



Journal of Rehabilitation Research and Development

Clinical Supplement #2

CHOOSING A WHEELCHAIR SYSTEM

**Department of Veterans Affairs
Veterans Health Services and Research Administration
Rehabilitation Research and Development Service
Prosthetics Research and Development Center—Office of Technology Transfer**

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Margaret J. Giannini, M.D.

Deputy ACMD for Rehabilitation and Prosthetics
Director, Rehabilitation Research and Development Service
Veterans Health Services and Research Administration
Department of Veterans Affairs

Seldon P. Todd, Jr., *Editor*

Tamara T. Sowell, *Associate Editor*

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The cover

Design: Holly Jellison

Illustrations: Samuel R. McFarland

Production: Frank Vanni

Address correspondence to: Editor, *Journal of Rehabilitation Research and Development*, Office of Technology Transfer (110A1), VA Prosthetics R&D Center, 103 South Gay Street, Baltimore, Maryland 21202.

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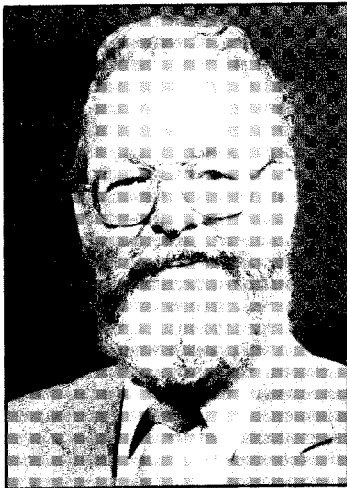
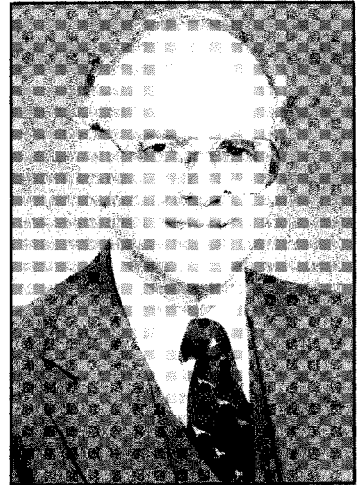
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EDITORIALS

"The Department of Veterans Affairs (VA) is proud of the continuing efforts of the Rehabilitation Research and Development Service to provide better wheelchairs to veterans. Lighter, stronger and more adaptable wheelchairs have been developed which can greatly improve the mobility of the physically impaired. This publication provides information to the clinician about wheelchair prescription. It will be a valuable tool for enhancing the quality of life for the disabled."

John A. Gronvall, MD
Chief Medical Director

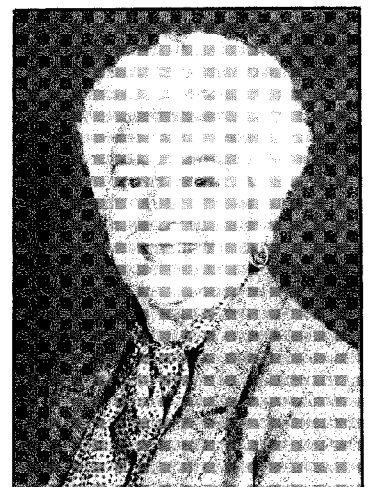


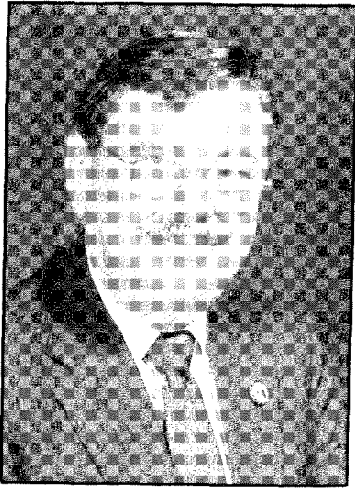
"The significant number of advances in wheelchair technology in recent years pose a challenge to clinicians in keeping abreast of the latest developments in wheelchair prescription. This Clinical Supplement to the *VA Journal of Rehabilitation Research and Development*, prepared by the Office of Technology Transfer, provides the clinician with a valuable aid to assist in providing disabled veterans with mobility aids which best meet their individual needs."

David H. Law
ACMD for Clinical Services (Acting)

"The VA is deeply committed to making the best possible wheelchairs available to veterans who have served their country. Aggressive investment in research and development along with the initiative of veterans service organizations have resulted in development of chairs which are far superior to those available only a few years ago. Now we face the challenge of evaluating chairs and seeing that appropriate chairs are properly fitted to veterans in need. I pledge that a major commitment of my offices will be to see modern wheelchair standards adopted by the VA and an aggressive VA program of wheelchair evaluation implemented."

Margaret J. Giannini, MD
*Deputy ACMD for Rehabilitation and Prosthetics
Director, Rehabilitation Research and Development
Service*





"Of approximately 25,000 veterans with spinal cord injury, about 18,000 are treated in the VA's 20 spinal cord injury centers and other facilities of the VA medical care system. It is critical that VA clinical practitioners have the most comprehensive knowledge in the wheelchair selection process in order to make the best prescription. This clinical supplement will assist the physician and his team in making the most appropriate wheelchair prescription."

Joseph E. Binard, MD, FRCS (C)
Director, Spinal Cord Injury Service

"The Department of Veterans Affairs is the largest procurer of wheelchairs in the United States. As the director of the service responsible for the issuance of these devices, it is my concern that every veteran is evaluated to assess his/her individual needs. It is critical that each person receive the right wheelchair from the onset. I believe that this supplement will improve the quality of the wheelchair selection process."

Frederick Downs, Jr.
Director, Prosthetics & Sensory Aids Service



"Consumers have been a major force in the development of improved wheelchairs. Sports chairs, *Sports 'N Spokes*, wheelchair games, etc., have been dramatic forces in the improvement of wheelchair mobility. The Paralyzed Veterans of America (PVA) has also been a leader in the development of wheelchair standards. PVA, along with the VA Rehabilitation Research and Development Service, and other organizations, has sponsored significant research on wheelchairs. Now it imperative that VA clinical practice make the best possible wheelchairs available to veterans in accordance with their unique individual needs. I endorse this publication as a step towards this goal."

Victor McCoy
*Associate Executive Director,
Paralyzed Veterans of America*



Samuel Robert McFarland
1941 – 1989

We take pride in dedicating *Clinical Supplement No. 2* to Samuel McFarland, who served as Director of the Rehabilitation Engineering Program at the National Rehabilitation Hospital in Washington, DC, and Director of the Rehabilitation Engineering Center on Evaluation of Rehabilitation Technology, funded by the National Institute on Disability and Rehabilitation Research.

Mr. McFarland began his career at Southwest Research Institute in San Antonio, Texas in 1969. His work focused on the design of innovative new products for disabling conditions such as deaf-blindness, quadriplegia, and mental retardation. His work involved the transfer of engineering and scientific technology to the medical and rehabilitation field, as it related to the home, vehicle, and worksite. He participated in the development of performance standards for automobile adaptive devices and wheelchairs, and played a role in the development of the Unistick vehicle controller.

A founding member of the Association for the Advancement of Rehabilitation Technology (RESNA), Mr. McFarland was also a member of the American Society of Mechanical Engineers, the American National Standards Institute, and the Society of Automotive Engineers. In April, 1989, he was selected as one of 20 rehabilitation technology experts from across the country to be a Switzer Scholar.

We commend his achievements in the field of rehabilitation technology. We also appreciate his extensive contributions to this publication. He authored one of the articles, he provided technical assistance for the entire text, and his illustrations appear throughout.

Samuel McFarland was a highly respected, knowledgeable, and devoted professional. He will be missed.

The Editors

Journal of Rehabilitation Research and Development

JOURNAL OF REHABILITATION RESEARCH AND DEVELOPMENT
Clinical Supplement #2

Choosing a Wheelchair System

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EDITOR'S NOTE

Wheelchair selection used to be a simple process of prescribing essentially the same chair, modified only by an individual's measurements. However, advances in research and technology have changed that and a wide choice of chairs, seating options, and accessories have created the need for a *system of selection*. Each person can now be equipped with a wheelchair tailored specifically to his or her needs and lifestyle.

Proper selection is essential. An appropriately prescribed chair can increase mobility, provide the opportunity to participate in sports, and expand employment opportunities. Proper selection results in improved health and quality of life.

Progress made in the range of choice has been so dramatic and so rapid that a wide gap now exists between the available technology and clinical practice. Having choices offers us the opportunity for a successful match between user and wheelchair. It also increases our chance for error. The possible consequences of an improperly prescribed chair include pressure sores, thrombosis, and spinal deformity as well as unnecessary limitations on mobility and lifestyle.

This gap is costly in other ways. The VA alone spent over \$18,000,000 in 1988 for prescription wheelchairs (including repairs). A more effective use of technology would save significant dollars while providing better service. A proper initial prescription would reduce the number of replacements made because of improperly-fitted chairs. It would also cut maintenance costs, thereby effecting an overall decrease in the cost of prescription chairs.

This book details the prescription considerations for individuals with physical disabilities. It is presented in a multiple author format, representing a team approach to wheelchair selection.

Section I, *Clinical Perspectives on Wheelchair Selection*, emphasizes the philosophy that wheelchair selection is an inclusive process—the consumer working in conjunction with a professional team, choosing from a wide range of components to meet the requirements of various settings (work, leisure, travel, recreation).

The second section, *Technical Considerations*, examines the technical aspects of seat selection, factors that affect the ergonometics of wheelchair operation, and the influence of powered mobility.

Section III, *Future Developments*, reviews the Wheelchair Standards, as defined by the American National Standards Institute (ANSI), examines current research, and includes *A Call for Action*, which delineates the need for a national clearinghouse for all information related to rehabilitation research and technology.

