Chapter 26

ASSISTIVE DEVICES FOR SERVICE MEMBERS WITH DISABILITIES

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INTRODUCTION

Assistive devices provide essential support for people with disabilities, allowing them to participate in community, vocational, and recreational activities and to perform activities of daily living (ADLs). A service member with a severe disability will likely rely on a variety of assistive devices to maximize function and independence. It is critical to properly fit the technology to the individual and train the user to effectively manipulate it. The availability of transportation (personal or public), accessible housing, personal assistance services, and assistive technology (AT) are among the most critical factors to be addressed once the acute rehabilitation phase has been completed.

A team approach is most effective when assessing an individual for AT. Ideally, the clinical team includes a physiatrist, therapists (physical, occupational, and speech), a rehabilitation engineer, a vocational rehabilitation counselor, and a rehabilitation technology supplier. The service member and family should be at the center of the team and ultimately decide on the most appropriate technology. This will often require patient education, but eventually many people with disabilities gain considerable knowledge about their AT needs.

The goal of AT is to allow the individual with the disability to perform activities as independently as possible in a variety of situations and environments. A thorough AT assessment includes evaluating the individual's physical abilities (eg, strength, endurance, flexibility), cognitive abilities (eg, decision making, information processing, comprehension), sensory function (eg, vision, hearing, sensation), living environment (eg, home, work, school), support systems (eg, family assistance, paid assistance), and affect (eg, acceptance of disability, participation in process).

AT has been shown to be associated with successful rehabilitation outcomes. As injuries become more severe and the resulting disabilities greater, an individual's need for AT grows. Social support becomes more important as the severity of the injury and disability increases. Although there are methods for severely injured service members to receive paid personal assistance, it is often family members who provide the bulk of their care, especially in the early years. AT provides independence and reduces the exertion placed on others. For example, powered wheelchair seating functions can allow an individual with a disability to change position to increase comfort or alter pressure without relying on the assistance of others.

When making recommendations for AT, consideration must be given to the home environment and fixed and movable features.[1–3] Ramps, stair lifts, and widened doorways may be needed to allow effective use of some devices within the home. Moveable features, such as furniture, can be rearranged to allow access pathways through the home and, in some cases, may need to be replaced. For example, it is more difficult to get in and out of a soft low couch than a higher recliner with armrests. Community activities also need to be included in a thorough evaluation. Community-based tasks, such as shopping, using automated teller machines, and eating in restaurants, all provide important insight into AT needs and associated training. It is also important to provide exposure to integrated activities, such as skiing, hand cycling, swimming, and playing billiards, because they build self-confidence and help individuals adjust to a new self-image. It is easy to forget that travel is also an important community activity. Individuals with disabilities should be taken to events during their rehabilitation that require an overnight stay in a hotel so they can learn to perform tasks outside the structure of their homes.

Very severely injured soldiers and their families present with some unique needs and situations. Typically, severely injured soldiers must adjust to loss at a young age. These losses may include limbs, bodily functions, friends, and separation from the military unit that has served as a source of support. Losses may be complicated by the service members' duty status (National Guard, reserve, active duty) and proximity to their duty stations or homes. Soldiers and their families have unique social support systems, such as their units, other soldiers, veterans' service organizations, various Department of Defense programs, and the Department of Veterans Affairs. Each can make important contributions and bring resources to the severely injured soldier. It is also important to consider the preinjury socioeconomic status of the severely injured soldier, because this may impact the ability of the family to provide support and therefore influence the living environment. Soldiers have a unique occupation and even after sustaining severe injury, some want to return to active duty. AT may help some individuals pursue this career choice, while others may need to be guided toward other occupations.

Individuals with lower limb loss are likely to use multiple assistive devices, and the types of devices they use are likely to change over the individual's course of rehabilitation and lifespan. Nearly all service members with lower-extremity amputations will start out using wheelchairs, often in combination with prosthetic limbs. The wheelchair will serve as their source of mobility as they learn prosthetic ambulation skills. Some people will progress to the point where they will only require the wheelchair on rare occasions (eg, people with unilateral transtibia amputations), whereas others may decide to use their wheelchairs as their primary means of mobility (eg, those with short bilateral transfemoral amputations). Over a lifetime, comorbid conditions may make it necessary to rethink the individual's technology needs. For example, a manual wheelchair user may transition to an electric-powered wheelchair (EPW) because of severe shoulder pain from repetitive strain injury,[4–9] or a prosthetic-limb user may transition to a manual wheelchair because of reduced metabolic capacity.[10–14] A substantial challenge for service members to overcome is their own perceptions of disability and their potential to reintegrate into society, including active duty, and to return to an active lifestyle. Few service members have experience with disability, and many may base their views on popular perceptions and stereotypes. One goal of rehabilitation is to help the wounded, injured, or ill service member adapt and objectively evaluate the pros and cons of AT in pursuing their life goals.

Like other areas of rehabilitation, AT services are best provided using a team approach.[2,15–17] Individuals with disablities and their families are critical members of the rehabilitation team, and they should set the goals. The ideal prescription process includes six steps:

1. The clinical team assesses the user's impairments, diagnosis, prognosis, residual abilities, extent of social participation, goals of wheelchair use, financial resources, priorities (trade-offs will invariably be necessary), and dimensions.
2. The clinical team and user develop a generic list of ideal AT features.
3. The ideal-feature list is compared with items available from a reputable manufacturer and that can receive reliable service.
4. The user tests the device under consideration in the presence of a member of the clinical team.
5. Once the appropriate AT has been selected, the user is trained in its optimal use (including static indoor and outdoor challenges, or simulations thereof) and the results of training are documented.
6. After the AT has been used for a few months (and periodically thereafter), the situation should be reviewed and adjustments made.

Ideally, an AT team includes a physician, therapist, AT supplier, and rehabilitation engineer. Each professional has a unique but complementary role and, in cooperation with the end user, provides a comprehensive view of the AT needs. Physiatrists make the best physicians on AT teams because of their residency training and the opportunities that AT provides to benefit people with disabilities. The increasing complexity of AT selection, justification, fitting, tuning, and training requires specialized knowledge. Physical therapists are well qualified to assess physical capacities and limitations, especially as they affect mobility. Occupational therapists can assess functional capacity and deficits in performance of basic and instrumental ADLs. It is important to know how people perform tasks, where they are deficient, and how AT can compensate for the deficits in order to augment task performance. Rehabilitation engineers have an important role in understanding the capabilities and application of various technologies to assist in the selection process and product design. It is also important to include a qualified equipment supplier early in the rehabilitation process because the supplier will be familiar with the available devices and how they can be applied to solve problems.

The Rehabilitation Engineering and Assistive Technology Society of North America (RESNA) acknowledged the need for consumers and insurers to recognize individuals with relevant experience and specialized knowledge. RESNA has created three levels of credentials to help enssure that consumers and insurers receive reliable information about AT. The AT supplier credential is intended for distributors and manufacturer representatives of AT. This is the most important credential offered by RESNA because it has started to bring order to an area of AT that was previously largely unregulated; before RESNA created the certification, there was no reliable credential for a supplier or manufacturer representative to demonstrate competency, and no way for consumers to readily identify qualified suppliers. The AT professional credential is geared toward therapists (physical, occupational, speech–language, counselors, and special educators). This credential recognizes qualified clinicians for their specialized knowledge and expertise. For decades, rehabilitation engineers provided clinical services without formal recognition of their expertise and, in many cases, their services were not reimbursed by insurance agencies. The rehabilitation engineering technology credential addresses the needs of rehabilitation engineers and provides other professionals and consumers a way to recognize them. To obtain the rehabilitation engineering technology credential, the engineer must also have obtained the AT professional credential. All of the RESNA credentials require proof of relevant experience and a passing score on a comprehensive examination. The credentials appear to have improved the quality of available AT services.

WHEELCHAIRS: SELECTION, FITTING, AND SKILLS TRAINING

Mobility devices, in particular wheelchairs and scooters, make up a significant portion of the assistive devices in use today.[2] Manual wheelchairs are mainly used by individuals who have the necessary upper body strength, function, and stamina for everyday propulsion.[7,10,14,18] Comorbid conditions, such as excessive body weight, overuse of the upper limbs, long time living with a disability, and poor health and nutrition, can impair a user's ability to independently propel a manual wheelchair, making EPWs more functional. For individuals who cannot use power wheelchairs, a manual wheelchair is prescribed and mobility is facilitated by an attendant or caregiver.

Only wheelchairs that comply with RESNA or International Standards Organization standards should be recommended. These criteria are intended to ensure minimal quality.[19] Best results are often obtained through independent testing conducted within a reputable testing laboratory.

Manual Wheelchairs

Design is critical to a manual wheelchair user's mobility because upper body strength needs to be sufficient to bear the load of the wheelchair in addition to the individual's bodyweight.[4,5,7,9,19] Standard manual wheelchairs (typically used in hospitals and nursing homes) tend to be bulky, heavy, and generically sized. They have the benefit of folding, which allows for simple storage and transportation. However, the seat and backrests are sling upholstery, which provides little comfort and does not relieve pressure. These wheelchairs are not intended for long-term use, but rather for temporary use of less than a few hours a day. Strong, ultralight wheelchairs have been designed for individuals requiring long-term use.[2,19–21] These wheelchairs can be customized to fit the user, allowing for better comfort and mobility. They are typically made of materials such as aluminum and titanium rather than the heavy steel used in standard wheelchairs (Figures 26-1 and 26-2). Ultralight manual wheelchairs are often appropriate for soldiers, who tend to be very active.

