Human-Friendly Equipment for the 21st Century

-Innovations in materials technology for sports equipment for people with disabilities-

Shigeo HIRANO[1, 2] Susumu KISE[2], Sozo SEKIGUCHI [2] , Kazuya OKUSAKA[2]

Masahiro YASUI[2] , and Tsutomu ARAKI[3]

[1] Professor emeritus, Tokyo City University

1-28-1 Tamazutsumi, Setagaya-ku,Tokyo 158-8557,Japan

[2] Artner Co. Ltd

Sumitomo Nakanoshima Building 2F, Nakanoshima 3-2-18, Kita Ward, Osaka City

530-0005, Japan

[3] Professor emeritus, Tsukuba University of Technology

4-3-15 Amakubo, Tsukuba City, 305-0005, Japan

[1]*rs4775hirano@ybb.ne.jp*, [2]*kise@artner.co.jp*, [3]*tutaraki@yahoo.co.jp*

ABSTRACT

Recently, sports for people with disabilities (disabled sports) have attracted increasing interest and sports equipment for people with disabilities such as wheelchairs has made marked progress. Highly functional equipment has been developed owing to advances in diversified materials and processing technologies. Sports equipment needs to meet various requirements such as safety, durability, and operability.

The environment surrounding disabled sports has improved through large-scale international competitions. As we approach the 2020 Tokyo Paralympics, improvements in sports equipment from that used at the 2016 Rio Paralympics are expected. The technologies applied to equipment for disabled sports have been improved to satisfy various technical requirements and are expected to also be effectively used in an aging society.

However advanced the technology used in supporting human welfare may become, humans wish to be treated by humans rather than machines. However, it is also desirable for machines to be used as tools that support care receivers and givers. I believe that mechanization that leads to the treatment of humans as objects is wrong. Technology should be used to make people happy. The ultimate goal of technology as well as background features including the economy, religion, and culture should be all examined before using technology. After all, technology is designed by humans, developed by humans, and used by humans. Our society is formed by humans and by their technology. The mission of engineers in society is to raise our current culture and civilization to a higher level using technology and to pass the technology onto the next generation.

In this article, we discuss innovations in sports equipment, focusing on the materials used in wheelchairs for disabled sports and prosthetic legs for running.

Keywords: innovations in materials technology, spots wheelchairs, prosthetic legs for running, coexistence of humans and machines

1. INTRODUCTION

Recently, sports for people with disabilities (disabled sports) have attracted increasing interest and sports equipment for people with disabilities such as wheelchairs has made marked progress. Highly functional equipment has been developed owing to advances in diversified materials and processing technologies. Sports equipment needs to meet various requirements such as safety, durability, and operability.

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2. SPORTS WHEELCHAIRS

The history of wheelchairs in sports originated from the Paralympic Games. The first use of a wheelchair was by an archer who participated in the Stoke Mandeville Games held at the 1948 London Olympics.

In line with the spread of wheelchair sports, the performance of athletes has improved. As competitive wheelchair sports have attracted more interest than the use of wheelchairs in rehabilitation and treatment, wheelchairs with functions specialized for each sport have been developed.

2.1 Racing wheelchairs

Racing wheelchairs have been improved by various approaches, enabling users to run faster while complying with the rules of racing. As a result, three-wheeled chairs that are highly stable during forward motion have become the mainstream. The front wheel of the chairs is located considerably forward, and the rear wheels, with a large tilt angle, are attached to the chair at a point near the ground, realizing stable running and easy operation.

Frames are made of light, rigid materials, such as aluminum and titanium alloys, and also carbon fibers with high shock-absorbing ability. For the rear wheels, light and rigid disc wheels with small energy loss, such as those used in bicycles, are used despite their high air resistance in the case of crosswinds. In the fabrication of racing wheelchairs, some accommodation is required in accordance with the user's status of disability, physical size, and muscle strength (Fig. 1: racing wheelchair).

Figure 1. *Racing wheelchair*

2.2 Basketball wheelchairs

There are large differences between wheelchairs for general purposes and those for basketball. The features of basketball wheelchairs are (1) a bumper attached to the front of the chair to protect the user's legs in the case of collision, (2) a rear caster to prevent toppling, and (3) wheels whose lower side is tilted outward, rather than perpendicular to the ground. These features enable the smooth rotation of the wheelchairs.

