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Assistive Wearable Lower Limb Robotics: A Review

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Abstract: Assistive wearable lower limb robotics, including exoskeletons and wearable robotic devices, enhances mobility and rehabilitation for individuals with lower limb disabilities. This review provides an overview of the state-of-the-art in this field, focusing on recent advancements, challenges, and future directions. It explores various wearable robotic systems, such as exoskeletons, soft robots, and active orthoses, examining their design, actuation, sensing, control, and interfaces. The review thoroughly examines the clinical implications of these technologies, particularly in neurorehabilitation, gait training, and mobility assistance. It also discusses challenges like power autonomy, user comfort, adaptability, cost-effectiveness, and regulations. By offering a comprehensive overview, this review aims to inspire further research and innovation in assistive wearable lower limb robotics by highlighting progress made and identifying areas for improvement. Ultimately, integrating wearable robotics into clinical practice can significantly enhance the quality of life for individuals with lower limb disabilities, promoting independence, mobility, and functional recovery.
Keywords: Active orthoses, Assistive Exoskeletons, Lower Limb, Wearable Robotics

1. Introduction

At the nexus of robotics, biomechanics, and rehabilitation, assistive wearable lower limb robotics has evolved as a paradigm-shifting field. The goal of this quickly developing field is to create intelligent robotic devices that enhance the physical capabilities of people who have mobility issues, allowing them to regain independence and enhance their quality of life. Due to its potential to transform the area of rehabilitation, these wearable robotic systems, also known as exoskeletons, have drawn great interest from researchers, doctors, and people with mobility issues [1]–[5]. Full lower limb exoskeletons and partial lower limb exoskeletons are two different types of assistive exoskeletons. The number of human joints that a device runs parallel to is the distinguishing factor. For instance, the hip, knee, and ankle joints of a full lower limb exoskeleton all have joints. The joints that act in conjunction with the knee or ankle joint are the main focus of partial lower limb exoskeletons [4].

Soft wearable robots, sometimes referred to as soft exosuits or soft robotic exoskeletons, are a type of robotic device that is worn by people to improve their physical capabilities or help them complete particular jobs. Soft wearable robots, as opposed to conventional rigid exoskeletons, interact with the wearer in a more pleasant and natural way by using flexible and lightweight materials that are frequently modeled after biological components [6]. Active orthoses, also known as active orthotic devices or powered orthoses, are wearable devices that provide assistance or augmentation to the wearer's physical movements. These orthotic devices incorporate active components such as motors, sensors, and control systems to actively interact with the wearer and provide targeted support or movement assistance [7].

The aim of this review paper is to provide a comprehensive overview of the current assistive wearable lower limb robotics, highlighting recent advancements, challenges, and future directions. By examining the existing body of knowledge and research in this area, we seek to offer insights into the development and application of wearable robotics for individuals with lower-limb disabilities. In recent years, significant progress has been made in the design, control, and functionality of wearable exoskeletons. Researchers have explored various approaches, including robotic exoskeletons, soft wearable robots, and active orthoses, each with its own set of advantages and limitations. These devices can be tailored to address specific impairments, such as paralysis resulting from spinal cord injuries, stroke, or musculoskeletal disorders. They provide external support and assistance, promoting mobility, improving gait patterns, and reducing the effort required for walking and other activities. This review will delve into the technical aspects of assistive wearable lower limb robotics, covering topics such as mechanical design, actuation systems, sensing technologies, control algorithms, and user interfaces.

The structure of this paper is as follows: In Section 2, full lower limb exoskeletons are shown. Section 3 presents partial lower limb exoskeletons. The challenges that these robots must overcome are outlined in Section 4. Finally, Section 5 provides a summary and concluding observations.