The importance of a properly prescribed wheelchair system cannot be overestimated. A wheelchair tends to become a part of the self and self-image of the user. All clinical team members as well as the client and his or her family members are obliged to be well informed and take an active role in the selection process. This book provides guidelines to that end.

Seldon P. Todd, Jr.

Editor, *Journal of Rehabilitation Research and Development*

Clinical Perspectives on Wheelchair Selection

Prescription Considerations and a Comparison of Conventional and Lightweight Wheelchairs

by Kristjan T. Ragnarsson, MD

Dr. Ragnarsson is Dr. Lucy G. Moses Professor and Chairman of the Department of Rehabilitation Medicine at the Mt. Sinai Medical Center, New York, NY.

INTRODUCTION

Despite its obvious benefits to the user, the wheelchair represents a changed and intensely disliked lifestyle. It identifies the user as disabled and is a constant reminder of the disability. Moreover, the wheelchair becomes part of that person's self-image. For the prescribing physician or clinician, it is a frustrating reminder of an inability to cure the condition. An appropriate wheelchair prescription for a permanently disabled person demands the utmost attention and care, involving the assessment and integration of the user's needs with the most currently available technology. Since each user's needs are unique and scores of basic wheelchair types, each with numerous options, are available, hundreds if not thousands of possible combinations and choices exist.

Over the past few years, available technology for wheelchairs has been changing rapidly. This trend is expected to continue. Wheelchairs, component parts, and even new concepts of wheelchair usage are changing radically. Thus, excellence of practice makes it imperative for the prescribing physician and clinician to be aware of new technology and trends.

An example of both the application of new technology and new concepts of wheelchair use is provided by what are now called lightweight wheelchairs. Lightweight wheelchairs, originally designed

exclusively for athletes, have had a dramatic impact upon the very image of a wheelchair, and are now preferred by users with a wide range of non-athletic needs and interests. However, conventional wheelchairs are still the most appropriate choice for many individuals. Thus, the prescriber must consider and evaluate the latest engineering trends along with input from the users and their families, as well as from nurses, physical therapists, occupational therapists, and knowledgeable suppliers in order to write the optimal wheelchair prescription.

This article traces the primary and ongoing concerns of the wheelchair prescriber in meeting the individual physical and environmental needs of prospective users. It also presents a comparative description of conventional and lightweight wheelchair components and functional characteristics to help the prescriber and user make the best choice.

INITIAL RESPONSIBILITIES OF THE CLINICIAN

The most important factors the clinician must take into consideration when writing a wheelchair prescription are summarized in **Table 1**. The principal wheelchair features and options selected are based on the individual's characteristics and needs. In order to avoid unnecessary cost, the wheelchair prescribed should have only those optional features that are useful and necessary to

Table 1.
Considerations for a Wheelchair Prescription

1. User's age, size, weight, etc.
2. User's disability and prognosis
3. User's functional skills and preferences
4. Indoor/outdoor use
5. Portability/accessibility
6. Reliability/durability
7. Cosmetic features
8. Options available
9. Service
10. Cost
11. Level of acceptance (total environment)

achieve optimal functioning. The wheelchair must fit the user properly in order to be comfortable, to provide maximum mechanical advantage and energy expenditure efficiency, and also to prevent medical complications. Incorrect fit may result in poor posture, joint deformities, restriction of joint movement and general mobility, pressure sores, circulatory impairment, and actual pain.

Many clinicians work in institutions where there are wheelchair clinics. Here the user can discuss his needs with a clinician and other professionals in the rehabilitation field. The setting allows the opportunity to test and evaluate various wheelchair types, sizes, and options before an actual selection is made. Special prescription forms listing the options for each wheelchair type are frequently used to facilitate the process and ensure accuracy.

Functional disability considerations

The nature and extent of a user's disability obviously will influence the prescription. For example, extensive paralysis or musculoskeletal problems of the upper extremities may make manual propulsion impossible and warrant the prescription of a powered wheelchair. Extensive paralysis of the trunk and neck requires a reclining backrest of extra height, perhaps with a neck extension. Elevating legrests are indicated for users who may not or cannot bend their knees or who have dependent edema of their feet. In order to prevent backward tipping, a person with lower extremity amputation, especially bilateral above-knee, requires a wheelchair in which the rear wheel axles are posteriorly placed. Those with triplegia require a one-wheel-drive manual wheelchair. Disabled people capable of ambulating with assistive devices, but with significant gait deviations, not only ambulate at slower speeds but

also have significantly increased energy expenditures. Physiological responses to wheelchair propulsion, i.e., heart rate, respiration, and blood pressure are greater when using the upper extremities than the lower extremities, as is cardiac work and metabolism, a clinical fact to be considered when prescribing a wheelchair for persons with a known heart condition.

Mobility needs and preferences

Several questions need to be addressed regarding the potential user's mobility needs and personal preferences. People with the same disability may function very differently, especially with respect to transfer techniques. For example, questions arise when considering a user's upper extremity strength and hand skills. Will a motorized wheelchair be needed? Will the user propel the chair or will someone else push it? Will the user require detachable armrests or footrests, or will fixed wheelchair components be sufficient? Will the wheelchair be used at home, at work, or both? Indoors or outdoors? For recreation and sports? Will the chair be used when traveling? Will it be used extensively on a daily basis by an active and/or heavy person, demanding increased durability of the device? Does the user have the skill to maintain the chair or have access to people who repair chairs?

And not inconsequentially, the wheelchair needs to reflect the user's personal preferences for appearance—its style and color. Ultimately, the most important factor in the success of a wheelchair prescription is the user's total level of acceptance and satisfaction with his chair as it combines looks, comfort, and function.

Purchasing concerns

Once the user's needs have been established, the clinician directs the user to a knowledgeable and reliable supplier who can help to finalize the prescription and deliver the product without undue delays or extra costs. The supplier should stock a variety of wheelchairs and options available for lease or rent when there is a delay in delivery or extensive repairs are required. The supplier should also provide a reliable maintenance and repair service at a reasonable cost.

Without compromising quality, and in order to avoid unnecessary cost, the wheelchair prescribed should have only those options that achieve optimal

functioning and user satisfaction. Finally, the user's means and ability to pay for the chair that serves his needs must be addressed. For example, will the insurance company agree to pay for the wheelchair which most closely matches the user's needs? If not, how can an affordable wheelchair best be prescribed without compromising function?

Adjustments for proper fit

Wheelchair fit is the next consideration. The clinician should carefully examine the chair for proper fit and make appropriate adjustments when the wheelchair is delivered and on follow-up visits as well.

The components of the wheelchair system should be adjusted to the user in order to obtain the optimum biomechanical advantage necessary for efficient propulsion. This means that the muscles should be close to the resting length in the starting position. Therefore proper measurement of the user's dimensions prior to prescription is of great importance. It is also important that *the chair and the seat cushion be fitted as a unit, rather than as separate units*, to ensure that the final wheelchair is neither too high nor too low, too narrow nor too wide. For example, a wheelchair that is too wide results in poor posture because insufficient support is provided, frequently causing a person to lean to one side and have ineffective bimanual propulsion. On the other hand, if the wheelchair is too narrow, pressure on the trochanteric regions results in pressure sores or discomfort.

Excessive seat depth results in pressure on the popliteal region. This in turn results in restricted blood flow or in poor seating posture because the user may slide forward in the seat. Inadequate seat depth results in excessive pressure on the ischium since there is less distribution of weight on the thighs. Generally, when the user is properly seated, there should be a clearance of 1-2 inches between the anterior edge of the seat and the popliteal regions.

Excessive seat height impedes effective propulsion and reduces stability as the center of gravity is elevated. But a seat that is too low or footrests that are too high also increases ischial pressure due to less weight bearing on the thighs. Excessive height of the backrest restricts shoulder and trunk motions whereas a low backrest provides inadequate body support and results in poor posture.

CONTINUING CONCERNS AND RESPONSIBILITIES OF THE CLINICIAN

The clinician's responsibilities do not end with ensuring that the delivered wheelchair matches the prescription. On each follow-up visit the user's overall condition needs to be reassessed. Sitting posture and mobility should be checked. The wheelchair's condition and service to the user should also be reevaluated.

Since clinical conditions affecting the upper extremities may interfere with operation of a manual wheelchair, they need to be regularly monitored. For instance, after many years of propelling a wheelchair and performing all ADL with the upper extremities, symptoms of degenerative changes of the musculoskeletal system may appear, e.g., osteoarthritis of the shoulders, elbows, and wrists; rotator cuff tears; bursitis; lateral epicondylitis; and tenosynovitis.

It is also the clinician's responsibility to see that the user is properly trained in the operation of the wheelchair, not only on level surfaces and inclines but on curbs and steps, indoors and outdoors, performing various kinds of transfers in and out of the chair, falling safely from the chair, getting back into the chair from the ground, pulling the chair into an automobile after transfer, and so on.

The user's environment must be made as accessible as possible to the wheelchair. This may require widening of doorways, expanding space to allow wheelchair turning, and the building of ramps.

Finally, the importance of wheelchair maintenance should be stressed. Regular lubrication of the chassis and detachable items, fastening of bolts and screws, adjusting of casters and wheels, changing of flat tires, and cleaning of the entire wheelchair often become highly developed skills and routine tasks of the user.

