Revolutionizing Speed Skating: The Development of a Functional Prosthetic Speed Skate for Athletes with Limb Loss

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Abstract

Speedskating is renowned for its combination of speed, agility, and precision, but it remains largely inaccessible to para-athletes, especially those with below-the-knee amputations due to the lack of suitable prosthetic designs. This study addresses this gap by conceptualizing and prototyping a prosthetic short track speedskate. The proposed design integrates a flexible carbon fiber bridge coupled to a steel plate, an innovative ankle design with adjustable extension springs, and a universal pyramid adapter for attachment to existing prosthetic limbs. The ankle mechanism allows for crucial movements such as dorsiflexion, plantar flexion, eversion, and inversion, thereby mimicking the natural range of motion necessary for effective speedskating. The methods involved detailed analysis and adaptation of previously existing prosthetic design technologies, with a greater focus on the optimization of power transfer, stability, and comfort. The final prototype demonstrates the significant potential of enabling below-the-knee amputees to participate in speedskating. This marks a pioneering step in adaptive sports technology. Not only does this research enhance the inclusivity of speedskating, but it also lays the foundation for future advancements, contributing to the accessibility and diversity of the sport.

Introduction

Speedskating stands as one of the fastest human-powered sports globally, characterized by its demand for both speed and agility. While this sport necessitates an athlete to perform explosive movements, it also requires precision of movement. Despite the sport's popularity during the Winter Olympic Games, speedskating's prominence often diminishes once the Olympic fervor subsides. Participation in speedskating requires access to both an ice rink and basic equipment, like skates. The demographic excluded from this experience is individuals with limb amputations due to the unavailability of equipment. While some amputees have created personal prosthetic solutions for skating, no accessible or successful speedskating-specific prosthetic has been developed, until now.

One individual in particular attempted to take prosthetic speedskating to the next level. The prosthetic device designed by this individual exhibited significant functional deficiencies: the blade of their boot was mounted backward, the prosthetic lacked sufficient dorsiflexion, a movement critical to speedskating, and the lack thereof significantly hindered their ability to speedskate. The instability of the design endangered the user, posing safety risks to the skater. Given that the sharpness of a speedskate is much greater than that of a hockey blade or figure skate, ensuring the precision and stability of the prosthetic skate design is vital to the prevention of serious injuries to both the skater and bystanders.

Why create a prosthetic speedskate? This research and design process is a way to finally bridge the gap between current prosthetic technologies and the specific demands of speedskating. Drawing on the extensive experience as a speedskater, including participation in the Gangwon 2024 Youth Olympic Games, Junior World Team member, Vice Junior World Champion, and United States Junior National Champion, alongside comprehensive research,

this process aims to conceptualize, design, and fully prototype a prosthetic skate that will meet the technical, precision, and safety requirements needed to bring speedskating to the Paralympic world. The goal is to enhance both performance and safety, thereby enabling para-athletes to fully engage in the world of speedskating.

Inclusivity and adaptivity are essential in the athletic world, both of which foster a sense of belonging and equality. By allowing individuals with lower limb deficiencies to participate in speedskating, the sport can once again break down barriers and stereotypes, deeply enriching the athletic community with diverse perspectives and experiences. Creating equal opportunities in speedskating, irrespective of physical ability, promotes fairness, unity, and a sense of mutual respect. This contributes to a more equitable and harmonious society.
The driving force behind this project arises from the recognition of the transformative power of athletics in an individual's physical and mental well-being, alongside the camaraderie built through the promotion of inclusivity. Despite significant advancements in prosthetics for other sports, speedskating continues to remain largely untouched by such technological advancements and innovations. This research aims to address this gap, contributing to the broader goal of inclusivity and accessibility in speedskating.