2. Full Lower Limb Exoskeletons

A wearable exoskeleton suit called the Hybrid Assistive Limb, or HAL (Cyberdyne Inc., Tsukuba, Ibaraki Prefecture, Japan), is made for a range of uses, including treatment, medical assistance, and emergency relief [4]. The HAL is made of a rigid frame with active and free joints that connects to a user's hips and legs using cuffs and belts. [8]. Two complementary systems work together to provide control; one activates the actuators, and the other records the operator's gait patterns in memory. Data from EMG (Electromyography) sensors, GRF (Ground Reaction Force) sensors, potentiometers, gyroscopes, and accelerometers are used to power the control system [9]. The most recent commercially available version, HAL-5, adds enhancements to the exoskeleton's upper limbs (CYBERDYNE Inc., Japan). With this improvement, an operator can move loads up to 40 kg heavier than they could before HAL. HAL-5's most recent iteration is only meant to be worn on one side of the body [10].

Researchers from Fujita Health University in Toyoake, Japan, first came up with the idea for the WPAL (Wearable PowerAssist Locomotor) with the intention of enabling safe and organic walking for people with paraplegia [11]. It has bilateral motors for the hip, knee, and ankle joints and can walk at a speed of 0.36 m/s. To make it easier to use with a user's own (standard-width) wheelchair, the primary structural difference is the positioning of the motor, which is now medial rather than lateral. Additionally, the system is relatively modular; while the user is in the wheelchair, flexible inner thigh cuffs can be worn. These cuffs easily articulate with the rest of the exoskeleton, which folds and can be transported in a rolling bag. The gait controller's initial design was based on the minimal jerk standard to make computing a smooth gait trajectory as easy as possible. Inverse kinematics was used to calculate joint angles. For control and security, the unit is attached to the walker [11], [12].

Sogang University has proposed an assistive device called EXPOS that includes an exoskeleton and a caster walker with four active joints for elderly locomotion assistance [5]. A lighter system with a reduced volume was the aim of the research in order to make it more comfortable to use during daily activities. The exoskeleton's overall weight is no more than 3 kg. The castle walker is filled with all the heavy components, including the motor, battery, and controllers. Later, a more sophisticated version of EXPOS called SUBAR (Sogang University's Biomedical Assistive Robot) was created. SUBAR can offer more efficient assistance because of its enhanced actuation power and a transmission system designed to reduce impedance [13]. SUBAR was given a control algorithm that was modeled after aquatic therapy, and this algorithm was experimentally validated [14].

The Indego (Parker Hannifin Corporation, Macedonia, OH), developed by Vanderbilt University researchers, assists in gait for people with lower limb weakness or paralysis brought on by SCI (Spinal Cord Injury) conditions. Unlike other exoskeletons, the Indego has separate right and left leg segments for the thigh and shank, as well as five modular hip segments [15].These parts can be combined to fit a person's anthropometrics and are available in three different sizes. Because of its modular construction, the Indego may theoretically be put on and taken off in a wheelchair if there is enough room. Movement is powered by four motors, one at each hip and knee joint. Ankle-foot orthoses are also included to assist both ankles [16]. The Indego features three operating modes (sit, stand, and walk), each of which has two states (standby, which allows a user to pause between modes, and Go!, which allows a user to change modes). A wireless tablet application allows therapists to modify control settings for gait, feedback, and other factors. Based on postural signals and shifts in the user's center of gravity, the Indego's control system, which collects and analyzes data from embedded sensors distributed throughout the exoskeleton, calculates the user's desired movements [15]–[17].

eLEGS, an assistive device that helps persons with paralysis to stand up and walk, was introduced by Berkeley Bionics (USA) in 2010 [18]–[20]. eLEGS is mostly based on HULC and actively assists knee and hip flexion and extension [18]. To lessen the abnormal posture the patient suffers, the hips are loaded with stiff elastic components during abduction and adduction, and the ankle is spring-loaded during toe drop. Pressure sensors under the soles, potentiometers, and an accelerometer/gyroscope board on the torso, which measures the angle of the torso in the sagittal plane, are some of the sensing modalities used by the system for control. With eLEGS, crutches are necessary. Specially designed for usage with paraplegics, this device.