The basic features of an ultralight wheelchair include adjustable seat height, width, and depth; backrest height; armrest height; seat and back angles; rear wheel camber; and rear axle position (Figure 26-3). Lightweight wheelchairs have limited adjustability and standard wheelchairs have no adjustability. Manual wheelchair frames are made of aluminum, high-strength steel alloy tubing, titanium, and lightweight composite materials. The frame structure affects durability, transportability, and storage. For example, rigid

Figure 26-1. A standard manual wheelchair with a folding steel frame and sling seat.

Figure 26-2. An ultralight manual wheelchair with a rigid titanium frame.

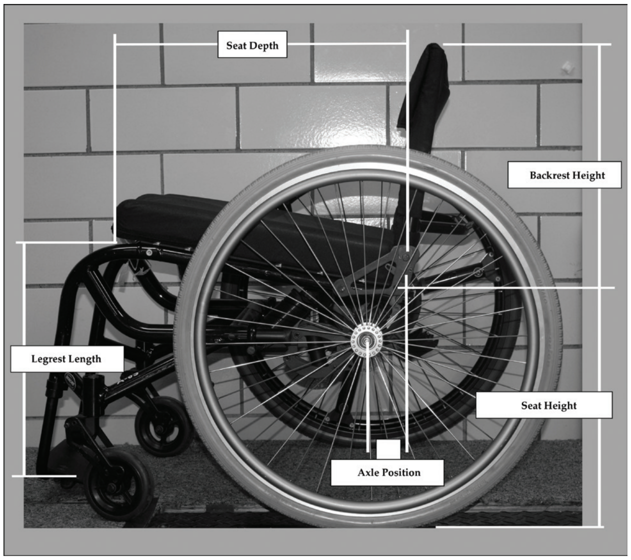

Figure 26-3. Key dimensions of an ultralight manual wheelchair: axle position, seat height, seat depth, backrest height, and footrest length.

frame chairs are one piece with removable wheels and foldable back supports for transport and storage, while cross-brace frames allow the wheelchair to collapse in the middle for storage. Some frames have suspension elements to decrease shock and vibration and make for a smoother overall ride.[22]

In some instances, none of the previously mentioned wheelchairs meets the needs of the user. For example, obese or overweight individuals need a larger, stronger wheelchair to support their weight. This class of wheelchairs is called heavy-duty or bariatric. They can support individuals ranging from 300 to 1,000 pounds.

Seat Height

Seats should be positioned so that leg length is accommodated, leaving about 50 mm under the footrest for obstacle clearance. Seat height needs to be at a level that allows the individual the necessary knee clearance to fit under tables, counters, and sinks.

Seat Depth

Seat depth provides support for the thighs. There should be about 50 mm behind the popliteal area of the knees. Improper depth may cause increased pressures on the thighs or buttocks. Shallow-depth seats increase sitting pressure because there is less contact between the thighs and seat, which may decrease the overall pressure distribution. If the seat depth is too great, pressure behind the knees and on the calves is increased.

Seat Width

The width of the wheelchair seat should be slightly larger than the user's buttocks (about 25 mm). The hands should be able to just slip between the hips and the side guards or armrests. If the seat is too narrow, pressure increases on the sides of the hips, which may result in pressure sores. If the seat is too wide, the user will be forced to use a more abducted arm position for propulsion and will have more difficulty negotiating doorways and narrow passages.

Back Height

A wheelchair's back height depends on comfort and the amount of postural support needed. The backrest should be low enough that it does not impede the range of motion of the arms during propulsion. If the backrest is too high, the user will not be able to contact as much of the pushrim; if it is too low, the user will not have the necessary postural support and may experience discomfort or long-term deformity.

Seat and Back Angles

Seat angle is the horizontal angle between the seat and back, and back angle is the vertical angle between the seat and back with respect to vertical. Both are selected or adjusted to provide the most comfort and support for the user. Increasing the seat dump (declining the seat toward the rear) can help stabilize the pelvis and spine, which may improve propulsion. However, too much dump may increase the sitting pressure on the ischial tuberosities and make it more difficult to transfer from the wheelchair. Increasing the back angle is another way to ensure user comfort. If an individual has difficulty with hip flexion, the back can be opened to alleviate discomfort. However reclining too far can shift the center of gravity, making the chair unstable.

Armrests and Footrests

There are a variety of armrest lengths and styles. The armrest should be positioned at a comfortable height so the arm lies parallel to the ground. Armrests that are too high or too low may cause discomfort in the user's neck and shoulders. Many ultralight wheelchair users prefer not to have armrests because they tend to increase the overall width of the wheelchair, cause the arms to abduct more during propulsion, and may inhibit access to desks and tables. Cross-brace framed chairs typically have foot rests that can flip up or down, swivel, are angle-adjustable, or can be removed, while rigid-framed chairs have the footrest built into the frame. Although these footrests cannot typically be removed, they can be slightly adjusted to accommodate various leg lengths.

Wheels and Tires

A typical manual wheelchair has four wheels, two large rear wheels and two small front wheels called "casters." The casters are usually solid rubber, but can be polyurethane, pneumatic, or a combination. Caster size varies from 50 mm to 200 mm in diameter, depending on the wheelchair type and user preference. The standard rear wheel is a pneumatic 24-inch (0.6096 m) tire. Different tire types are available, such as solid insert tires, semipneumatic, or synthetic. Ultralight wheelchairs have quick release axles so the wheels can be easily removed for repair, storage, and transport.

Rear Wheel Camber

Camber is the amount of rear wheel vertical angle. At 0° camber, the wheels are vertical. To increase camber, the top of the wheel is tilted inward, moving the bottom of the wheel outward. Ultralight wheelchairs have up to 8° of camber, but about 3° camber is typical. Increasing camber provides more stability at the cost of increased wheelchair width. More than 8° camber is seen on many special-purpose sport wheelchairs.

Rear Axle Position

The rear axle position can be adjusted or selected horizontally and vertically. Horizontal positioning affects propulsion ability and technique. Placing the axle position forward allows users to grasp more of the wheel during propulsion. Moving the position further back limits the amount of pushrim that the individual can reach. Moving the axle forward increases the tendency of the wheelchair to tip backward. Users can take advantage of this feature to perform wheelies (when a manual wheelchair user lifts the front wheels from the ground by applying forward force to the pushrims and maintains balance on the rear wheels by forward and backward forces on the pushrims) and traverse obstacles more easily. Antitippers can be added to reduce the risk of tipping backward. Forward axle position also decreases the number of strokes and amount of effort used for propulsion.

Vertical axle adjustments can provide similar propulsion advantages. Moving the axle position up with respect to the seat lowers the seat height, which improves stability. However, if the seat is too low, arm abduction can lead to poor propulsion patterns. An appropriately placed axle can lower the stress on the arms that results from everyday wheelchair propulsion.

Manual Wheelchair Propulsion and Skills

Various features of a manual wheelchair can affect a user's overall propulsion capability.[6,13,21,23] Wheelchair propulsion can be broken down into two components: the propulsion phase and the recovery phase. The propulsion phase begins with the initial hand contact on the pushrim and ends with the release of hand contact from the pushrim. The recovery phase begins with the release of hand contact from the pushrim and ends with the hand contact onto the pushrim.[21] Individual propulsion styles impact push frequency (the number of times the pushrim is contacted over a given distance or for a given time), push length (the distance the hand travels while in contact with the pushrim), push force (the magnitude of force applied to the pushrim in multiple dimensions), and the speed (the distance the wheelchair moves over a given time). Understanding and recognizing the effects of these key components in an individual's wheelchair propulsion style reduces the risk of secondary repetitive strain injuries associated with wheelchair prolusion.[5,6,21,24] Ultimately, the user should be trained to use a smooth, long stroke; a semicircular pattern that corresponds to a decreased push frequency with more time spent on the pushrim; decreased forces; and increased propulsion efficiency.[21,25]

Manual wheelchair skills further enhance the user's safety, efficiency, and independence. Maneuverability and adaptability in multiple environments are key goals of wheelchair skills training. Training may begin with basic skills, such as negotiating obstacles, turning in tight areas, and opening and closing doors—skills needed to allow a person to conduct all mobility-related ADLs within their homes. Eventually, training advances to higher-level skills, including wheelies. The wheelie position is useful for transiently reducing the loads on the ischial tuberosities, decreasing neck discomfort when talking to a standing person, turning in tight spaces, and negotiating obstacles, such as rough or soft ground, inclines, and curbs.