The material used for the frames has become lighter over time and has changed from iron to stainless steel and aluminum. In addition to aluminum alloys with high strength and toughness, chrome molybdenum steel, carbon fibers, titanium, and magnesium are also used.

For the spokes of wheels, elastic nylon wires are used because they are damaged less than metals in collisions and can be easily replaced when damaged.

Basketball wheelchairs have been improved by improving their operability and installing a system for preventing toppling. In addition, their weight has been reduced and their turning performance and mobility improved, enabling players to move with greater speed (Fig. 2: basketball wheelchair).

Figure 2. *Basketball wheelchair*

Figure 3. *Tennis wheelchair*

2.3 Tennis wheelchairs

The tilt angle of the wheels of tennis wheelchairs is larger than that of basketball wheelchairs because tennis wheelchairs do not need to pass through narrow spaces and rotation with a small radius is prioritized. The moment during rotation is decreased by allowing players to bend their knees. Tennis wheelchairs are designed so that the racket does not come into contact with the chair when the player hits a low ball. Moreover, casters are attached to the front and rear of the chair to prevent toppling. The current standard is a five-wheeled chair (Fig. 3: tennis wheelchair).

3. DEVELOPMENT OF PROSTHETIC LEGS FOR RUNNING

When running in the wind, we sweat, breathe laboriously, and find it difficult to raise our legs. However, we may sense that our body feels alive. We may even feel that each body cell is stimulated. Running is not just exercise but provides something else of value. Running in itself is pleasant for some people. However, there are people who are unable or find it difficult to run, such as those who wear prosthetic legs.

In Japan, approximately 60,000 people use prosthetic legs after having lost their legs because of injury or disease, and they live their lives without major problems. Although progress is made every year in the design of prosthetic legs, they are merely tools and not living parts.

Amputees who wear prosthetic legs in place of their own legs experience more difficulty in moving their body than healthy people realize. Therefore, people with prosthetic legs cannot easily start running. For many years, people with prosthetic legs would not try to run. Although some of them with high physical ability might have tried running, many thought that they could not run, they would never run, they would live their lives without running, or they could manage to run a little but might be injured or topple. Alternatively, their prosthetic legs might break as a result of running, meaning that they were unable to go to school or work, and they did not want to damage their expensive prosthetic device. Thus, people with prosthetic legs did not try to run. The staff of hospitals and rehabilitation centers also did not recommend running. The concepts of running and prosthetic legs were mutually exclusive.

At the 2012 London Olympics and Paralympics, athletes with prosthetic legs attracted great interest. In 2014, a male long-jumper with a below-the-knee prosthesis achieved a world record distance longer than that of the silver medalist at the London Olympics. Consequently, the advantages of prosthetic legs have been continuously discussed.

The shape of prosthetic legs used in daily life and those used in running are very different apart from the shape of the socket. Prosthetic legs for running basically consist of a socket for storing the amputation stump, a plate spring for a foot, and a knee joint that can bend and connect the socket and the spring (Fig. 4: prosthetic legs for daily life and running fabricated using commercially available products).

The shape of prosthetic legs is designed so that they can withstand a load eight times larger than the user's weight instantaneously applied to the prosthetic leg during running. Various materials, such as carbon, Kevlar, reinforced fiber plastic including glass fiber, and aluminum and titanium alloys, are used in accordance with the physical properties required for each part of the prosthetic leg.

The plate spring for the foot is specific to the prosthetic leg for running and is made of carbon fiber reinforced resin. A propulsive force is supplied by the repulsive force of the plate spring. Spikes are used to increase the grip of the plate spring.