COMPARISON OF CONVENTIONAL CHAIRS AND LIGHTWEIGHTS

The vast majority of wheelchairs prescribed are manually propelled. In recent years, manual wheelchair design has been significantly modified to meet the demands for better performance in daily activities and recreation. The newer lightweight and ultralight designs have been frequently referred to as

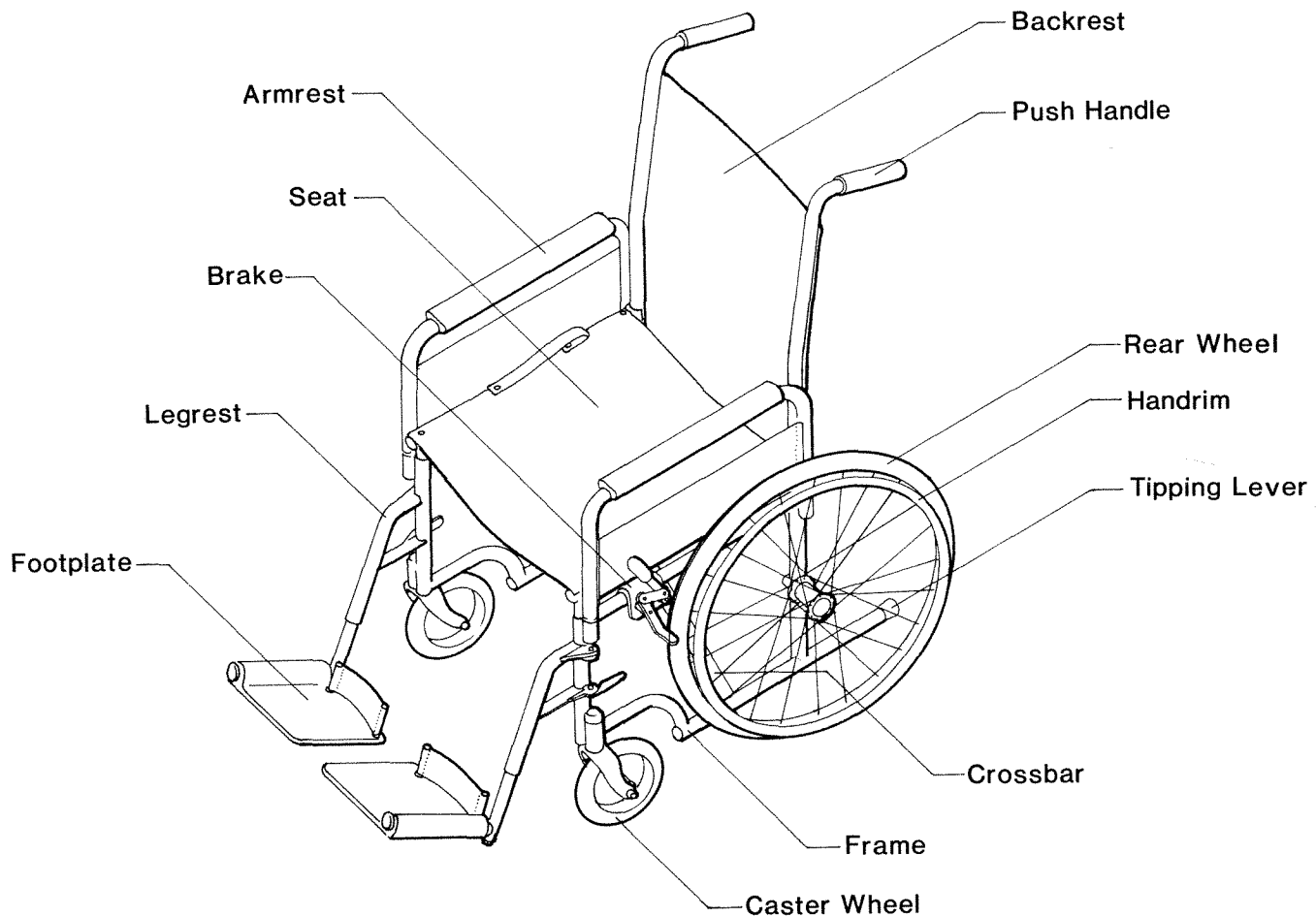


Figure 1.
The conventional wheelchair. (Drawing by Samuel McFarland)

“sports” wheelchairs. Presently, however, these chairs are prescribed for use by an increasing number of individuals who are not necessarily involved in sports, but who find that the modifications provide for better and more varied mobility. The sporty look of the lightweight and ultralight chairs is appealing and has contributed greatly to their popularity. Although these designs are in many ways technologically superior, they are not the best choice for every individual. Conventional wheelchairs have features that still warrant prescription for certain people and circumstances. Each case should be considered individually using the factors presented in **Table 1** as guidelines.

The Conventional Wheelchair (Figure 1)

1. The *frame* is made of chrome-plated, cold-rolled steel. Colors are not available. The *weight* aver-

ages 50 pounds. In 1967, a stainless steel model weighing approximately 40 pounds was introduced and was often referred to as a lightweight wheelchair.

2. *Push handles* are always in the back. The axle for the large rear wheels is positioned directly underneath the backrest.

3. The height of the *backrest* is fixed and usually measures 16 1/2 inches. An extended and manually reclining adjustable backrest is optional.

4. The *armrests* may be either full length or desk type, fixed or removeable, and adjustable in height. They are sturdy, attached to the wheelchair frame in 2 places, front and aft, with a metal skirt to prevent the user's clothes from being soiled by the tires or caught in the spokes.

5. The *seat* is a sling seat and made of vinyl like the rest of the upholstery. The upholstery is usually available in several colors.

6. The *front rigging*, with or without legrests, though fixed in the less expensive models, can be detached. Detachable front rigging generally has a swing-away feature and may have an elevating mechanism and a legrest.

7. The *footrest* (footplate, footpedal) is adjustable for length and rotation. It is available in 2 sizes and has the option of heel and toe loops.

8. With the conventional wheelchair the front *caster wheels* are usually 8 inches in diameter, although occasionally, they are 5 inches in diameter. The tires are made mostly of solid rubber. Pneumatic tires are now recommended for outdoor use.

9. The frame has *crossbars* underneath the seat to allow easy folding. There are no locks on the conventional wheelchair that securely maintain the open position.

10. *Brakes* are located in front of the large rear wheels and are either of the toggle or lever types.

11. The *rear wheels* measure 24 inches in diameter and have *handrims* for pushing that are attached to the periphery. The handrims are made of chrome-plated, cold-rolled steel and do not have a covering. Pneumatic tires or solid rubber tires can be used.

12. In the rear of the wheelchair, below the frame, are short *tipping levers*. They are used to negotiate curbs. Anti-tipping extensions can be attached to these levers to prevent backward tipping of the wheelchair.

The Ultralight or Sports Wheelchair (Figure 2)

1. The *frame* is made of lightweight metals such as aircraft aluminum alloys, titanium, or graphite. The entire wheelchair generally weighs about 25 pounds, which is half the weight of a conventional wheelchair. (Some racing chairs weigh less than 15 pounds.) The lighter weight makes propulsion more energy-efficient, and lifting and handling easier. Many models have as many as 12 to 24 frame colors

to choose from; none are in chrome. Initially, these models all had rigid frames. This made them sturdier and resulted in better performance for active individuals. Without crossbars, the weight of the wheelchair was reduced. However, it made transportation more difficult because the wheelchair could not collapse. In order to transport the chair, the backrest folded forward and the large rear wheels were removed, allowing the wheelchair to fit into the trunk of most cars. Recently, several manufacturers have produced folding frames, with or without crossbars, usually fitted with locks to prevent even minor folding during activity (e.g., the Quadra in 1979, the Quickie in 1983, and the Rolls in 1984). This has further eased the transportation of these wheelchairs.

Push handles may or may not be present but, more frequently, straps are added to the backrest upholstery for grabbing. Some active and independent individuals choose not to have push handles because they add to the weight and some users find them demeaning.

2. The *rear wheel axle* on the conventional wheelchair is located directly underneath the backrest, below the seat. The newer wheelchair designs have multiple axle positions that can be adjusted up or down, forward or backward. If the axle is moved forward the wheelbase is shortened. Many users find that when the axle is in this position the wheelchair becomes easier to maneuver and a shorter turning radius is needed. Likewise, it is easier to push the wheelchair when the large wheels are placed forward. A disadvantage of forward placement is less overall stability because the chair becomes lighter in front and is more prone to tip backwards. As the axle is moved backwards, stability is increased. If the axle is moved upward the seat is lower and the center of gravity is lowered. This results in increased stability of the wheelchair. The stroke propulsion also becomes stronger, a fact recognized by wheelchair racers who frequently have the top of the wheels right underneath their axillae. When the axle is moved upward, the seat tilts backwards unless the caster height also is adjusted. Such backward tilting elevates the knees and raises the thighs off the seat. This may increase trunk stability, but also increases pressure on the buttocks and the risk of pressure sores. Instead of moving the axle some models have moveable seats