Although engaging in an active lifestyle is beneficial for maintaining quality of life, a majority of wheelchair users are inactive. Using a custom logging device, Tolerico et al studied the wheelchair activity patterns of 52 veterans at the National Veterans Wheelchair Games and in their home communities for a period of 13 to 20 days.[12] They found that individuals traveled

2,457 m/d, at an overall average speed of 0.8 m/s, over 8.3 h/d. Veterans who were employed covered more distance, accumulated more minutes of movement, and traveled a greater distance between consecutive stops than those who were unemployed. Cooper et al examined the activities of two groups of power wheelchair users over a 5-day period.[26] Results indicated that the group of individuals who attended the National Veterans Wheelchair Games was more active in terms of distance and speed traveled compared to a group of subjects monitored in their home environments (Pittsburgh, Pennsylvania). Fitzgerald et al tracked the activities of community-dwelling manual wheelchair users who used pushrim-activated, power-assisted wheelchairs and personal wheelchairs.[13] No significant differences were found in the distance and speed traveled using either wheelchair. Hoover et al[27] collected data from both the National Veterans Wheelchair Games participants and those in their home environments. The speed at which the power and manual wheelchair users traveled was 0.711 m/s and 0.3092 m/s, respectively.

A properly fitted manual wheelchair used by a well-trained and skilled individual can provide a high degree of mobility. Many service members with lower limb amputations can develop remarkable wheelchair skills. Tasks such as negotiating curbs, escalators, stairs, uneven terrain (sand, grass, and gravel), slopes, and narrow spaces are all teachable skills. Wheelchair skills training is a critical component of the rehabilitation and mobility training of individuals with lower limb amputations. Individuals with lower extremity amputations should be thoroughly assessed for wheelchairs and provided training in their use (Figure 26-4).

Figure 26-4. Wheelchair athlete demonstrating advanced mobility skills.

Electric-Powered Wheelchairs

EPWs are indicated for a wide range of individuals with disablities.[28–30] For some individuals with severe sensory–motor impairments (eg, individuals with high-level tetraplegia, traumatic brain injury, or multiple amputations), EPWs are the only functional mode of mobility.[28,29,31] Sensory–motor impairments can limit functional motor control to individual parts of the user's body. In these cases, EPW input devices must be customized to take advantage of the user's intact motor function.[26,29,32] Microswitching mechanisms that can be activated with the mouth (sip-and-puff) or other parts of the body (feet, head, etc) must be used as controller input. EPWs are also indicated for people who are at risk of falling or in pain when ambulating and who cannot safely or functionally propel a manual wheelchair. For these individuals, the EPW represents a safe and pain-free means of mobility.[33] For all users, the goal of the EPW is to provide greater independence and quality of life.[2,30,34,35] As EPWs have become more technologically advanced, they have been able to serve this need for a broader range of people with disabilities.[30,31,34,35] Because people with disablities have diverse and complex needs to achieve independence, customizable EPWs can reach a larger proportion of the population with disabilities.[19,36] The technological advances of controller programmability, special seating systems, and integrated control units (with augmentative communication devices, environmental control units, etc) have allowed a wider population of people with disabilities to become independent.

There are two types of EPW frame designs: traditional (based on a manual wheelchair design) or power-base. Because the manual wheelchair design predates the power wheelchair, the first designs for power wheelchairs included simple power devices added on to manual wheelchairs (Figure 26-5). These devices still exist, especially for portable EPWs that can be easily disassembled, but the majority of EPWs are power-base styles. The conventional frame design was an easy first step in EPW development, but adding special seating features (eg, tilt and recline) made

Figure 26-5. A traditional power wheelchair.

Figure 26-6. A pushrim-activated, power-assist wheelchair.

the wheelchair heavy and unstable. To accommodate these additional features, the EPW was redesigned in a two-component power-base style. The bottom power-base component houses the batteries, motors, and, in most cases, the controller. The seat component attaches to the power base, and thus can be swapped for whatever style of seat best meets the user's needs. A secondary benefit of separating the seating and power and control system is that the power-base design can be optimized nearly independently of the user's seating requirements. Consequently, power-base designs have progressed rapidly to include complex suspension systems, a low center of gravity, and excellent maneuverability. Likewise, seating technology has advanced to meet the needs of a wide range of users.

An EPW seating system can be as low-tech as a captain's chair or as complex as a power-actuated seat, which has any combination of the following features: tilt (changing the whole seat angle relative to the horizontal), recline (changing the seat-back to seat-bottom angle), elevating leg rests (leg-rest-to-seat-bottom angle), seat elevator (changing the height of the seat), and a standing mechanism (raising the person into a standing posture). Depending on the user's pressure management needs and musculoskeletal system state, any combination of the above motions may be prescribed. Seat tilt is one of the most common features because it allows pressure to be shifted from the buttocks to the back, which can prevent the pressure ulcers common to wheelchair users with sensory loss.

Power-Assisted Wheelchairs

Power-assist devices include standalone-powered units external to the wheelchair that the wheelchair user holds onto, power add-on devices that attach to the wheelchair and have steering mechanisms or input devices for control, or pushrim-activated systems (PASs) with motors in the wheelchair hubs (Figure 26-6).[14,36,37] A PAS operates much like a manual wheelchair but requires less effort,[11,14] making it suitable for people with, or at risk for, upper extremity joint degeneration, reduced exercise capacity, and low upper-extremity strength or endurance.

One type of PAS measures pushrim forces using a linear compression spring and a simple potentiometer that senses the relative motion between the pushrim and the hub. A microprocessor uses these signals to control a permanent magnet direct current motor attached to each rear wheel. Each motor is connected to a ring gear, resulting in a 27:1 gear reduction. The PAS controller provides the feel of a traditional manual wheelchair by simulating inertia and compensating for discrepancies between the two wheels (eg, differences in friction), and increases user safety with an automatic speed limiting and braking system through the use of regenerative braking. Power is supplied by either a single, custom-designed, nickel–cadmium battery or a nickel–metal hydride battery.

Multifunctional Wheelchairs

Multifunctional wheelchairs are capable of changing drive configurations to adapt to environmental changes or challenges.[31,38–41] An example of this is the iBOT transporter, which uses a two-wheel cluster design (Figure 26-7).[38,40,41] With this design, the iBOT transporter can assume five different drive configurations: standard, four-wheel, balance, stair, and remote. In standard function, the transporter resembles a rear-wheel–drive wheelchair by raising the foremost drive wheels and lowering the front casters. In four-wheel configuration, all four drive wheels are in contact with the ground and the front castors are elevated. This configuration enables the user to climb curbs (up to 10 cm high) and easily traverse uneven and sloped terrain. The stair-climbing ability is achieved by controlling the cluster rotation on the basis of the position of the center of gravity. The device strives to keep the system's center of gravity above the ground-contacting wheels and between the front and rear wheels at all times, regardless of disturbances and forces operating on the system. Pitch-and-roll motion, recorded with gyroscopes, is used by a closed-loop control algorithm to drive motors to keep the seat level. The joystick is deactivated during stair climbing to prevent unintentional deflection. Users can initiate the function on their own and can maintain stability by holding the stair handrails, or assistants can control the rate of climbing through the assist handle. When a user or assistant leans forward or backward, shifting the center of gravity, the device rotates the wheel cluster, allowing the device to climb down or up one stair. The control system requires the device to dwell on each step for a few seconds before allowing another cluster operation. This hiatus helps keep the device from going out of control on stairs. The stair configuration performs well in descending and ascending stairs that are standard height, width, and depth.

In balance configuration, the clusters are rotated so that one set of drive wheels is positioned directly over the other set, leaving only two wheels in contact with the ground. The gyroscopes and closed-loop control system enable the user to remain balanced even during perturbations. For example, if a user shifts forward to reach something off a shelf, the transporter responds by bringing the wheels forward to compensate for the change in the occupant's center of gravity and to keep the occupant balanced. Although driving is possible in this configuration, the main purpose of the balance mode is to enable users to interact at eye level with their able-bodied peers and to extend their reaching height. Remote configuration allows users to detach the joystick and drive the device into a vehicle for easier transport. The iBOT can be connected to a computer so system logs, errors, and software updates can be downloaded and uploaded. This feature allows a remote technician to connect to the transporter and determine and potentially fix problems related to its operation or perform software updates.

Figure 26-7. The iBOT transporter in standing mode.

The iBOT is the first stair-climbing device to appear on the market that does not use a track-based design. The major advantage of tracked-based stair-climbing wheelchairs is simple control and robustness in operation on irregular stairs. However, a disadvantage is the high pressure exerted on the stair edges and the difficulties associated with everyday use (it tends to be bulkier, heavier, and less maneuverable).

SEATING SYSTEMS

The human body is not designed to sit in the same position for prolonged periods of time.[39] It alters its position frequently from various lying, sitting, and standing positions, depending on the task being performed. For people with disabilities who are unable to walk and require wheeled mobility and seating devices, sitting is necessary, and identifying the most effective seating system for a specific individual's needs can be challenging.

The human body is a dynamic structure that is designed to perform and engage in a number of tasks in a variety of positions. Even while in a lying position, the body frequently (and subconsciously) changes position. The same applies in a standing or seated position. In a standing position, the body is a constantly dynamic structure, able to change its base of support frequently depending on movement and placement of the feet (base of support) in relation to the torso. The same applies to the body in a seated position, where the pelvis and thighs act as the base of support and the hip joints are placed in a flexed position, resulting in a potentially unstable base of support. In a seated posture, the pelvis is free to tilt and rotate in multiple directions, ultimately affecting the position and posture of the rest of the upper body (including the spine, trunk, upper extremities, and head). The seated body is therefore dynamic but also unstable.