By advancing prosthetic design and innovation, this study aspires to contribute to the empowerment of athletes of all abilities to participate in all that speedskating has to offer and encourage them to pursue other interests while enriching the sport's diversity and legacy. This research aims to boost accessibility to a sport buried in the minds of most. By advancing the frontiers of prosthetic design and innovation, this prosthetic will paint the lasting impact of speedskating as an inclusive sport by increasing the demographic to which speedskating is available.

Methods

In speedskating the curvature and bend of a skater's blade, referred to as the rocker, and simply the bend, are crucial. The rocker denotes the blade's edge curvature, facilitating the skater's ability to turn. While a smaller radius allows for a sharper turn, it also reduces the area of the blade in contact with the ice. Consequently, a larger rocker is preferred to maximize the amount of blade in contact with the ice. The blade is also bent to the left to aid in the skater's navigation of the bend of the track's curvature. The design of this prosthetic must integrate these elements to be effective.

The primary objective in designing this prosthetic speedskate was to model its functionality closely to that of a conventional speedskate, focusing on joint mobility to mitigate any potential stress and injuries that could be caused by faulty movements. Key goals included ensuring the comfort of the skater, allowing the skater to exert adequate power on the ice, and enabling a full range of motion for the ankle to utilize the curve of the edge and the bend of the blade effectively.

Analyzing existing prosthetic designs, such as the speedskate previously mentioned, and a prosthetic hockey skate, provided valuable insights applied in this design. More specifically, the design of the hockey skate prosthetic utilized a metal plate as the bottom of the skate, foregoing a cover to mimic the skater's other skate. This indicated that the prosthetic's shape

was not crucial to its functionality. However, the shape of the prosthetic affected the skate's maneuverability. The user of this hockey skate prosthetic noted that it was difficult to change direction and skate backward, highlighting the need for unrestricted mobility to safely navigate the ice.

Two functionalities were identified as crucial: plantar/dorsiflexion and inversion/eversion. The hockey and preexisting speedskate previously mentioned lacked both. By incorporating these functionalities into this research's prosthetic speedskate, ankle mobility would exist, allowing for lean in the bend and utilization of the curvature and bend of the blade, ultimately facilitating smoother turns.

The preliminary design of this study was based on the design of an earlier prosthetic skate that had its flaws. The prosthetic was characterized by a triangular base for stability, but it notably lacked ankle flexion. Their design was inadequate as speedskaters spend most of their time with their ankles flexed. To address this, the prosthetic designed in this research used a flexible carbon fiber bridge, similar to the blade on a runner's prosthetic. This bridge, made from layered carbon fiber, would be durable yet flexible, allowing the skater to apply power down into the ice effectively and efficiently.

The triangular base's limitation in the skater's mobility prompted this redesign. The carbon fiber plate was attached near the ball of the wearer's foot. The bridge curbed upward, with a flexible connection at the front, and an open heel to allow for flexion. Through this configuration, the skater is granted a greater and more focused center of control over their extended push, similar to long track speedskating. To prevent the over-flexion of the carbon fiber, an optional damper may be placed below the heel, and a restrictor above the plate to limit forward flexion, but neither is necessary for the functionality of the design, although, elements ensure that the blade remains within a beneficial range of motion, reducing the risk of injury.

While the carbon fiber bridge could not provide the user with the full range of motion necessary for efficient speedskating, the speedskate designed for this study contains an additional mechanism that allows for the inversion and eversion typically seen in the ankle joint. A steel box is attached to the top of the prosthetic to the carbon fiber bridge. This box, the innovative ankle device, pivots left and right, supported by extension springs to maintain the skater's stability. The preference for extension springs over compression springs is due to the instability provided by compression springs. Essentially, the use of compression springs would allow the speedskater to "bounce", providing unnecessary instability. The extension springs provide resistance to movement, keeping the skater stable in an upright position, yet extending slightly depending on the spring constant to allow the ankle device to flex and enable the user to apply a strong push. To protect the knee joint of the wearer's residual limb, it is important to maintain constant ankle mobility, not only to prevent the twisting of the knee and the potential for a torn tendon or meniscus but also to absorb stress and shock. The springs allow the speedskate to absorb the additional shock of the skater pounding their feet on the ice. This both enhances comfort and reduces the risk of injury by lessening the amount of stress placed on the knee. By integrating all of these features, this design provides a functional, safe, and effective prosthetic that enables para-athletes to participate fully in speedskating.