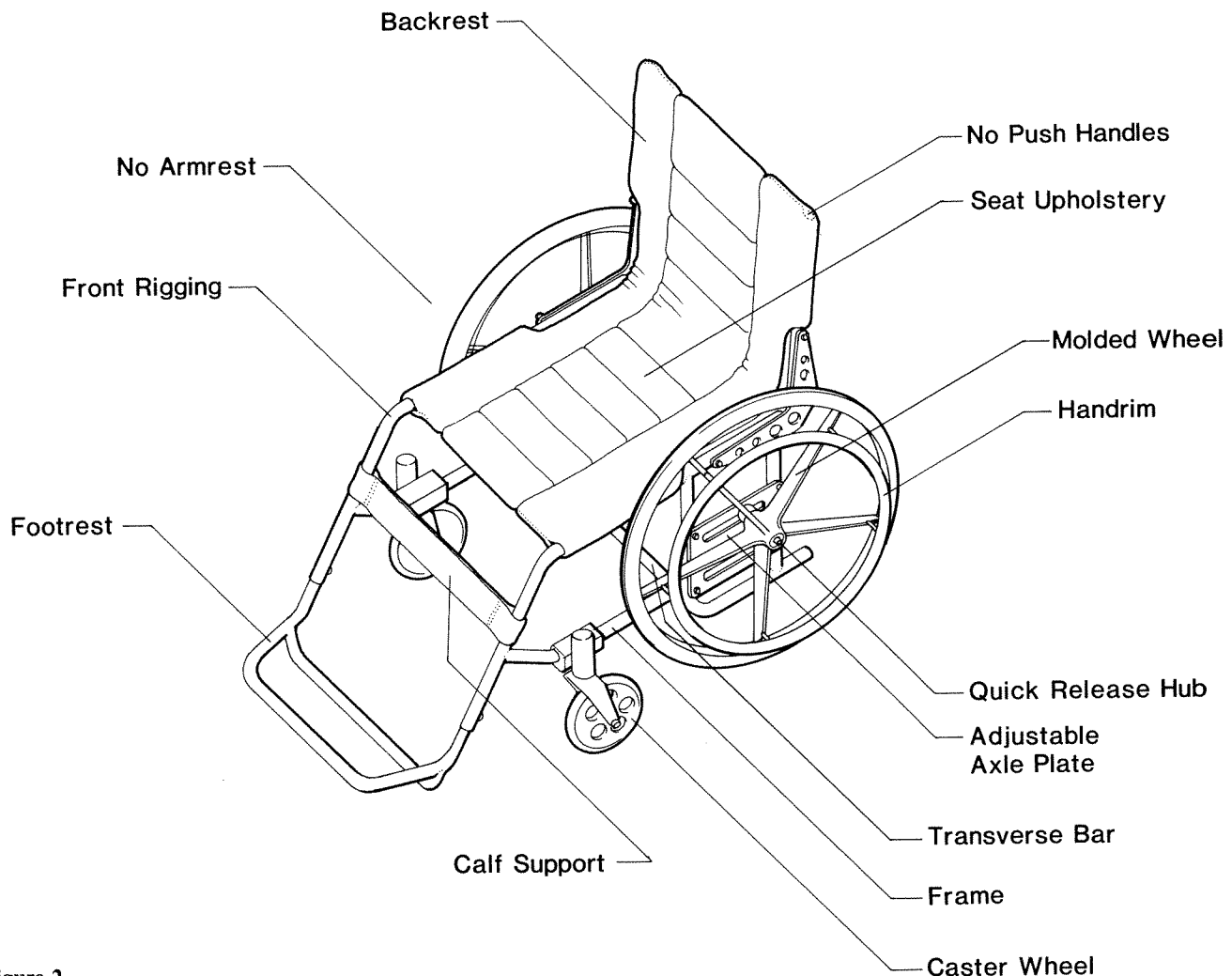


Figure 2.
The ultralight or sports wheelchair. (Drawing by Samuel McFarland)

(up and down, forward and back) and the results are similar.

3. On the newer wheelchair designs the *backrest* height is generally adjustable, most commonly between 11 and 15 inches, although adjustable backrests between 7 and 11 inches and between 15 and 19 inches are also available. The backrest is generally used in a position that is lower than on the conventional wheelchair, giving the upper body more mobility, although trunk stability may be reduced. The *upholstery* is usually made of reinforced nylon or dacron and is light, strong, and stretch resistant, but more difficult to clean than vinyl. The upholstery may be available in many colors.

4. *Armrests* are frequently missing on the newer

models. This reduces the weight of the wheelchair and also increases the range of lateral movement of the user, a definite advantage during wheelchair basketball and tennis. When the armrests are used, they are usually of adjustable height, swing-away and removeable, simply designed, and attached only to the posterior part of the wheelchair frame. The armrests are not sturdy enough to sit on, thus they cannot be used for transfers to higher surfaces. Sometimes skirts are not attached to the armrests and clothes can be soiled or caught in the wheels. However, some of the newer designs do provide skirts as part of the upholstery that extend diagonally from the backrest to the front of the seat.

5. The *seat* is frequently adapted for wheelchair cushions by providing velcro straps that are used to

attach the cushion to the seat, or by a pouch in which the cushion fits. As previously noted, lowering the back of the seat results in the elevation of the knees. This provides for better trunk stability during racing.

6-7. *Front rigging with footrests* was originally part of the wheelchair frame and not detachable. This made the wheelchair sturdier and prevented mechanical failures, but made some transfers and turning in small spaces more difficult. On some of these chairs the footrests are closer to the frame than those on the conventional wheelchairs, and this reduces the turning radius. The footrest is adjustable for leg length, but in order to provide calf support a soft sling often extends between the bars. Recently, certain designs have provided swing-up footrests and even swing-away detachable legrests. Many paraplegics feel that detachable front rigging is only useful when transfers are difficult.

8. The *casters* are generally made of solid polyurethane, although occasionally they may be fitted with pneumatic or solid rubber tires. Usually 4 to 5 inches, they are smaller in diameter than the casters on conventional wheelchairs. However, some users choose the regular 8-inch diameter caster and on some racing wheelchairs, 12 to 18-inch diameter casters are chosen. The 4-inch polyurethane caster, which is common on the newer wheelchair designs, is in many ways, similar to the wheels on a skateboard: it turns quickly, handles well with minimal flutter, and is very durable. However, the ride is somewhat rougher than on a pneumatic tire. The 8-inch polyurethane caster rolls easily over obstacles and an 8-inch pneumatic tire gives a smoother ride outdoors. Some designs provide a soft urethane in the liner of the caster for a puncture-free tire and a smooth ride.

9. *Crossbars* on rigid frames have been replaced by transverse bars. The recently developed folding frames are equipped with locks.

10. *Brakes* are optional because many users of the newer wheelchairs find them unnecessary. Some users do choose toggle brakes or the so-called scissors brakes. The scissors brakes are mounted lower on the frame, away from the fingers, and have become popular among very active users because

fingers may accidentally hit the toggle brakes during rapid propulsion. A way to prevent this problem is seen on some recently designed toggle brakes that have added space between the wheel and the brake when in the disengaged position.

11. The *large rear wheels* measure 24 inches in diameter as on the conventional wheelchair, although some racing chairs have wheels that measure 27 inches in diameter. The hub of the wheel is designed like the one used on a racing bike, lighter in weight with sealed precision bearings that give very low friction resistance. The hub can also have a quick release mechanism for removing the wheel when changing axle position or facilitating transport of the chair. The detachable wheels have hubs that protrude 1/4 to 1/2 inch on each side, thus adding to the total width of the chair. The spokes of the wheels are similar to the conventional models, although some designs use molded wheels.

The *tires* are generally pneumatic, not solid rubber, and may allow higher pressure, up to 160 pounds of pressure per-square-inch (PSI) on racing models. The pneumatic tires give a cushion effect for outdoor use. As on racing bikes, racing wheelchairs frequently have narrow tires that provide reduced resistance. Occasionally, the tires are made of soft polyurethane.

The *wheel camber* is adjustable on the newer wheelchair designs. As seen on many sport cars, the bottom of the wheels may be further apart than the tops. This has several advantages. The wheels are brought closer to the body for more effective propulsion. The wheelchair is easier to steer and is more stable, especially when turning. This is because the lateral width of the base is increased. However, it is more difficult to get through narrow doorways or, even when collapsed, to fit the wheelchair in the trunk of a car. Many of the newer models also have an adjustable "toe-in" on the rear wheels, thus more distance separates the wheels in the back than in the front.

The *handrims* for pushing are made of metal but are plastic foam coated with vinyl and are often available in assorted grip sizes. Although this gives the user a firmer and more comfortable grip, the vinyl coating increases the friction coefficient which may result in finger burns when the hands are used to stop the wheelchair. Handrims are available in many sizes, but are usually small on racing wheel-

chairs. The smaller handrims may give a slower and more difficult take-off, but they provide for a higher top speed and require less effort to sustain high speed. This is an advantage for strong people. Different handrim diameters are analogous to the different gears on bicycles, i.e., the highest gear (rim) has the smallest diameter. This makes starting and ascending inclines difficult, but, once momentum is reached, it can allow for the highest speed and greatest distance to be travelled with each stroke. Likewise, the lowest gear (rim) has the largest diameter, which makes starting and acceleration easier.*

12. Step-on *tipping levers* are shorter and part of many chairs. Anti-tipping extensions, although optional, are generally not included on the newer wheelchair, especially on wheelchairs prescribed for skillful individuals.

13. *Seatbelts* are an option. They are used in the same manner as in the back of an automobile or seatbelt in an airplane. For high level paraplegics and quadriplegics, safety vests and harnesses are available. It may be enough support to use the same arrangement used in the front seat of today's automobile. For those clients that experience severe extensor thrust spasticity of the lower limbs, it is absolutely necessary to have a seatbelt.

Summary. Perhaps the most important aspect of the newer wheelchair designs is that they promote self-confidence, a better self-image, and a greater feeling of acceptance by the public. These factors can help facilitate community reintegration and greater life accomplishments, which indeed, are the ultimate goals of rehabilitation.

RACING WHEELCHAIRS

A wheelchair meant for sports use exclusively is not a prescription item, but can be purchased directly by the user from a supplier or builder. The

clinician, however, should have some knowledge of the options for a wheelchair athlete.

The serious wheelchair racer frequently has a custom-built chair designed with numerous features that are used to obtain optimum energy-expenditure, efficiency, and high speed. The rear wheels are large, 26 to 27 inches, and the set is low so the top of the wheels almost touches the axillae. The wheel camber is variable. The handrim is small in diameter, approximately 12 inches, and is attached to the spokes with clips. The pneumatic tires are narrow with 160 PSI. The front casters or wheels are large—12 inches in diameter, with spokes and a hub with low friction, and sealed, precision bearings to facilitate rolling. Attached to the front wheel mechanism are steering handles and brakes. The seat is low to lower the center of gravity and thus, increases stability.