Before providing a seating system, an individual's muscle strength, joint range of motion, coordination, balance, posture, tone, endurance, sitting posture, cognition, and perception must be assessed to obtain a basic understanding of the individual's capacity and needs. These assessments should be performed by a qualified professional with specialty training, certification, and knowledge of wheelchair seating and mobility applications. A proper assessment begins with listening to the user's needs, concerns, and goals for a device. Realistic goal setting fosters discussion related to the technology's capabilities.

The physical–motor assessment begins by observing and noting the person's seated posture; this provides a baseline of the seated postures the user may assume. A person may sit in a particular position because of preference, limitations, or the design of the seating system. It is therefore necessary to move the person from the existing system to an unsupported seated position on a flat surface, such as a therapy mat table, to observe the individual's posture without postural supports. If the user's unsupported sitting balance is limited, the examiner may need to provide support. Careful attention should be paid to the individual's pelvic and spinal alignment. While the person is sitting on the mat table, the examiner should apply appropriate forces (with the hands) to determine if observed deformities of the pelvis and spine are fixed or flexible. A fixed deformity cannot be corrected by a seating system and needs to be accommodated by the system. A flexible deformity can be corrected in varying degrees, depending on complexity, and needs to be supported by the seating system.

The user should then be asked to transition or be assisted to a supine position, where pelvic and spinal alignment can be reassessed with the pull of gravity working in a different plane on the body. Range of motion at the hips and knees should be assessed in this position. Limitations in hip flexion will affect the seat-to-back angle configuration of the seating system. With the hip flexed, knee range of motion (especially extension) needs to be assessed, considering the hamstrings cross the hip and knee joints. This will determine the optimal angle of the leg rests and position of the feet. In either a seated or supine position, upper extremity strength and range of motion need to be examined using commonly accepted measures and procedures. During this assessment, it is also necessary to note the quality of movements related to coordination because it is affected by tone, spasticity, tremors, and primitive reflexes.

Seating systems can be classified in three general categories: prefabricated, modular or adjustable systems, and custom contoured systems. Every user should be given a seating system designed and provided specific to the individual's medical, functional, and personal needs. A system should address issues of soft tissue management, comfort, orthopaedic deformities, and maintaining vital organ capacity. Functionally, the system should address the movements the user needs to perform, such as reaching or accessing objects, transferring, getting under tables, and completing ADLs. This requires carefully matching critical chair dimensions to body dimensions, user ability, and intended use. The user's goals and priorities need to be primary considerations; for example, a user may forgo pressure relief and comfort for a firmer system that provides greater stability and allows sliding off the seat for transfers.

The simplest form of prefabricated or premanufactured seating system is a linear seating system. A linear seating system refers to a planar seat and back with fixed angles and orientations. These types of systems may not provide a great deal of contour or support; however, they may be indicated for users who need more freedom of movement or who will experience rapid changes in size. Generically contoured systems are indicated for people who have minimal to moderate postural support needs and who have body shapes and dimensions that fit within these generic contours. Modular systems are composed of components that can be adjusted, added, or removed to address a specific postural need, such as lateral trunk supports and thigh guides. These systems are ideal for people with progressive conditions, such as multiple sclerosis, whereby postural needs may increase over time. They are also indicated for conditions that might improve, such as stroke or brain injury. Modular components are also ideal when a user's needs change throughout the day or activity. For example, a person may fatigue toward the end of the day and need more lateral trunk support added to the backrest, but may want these supports removed because they interfere with reaching activities or transferring out of the wheelchair.

Custom molded and contoured systems are more complicated to design and apply clinically. These systems are indicated for people with moderate to severe fixed or semifixed postural deformities, including curvatures of the spine, pelvic obliquities, and windswept postures of the lower extremities. A disadvantage of custom seating is it may limit function and movement because the system is specific to body shape. There are also concerns with people who might grow, change, gain or lose weight, or have seasonal variations in the thickness of their clothing. Designing these systems requires liquid foam, molding bags, and computer-aided design or computer-aided manufacturing technologies. Seating systems should not attempt to overcorrect postural deformities, but should accommodate them. Reduction or correction of postural deformities and joint contractures is best addressed through other interventions, including surgery, controlled passive stretching, or orthotic devices.

Seating systems are composed of several components, including at least a seat and back support. Other components often include supports for the arms, legs, and head. Adjustable features may include a reclining backrest, tilt-in-space ability, elevating seats, and standing capabilities.

Seat Support

The seat interface should balance pelvic stabilization and pressure distribution, allow for some degree of movement, and be functional to the individual's needs. The seat is the base of support for the pelvis, which supports the rest of the upper body. A seat should have an underlying, rigid base of support. Sling seats, commonly found on standard manual wheelchairs, provide limited postural support and are intended to allow easy folding. Sling upholstery tends to stretch and bow over time, and may contribute to adduction and internal rotation of the hips as well as a posterior pelvic tilt and kyphotic posture. The angle and shape of the seat contributes to pelvic stabilization. Without stabilization, the pelvis tends to rotate posteriorly, causing the buttocks to slide forward in the seat. This can result in shearing forces in the buttocks and may lead the spine to further collapse into a slouched posture. Providing a posterior slope to the seat angle, wedging the seat, or designing an ischial shelf in the shape of the cushion can provide greater pelvic stabilization and a better sense of balance, but may not always be ideal. It could make it more difficult to slide forward out of the seat for transfers, increase pressure in the ischial tuberosity and coccyx regions, or promote greater posterior pelvic tilt if the back support is not adequate. A posterior slope may also be inappropriate for people who self-propel with their feet. However, wheelchair users sometimes want to slide forward in their seats, slouch to relax, and change position because sitting upright continuously is difficult and fatiguing.

Back Supports

Long-term collapsing deformities of the spine, including kyphosis and scoliosis, can compromise breathing and other vital organ functions. Properly applied back supports can slow the onset of these problems. Back supports can be categorized by their shape, height, and stiffness. The preferred backrest provides posterior and lateral support but does not inhibit movement in the trunk and upper extremities (which may be needed for the propulsion of a manual wheelchair or other activities, such as reaching). A contoured or curved back should accommodate the width of the user and follow the natural curves of the spine to provide enough trunk support without compromising movement or function. Standard sling-back upholstery also tends to stretch over time, which can result in a posterior pelvic tilt and contribute to a kyphotic posture. Flat or planar backs allow for more movement, but might be uncomfortable and less stable because they do not provide lateral stabilization or conform to natural spinal curves. A high back provides greater support through the spine, but may interfere with trunk rotation and shoulder movements. Back supports below the scapulae and thoracic spine allow for greater freedom of movement, but may result in long-term spinal deformities. Fabric backs with adjustable tension straps are now more common, especially in manual wheelchairs, and tend to be lightweight compared to rigid, shell-back supports. They can be adjusted for varying needs and shapes; however, they stretch and wear out over time and do not provide rigid stabilization.

Current trends in backrest design focus on styles with taller backs, lateral curves around the thoracic-lumbar regions, and cutouts in the scapular region to provide spinal support while allowing for shoulder movements. Attention is also being focused on using adjustable, durable, carbon-fiber materials to construct back supports.

Arm Support

Arm supports may be necessary to rest the arms, provide a greater sense of lateral trunk stability, and decrease pressure loads in the buttocks by bearing weight through the upper extremities. They may also provide a place to hold onto with one hand while reaching with the other, and to push off of for weight shifts or transfers. Armrest assemblies can also contain the pelvis and thighs to keep the thighs in alignment, and can protect clothing and skin from rubbing on the tires of a manual wheelchair. However, armrests add weight to manual wheelchairs and can get in the way of accessing the pushrims for effective propulsion. Therefore, many active manual wheelchair users choose to forgo arm supports. If arm supports are used, they should be removable or capable of swinging out of the way. They should also be set at an optimal height for the user or be adjustable.

Foot Supports and Leg Supports

Foot supports and leg supports can be classified by the angle at which they position the knees and where they place the feet. Traditional swing-away footrests are designed to keep the user's feet out in front, with about 60° to 70° of knee flexion, to avoid interference with caster swivel and rotation. This is not necessarily a natural seated position; it promotes slouching by pulling the hamstrings and the pelvis into a posterior pelvic tilt.

Elevating leg rests pose an even greater problem. A perceived purpose of elevating leg rests is to help manage edema (swelling) in the lower extremities. However, being seated in an upright position with the hips flexed and the knees extended does little to reduce edema unless the feet and legs can get to or above heart level, which can only be accomplished by tilting the seat back and reclining the backrest. Elevating leg rests without these features will also likely place greater pull on the hamstrings, promote a slouched posture, and cause significant problems for people with limited knee extension (Figure 26-8).

Some people (eg, active manual wheelchair users) prefer to sit with their knees at a more natural, 90° (or greater) flexed position, with their feet tucked under the seat to provide greater postural stability and shorten the length of the wheelchair for maneuverability. This position also warrants tapering the footrests inward to keep the feet from interfering with front caster swivel. In a power wheelchair, a front- or mid-wheel drive configuration positions the feet so the knees are flexed at 90° because front casters are not needed. Some active wheelchair users also prefer to have the foot supports fixed in a one-piece structure to add rigidity and durability. However, removable or swing-away foot supports should not be eliminated for people who stand for transfers out of the wheelchair or propel a manual wheelchair with their feet.