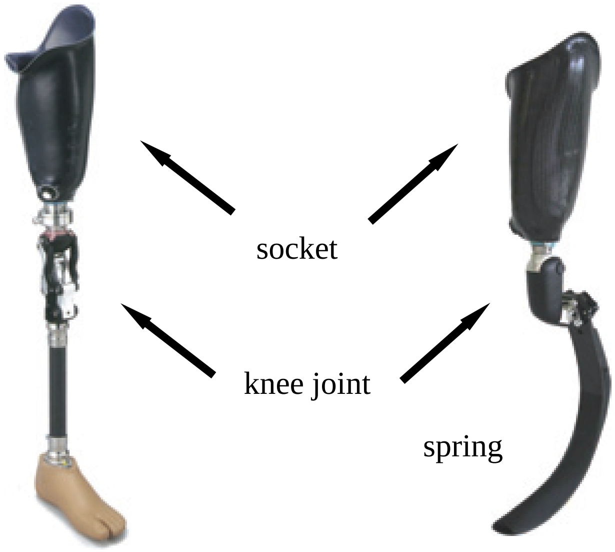

Figure 4. *Prosthetic legs for daily life and running fabricated using commercially available products*

The socket used to hold the amputation stump is a key interface at which an artificial object and the human body directly come into contact. Particularly for sports, the socket needs to meet various requirements; for example, (1) the socket should be light, strong, and durable, (2) the socket can distribute a large impact at the time of standing up and does not limit the movable range, and (3) the socket grips the stump even when its shape changes within the socket and sweat is generated during running.

Sockets are important parts that support the entire weight of the user. They are made of acrylic resin or carbon fibers to increase their strength. Sockets are cast using plaster in accordance with the shape of the user's amputation stump by setting cylindrically woven carbon cloths or cloths- or tape-shaped fibers, and introducing a matrix resin into a depressurized bag. Thus, the strength of the material is a major issue for sockets. The shape of sockets should be accurately adjusted to users for not only their standing posture but also for when they are running. High skill and trust from users are required for prosthetists.

3.1 Can athletes with prosthetic legs win against healthy athletes?

Because lower-extremity prostheses are lighter than human legs, Paralympic 100 m sprinters are expected to achieve faster times than able-bodied Olympic sprinters in the future. Researchers familiar with prosthetic legs at the National Institute of Advanced Industrial Science and Technology estimated that faster times than able-bodied sprinters may be achieved in the men's 100 and 400 m sprints by 2028 and 2020, respectively.

Around 1980, athletes with prosthetic legs started participating in races and the 100 m sprint record was about 13–14 s. The record time has improved yearly with the advances in the materials and shapes of prosthetic legs. A Brazilian athlete achieved 10'57" in 2013, which is only 0'99" slower than the world record of 9'58" by Usain Bolt from Jamaica.

3.2 Carbon fiber technology

Carbon fibers are light and strong and weigh approximately a quarter of iron while exhibiting 10 times higher strength. Three major Japanese manufacturers, including Toray Industries, Inc., account for approximately 65% of the world market

Japan has been actively developing prosthetic legs for racing in the Paralympics to show its manufacturing prowess to the world. Mizuno Corporation and Imasen Engineering Corporation have been jointly developing a prosthetic leg for international use at a total cost of 40 million yen. In cooperation with Atsushi Yamamoto, who won the silver medal in the men's long jump at the 2008 Beijing Paralympics, this prosthetic leg has been repeatedly tested and improved. The prosthetic leg (the main body with a plate spring) is expected to be sold for approximately 250,000 yen.

It is hoped that people with prosthetic legs feel that they can run and realize their dreams (Fig.5: systematic cooperation and interactive movement between human muscle and spring).

Figure 5. *Systematic cooperation and interactive movement between human muscle and spring*

3.3 Carbon athletes

A book entitled "Carbon Athletes –A Dream with Beautiful Prosthetic Legs-" was published by Hakusuisha Publishing Co., Ltd. This was written by a designer, Shunji Yamanaka, who attempted to design prosthetic legs for sports over a three year period.

The play of athletes actively moving around a court despite their disabilities, tackling by wheelchair athletes, and the mysterious dynamic movement of athletes with prosthetic legs have captured the imagination of audiences. Yamanaka is one such person fascinated by the aesthetics of prosthetic legs.

When he watched Oscar Pistorius (South Africa), who won three gold medals at the Beijing Paralympics and participated in a track race at the London Olympics, running in a video, Yamanaka saw for himself the ultimate functionality and aesthetics of prosthetic legs and said the following:

"As a product designer, I have designed various daily commodities while considering the relationship between humans and products. For me, the relationship between Oscar's physical body and his prosthetic legs, which allowed him to reach a very high speed immediately before the finish, embodies the ideal relationship between humans and artificial objects. (…) This is the ultimate functionality and aesthetic created by humans. I was mesmerized by the video."