The Robotics & Human Engineering Laboratory at the University of California, Berkeley created the Ekso, a lower extremity exoskeleton, with funding from the Department of Defense and license agreements with Lockheed Martin Corporation. It was referred to as the BLEEX (Berkeley Lower Extremity Exoskeleton) and subsequently eLEGS in earlier versions. Its primary parts include foot, shoulder, chest, and backpack straps, as well as motorized hip and knee joints, passive ankles, lithium-ion batteries, and femoral and tibial shanks to support body weight [21], [22]. Its control system consists of an LCD controller navigation panel that the physical therapist can utilize to regulate weight-shifting objectives. Targets can be adjusted wider or narrower so that a user must move farther to activate a step [22]. The Ekso has a unique feature called variable assist software that enables therapists to customize the machine's level of assistance to each user's specific needs [23].

Mina is a second-generation robotic gait orthoses for the lower extremities that was created and constructed by scientists at the IHMC (Institute for Human and Machine Cognition)[24]. For a total of four actuators, it has two actuated degrees of freedom in each leg: hip flexion and extension and knee flexion and extension. No hip adduction, medial or lateral rotation of the leg is offered by Mina. A stiff back plate with the same curvature as the human spine makes up Mina's torso portion. The Mina is made to fit a variety of body types. Adjustments are made to the structure to fit the user by using nested aluminum tubing as the structural linkages. An embedded computer system located on the back plate controls Mina [24], [25]. At the moment, Mina can enable paraplegics to walk at rates of up to 0.20 m/s. The Mina v2 exoskeleton is the most recent model [26].

The MindWalker is a project being worked on by the Department of Biomechanical Engineering at the University of Twente in Enschede, Netherlands. It intends to give paraplegics with crutch-free ambulation at up to 0.80 m/s [27]. Human-machine coupling is tight at the feet and pelvis and loose at the thighs, shanks, and torso in order to maximize comfort and account for offsets between human and machine joints. Along with powered hip abduction and adduction, knee flexion and extension, spring-assisted ankle plantar and dorsiflexion, and hip internal and external rotation, this device also includes hip flexion and extension. The rotational motion of the joint is powered by linear joint actuators, which were specifically created to maximize power to weight ratios and are back-drivable [27], [28]. By establishing brain-neural computer interfaces, MindWalker works on the user command center of mass control approach for walking [27].

A lightweight, user-friendly technology called the Austin exoskeleton was created by the University of California, Berkeley to help paraplegic people walk. A mechanical hip-knee coupler and a single actuator are used by the suit in each leg to power the knee during the swing phase and give powered assistance for sitting and standing. By integrating gait generation into the hardware, the Austin design reduces controller complexity in addition to the exoskeleton's weight and cost [29], [30]. This device could reach a larger audience than current exoskeleton systems by giving paraplegic people a dependable, affordable mobility alternative [30].

Amit Goffer, PhD, directed the development of the ReWalk (ReWalk Robotics, Inc., Marlborough, MA) in 2006. It is a lower extremity-powered exoskeleton that enables people with SCI who have lower-level or thoracic motor completion to walk on their own [29]. The ReWalk was made up of a motorized exoskeleton, a battery pack, a backpack-style computer controller, a wireless mode selector, and a number of sensors that monitored ground contact, joint angles, and upper-body tilt. The battery and the main computer both have built-in backup systems. The exoskeleton is articulated to foot plates distally and to a sacrum band proximally, features hinged knee joints, and bilateral lateral uprights for the thigh and leg [31]–[33]. For software control, a closed-loop algorithm is employed. Instead of using motors to regulate movement at the hip and knee joints, the ankles are articulated using a mechanical joint with spring-assisted dorsiflexion. Walking speed is 0.60 m/s [32].