Figure 26-8. Elevating leg rests.

Head Support

The head can be difficult to position because of its size and movements in the cervical spine or neck. A head support is warranted for those with poor head control. Prior to positioning the head, the pelvic and spinal support and balance should be addressed because the head is more distal to these structures and will tend to position itself based on their position. A head support is also almost always indicated in wheelchairs that include tilt and reclining backrests because the head needs to be supported in these positions. A head support may be warranted if the user needs to rest in the wheelchair and if the wheelchair is to be used as a seat in a vehicle (to provide support in the event of a collision).

Figure 26-9. A powered tilt seating system.

Figure 26-10. A powered reclining backrest system.

Like all other seating components, head supports come in various shapes and sizes to address different needs and preferences. Some people prefer to go without head support because it interferes with head movement and can reduce field of vision. Flat head supports provide a surface to rest against, while curved supports provide some degree of lateral stability. Wide head supports allow for greater area to place the head, but tend to interfere with field of vision. Head supports can be aggressive for people with poor head control (eg, those with amyotrophic lateral sclerosis), and may include lateral head and suboccipital supports. Head supports should be mounted to the seating system using adjustable hardware so they can be moved, adjusted, and removed as needed.

Tilt Frames and Reclining Backrests

Because it is unnatural to sit in one position for prolonged periods of time, tilt frames and reclining backrest systems are options that benefit those unable to move or reposition themselves effectively. These options redistribute pressure, manage posture and tone, provide comfort, and help with personal care activities. Tilt frames and reclining backrests are available for both manual and power wheelchairs and can be operated by the wheelchair user as a powered feature or manually by an attendant.

Tilt allows the entire seating system to pivot posteriorly while keeping the hip and knee joints in the same position. This helps redistribute pressure away from the buttocks region and into the back support. It is also useful in repositioning because people tend to slouch and slide forward when sitting upright for prolonged periods of time. The trunk is able to extend in a tilted position, countering a kyphotic posture and potentially reducing or slowing the development of trunk and spinal deformities (Figure 26-9).

A reclining backrest allows the hip flexors to stretch and opens the hip angle to assist with attending to catheters, toileting, dressing, and dependent transfers. However, reclining the backrest creates shear forces in the seat and back because the user tends to slide down in the seating system. The addition of a tilt-in-space feature will counter this tendency and should be considered when recline is warranted. Both systems also allow a person to rest in the wheelchair without having to be transferred to a bed. Research supports use of combined tilt and reclining backrest interventions to optimally distribute pressure (Figure 26-10).

Standing Systems

Wheelchairs that allow the user to passively stand benefit individuals who would typically be unable to do so otherwise. The benefits of passive standing may include decreased bladder infections, reduced osteoporosis, and decreased lower extremity spasticity. In addition, there are likely psychological benefits resulting from the sensation of upright posture and the ability to interact at eye level, and functional benefits associated with being able to reach objects in higher locations. It is critical to carefully assess a person's posture and range of motion prior to considering a standing device because those with range-of-motion limitations and postural deformities cannot stand upright. A candidate for a standing wheelchair should be carefully assessed by a physician or other qualified practitioner before standing to address concerns with orthostatic hypotension in cases where people have not stood for a prolonged period of time.

Seat Elevation Systems

Some of the benefits obtained from a standing system, such as reaching objects in higher locations, accessing high surfaces, and being at eye level with standing people, can be accomplished through the use of a seat-elevating system (Figure 26-11). This is a feature typically available only on power wheelchairs. Raising the seat is also sometimes critical to facilitate safer and more efficient transfers. For a person using a sliding board or performing a lateral transfer, a seat elevator allows for transfers in a downhill direction, which has been shown to require less strain on the upper extremities as compared to transferring to a level or higher surface. In other cases, the seat elevator can facilitate transfers for people who stand to transfer but have difficulty rising from a low seat to floor height.

Figure 26-11. A seat elevator can be used to reach higher objects.

SPORTS AND RECREATION EQUIPMENT

The human need for recreation is especially important in the presence of physical, sensory, or cognitive impairment that affects the ability to function in everyday activities and environments. Primary rehabilitation interventions emphasize self-maintenance, education, and employment activities. Recreation allows humans to challenge their physical limits in a setting that accepts new participants, provides instruction and emotional support for learning, includes social participation, and promises fun and escape from the realities of everyday life. Recreation puts humans in touch with their imagined self (eg, a person who is adventurous, strong, or graceful) and does not need to be justified in the same way as work and self-maintenance activities; it is chosen just because it is appealing to the participant.[42] Healthy competition with self and others through sports and recreation creates an arena for continuing the gains of medical rehabilitation, challenging personally held ideas about disability and handicap learned from culture, and testing out a new self-concept that can include acceptance of disability.[43]

Basketball wheelchairs are similar to typical manual wheelchairs but incorporate features to enhance stability and maneuverability. They are lightweight to allow for speed, acceleration, and quick braking. Although wheelchair basketball is not a contact sport, some incidental contact is inevitable, so spoke guards cover the rear wheel spokes to prevent damage. Spoke guards made of high-impact plastic provide several additional benefits. They allow players to pick the ball up from the floor by pushing it against the spoke guard and rolling it onto the lap, they protect hands and fingers from aggressive play when reaching for the ball, and they provide space to identify team affiliations and sponsor names. Stability comes from the camber in the wheels, which creates a broader wheelbase; it brings the top of the wheel closer to the body, making the wheelchair more responsive to turns, and protects a player's hands during collision because hands are located away from the plane of contact. To gain an advantage for shooting baskets, forwards usually try to make wheelchair seats as high as possible within the 53-cm limit. Seats typically angle toward the rear, creating "squeeze" or seat bucketing of 0.085 radians to 0.255 radians (5°–15°) to increase the player's pelvic stability. Guards prefer lower seat heights, which, combined with increased seat angle, makes chairs faster and more maneuverable for ball handling. Cushions may be used if made of flexible material the same size as the seat of the wheelchair and no higher than 10-cm thick, unless a player is classified as being restricted to a cushion that cannot exceed 5 cm. Because equipment can be used to create competitive advantage, it is carefully regulated. Equipment cannot completely equalize player performance, so modified rules and classification work to create functional equivalence between teams. These parameters work together to create a sport that is equal in challenge and excitement to stand-up basketball.

Wheelchair rugby differs from basketball in that players must have both an upper and lower extremity impairment to be eligible to participate. The object of wheelchair rugby is to cross the opponent's goal line with two wheels while in possession of the ball. While the offensive team tries to advance the ball, the defense works to halt its progress with turnovers. Players tend to use extreme wheelchair configurations, elastic binders, foam arm protectors, and special tacky gloves to improve performance. As in basketball, players become extremely proficient in adapting their equipment to promote balance and speed, so much that they often appear to possess more functional capacity than their diagnoses would suggest. Wheelchair styles are strictly regulated to ensure fairness, but vary considerably depending on a player's preferences, functional level, and role on the team. Rugby chairs have extreme amounts of camber (16°–20°), significant bucketing, and antitip bars. Camber provides lateral stability, hand protection, and ease in turning. Bucketing helps with trunk balance and ball protection.

Serious tennis players use special wheelchairs that are equipped with three wheels—two large for propulsion, and a single, 5-cm caster in the front under the feet that allows for quick turning. The large wheels are typically 61 cm to 66 cm (24–26 in.) in diameter and use high-pressure tires (8.4 k/cm–14.1 k/cm, or 120–200 psi) to reduce rolling resistance on the court. Wheels are set with extreme camber to maximize mobility and stability on the court, especially when making shots. Players with high-level spinal cord injury play with power wheelchairs and with longer rackets to compensate for length taken up by strapping the racket to the hand.

The track and field sports have been adapted to disability since the Stoke Mandeville Games, and include throwing and racing events.[44] The throwing events allow competitors to use specially designed throwing chairs attached to holding devices because they offer greater stability and support. Throwing chairs are taller and eliminate the large wheels that could potentially interfere with the dynamic upper body movements required in throwing events. When a wheelchair is used, the seat and cushion must not exceed 75 cm in height.[45] The chair design is important because it can significantly enhance performance, depending on how well it matches the thrower's body and functional abilities. Consequently, athletes select chairs of different configurations to optimize their throwing performance.

Wheelchair racers and others with physical impairments compete in events from short distance sprints through marathons. Wheelchairs used in racing are customized and designed to fit the body of each user. The design of a racing wheelchair optimizes the abilities of each user, incorporating features such as three-wheeled design, use of high-pressure tubular tires, lightweight rims, precision hubs, carbon disc or spoked wheels, compensator steering, small push rings, ridged frame construction, and 2° to 15° of camber. The fit of the racing chair to one's body and abilities is critical to overall performance.[46] Racing chair manufacturers require many body measurements when a chair is ordered because the frame and seat cage are made to fit each individual.[47] Individuals with upper transradial amputations may use cosmetic prosthetic hands that have been positioned into a fist or ball with a high-friction surface to simulate racing gloves.