MOTORIZED WHEELCHAIRS

Motorized wheelchairs are prescribed for persons who cannot propel a wheelchair with their hands or feet or who have a medical condition, or other reasons that contra-indicate the energy expenditure associated with such exertion. Generally, a motorized wheelchair would not be prescribed for a person with a temporary or minor disability. It is frequently prescribed for people with severe neuromusculoskeletal disabilities or poor endurance due to cardiopulmonary diseases. Some might use the motorized wheelchair only in a given situation, e.g., to travel long distances, but might be capable of ambulating or propelling a manual wheelchair for shorter distances at home. Obviously, the prospective user must be mentally competent and observant, have adequate sitting balance and adequate vision. Coordination and strength of some muscle groups in the upper extremities, neck or face, is required to operate the wheelchair control mechanism. However there are special control systems for individuals with poor hand/arm function, i.e., people with cerebral palsy.

In recent years, the designs of motorized wheelchairs have improved in many ways. Although a motor, batteries, and control mechanisms can be added on virtually any heavy-duty wheelchair, most motorized wheelchairs prescribed today are designed and built with these components as integral parts.

*Editor's Note. Handrims: For clients with limited use of their upper limbs, particularly quadriplegics, vertical or oblique projections may be mounted on the handrim to assist in propulsion. These are pushed against by the radial border of the forearm or hand or by the hypothenar eminence of the hand in supination.

This has resulted in a cosmetically improved appearance. Since people requiring motorized wheelchairs tend to be more severely disabled than those requiring manual chairs, certain aspects of the prescription require special attention. A detailed description of motorized wheelchairs is presented in Chapter 6, "Powered Mobility and Its Implications."

CONCLUSION

The wheelchair is the single device that can most radically improve the mobility and functional

independence for a disabled person. Although most wheelchairs appear similar, relatively minor modifications in design, components, and appearance can have a major impact on the user's self-image and ability to function.

Wheelchair prescription for a permanently disabled person should never be based on limited knowledge. It should be done by rehabilitation professionals who know both the disabled user and the current wheelchair technology, and only after careful observation and evaluation that combine the user's personal preferences, skills, and lifestyle as well as his/her medical needs.

Clinical Perspectives on Wheelchair Selection

A Participatory Planning Process for Wheelchair Selection

by Mark N. Ozer, MD

Dr. Ozer is Assistant Chief of the Spinal Cord Injury Service, McGuire Veterans Affairs Medical Center, Richmond, VA, and Associate Professor of Neurology at the Medical College of Virginia, Richmond, VA.

INTRODUCTION

The wheelchair serves to increase a person's ability to function effectively and efficiently in his/her environment. Optimal performance depends on the successful selection of a wheelchair. The wheelchair selected must "fit" the individual and facilitate the ability to manipulate a variety of environmental barriers.

The process of defining that "fit" requires identifying the characteristics of two halves of an equation: the person and the environment. The aim of the wheelchair user is to control his/her mobility as much as possible. The clinician works with the user to define the range of mobility goals. This interaction can enhance the degree to which the wheelchair becomes a part of the user. Only through user involvement can optimal mobility be achieved.

The methodology presented here is based on wheelchair selection as an ongoing planning process comprised of a number of sub-plans. The overall plan is subjected to periodic review and further modification throughout the life of the user, just as the various technical aspects of the wheelchair itself must be regularly evaluated in terms of their effectiveness in meeting the goals of mobility. Each sub-plan consists of a goal, and each of the technical aspects of the wheelchair is a means for accomplishing these goals. For example, one sub-plan goal may relate to the goal of maintaining sitting balance

utilizing a range of back and seat heights as the means for achieving such balance.

Several criteria for the evaluation of a planning process have been established.* The first step in planning is to properly identify the problems to be remediated. The next step is to define clear objectives or goals for solving these problems. The third objective is to maximize user participation in this process of goal definition.

Ideally, contributions should be made by the user throughout the planning process. Initially, the professional will contribute most of the technical information about the general design and functions of wheelchair components, as well as the process of selection. Over time, as goals and means are defined and revised, the degree of user participation should be expected to increase to include contributions to technical aspects as well as goals.

THE PLANNING PROCESS

Identification of the Problem(s)

In the case of wheelchair selection, the task of identifying the problem will involve physical, social,

*Ozer MN: Design Process Viewed as Technology. In *Proceedings of the 9th Annual Conference on Rehabilitation Technology*, 6:143-144. Washington, DC: Association for the Advancement of Rehabilitation Technology, 1986.

economic, and technological considerations. For example, for those with spinal cord injury the problem is not only impairment in the use of limbs but the functional consequences of the impairment in that person's own environment. For a person with excessive spasticity, a major problem may be trouble with steering a motorized chair though the relatively bumpy area from his house to that of his next-door neighbor; the control system must be responsive to this need. Another person with paralysis may have trouble navigating even a slight incline because of insufficient strength; anti-slip devices as well as a lightweight chair may be useful here. For some, problems may pose only occasional difficulties, but for others they might become constant crises.

It is necessary to explore with the user his or her lifestyle in order to identify all of the possible problem areas. Consideration must be given to activities carried out on weekdays and weekends—all activities carried out when the person was “on his feet.” If one of the priorities in the past was to walk along the riverbank in the evening, is this still a high enough priority to be considered in the selection of a wheelchair? The most precise definition of any user's problem must arise from as complete an exploration as possible of that person's unique situation and way of life.

The more complete the delineation of the problem, the more likely that the goal statement established will reflect the needs of the user. This process of problem identification is, ideally, an ongoing one. The user becomes better able to state his problems as he gains experience in recognizing and expressing them to informed, attentive listeners. Furthermore, problems may arise and mobility needs may change over time with regard to use of a particular wheelchair.

For example, returning for his annual check-up, a person with longstanding quadriplegia wanted to replace a worn out back-up manual wheelchair. When asked what problems he encountered with it, he first mentioned his concern about tipping, then not being able to maneuver in tight places in his house trailer, then not being able to cross even a short distance of gravel outside his house. When asked which was most important, he responded that he would like to be able to maneuver his chair so that the gravel between paved surfaces in the rural area where he lived would not be such a barrier.

This is the sort of problem that is often difficult for clinicians or users to identify initially.

Determination as to whether the problems are properly identified and prioritized is basically a “check-out” procedure. Before going on to the definition of the goal statement, the user is asked to confirm what he has stated initially as his major concern by once again stating his major concern. (**Figure 1**)

Definition of the Goal

Exploring several alternatives is useful before selecting the highest priority goal, or the “best” statement of the goal. It is necessary to describe the goal in functional terms—those that are most meaningful—in order for the user to become a major participant in evaluating the degree to which the goal is accomplished.

As illustrated in the case above, it is important to encourage the user to become involved in exploring and selecting goals in terms of his/her own life setting. It is also an important aspect of the evaluation of the planning process to express the goal as specifically as possible. The clearer and more specific the goal statement, the more likely it is to be recognized when accomplished. A three-point criterion of specificity would include:

WHAT is to be accomplished;
WHEN (or WHERE), describing the setting;
HOW MUCH (or HOW WELL or HOW LONG), describing a measure of degree of accomplishment.

For instance, the person described above set the criteria for specificity when he described his goal to “be able to push my chair through the gravel near my house without getting winded.”

The purpose—user satisfaction—sought by such planning questions is not new. What is important is the degree to which people are involved in the planning process; consciously exploring the problem, specifying the goals, and evaluating and modifying the effectiveness of the ongoing plan.

A Measure of User Participation

A scale to help the clinician measure the user's degree of participation is shown in **Figure 2**. At the first level, “independence,” the user asks himself the questions and provides the answers. At the

Name: _____ Date _____
 Therapist _____

1. WHAT ARE YOUR CONCERNS?

a) _____
 b) _____
 c) _____

2. WHAT IS YOUR GREATEST CONCERN?

Check-out: _____ Agreed _____ Confirmed _____

3. WHAT DO YOU WANT TO SEE HAPPEN? WHAT WOULD MAKE YOU FEEL THAT YOU ARE MAKING PROGRESS? WHAT ARE YOUR GOALS?

a) _____
 b) _____
 c) _____

4. WHAT IS YOUR SPECIFIC GOAL?

A	B	C	D
A	B	C	D
A	B	C	D

What?
 Conditions?
 Degree?

5. Please circle the "lowest" level of participation used in answer to the various portions of the goal statement.

A = open-ended question FREE CHOICE
 B = suggestions (3 options) MULTIPLE CHOICE
 C = recommendation (1 option) FORCED CHOICE
 D = prescription (tells what to do) NO CHOICE

Figure 1.
 Client response form.

Measure of Degree of Participation in Planning

	Professional	User	USER Percent contribution
1. Independence	-----	Asks himself Answers for himself	100%
2. Free Choice	Asks open-ended questions without providing answers.	Answers for himself	80%
3. Multiple Choice	Asks Provides several (3) answers from which to choose. "Suggests"	Selects answer(s) for himself	60%
4. Forced Choice	Asks Provides one answer for discussion prior to action. "Recommends"	Agrees (or disagrees)	40%
5. No Choice	Does not ask. No option for discussion of already determined action. "Prescribes"	Compliant in carrying out action (or non- compliant)	20%

Figure 2.

second level, "free choice," the professional interviewer may ask the questions that help define the problem and goal, but the user provides the answers on his own. When necessary in order to meet the objective of developing a "specific" statement, the interviewer may then move to the third level, "multiple choice," in which the user has merely to choose from the several suggestions supplied by the interviewer. At this level the user is still making a major contribution to decision making. The fourth level, "forced choice," marks a significant shift in the degree of user control exerted on the planning process. At this stage, the user has merely to state "yes" or "no" to the recommendation made by the interviewer. Even less control would be exemplified by the fifth stage, "no choice," where the action is "prescribed" and the user is merely expected to be "compliant."

