XVII International Symposium on Computer Simulation in Biomechanics
July 28th – 30th 2019, Alberta, Canada

DESIGN AND DEVELOPMENT OF A PADDLE FOR A SWIMMER WITH TRANS-RADIAL AMPUTATION

Motomu Nakashima[1], Arthur Favreau[1,2] and Masahiro Terada[3]

[1]Department of Systems and Control Engineering, Tokyo Institute of Technology, Japan
[2]School of Engineering, Ecole Nationale Superieure d'Arts et Metiers, France
[3]Japanese Para-Swimming Federation, Japan
Email: motomu@sc.e.tjtech.ac.jp, Web: www.hei.sc.e.titech.ac.jp/nakashima_labo/motomu/

INTRODUCTION

Swimming is one of the physical activity the most practiced in the world. Recently many improvements have been realized to make its accessibility easier for people with physical disabilities. However, devices for swimmers with arm amputation have not been developed a lot and therefore many improvements can be realized. Even if prostheses are not allowed during competition, the training time is very important for swimmers. Having arm amputation creates an unbalanced movement during swimming. Consequently the swimmer's shoulders do not produce the same effort and muscles are not trained in the same way. This unbalance might cause some injuries. Although swimmers often use paddles during training, paddles on the market are basically for swimmers without amputation. The objective of this study were to design a paddle for a swimmer with trans-radial amputation based on the results obtained by computer simulation, and to develop an actual paddle that improves the swimming performance and balance between both shoulders.

METHODS

The swimming human simulation model SWUM [1-4] was employed for the analysis of the swimming motion. It computes the absolute motion of the swimmer's whole body as one rigid body, by solving the equations of motion with the given relative body motion as joint angles. In SWUM, the swimmer's body is represented as a series of 21 segments using truncated elliptic cones. The joint motion and the body geometry are the input data and can be modified. The swimming speed, motions of roll, pitch, yaw, fluid forces and joint torques are obtained as the calculated results.

Using SWUM, the crawl and the backstroke have been investigated in this study. The body geometry and the joint motion have been modified to match with the case of study. The forearm geometry has been updated and the joint motions of the wrist and the elbow have been removed.

The design of the new paddle was evaluated by two indices. One was the swimming speed and the other was the difference between the efforts (joint torques) at both shoulders. The difference was calculated as:

$$\Delta T_i = \frac{\sqrt{(T_{Rx}+T_{Lx})^2+(T_{Ry}-T_{Ly})^2+(T_{Rz}+T_{Lz})^2}}{\sqrt{{T_{Rx}}^2+{T_{Ry}}^2+{T_{Rz}}^2}+\sqrt{{T_{Lx}}^2+{T_{Ly}}^2+{T_{Lz}}^2}}$$

where ΔT_i is the difference for one time step. The symbols $T_{Rx,y,z}$ and $T_{Lx,y,z}$ represent the joint torque components computed at the right and shoulders in the swimmer's body fixed coordinate system O-xyz. Then, the index value T was defined as the root mean square for one complete stroke cycle:

$$T = \sqrt{\frac{\sum_i^n \Delta T_i}{n}}$$

The smaller the value T, more balanced the torques on shoulders. This quantity was calculated for different simulations of the crawl and backstroke.

RESULTS AND DISCUSSION

From the parameter study, it was found that the paddle should be fixed on an attachment as the substitute of the forearm, and that the length of the attachment had an optimum value. It was also found that the relative angle between the upper arm and the attachment should be 20 degrees as the substitute of the elbow flexion. Based on these findings, a trial paddle was initially fabricated, as shown in Fig 1. However, by the evaluation by an actual swimmer, it was found that this initial paddle had a major problem, which is explained in Fig 2. As shown in Fig 2(a), when the swimmer is in gliding phase during swimming, the water comes from the front of the paddle. In that case, the fluid force acts to rotate the paddle more thus an instability to turn over the paddle occurs, as shown in Fig 2(b). Therefore, we invented a new structure shown in Fig 2(c). This new paddle had a pivot around the tip of the paddle. In this case, the paddle automatically rotate in the direction reducing the