Wheelchairs have also been redesigned for use in backcountry and wilderness. Athletic individuals with a desire to hike, camp, and go where conventional wheelchairs cannot have designed adaptations to make rough terrain navigable. They use 66-cm (26-in.) knobby tires like those on mountain bikes to gain traction on soft, wet, or difficult terrain. Front casters are significantly larger to decrease the chance of getting stuck on obstacles. Larger casters require frame redesign, so an off-road wheelchair looks more like a four-wheel buggy than a typical wheelchair.

Cycling using adaptations to typical bicycles, tandem cycles, or hand cycles opens this recreational and competitive sport to individuals with many types of impairments. Using toe clips, altering the size of the arc of the pedals, or modifying the handlebars, handgrips, or placement of the gears and brake levers are the only modifications some need.[48]

For those with lower extremity impairment, such as spinal cord injury, multiple sclerosis, hemiplegia, and amputation, hand cycles substitute use of the upper extremities and provide the greater stability of three wheels and placement close to the ground.[49] Cuffs can be mounted to the arm crank handles for those with reduced grip strength. Two types of hand cycle designs are typically used: upright and recumbent. In an upright hand cycle, the rider is in a vertical position, as in a wheelchair. Upright hand cycles use a pivot steer in which only the front wheel turns while the rear wheels of the cycle follow.

It is easier to transfer into and balance an upright cycle. In the recumbent hand cycle, the rider's torso is semireclined and the legs are positioned in front of the pelvis. Steering occurs in one of two ways. In one, as the rider leans toward the turn, force is transferred through a linkage bar, causing the frame to pivot and turn, which is challenging for riders without trunk stability. A pivot-steering, recumbent hand cycle uses the rider's arms and shoulders to execute turns like a typical bike. Recumbent hand cycles are ideal for racing because they are light and fast.[50] Individuals with upper limb amputations require modifications to the pedal handle and to the terminal device to facilitate a firm interface that promotes pushing and pulling on the handle throughout the pedal cycle (over 360°).

Water sit skis can compensate for trunk instability and hand weakness and incorporate a variety of adaptive features to suit a wide range of functional levels. Some skis adjust vertically, horizontally, and diagonally at the fin, allowing users to fine-tune their equipment to meet various skiing styles, body weights, and boat velocities. At the competitive level, sit-skiing events include men's and women's slalom, tricks, and jumping.[50]

Adaptive ski equipment (eg, outriggers, monoskis, and biskis) emerged from analyzing the physics of skiing and applying mechanical concepts to compensate for a skier's movement limitations. Veterans with limb loss learned stand-up methods that added outriggers. Originally, outriggers were made from the tips of outriggers from damaged skis mounted to the ends of forearm crutches. The Austrians used outriggers with the ski tips in a continuous running position, but flip-skis use a spring-loaded mechanism to allow the tip to either parallel the snow in running position or, when released, to flip up on the heel of the ski tip so outriggers can function more like poles or crutches. A claw bolted to the heel of the tip provides traction in icy lift lines. The monoski combines a fiberglass, form-fitting cab with a suspension mechanism attached to a single ski. A lever mechanism allows the skier to raise the height of the cab to the level of a chairlift. Once up, monoskiers can push forward in the lift line, using outriggers in pole position, and allow the chairlift and its momentum to scoop them up. To dismount, the skier leans forward as the lift reaches the dismount down slope, creating the momentum to drop off the lift.

In sled hockey, typical ice hockey rules apply, with some changes because of the nature of the game and its participants. The ice surface, goal net, and pucks are all the same as in stand-up hockey.[51] The primary piece of equipment used in sled hockey is the sledge, a metal-framed oval sled with two blades and a small runner; a seat with a backrest; leg straps; and optional push handles. A typical hockey stick is shortened to 73.6 cm (29 in.) and modified with two picks (metal pieces with a minimum of three teeth, measuring a maximum of 4 mm) attached to the end.[51] Picks provide traction to move the player down the ice and give the player leverage for shooting the puck with the blade end of the stick. With a quick flip of the wrist, players are able to propel themselves using the spikes, then play the puck with the blade end of the stick. Players generally use two sticks with blades to facilitate both propulsion and shooting with either hand.

TRANSPORTATION

Transportation is a key component of full integration into the community. Accessible public transportation is necessary to provide persons with disabilities the same opportunities as others: employment, education, religious worship, and recreation. In the United States, the Individuals with Disabilities Education Act[52] and the Americans with Disabilities Act of 1990[53] have provided people with disabilities the opportunity to access schools and public transportation. The Americans with Disabilities Act transportation requirements mandate accessible fixed-route vehicles, as well as complementary paratransit services for those unable to use the fixed-route service. A subset of the disabled population is the wheelchair user, who may not be able to transfer to a vehicle seat and might, therefore, remain seated in a wheelchair.

The wheelchair user should be afforded the same level of safety as passengers sitting in vehicle seats that meet federal safety standards. However, the wheelchair-seated passenger is usually at increased risk of injury in event of a vehicle collision or emergency maneuver. Currently, there are no federal safety standards for devices used to transport wheelchair-seated passengers. However, there is a national and international effort to develop product safety standards for wheelchairs used as seats in motor vehicles. The standards establish the severity of vehicular crashes the wheelchair should withstand, as well as set the design criteria for securing the wheelchair in a vehicle.[54,55] They evaluate the complete wheelchair, frame, base, and seating system; however, seating systems are often added aftermarket. Wheelchairs using aftermarket seating systems are not likely to be tested to evaluate their ability to withstand crash forces, or they may invalidate some testing. Because the seating system directly interfaces with the user, it is critical that these systems do not fail during a vehicular crash.

Motor vehicle seats must be effectively anchored to the vehicle floor to ensure that their mass does not add to the restraint loads on the occupant. When an occupant remains seated in the wheelchair, the wheelchair becomes the vehicle seat. Aftermarket securement systems must be used to anchor a wheelchair to the vehicle floor. Again, due to the lack of federal safety standards for devices used to transport wheelchair-seated passengers, national and international efforts strove to develop voluntary product safety standards for wheelchair tie-down and occupant restraint sys-

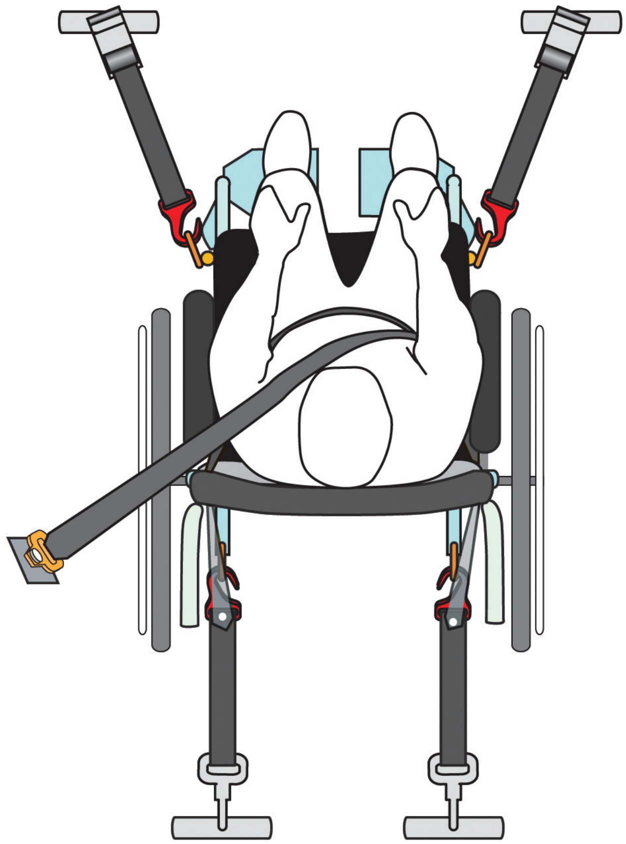

Figure 26-12. A four-point tie down system for wheelchair transportation.

tems. In the United States, the Society of Automotive Engineers' Adaptive Devices Subcommittee developed *SAE J2249: Wheelchair Tie-Downs and Occupant Restraint Systems for Use in Motor Vehicles*.[55] Shortly after, an international standard was published.[56] The most common securement system found in public transportation is the four-point tie-down system (Figure 26-12). This system consists of four tie-down straps that anchor to the vehicle floor and four points on a wheelchair (two front and two rear). The end fittings that attach to the wheelchair can be hooks or loops that wrap around the wheelchair frame. The main advantage of this type of system is that it can be used with a wide variety of wheelchairs and does not require special hardware to be added to the wheelchair.

A second method of securement is an automatic docking system, which uses a wheelchair adaptor—special hardware mounted on the wheelchair—to engage with a docking station or receptacle mounted to the vehicle floor or sidewall. The advantages of wheelchair docking technology have been seen with proprietary systems that have been used for independent securement of wheelchairs in private vans.

Driving Controls

Adaptive driving controls for an individual's vehicle are prescribed after the individual completes a comprehensive driving evaluation and education and training program provided by a certified driving rehabilitation specialist. The evaluation assesses the individual's basic skills necessary for driving, such as vision, perception, cognition, physical functioning, and knowledge of driving, and an on-road assessment that evaluates actual driving skills. After completing the program, the certified driving rehabilitation specialist and the individual can determine if the person will be able to drive with the recommended equipment.