A method to maximize the user's degree of participation in the planning and selection process would be to: 1) initiate the questioning at the free choice level; 2) go down the scale one step at a time and only when it is necessary to meet the need for specificity; and, 3) return to the higher stages of participation as soon as possible during any course of planning.

Given certain limits in wheelchair design, matching the technical aspects of the problem with goals and priorities may require some compromise. Cost must be considered—not only dollar costs but costs in terms of reliability and maintenance.

Review and Revision

Over time, the user's environment or his capabilities may change, or there may be a significant

breakthrough in some aspect of wheelchair design that could increase his mobility options.

As the individual gains daily life experience with the use of a wheelchair, there is more opportunity for him to participate in identifying technical aspects that would improve his mobility system. If, for example, the user initially participated at a level of "concurrence" by merely following the recommendations of the professional, then the aim would be to reach a higher level of participation during the ongoing phase—for example, that of "multiple choice."

A CASE STUDY

The following example of a person with a recent spinal cord injury at the level of C6 is presented to illustrate the successful use of the participatory planning process in wheelchair selection.

During the early post-injury phase, the user described on the "free choice" level a number of goals for evaluation and selection of an appropriate wheelchair. One goal was to be able to balance himself while sitting so that he would still be able to use both arms in carrying out tasks. Because of his lack of finger dexterity, he felt it would be important to have armrests that were easily removable. Another goal was to continue to travel widely, as he had done prior to his injury. He wanted a wheelchair that was portable and that could be stored in a relatively small space in the cabin of an airplane. He did not want it to be stored in the cargo bay during travel. Another high priority for this person, who was also diabetic, was to maintain his health and cardiovascular endurance through physical activity. "I was athletic before my injury and want to continue."

In selecting the means for meeting these goals, the young man requested a lightweight wheelchair with a variety of levels of back support. He learned that he could counterbalance his weight by leaning rather far back and thus have both his arms free to carry out tasks. When he was placed in a chair with a high back, which is the usual method for dealing with problems of balance, he was unable to use the weight of his trunk for counterbalance and needed to use one of his arms to steady himself. Thus, he was able to demonstrate for his own needs the value

of a chairback lower than that ordinarily recommended for persons with his level of spinal cord injury.

The selection of the other appropriate means for meeting his goals was aided by a magazine article he had read about alternatives now available in lightweight wheelchairs. "I knew what the options were myself and had a chance to think things through before finally selecting my chair." The chair he chose had moveable rotating armrests and could be modified for exercise and be disassembled for storage in small spaces.

This user functioned at the level of "free choice" with respect to setting goals, and at the level of "multiple choice" in selecting the means for meeting those goals by having the options available for him to review. For example, in respect to the decision for the height of his back support, his ability to experience a range of back heights enabled him to select one which was particularly effective for him.

During a review session several months after discharge from the hospital, he described his wheelchair as meeting his needs. When asked to evaluate the degree to which it was meeting his goals, he mentioned that he had been able to take several airplane trips, balance had not been a problem, and he had participated in wheelchair slalom racing regularly. An initial concern that his lightweight chair might interfere with "boardless" transfers had not turned out to be a problem.

There had been some difficulties, however. The padded material covering the armrests had deteriorated very quickly. He also found the gloves he had been issued to use did not give adequate padding for his palms. He found it worked better to buy gloves available in bicycle shops and to use the sort of handlebar covers used for bicycles to cover his armrests. He planned to mention these alternatives to the prosthetics service for consideration by other users. He had now moved to a new level of participation; he was contributing new ideas to the solution of problems. He was operating at the level of "independence." He was identifying problems on his own and finding solutions without the need for interaction with a professional. Indeed, he was offering a perspective to the professionals that could be helpful to other users.

CONCLUSION

The clinical use of a structured participatory planning process can facilitate a wheelchair selection that most effectively meets the user's mobility requirements and results in personal satisfaction. Evaluation is done on the adequacy of problem identification, specificity of the goal statement, and the degree to which user participation is maximized during the planning process. Particularly during the ongoing process of review and revision, the opportunity exists to increasingly involve the user in the selection and modification of the wheelchair components, as well as in identifying problems and defining new goals.

AUTHOR'S NOTE

The participatory planning process referred to in this article is described in greater detail in a recent publication, *Patient Participation in Planning: A Manual for Therapists*, by O. Payton, C. Nelson, and M.N. Ozer (F.A. Davis Publishers, Philadelphia, PA, 1989). The manual includes procedures for self study in the development of the skills necessary for carrying out this process, as well as formats for the training of therapists during inservice and professional workshops.

Technical Considerations

Ergonomic Considerations

by Clifford Brubaker, PhD

Dr. Brubaker is Director, Rehabilitation Engineering Center, and Associate Professor of Orthopedics and Rehabilitation at the University of Virginia, Charlottesville, VA.

INTRODUCTION

Wheelchair performance is directly related to the client's position in the wheelchair. Client position, i.e., the distribution of mass with respect to the wheel axis and the position of the client's shoulder axis relative to the handrim, is related to several ergonomic factors:

- Rolling Resistance (RR)
- Downhill Turning Tendency (DTT)
- Yaw Axis Control (YAC)
- Pitch Axis Control (PAC)
- Propulsion Efficiency (PE)
- Static Stability (SS)
- Weight/Portability

These factors influence performance as follows:

Rolling Resistance (RR): The conventional configuration results in a weight distribution with approximately 60 percent on the main wheels and 40 percent on the casters. By moving the seat rearward 2.5 inches, the weight is redistributed to a 75 percent/25 percent ratio. If other factors remain constant, this has been found to reduce RR by 6 percent (1) (Figure 1). While this difference appears small, it could be quite significant over a long distance for a marginal wheelchair user.

Downhill Turning Tendency (DTT) or Side-Slope Effect: Whenever there is a lateral incline there is a DTT. Since virtually all improved outdoor surfaces have a 1- to 2-degree slope for drainage, this is an ever-present condition. A 2-degree slope results in nearly a two-fold increase in the energy required to propel a conventional wheelchair (2). Moving the seat rearward shifts the center of gravity and significantly reduces DDT (Figure 2. See also Figure 4b).

Yaw Axis Control (YAC): The forces required to maneuver the wheelchair are inversely related to the polar moment of inertia of the wheelchair. This moment of inertia can be reduced by decreasing the distance from the main axis to the center of gravity by moving the seat rearward.

Pitch Axis Control (PAC): The ability to do a wheelie is essential for curb-climbing and provides for a greater degree of control and maneuverability (Figure 3). Pitch axis control is inversely proportional to the moment of inertia (1) and is improved by a rearward seat position. The trunk also has a large moment of inertia and is important in pitch axis control. A high seatback can limit the range of motion of the trunk and therefore limit the effect of trunk motion in PAC.

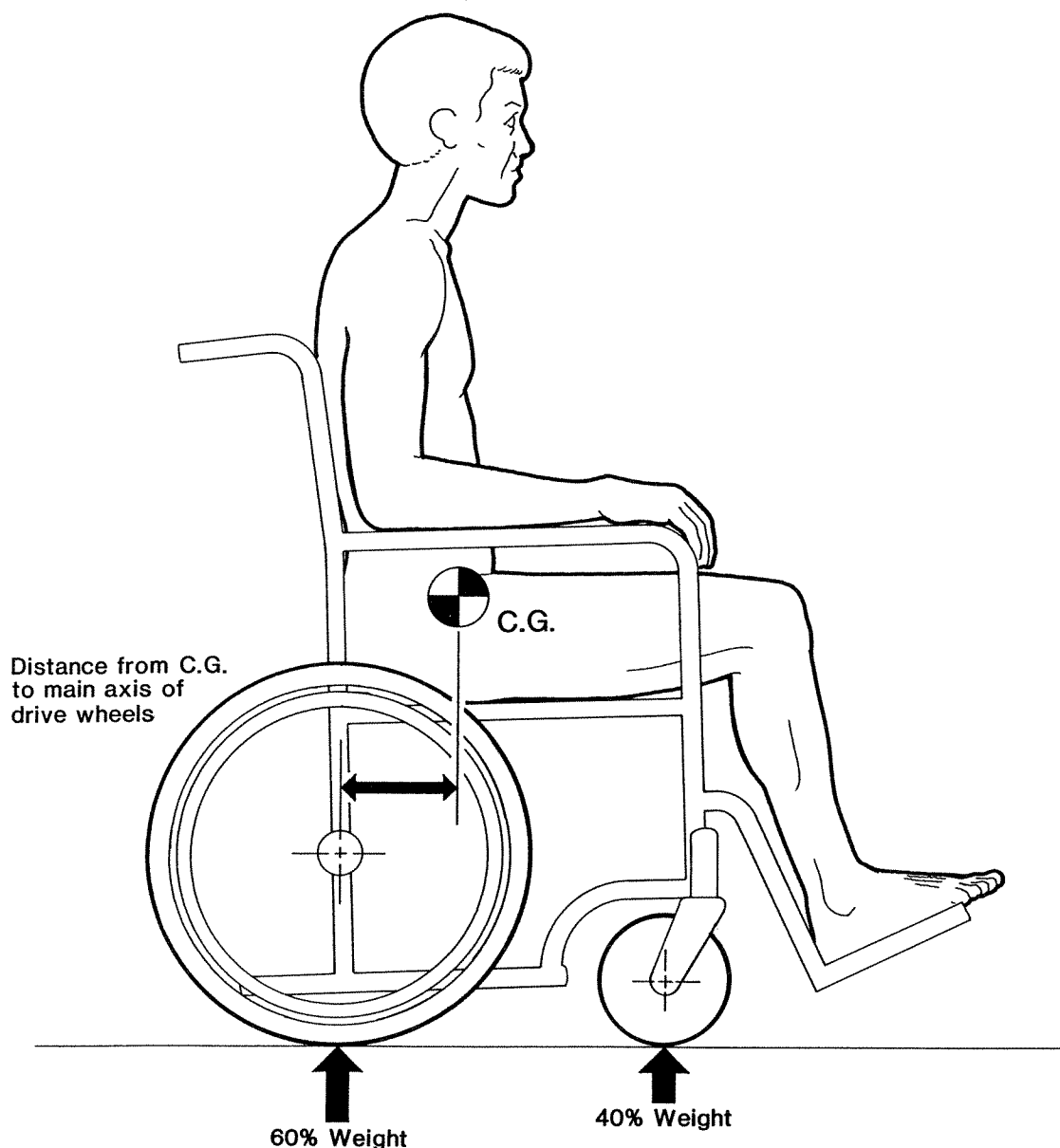


Figure 1.