To address lower limb paralysis and weakness, New Zealanders created the REX (Rex Bionics Ltd., Auckland, New Zealand). The business creates two products: the REX-P for personal use at home and the REX-Rehab for use by therapists during training sessions. The REX, which weighs about 48 kg and is one of the largest and heaviest exoskeletons in this evaluation, allows the user to move, albeit extremely slowly, without the need of an upper limb support or crutches. The apparatus includes two tethered leg straps, an upper harness, and extra abdominal support. Although it has been tested with a computer-brain link utilizing an electroencephalogram, the controller is a joystick [34], [35]. The REX is meant to provide movement assistance rather than walking, enabling users to engage in standing therapeutic activities [36].

The ROBIN was created in South Korea to help paraplegic individuals recover and improve their quality of life [37], [38]. It has a rather conventional design with a stiff frame fastened to the legs, bilaterally powered hip and knee joints, passive ankles equipped with control-enhancing spring-assisted dorsiflexion joints, and a backpack housing batteries and control gear. Crutches are necessary to keep your equilibrium. The employment of an array of eight force sensors, one in each crutch and beneath each foot to determine user intent and encoders in actuated joints to determine position, is one distinctive feature. The user's on-body backpack houses the primary controller and batteries. To give the exoskeleton a more ideal stride, the developers have used this to construct quite complex walking intent detecting algorithms[37]. The ROBIN-H1 device, which was "designed as a walking rehabilitation device for stroke patients" and appears to be consistent with the initial ROBIN exoskeleton previously mentioned, has since made an appearance [38], [39]. This device was employed as a gait measurement tool in a study that found artificial neural network algorithms may take the place of force sensor-based inputs in giving control of the apparatus.

The world's lightest exoskeleton of its kind, the Phoenix exoskeleton (SuitX, Berkley, USA) enables people with mobility problems to move and stand erect. Phoenix has been successful in enabling a lot of people to stand up, move around, and speak to peers' eye-to-eye at the clinic, at home, and at work [40]. The knee joints on Phoenix are made to allow for support during stance and ground clearance during swing; the hips only have two actuators. This exoskeleton is one of the most affordable and has features that are similar to those of the exoskeletons mentioned above, but it also has one disadvantage: it has an external power backpack that also houses the computing system. Additionally, for the patient's safety, the manufacturer also offers external support crutches that contain the trigger for the device that controls the exoskeleton's mechanisms [40], [41].

In Table 1, more details about full lower limb assistive exoskeletons are provided.

