4	3	2	11.3	8.2
9	3	1	3	4	21.5	18.1
10	3	2	4	3	14.9	8.2
11	3	3	1	2	33.9	38.4
12	3	4	2	1	20.8	16.5
13	2	1	4	2	14.9	9.3
14	2	2	3	1	22	16
15	2	3	2	4	14.2	9.4
16	2	4	1	3	20.2	20.4



(a) (b)

Figure 1. (a) Geometry for FE analysis; **(b)** Plot of factor effect.

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