Adaptive driving controls may include modified steering devices, accelerators, and a variety of secondary vehicle controls. A steering device, such as a spinner knob attached to the steering wheel, can allow for one-handed steering (Figure 26-13). A left-sided accelerator can be used if the individual's right foot cannot operate the gas or brake pedals. A turn signal crossover, which relocates the turn signal indicator from the left side of the steering wheel to the right, can be used to allow individuals to access the turn signal using only the right hand if the left is impaired. Other secondary vehicle controls, such as windshield wipers, lights, and horns, can be relocated to provide timely and accurate access with the functional or dominant hand.

Positioning straps (eg, chest harnesses), used in combination with the seatbelt, provide additional trunk control if sitting balance is compromised and interferes with functional operation of the vehicle. A strap or other modification for seatbelt retrieval is helpful if grasp or reach is limited. A parking brake extension allows access to floor-mounted parking or

Figure 26-13. A steering knob can aid in driving.

emergency brake pedals. Mirrors may compensate for partial loss of visual fields or the presence of scotomas. As with all adaptive equipment, specialized education and training is required to assure correct placement and proper use of the additional mirrors.

Vehicle Access Technology

A variety of adaptive equipment and vehicle modifications can be used for vehicle ingress and egress. Automatic car door openers (ie, keyless entry), built-up key holders, or key turners are recommended if hand function is impaired. To ease the transfer for driver or passenger from the wheelchair into the vehicle seat, a power base seat can swivel out, glide out of the vehicle, and lower to a desired level. Portable wheelchair ramps are available to load and unload unoccupied mobility equipment, such as manual or power wheelchairs or scooters, into the vehicle without significant vehicle modifications (Figure 26-14). Car topper lifts attach to the top of a sedan and lift and store a manual wheelchair on top of the vehicle. Wheelchair or scooter users may require a vehicle ramp or lift to get into their vehicles or to lift their mobility devices into their vehicles. Before the recommendation and installation of any adaptive equipment in a vehicle, the individual, mechanical device, and vehicle compatibility should be verified.

Figure 26-14. A portable wheelchair ramp can be used to access vehicles.

REHABILITATION ROBOTICS

Rehabilitation robotics can be categorized into three main categories: mobility aids, manipulation aids, and therapeutic robots. The use of robots in rehabilitation is quite different from industrial applications, where robots operate in structured environments with predefined tasks and are usually separated from human operators. Many tasks cannot be preprogrammed in rehabilitation robots, such as picking up a newspaper or opening a door. Although some evaluations and studies have looked at rehabilitation robots, the benefits and disadvantages of systems in service need to be further analyzed to better understand the users and their needs. Many individuals with disabilities can be satisfied with traditional mobility aids (eg, canes, walkers, manual wheelchairs, power wheelchairs, scooters). However, for some people with disabilities, it is difficult or impossible to use current mobility devices without assistance.[58] Individuals with low vision, visual field neglect, spasticity, tremors, or cognitive deficits may benefit most from "intelligent" mobility aids that have evolved from mobile robots. People with these conditions often lack independent mobility and rely on a caregiver to provide mobility. Intelligent mobility aids often consist of either a wheelchair or walker, to which a computer and a collection of sensors have been added, or a mobile robot base to which a seat or handlebars have been attached. Intelligent mobility aids have been designed based on a variety of traditional mobility aids and provide users with navigation assistance (eg, assuring collision-free travel, aiding the performance of specific tasks, and autonomously transporting the user between locations). Smart wheelchairs are ideal devices to test novel input methods because, unlike standard wheelchairs, the interface can be implemented on their onboard computers. More importantly, smart wheelchairs can avoid obstacles, providing a safety net for input methods that are inaccurate or that have limited bandwidth. For example, voice control has proven difficult to implement on standard wheelchairs; however, obstacle avoidance capabilities built into control software may protect a user from the consequences of unrecognized (or misrecognized) voice commands and can "fill in" the small, rapid navigation commands that are much easier on a high-bandwidth input device, such as a joystick.

Robotic manipulation aids provide people with disablities tools to perform ADLs and vocational support tasks that would otherwise require assistance. Operators usually control manipulation aids with joysticks, keypads, their voices, or other input devices. Robotic manipulation aids can be classified into three groups:

1. Task-specific devices: electromechanical devices used to perform simple tasks, such as powered feeders and page turners.

2. Workstation robots: the robotic manipulator may be built into a workstation and can be used in a vocational environment.
3. Wheelchair robots: a manipulator arm mounted on the electric-powered wheelchair that augments mobility and manipulation, allowing the user to accomplish ADLs and vocational tasks.

Both the interface between the user and the robot and the interface between the robot and the objects being manipulated affect the functionality of a robot manipulation aid. A robotís operation sophistication is limited because users are only able to exert so much control. The interface between the robot and the objects being manipulated is usually a simple pincer-like gripper; however, a large portion of activities performed in school, work, and daily living involve pick-and-place tasks that may be carried out with this simple end effector.

AUGMENTATIVE AND ALTERNATIVE COMMUNICATION

Augmentative and alternative communication (AAC) refers to any communication approach that supplements or replaces natural speech or writing. Effective communication is desired for individuals to be able to participate in work, school, leisure, and entertainment activities. Although a range of AAC interventions are possible to engineer solutions for improved function and participation, the demands of communication should be analyzed in terms of language requirements.

AAC endeavors to optimize the communication of individuals with significant communication disorders.[59] The basic elements of a comprehensive AAC assessment and the role of rehabilitation engineers in making decisions about AAC technology are critical to achieving successful outcomes. The significance of language issues and AAC language representation methods must be understood before evaluating solutions, emphasizing the need for AAC technology to support the spontaneous generation of language to optimize communication function and participation. Only by understanding the language issues can rehabilitation engineering professionals appreciate the technology, device features, and human factors associated with AAC interventions.

AAC interventions can be classified by the methods used to transmit messages (ie, aided or unaided).[60] Unaided symbols do not require an external device or apparatus; nothing other than an individual's body parts are needed to transmit a message (eg, using one's hands to gesture). Aided symbols, on the other hand, require an external device. Technology for aided AAC can be further classified into low, light, or high performance. High-performance technology solutions can then be delineated into nondedicated or dedicated AAC systems. Nondedicated technology generally refers to computers that are running AAC software, but the primary application of the technology is computer based. Conversely, dedicated AAC devices have been designed and evaluated specifically for communication, but frequently have secondary features that provide computer or environmental controls. The range of aided technology increases as the availability of power, voice output, electronics, and computer chips become part of the system.

Comprehensive Assessment

The AAC assessment may be the most important event in the life of an individual with a severe communication disorder that limits functional use of natural speech. For the beginning communicator, the AAC assessment process should establish AAC interventions to build communication competence to maximum potential across the individual's life span. However, for an adult with a degenerative neurological disorder, an AAC assessment should consider the individual's changing communication needs throughout the course of the disease.

An AAC assessment improves an individual's communicative functioning and participation in various activities and environments. The assessment is a client-centered, multidisciplinary team process.[61,62] Various AAC assessment models have been proposed that contain feature-match components, including the predictive assessment model[63,64] and the participation model.[65] With these AAC assessment models, data are collected and information is gathered to make intervention and management decisions.[66] The three primary objectives of an AAC assessment are to determine functional communication needs, identify (match) interventions to increase or maintain interactive communication, and monitor or measure the effectiveness of intervention.[65–67] The principles of evidence-based practice should be reflected in comprehensive AAC assessment.[59,68]

Language Representation

Three basic methods are used to represent language in AAC systems and are termed "AAC language representation methods" (LRMs). Evaluating the effectiveness of each method starts by considering the nature of a language. To be effective, AAC LRMs used with technology need to have the characteristics of natural language, such as being generative, recursive, and polysemous, in order to achieve maximum performance. Rehabilitation engineers systematically evaluate the performance of various methods against the characteristics of natural language.

The three common LRMs are based on single-meaning pictures or univocal pictures (intended to have only one meaning), semantic compaction or polysemous pictures (intended to have more than one meaning), and traditional orthography (the alphabet). Studies have shown that univocal LRMs, polysemous LRMs, and alphabetic LRMs have differential effects upon performance.

COMPUTER ACCESS

Client-side AT helps disabled users access computers. Computer operating systems and applications coevolved with the mouse, and some software cannot be used without one. This is problematic because the operations that are most troublesome for individuals with physical disabilities are often those that involve button presses. However, pointing devices come in a variety of shapes and sizes. The most familiar pointing devices are the mouse and the trackpad (most often seen on laptop computers). Other frequently seen pointing devices include the trackball and the trackpoint. Pointing devices more commonly associated with individuals with disabilities include touch screens, head-mounted mouse emulators, and mouse keys. Each pointing device requires a different set of skills, which a clinician can match to an individual's abilities.

ELECTRONIC AIDS TO DAILY LIVING

Electronic aids to daily living (EADLs; also referred to as "environmental control units") are specialized AT designed to enable individuals to operate household appliances and electronics if they cannot use the standard controls (eg, light switches, television, cable box, DVD player, stereo, heating and air conditioning, fans, doors, draperies or blinds, etc; Figure 26-15).