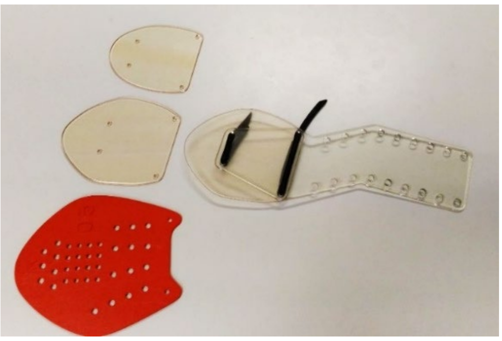

Fig 1: Initially developed paddle. The plate on the right is an attachment between the arm and paddle. The swimmer could choose the large (on the top left) or small (on the middle left) paddle. The bottom left is a paddle on the market.

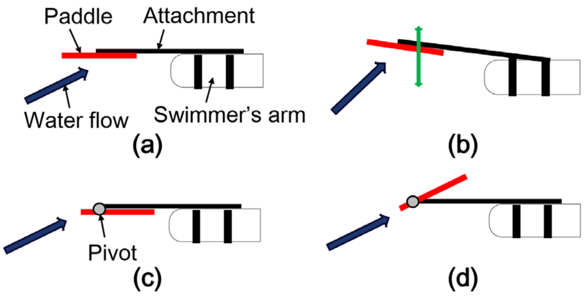

Fig 2: Schematic figures explaining the improvement of paddle. (a) The water flow comes from the front when gliding. (b) Instability to turn over the paddle occurs. (c) New structure with a pivot. (d) The paddle can rotate so that the instability does not occur.

fluid force when the water comes from the front, as shown in Fig 2(d).

The finally developed paddle is shown in Fig 3. The rubber tubes on the paddle prevent excessive rotation of the paddle for the swimmer's stroke phase. A simulation for this developed paddle was finally conducted. The snapshots of the simulations are shown in Fig 4. It can be seen that the paddle rotated at a certain degree in the case of the developed paddle. The comparisons between the paddle on the market and the developed paddle with respect to the performance for the crawl stroke and backstroke are shown in Tables 1 and 2, respectively. The values of T were nondimensional. Since the swimming speeds with the developed paddle were faster and the values of index T were smaller than those with paddles on the market, it was confirmed that the developed paddle enabled the swimmer to swim faster and more balanced than the paddle on the market.

REFERENCES

1. Nakashima M, et al. *J Fluid Sci Tech* **2**: 56-67, 2007.
2. Nakashima M, et al. *J Biomech Sci Eng* **8**: 79-93, 2013.
3. Nakashima M, et al. *J Biomech Sci Eng* **10**: 15-00375, 2015.
4. Nakashima M, et al. *Mech Eng J* **5**: 17-00377, 2018.

Fig 3: Finally developed paddle. The rubber tubes on the paddle prevent excessive rotation of the paddle. The rubber bands on the attachment are for the fixation to the swimmer's arm.

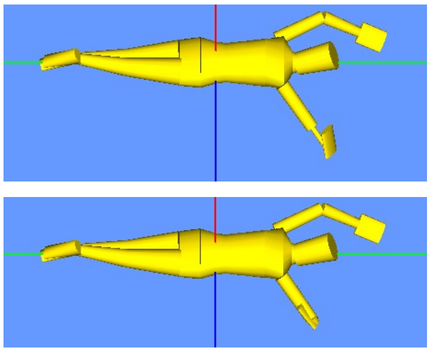

Fig 4: Snapshots of simulations. The top figure is the case of the developed paddle, while the bottom is the case of a paddle on the market.

Table 1 Comparison between the paddle on the market and the developed paddle with respect to the performance for crawl stroke.

Crawl	Swimming speed [m/s]	T
On the market	1.120	0.496
Developed paddle	1.337	0.493

Table 2 Comparison between the paddle on the market and the developed paddle with respect to the performance for backstroke.

Backstroke	Swimming speed [m/s]	T
On the market	1.139	0.526
Developed paddle	1.281	0.407

ACKNOWLEDGEMENTS

The authors would like to thank the swimmers with trans-radial amputation for cooperating to this study.