Triggered by his excitement at that time, Yamanaka began to conduct research on prosthetic legs for sports while engaged in commercial design and serving as a professor at Keio University.

Prosthetic legs for running primarily consist of a socket for covering the amputation stump, a carbon plate spring for kicking the ground, and, for above-the-knee amputees, a knee joint that plays the role of the human knee (see Fig. 4).

When Yamanaka looked at an actual prosthetic leg as a research target by standing near an athlete equipped with a prosthetic leg, he felt the same dynamism from the entire figure as he had encountered in the video but found that details such as the screws and connected surfaces were exposed and that there were only a few elements that looked attractive.

As in the well-known saying "God is in the details", he thought that a more aesthetic design was required for the details of prosthetic legs. He attempted to design an aesthetically pleasing appearance for prosthetic legs. However, many manufacturers of prosthetic legs and prosthetists responded negatively to his idea.

In Japan, there are approximately 60,000 lower-extremity amputees, among whom a few thousand live a normal daily life with prosthetic legs and fewer than 100 are able to enjoy running. Because prosthetic legs cannot be mass-produced, design is considered to be a luxury and of little practical use. The above response of manufacturers may therefore have been understandable.

Nevertheless, Yamanaka truly believes in the power of design and fabricates prosthetic legs with an aesthetically pleasing appearance to help people understand the future possibilities for individuals with attractively designed prostheses. Various elements such as motivation, skill, and tools, in addition to muscle strength, are required for amputees to become able to run.

Yamanaka considers that prosthetic legs are a very artificial skeleton and must be a complete skeleton because there are no muscles outside the prosthetic legs. His sketches based on this concept convey a dynamism exhibited by recognizing the skeleton, and we can understand the process from the idea to the completion of the prosthetic legs by looking at his sketches (Fig. 6: aesthetically developed prosthetic leg).

Figure 6. *Aesthetically developed prosthetic leg*

In an additional comment, Yamanaka said:

"Excellent design makes people happy, even if only slightly happier, in all contexts. This may not have a major impact but it will always have some impact. Aesthetically pleasing prosthetic legs will also make amputees happier. This may encourage people to make greater use of their prosthetic legs, leading to new opportunities in their lives. It is important to develop beautiful prosthetic legs that will be admired by surrounding people."

4. COEXISTENCE OF HUMANS AND MACHINES

However advanced the technology used in supporting human welfare may become, humans wish to be treated by humans rather than machines. However, it is also desirable for machines to be used as tools that support care receivers and givers. I believe that mechanization that leads to the treatment of humans as objects is wrong.

Technology should accommodate itself to humans, rather than humans to technology. Humans have both strong and weak points. Supporting these weak points using machines is one of the key tasks of welfare. Welfare services should be based on a humanistic rather than mechanistic viewpoint. Many people, particularly the elderly, have difficulties in daily life. Supporting such difficulties is a natural human response. It is desirable that welfare services are provided in harmony with human values and lifestyle. Such a society cannot be realized with only technology and engineers.

Technology should be used to make people happy. The ultimate goal of technology as well as background features including the economy, religion, and culture should be all examined before using technology.

After all, technology is designed by humans, developed by humans, and used by humans. Our society is formed by humans and by their technology. The mission of engineers in society is to raise our current culture and civilization to a higher level using technology and to pass the technology onto the next generation.

5. CONCLUSIONS

All sports equipment is required to meet various technical requirements, such as safety and strength, and in the case of outdoor sports, durability to exposure to wind, rain, and contaminants. The technology of lightweight wheelchairs with high mobility developed for a British wheelchair basketball team that participated in the London Paralympics has been applied to general-purpose wheelchairs. This indicates that the technology applied to sports equipment is also beneficial for non-athlete wheelchair users. Aluminum-based materials used to reduce the weight of basketball wheelchairs have been applied to general-purpose wheelchairs.

Thus, the technology applied to sports equipment that addresses various technical issues can contribute to improving the competitiveness of athletes. In addition, such developments are expected to expand the possibility of participation in sports for people with disabilities and also to be effectively used in changing consciousness and assisting sensory perception among the elderly. Supportive machines should be easy to use, not only for people with disabilities but also for able-bodied people. We should adjust technology to the environment rather than the environment to the technology.