Working Design

The final design of the prosthetic speedskate is a groundbreaking device that enables below-the-knee amputees to participate in speedskating, a sport already obscured from the world. This prosthetic skate features a flexible carbon fiber bridge coupled to a steel plate, which mounts to the cups of the skater's blade. Moving up the prosthetic, the ankle device is connected to the flexible bridge, and a universal pyramid adapter is attached to the top to allow the user to connect the prosthetic speedskate to their existing prosthetic leg at the limb socket. In a more detailed analysis, it is apparent that the ankle component consists of a lower and upper ankle bracket, both of which are connected by springs and mounted onto spring anchors. These springs, extension not compression, enable the ankle device to resist changes in motion, reducing the amount of bend in the ankle joint and the steepness of the angle created with the ice. The springs are additionally used to restore the ankle to the neutral, upright position.

The device includes adjustable links that allow the user to modify the spring length or swap them out with springs of a higher or lower spring constant based on the skater's strength and mass. This flexibility supports movements such as dorsiflexion, plantar flexion, eversion, and inversion, all essential ankle motions. The flexible carbon fiber bridge takes care of some of these movements and enhances ankle mobility by permitting the slight dorsiflexion and plantar flexion of the prosthetic skate. The collaboration between the ankle device, springs, and the carbon bridge provides the necessary mobility for effective speedskating.

This prosthetic speedskate prototype closely mimics a standard short track speedskate but can be adapted for long track speedskating. For a short track, however, this prosthetic allows the user to maintain essential ankle movements, experience stability during technical and high-speed maneuvers, and finally, adjust the prosthetic based on each individual's needs and preferences. In addition to these basic functionalities, the design incorporates advanced features to optimize an athlete's performance. These features are the modular spring system, a system that is highly customizable for both comfort and control, a shock absorption mechanism that reduces the impact of skating on the residual limb to prevent injuries, enhanced grip, and traction through the intentional exploitation of the bend and rocker, and finally, the lightweight construction through the use of carbon fiber to increase the comfort of the prosthetic and make the prosthetic easily maneuverable.

Conclusion

The development of a prosthetic speedskate marks a significant milestone in adaptive sports technology, but also in the world of speedskating. This research aimed to design a prosthetic that mimics the complex biomechanics of speedskating to enable amputee athletes to participate in this high-intensity sport effectively. More common materials were used to potentially keep manufacturing costs down and keep the device accessible. The design incorporates key elements of a flexible carbon fiber bridge, an adjustable ankle device, and a universal pyramid adapter to ensure a balance between stability, mobility, efficiency, and accessibility. While the technological side of this design is groundbreaking, whether it is the modular spring system or the enhanced safety features, the most important aspect of this design is the promise it holds for future generations of athletes. By providing a functional and high-performance prosthetic speedskate, this design opens up speedskating to a broader range of participants. Speedskating has traditionally remained inaccessible to many due to both its

physical and financial demands, but also due to the lack of suitable adaptive equipment, through this research and design, it is feasible that this gap will shrink, making speedskating a more inclusive and adaptive sport.

The next step in this line of research should focus on refining this speedskate's design based on user feedback, and extensive field testing should occur to optimize the prosthetic's performance. Collaborations with professional athletes, prosthetists, and engineers will be crucial to the continuation and evolution of this prosthetic to meet the highest standards of competitive sport. Through the continued innovation and dedication of the world of speedskating, we can ensure that the exhilarating experience of speedskating is accessible to everyone.