Table 1 Full lower limb assistive exoskeletons

Name of Devise	Targeted Group (Use)	Actuator type	DOF	Control modes and device functions
HAL[8]–[10]	Locomotion assistance and rehabilitation for individuals with incomplete SCI or who have paralysis due to stroke	DC motors	6 DOF, 4 actuated, 2 hips and 2 knees, 2 passive ankles	EMG is used to control phased sequence control, which generates a series of assistive motions with the exoskeleton being the master in the master/slave system
EXPOS [5], [13], [14]	Assisting the elderly and patients	DC Motor-cable driven	6 DOF, 4 actuated, 2 hips and 2 knees, 2 passive ankles	Fuzzy controller
Indego[15]–[17], [42]	Locomotion assistance for people with SCI and paraplegia can be split into three pieces and then coupled	DC brushless motors	4 DOF, 4 Actuated, 2 hips and 2 knees. Standard ankle orthoses	Lightweight system with reduced assistance and fewer control functions. wireless operation
eLEGS[18]–[20]	Locomotion assistance to rise and down the stairs, is useful in rehabilitation	DC motors	6 DOF, 4 actuated (hips and knees), passive ankle joint	Gesture-based human-machine interface to determine the user's gestural intentions and then act accordingly
Ekso[22], [43]	Locomotion assistive for individuals with SCI, paraplegias	Hydraulic actuators	6 DOF, 4 actuated, 2 hips and 2 knees. 2 passive ankles	Configurable assistance levels ("variable assist") Sit-to-stand, walking, stand-to-sit
Mina [24], [25], [34]	Locomotion assistance for people with paraplegia	DC motors	6 DOF, 4 actuated, 2 hips and 2 knees, passive ankles joint	Rigid position control for paraplegic users and assistive force control for paraparetic users; walking (start, stop, and real-time speed adjustments)
MindWalker [27], [28], [44], [45]	Empower people with paraplegia to stand and walk	DC motors with series elastic actuators	6 DOF, 6 actuated, 4 hips and 2 knees	Works on user command center of mass control strategy for walking, developing brain neural computer interface-based control
Austin [29], [30]	Locomotion assistance for individuals with mobility disorders	DC motors	6 DOF, 2 actuated, hip and knee joints are coupled	Austin exoskeleton systems have a limited range of motions. Austin allows users to stand, walk forward, stop, and sit
ReWalk [32], [33]	Locomotion assistance to people with spinal Cord Injury (SCI), Paraplegia	DC motors	6 DOF, 4 actuated, 2 hips and 2 knees, passive ankles	A closed loop algorithm software control, normal walking mode, sit-stand, stand-sit, up/down steps
REX [34], [36]	Locomotion assistance is provided to individuals with a complete SCI up to the C4 or C5 level	Linear actuators	6 DOF, 5 actuated each leg	Non-invasive brain interface, joystick for controlling the self-balancing system, standing up, walking, sitting down, ascending and descending stairs, and turning without the need for crutches
ROBIN [37], [39]	Locomotion assistance for people with paraplegia	DC motors	6 DOF, 4 actuated, 2 hips and 2 knees, 2 passive ankles	Crutches are instrumented (GRF and inertial measurement) as well as having an inertial sensor on the exoskeleton itself. Sit-to-stand, walking, standing, stand-to-sit, climbing stairs

Phoenix [40], [41]	Addressed to all the people who have lost the use of their legs due to traumatic events, neoplasms, diseases, and neurodegenerative	DC motors	6 DOF, 2 actuated hips	An intuitive interface makes it easy for users to control standing up, sitting down, and walking

- DOF (Degree of freedom)
- DC (Direct Current)

3. Partial Lower Limb Exoskeletons

A novel wearable robotic device called the SMA (Stride Management Assist) System was created by Honda R&D Corporation in Japan [46]. The SMA is a battery-powered, bilateral end effector device that weighs 2.80 kg. It was created to improve gait in people with gait abnormalities and elder people, as well as to facilitate community mobility and social contact [46], [47]. The SMA is worn around the hips and helps in ambulation by independently and actively flexing and extending each hip joint [46]. To help with hip flexion and extension during walking, two brushless DC motors are placed at the axes of each hip joint. The SMA recognizes asymmetry in the hip joint angle and offers torque support to improve the walk ratio (step length/cadence) in time with the user's gait cycle [47].

A wearable robotic device that can be used for gait training is called the Honda Walking Assist Device, or HWA (Honda Motor Corporation, Japan). Actuators are positioned at the hip joint to support flexion and extension motions while walking. The computer calculates the aiding torque to correct the gait once the angular and torque sensors are installed at the hip joint. [48], [49].

Hanqi Zhu et al. design a partial-assist knee orthoses for individuals with musculoskeletal disorders, e.g., knee osteoarthritis and lower back pain. A specially made brushless DC (BLDC) motor is created with encased windings to enhance the motor's thermal environment and subsequently its continuous torque production. With a high packaging factor for reduced weight and a smaller size, the 2.69 kg orthosesis built entirely from components that were designed specifically for it. Because of its compact design, back drivability, and torque output, the orthoses can offer some support without getting in the way of the user's normal mobility [50].