One of the most important factors affecting wheelchair performance is the distribution of mass on the wheels. The horizontal distance between the center of gravity (c.g.) of the combined mass of wheelchair and occupant (represented by the circular target) and the axle of the main drive wheel determines the distribution of mass between the rear and front (caster) wheels.

Propulsion Efficiency (PE): Propulsion efficiency is related to the above factors and is also consistent with a more rearward seat position (3,4). Optimizing PE requires minimizing energy consumption in the recovery phase of the propulsion cycle (5). This

depends on both the fore-aft and the vertical position of the seat. The conventional position requires excessive internal rotation, extension, and shoulder elevation in the recovery phase, in order to grab the rim for the stroke. If the client is ideally

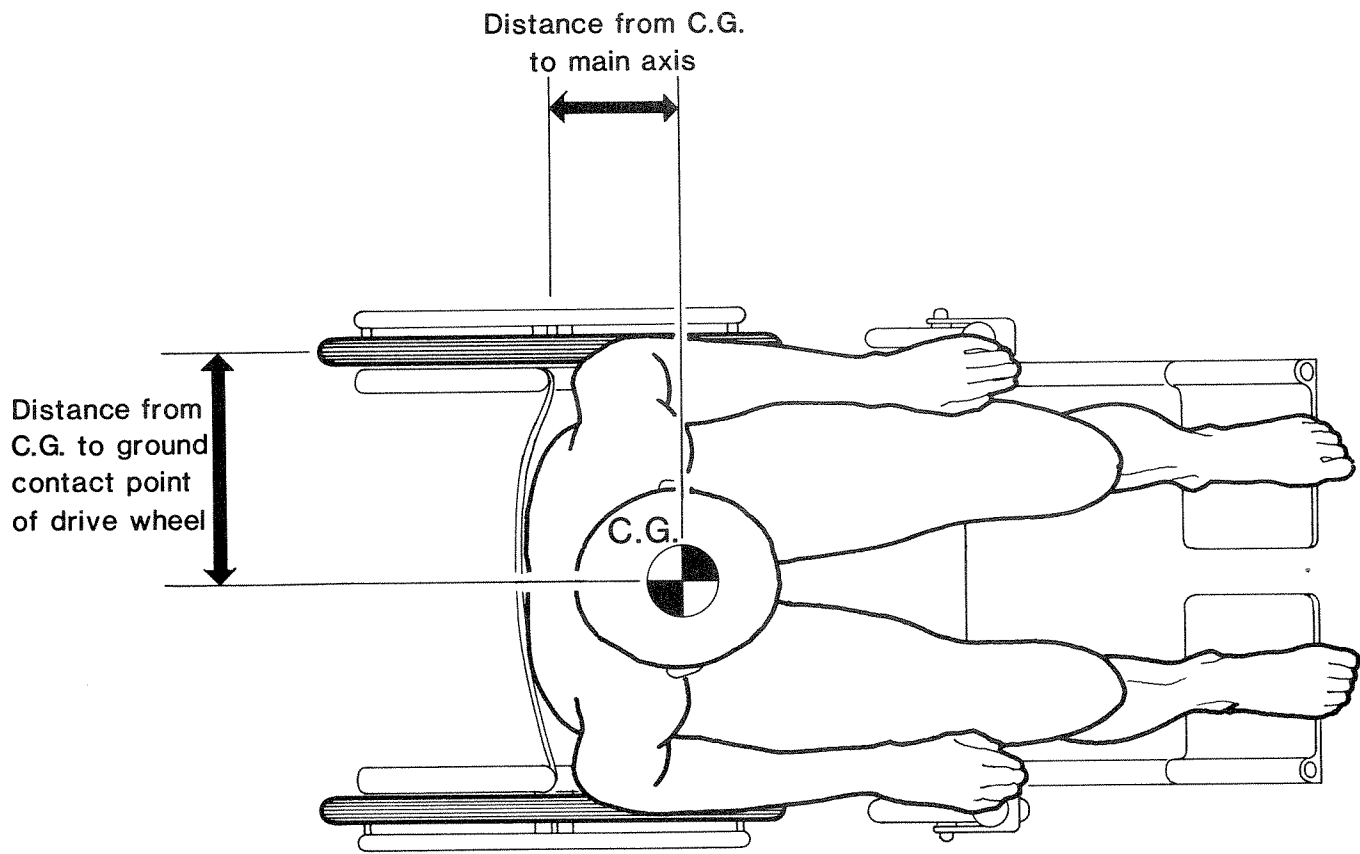


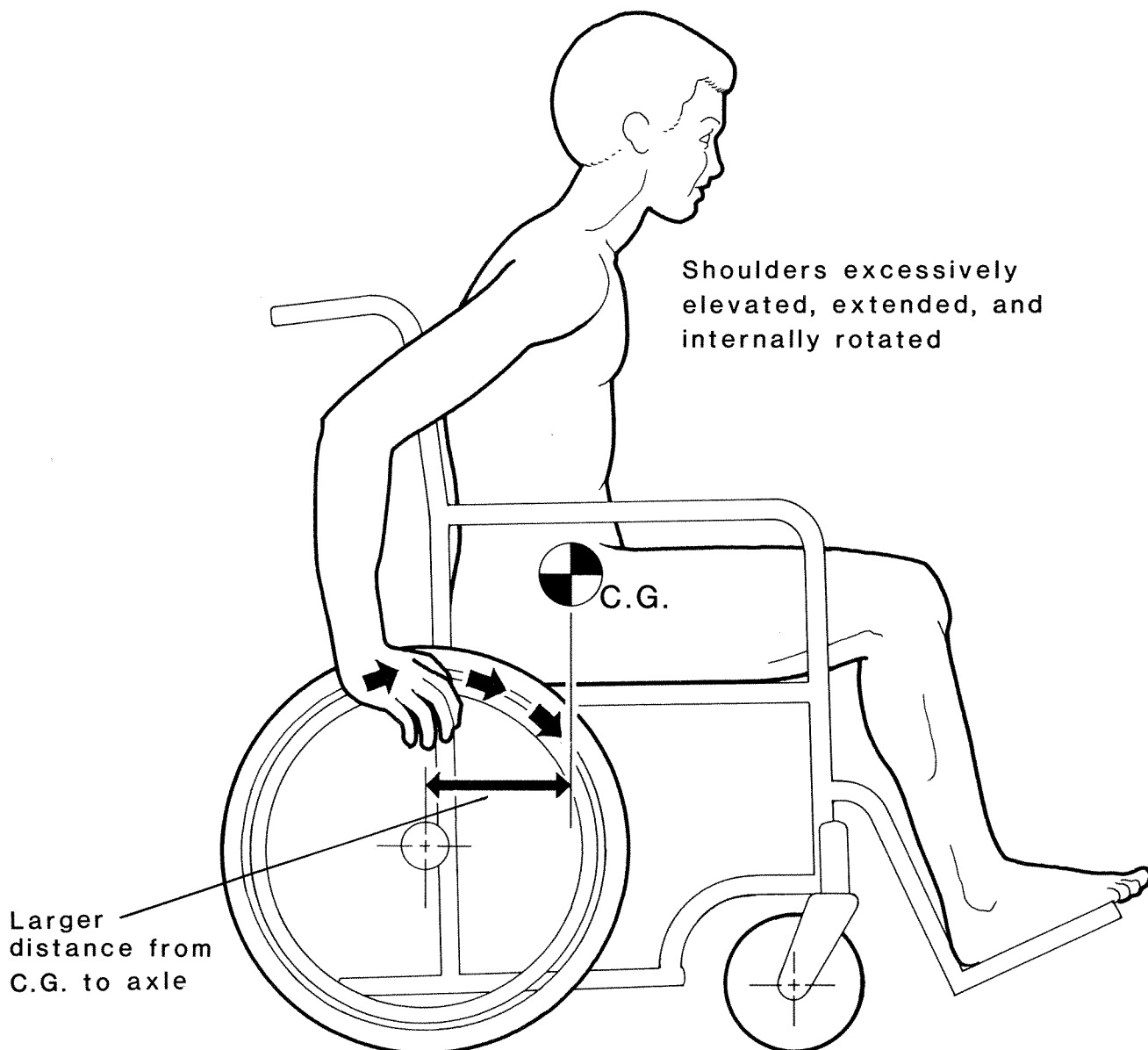
Figure 2.

The tendency toward turning downhill (DTT) and the ease of, or resistance to, turning while moving (YAC) are both related to the horizontal distances between the c.g. of the system mass and the axle or ground contact point of the drive wheels. The magnitude of the combined mass and the distances are elements of the polar moment of inertia of the system.



Figure 3.