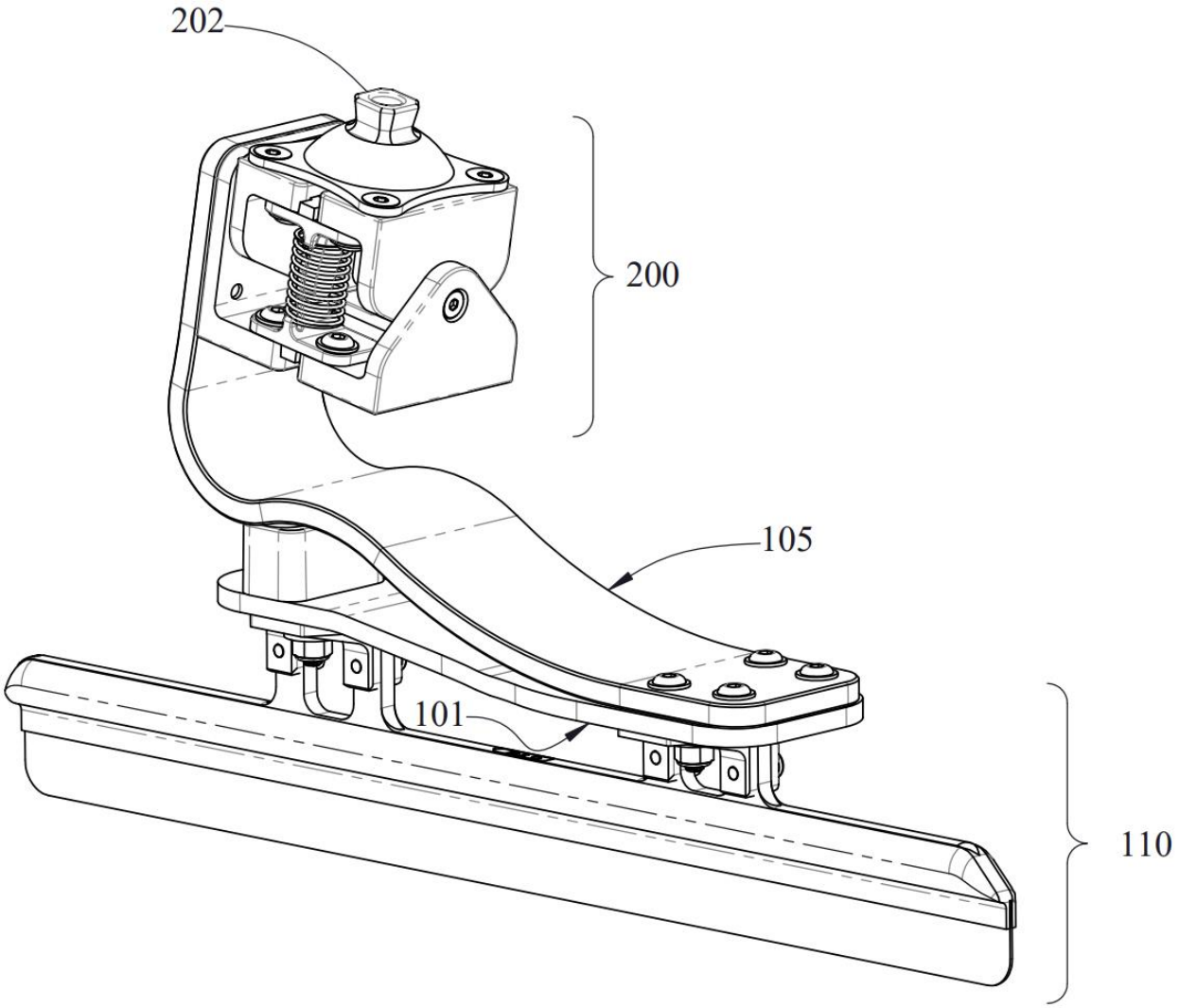

FIG. 1

This design is currently patent pending. Learn more with patent number: 63680036