A lower-extremity powered exoskeleton called Keeogo (B-Temia Inc., Quebec City, Canada) is designed to help people with gait impairment get around [51]. Bilateral motors for the left and right knees, a pelvis belt and chariot system to hang the device, and thigh and shank cuffs to secure the exoskeleton "links" to the wearer make up the device [52]. Standing, gait (walking, jogging, and running at top speed), stair ascent and descent, chair rising and sitting, squatting, lunging, and other locomotor tasks are all recognized by the controller. While the hip motion of the gadget is passive, the knee motor helps the user during particular stages of the work but does not start or stop movements. The device can be used in conjunction with other assistive devices, and the shin cuffs can accommodate the majority of ankle-foot orthoses (cane, crutches, walkers, rollators, wheel chairs, etc.)[52], [53]. Keeogo weighs 5.40 kg when the battery pack is attached and worn on the hip [52].

A SR-AFO (soft robotic ankle foot orthoses) that is affordable, lightweight, simple to use, and capable of assisting gait for rehabilitation both in the clinic and outside of it has been proposed by Junghan Kwon and colleagues for poststroke patients. A 3D-printed flexible brace and an ankle support that permit the ankle's normal flexion and extension while offering support in the vertical plane to prevent the structure from buckling are included in the device. Plantarflexion and dorsiflexion were both assisted by a bi-directional tendon-driven actuator. A wearable gait sensing module is also included in the system, which measures the leg trajectory and foot pressures in real time and provides feedback control. The device is completely untethered, making it portable and cozy. It is powered by a rechargeable battery and connects with the primary controller wirelessly. Although there are differences in each person's gait trajectories, real-time gait phase is detected using the observed sensor data and the biomechanics of the legs. A gait aid algorithm then accurately predicts a control phase and timing for both dorsiflexion and plantarflexion [54].

Another assistive robotic device named APO (Active Pelvis Orthoses) was designed to assist people in locomotion by guiding the hip flexion and extension motions, which were proposed in the work [55]. The waist is where the orthoses is worn. The device only weights a little over 5 kg. When equilibrium is lost, inbuilt sensors identify it and automatically activate "assistive mode." The technology can also recognize slippage and prevent it. People will be able to prevent falls and maintain their balance while walking thanks to this kind of mode. Additionally, APO performance has been measured, and the findings show that utilizing the exoskeleton during walking situations uses less energy [56]. It has been demonstrated that the ergonomic assessment of APO and human interaction is reliable and efficient [57]. Today, APO can be considered the best existing robotic device intended for the elderly.

Marta Moltedo et al. Introduce the mechanical layout of a flexible, light-weight AAFO (Active Ankle Foot Orthoses) that can be utilized for therapeutic reasons. The actuator can support the ankle during both plantarflexion and dorsiflexion because it is bidirectional. In contrast to the majority of the currently used AAFOs, the one given is flexible. The connections between the ankle actuator and the user's foot and shank are made to suit the AAFO to various users and to align the ankle joints of the human and robot without the need to construct specialized versions of them. A MACCEPA (Mechanically Adjustable Compliance and Controllable Equilibrium Position Actuator) was used as the ankle actuator, and it has a maximum torque capacity of 25 Nm. Due to the careful design of the actuator components, the total weight of the AAFO is only 1.70 kg. [58].

Table 2 provides an overview and comparison of partial lower limb assistive exoskeletons.

Table 2Partiallower limb assistive exoskeletons

Name of Devise	**Actuator**	**Mass**	**Actuator Torque**
SMA [46], [47]	DC brushless motors	2.80 kg	6 Nm
HWA [48]	DC motors	2.70 kg	4 Nm
Hanqi Zhu et al [50]	DC brushless motors	2.69 kg	10 Nm
Keeogo[52], [53]	DC motors	5.40 kg	40 Nm
APO [55]–[57]	DC motors	5.00 kg	17 Nm
Marta Moltedo et al [58]	DC motors	1.70 kg	25 Nm

4. Discussion

Assistive wearable lower limb robotics, also known as exoskeletons or powered prosthetics, offer tremendous potential to enhance mobility and quality of life for individuals with lower limb disabilities or injuries. However, there are several challenges that need to be addressed for these technologies to reach their full potential. Here are some key challenges associated with assistive wearable lower limb robotics:

4.1. Design and Ergonomics

Developing exoskeletons that are comfortable to wear for extended periods is crucial [59]. The devices must be lightweight, adjustable, and properly fit the user's body to ensure optimal comfort and minimize the risk of musculoskeletal issues.