The user display and user control interface constitute the human–technology interface.[69] The user control interface is the selection method used to control other AT (eg, direct selection, scanning, directed scanning, auditory scanning, voice recognition, and coded access). The user display is usually a visual feedback system that helps the individual operate the device; though auditory feedback systems can be used to help the visually impaired. The central processing unit is generally a microprocessor-based system designed to process input signals and direct output signals. The output signals may include infrared, radio, telephone, and electrical signals transmitted over house wiring (via an X-10 system). Typically, X-10 modules and receivers provide power control of household appliances (eg, lights, fans, etc). Additional control, such as channel changing and raising and lowering volume, requires infrared signals.

The ideal assessment for an EADL would include the client, an occupational therapist, and a rehabilitation engineer, and the evaluation would be conducted in the client's home. The occupational therapist can help establish the best user control interface, and the rehabilitation engineer can help choose the appropriate technology. The advantage of conducting the evaluation in the client's home is that all the options can be explored in the environment in which the system will be used. Factors to consider when performing an evaluation for an EADL include:

- client's goals (ie, what controls are desired?);
- client's physical abilities and ability to use a control interface;
- other AT the individual uses;

Figure 26-15. The principle components of an electronic aid to daily living.

- client's prognosis (ie, is the condition stable or expected to get progressively worse?);
- client's cognition;
- the system's purpose (ie, for use in the home or at work, in one room or throughout the house, etc);
- system reliability, flexibility, and ease of operation;
- local technological support for installation, configuration, service, and updates; and
- expense of the system and the funding source.

Some EADLs are available commercially, either as stand-alone systems (ie, they only perform environmental control unit functions) or systems integrated with other AT. Voice-activated systems have recently made progress. Once a system is identified and purchased, it is important that it is properly set up and configured in the home, and that the client is provided proper training in its use. Setup, configuration, and client training should be provided by the vendor or local representative. In addition, a local vendor should be able to provide the client with follow-up service and support (Exhibit 26-1).

VETERANS WITH DISABILITIES AND RECREATIONAL SPORTS EQUIPMENT

Today, the number of sports and recreation opportunities for veterans with disabilities is seemingly endless, due in large part to advances in AT that compensate for impairments. The Veterans Health Administration (VHA) provides adaptive recreational and sports equipment.

The *Clinical Practice Recommendations for Issuance of Recreational and Sports Equipment*, written by an interdisciplinary team with the Veterans Affairs Prosthetics Clinical Management Program, outlines the recommended approach for providing adaptive equipment to beneficiaries.[70] According to the published recommendation, each veteran is entitled to an individualized assessment for adaptive recreation and sports equipment. The evaluation includes examining the veteran's medical diagnosis, prognosis, functional abilities, and goals. The VHA defines "recreational leisure equipment" as any specialized equipment intended for recreational activity that does not inherently exhibit an athletic or physical rehabilitative nature. Examples include adaptive devices for hobbies and crafts or adaptive fishing or hunting devices. The VHA defines "recreational sports equipment" as any specialized equipment intended to be used in a physically active or competitive environment. Examples include sports wheelchairs, hand cycles, sit skis, and artificial limbs for recreational or sports applications. Powered devices for sport participation can potentially be provided to individuals whose activities are severely limited without their use when the individual meets general criteria for power mobility. An example of powered sports equipment is an EPW for powered wheelchair soccer. Recreation and sports technologies provided by the VHA must be adaptive in nature to specifically compensate for loss of or loss of use of a body part or body function. Standard nonadaptive equipment, such as skis, boats, and two-wheeled bicycles, are not provided by the VHA.

Veterans and active duty service members enrolled for VHA care who have lost or lost use of a body part or function for which an adaptive recreation device is appropriate may be prescribed and provided equipment. Adaptive sports or recreation technology may be issued to veterans seeking to enhance or maintain their health and attain a higher rehabilitation goal through sports or recreation and who also meet eligibility criteria. In order to qualify for adaptive sports and recreation equipment, the veteran must have (among other criteria):

- medical clearance to perform the activity;
- completed education on appropriate activity and equipment options;
- demonstrated commitment to the activity through regular participation;
- the opportunity to participate in the activity consistently (eg, must have regular access to snow for cross-country skiing);
- tried the appropriate equipment options configured for specific needs and abilities;
- selected a device that supports the veteran's sports and recreation goals; and
- demonstrated the ability to use, transport, and store the equipment.

Accessories for adaptive equipment can also be provided when justified (eg, a car carrier to transport the device to a safe training area, indoor rollers for hand cycles or racing wheelchairs in areas with inclement weather). Seating interventions for postural support and skin protection or specific adaptations for limited hand function may also qualify. The Veterans Affairs Prosthetics and Sensory Aids Service covers repairs and service on sports and recreation equipment. A knowledgeable clinical professional (ie, a recreation therapist, rehabilitation engineer, kinesio-therapist, physical therapist, or occupational therapist) must be involved in the comprehensive athlete evaluation, equipment trials, selection and modification, and education

EXHIBIT 26-1

CASE PRESENTATION

While serving in a combat zone, a 26-year-old male US Army officer was injured by an improvised explosive device. As a result of the blast, the patient sustained multiple injuries, including a right transtibial amputation, right transradial amputation, and massive soft tissue wounds and defects to the right posterior thigh and gluteal region. After evacuation from the combat zone to the continental United States, the officer underwent a prolonged hospital course that included multiple surgical procedures to the right upper and lower extremities for amputation revisions, wound washouts, and split-thickness skin grafting to his soft-tissue defects; multiple wound and blood-borne infections with multidrug-resistant organisms; acute renal failure induced by antibiotic medications; malnutrition; and sacral skin breakdown.

Once medically stable, rehabilitation was initiated to address the soldier's impaired functioning. Therapy initially focused on regaining independence with bed mobility and activities of daily living in the hospital bed, as well as a preprosthetic preparation. The patient quickly regained the ability to transfer from his bed to his hospital-provided manual transport wheelchair, and the importance of addressing his seating and mobility needs was immediately evident. While simultaneously being fitted for and training with his upper and lower extremity prostheses, the patient began wheelchair training. He consistently refused to use a power wheelchair, and he reported that he viewed a manual wheelchair as a tool to regain the strength and endurance that had been lost.

By 6 weeks after his injury, the patient was functioning at a level suitable for discharge to outpatient rehabilitation. His rehabilitation, including upper and lower extremity prosthetic fitting and training, continued on an outpatient basis. A few weeks after discharge, the patient was seen in a seating and mobility clinic for a customized wheelchair prescription. The weeks spent in a hospital-provided wheelchair allowed him to develop preferences and experience regarding his seating and mobility needs. With input from the patient as well as the rehabilitation and seating teams, the patient was prescribed an ultralight, folding wheelchair with an air-filled, adjustable volume cushion; removable, adjustable height, desk-length arm rests; 18-inch seat-to-floor height; spoke wheels with a quick-release mechanism; aluminum handrims; and push handles.

Because of right upper extremity amputation, the patient propels his wheelchair with his left arm and his left leg. After being successfully fitted with an upper extremity prosthesis, he was able to use his prosthesis to assist with wheelchair propulsion. His prosthetic device does not afford him the strength, agility, and coordination to grip, push, and release the handrim in a manner compatible with efficient wheelchair propulsion; however, he is able to create enough friction between his silicone prosthetic hand and the aluminum handrim to assist with propulsion. Even with this assistance, the patient chooses to propel with his left leg more than 90% of the time. A relatively low seat-to-floor height allows him to easily use his intact left lower extremity for propulsion.

The patient admits to having difficulties climbing hills in his wheelchair. He ascends hills with the wheelchair facing down the hill, locks the brakes for rest periods, and allows his wife or other companion to assist by pushing his wheelchair. He insists that he prefers to use these strategies rather than a powered wheelchair.

The patient opted for a folding frame because of the relative ease with which he could fold and maneuver the chair into small spaces. With trials of rigid framed chairs, he found the process of removing the wheels while suspending the weight of the chair in the opposite arm cumbersome, given his amputation and the limitations of his prosthesis. Given his limited upper extremity strength and function, an ultralight wheelchair was necessary to ensure efficient propulsion and ease of transport (ie, placing it in a vehicle).

The history of sacral skin breakdown, multiple wounds in the patient's right posterior thigh and gluteal regions, and insensate regions at the sites of his skin grafts necessitated the use of a pressure-reducing, air-filled, adjustable-volume seat cushion. By 6 months after his injury, his sacral pressure ulcer had fully healed, but his right lower extremity soft tissue wounds and skin grafts still needed to be monitored, requiring him to continue using this cushion.

The patient prefers ambulation with a prosthetic device as his primary means of mobility. Because of the extensive and severe soft tissue wounds and skin defects in his residual right lower extremity, he has a limited tolerance for weight bearing in a prosthetic leg. In addition, his prosthetic components frequently require maintenance, resizing, and other adjustments. For these reasons, the patient realizes the need to have an efficient and reliable secondary mode of mobility, and his wheelchair fills this need effectively.

and training. The clinician works closely with the athlete, other equipment experts, and coaches to support the long-term goals surrounding sports and recreation participation.

SUMMARY

AT has an important role in the rehabilitation, community reintegration, and vocational success of veterans with disabilities. Many veterans with major limb amputations use multiple forms of AT daily, including wheelchairs for mobility. In order to obtain maximal benefit and to minimize the risk of abandonment, a proper assessment by a qualified, multidisciplinary, veteran-centered rehabilitation team is necessary.

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