4.2. Natural Gait and Movement

Achieving natural and intuitive gait patterns is a significant challenge [60]. The exoskeleton should be able to synchronize its movements with the user's intention, adapting to changes in walking speed, terrain, and user preferences. Replicating the complex dynamics of human walking is still an ongoing area of research.

4.3. Power and Energy Efficiency

Exoskeletons require a substantial amount of power to operate, and ensuring a long-lasting and lightweight power source remains a challenge. Advances in battery technology, energy-efficient actuation systems, and energy recovery mechanisms are essential for extended use without frequent recharging or cumbersome power supplies [61], [62].

4.4. User Interface and Control

Developing user-friendly interfaces and control systems that allow individuals with varying degrees of physical ability to operate the exoskeleton effectively is critical [63]. Intuitive control mechanisms, such as brain-computer interfaces or adaptive control algorithms, can simplify the interaction between the user and the device.

4.5. Adaptability and Customization

Human bodies have diverse shapes, sizes, and mobility requirements. Creating assistive wearable robotics that can adapt to individual anatomies and provide customizable levels of assistance is a significant challenge [64]. Personalization should be considered for optimal fit, joint alignment, and support during different activities.

4.6. Cost and Accessibility

Affordability and accessibility are crucial factors in the widespread adoption of assistive wearable lower limb robotics [65]. Reducing manufacturing costs, leveraging mass production techniques, and exploring avenues for insurance coverage or funding support are essential for making these technologies more accessible to a broader range of users [66].

4.7. Social Acceptance and Psychological Factors

Wearing an assistive robotic device can have psychological and social implications [67]. Overcoming stigma and promoting acceptance among users and the general public are important for enhancing the psychological well-being and integration of individuals using these devices [67], [68].

Addressing these challenges requires collaboration among researchers, engineers, healthcare professionals, and end-users to ensure that assistive wearable lower limb robotics can effectively meet the needs of individuals with lower limb disabilities, improve their mobility, and enhance their overall quality of life.

5. Conclusion

In conclusion, this review paper has provided a comprehensive overview of assistive wearable lower limb robotics, highlighting their potential to revolutionize the field of rehabilitation and enhance the quality of life for individuals with lower limb impairments. By examining various aspects of this technology, including design, control systems, sensory feedback, and clinical applications, the paper has shed light on the advancements made in recent years.

The review emphasizes the significant benefits offered by wearable lower limb robotics, such as improved mobility, enhanced gait patterns, reduced muscle fatigue, and increased independence. Furthermore, it addresses the challenges associated with the development and implementation of such devices, including power consumption, user acceptance, and cost-effectiveness. The integration of advanced technologies, such as artificial intelligence, sensors, and actuators, has played a crucial role in overcoming these hurdles and pushing the boundaries of assistive robotics.

While significant progress has been made, the review also acknowledges that there are still areas requiring further exploration and refinement. These include addressing issues related to long-term comfort, ensuring intuitive control interfaces, optimizing power sources, and conducting rigorous clinical trials to assess the long-term efficacy and safety of these technologies.

In summary, this review paper highlights the tremendous potential of assistive wearable lower limb robotics in augmenting human capabilities and enabling individuals with lower limb impairments to regain mobility and independence.As technology continues to advance, it is expected that wearable robotics will become increasingly sophisticated, affordable, and seamlessly integrated into clinical practice. With continued research, collaboration, and innovation, the future holds great promise for the field, ushering in a new era of assistive technologies that positively impact the lives of countless individuals.

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