Wheelie balance. The ability to balance a wheelchair on its rear wheels is essential for curb climbing, as well as for providing extra control and maneuverability.



Figures 4a and 4b.

Figure 4a: If the user is too far forward or too low, the shoulders are excessively elevated, extended, and internally rotated and the propulsion stroke is predominantly downward.

positioned, i.e., rearward, the recovery phase is initiated by gravity and requires little or no muscular effort (**Figures 4a and 4b**).

Static Stability (SS): While it is evident that the SS

of the wheelchair is reduced with rearward seat placement it is doubtful if the consequence is well understood. The increased PAC and the lesser angular displacement required to reach the balance point make it much easier to recover from an

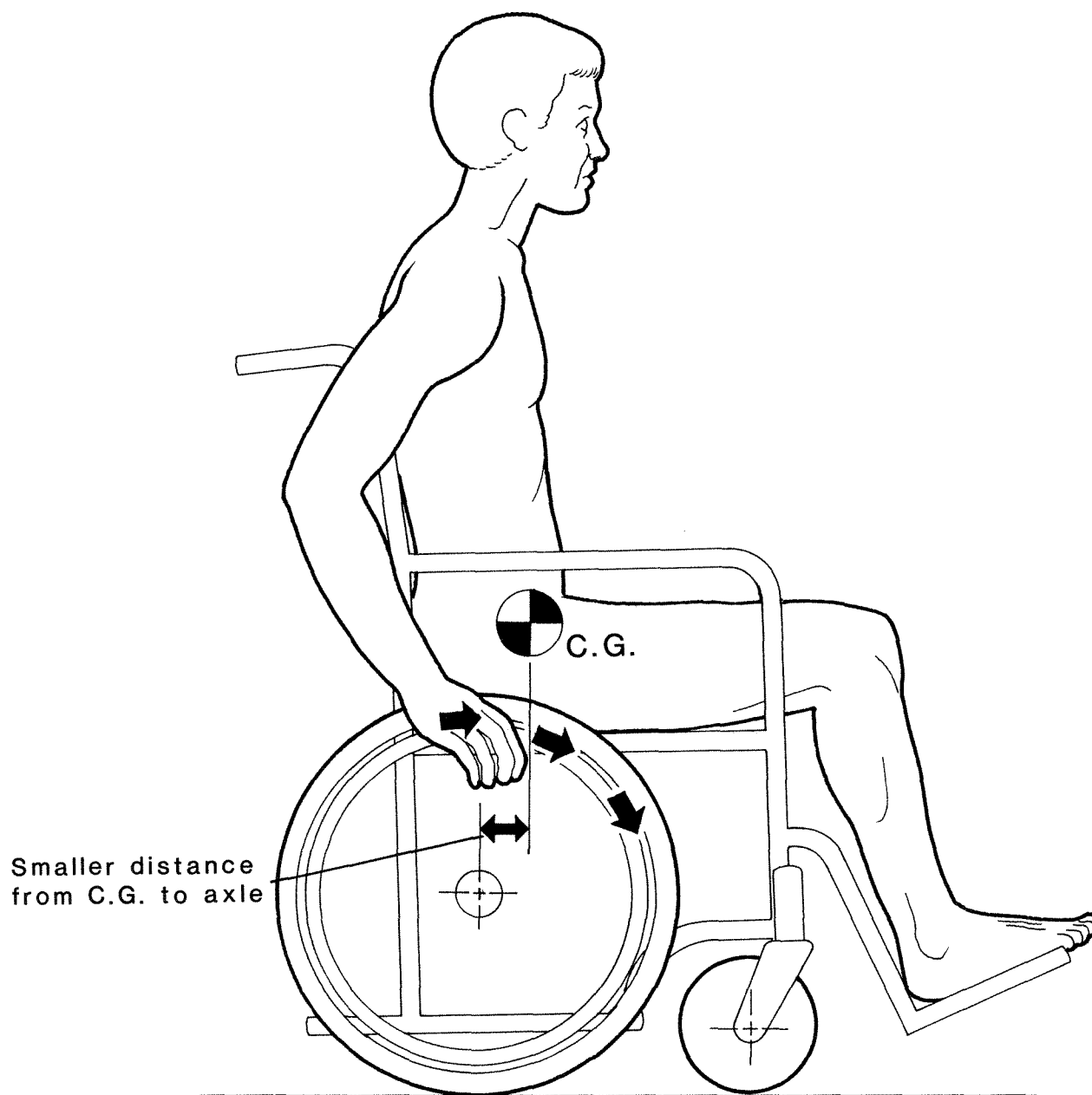


Figure 4b: If the user is higher or horizontally nearer the wheel axis, shoulder position is more normal and the propulsion stroke is more horizontal.

unstable position. The importance of SS is probably over-estimated by most prescribers.

Weight/Portability: Weight/Portability has very little effect on the propulsion performance of a

wheelchair on level surfaces. The additional cost associated with lightweight chairs is justified only if the client often needs to propel the wheelchair on grades, or if the wheelchair is loaded and unloaded frequently from a vehicle by hand.

MEASUREMENT: FITTING A PERSON TO THE MANUAL WHEELCHAIR

Unless there is a specific need for postural support (e.g., correction or prevention of deformity) the measurement process should be consistent for most clients. It is best accomplished if one or more sample wheelchairs are available. Both the accuracy and ease of measurement are facilitated with proper instruments. An anthropometer is desirable, although the task can be accomplished with a tape measure and a ruler.

In every case the selection of a seat cushion must be made prior to measuring for the wheelchair. Dimensions should be measured with the client seated on the cushion that will be used with the wheelchair. The most critical dimensions for seating are seat width, seat depth, and seatback height. (See also: *Seat Cushion Selection*, by Martin W. Ferguson-Pell, pp. 49-73.)

Seat Width: If the wheelchair has a sling seat (this will usually be the case) the seat surface will be somewhat concave. The degree of concavity is affected by the cushion. The distance between the sling supports (seat frame tubes) should be equal to the client's bi-trochanteric diameter (**Figure 5**). This

measurement should be taken by compressing the arms of the anthropometer against the greater trochanters and interpreted with respect to the manufacturer's seat width dimension. However, with an obese client, the width should be the minimum distance that avoids lateral compression of soft tissue by hard points on the wheelchair. The consequence of a narrower seat width is the possibility of pressure concentration on the client from the seat frame or armrest panels (if present). A wider seat can result in instability and an overall wider wheelchair with the obvious consequence of reduced accessibility (e.g., narrow doorways).

Seat Depth: The seat surface is the principal weight-bearing structure and supports the weight of the trunk and thigh segments. To minimize pressure (i.e., the weight/surface ratio) the thigh segment should be supported over most of its length. When the client is properly seated against the seatback, the front edge of the seat surface should be no more than 2 inches from the popliteal crease with his/her back, including the lumbar surface, firmly in contact with the seatback (**Figure 6**).

Seat Angle: The seat should be inclined from 1 to 4 degrees above horizontal (**Figure 7**). This will pro-

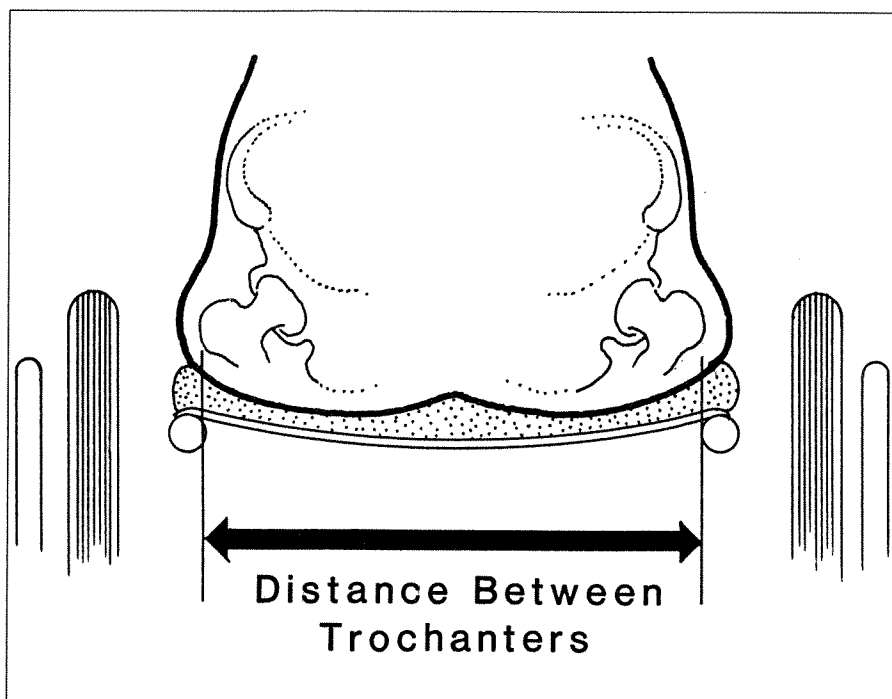


Figure 5.

The width of the seat is very important for posture, propulsion efficiency, and pressure distribution. The distance between the seat rails should be equal to the distance between the user's trochanters.

vide a small rearward force which will help keep the client positioned in the chair. A larger angle could put a strain on the hip extensor muscles (hamstrings) precipitating spasms (and perhaps other undesirable effects) unless the knees were flexed a comparable amount. This would impact on other dimensions such as legrest/footrest position and require an unconventional (and probably incompatible) geometry for most wheelchairs.*

Seat Height: Seat height, legrest angle and length, and vertical positioning are interdependent. Seat height is also limited by environmental factors such as furniture dimensions. An environmentally compatible floor-to-seat distance (i.e., 17 to 21 inches) contributes to optimal performance (Figure 7). In addition, a sufficient seat-to-shoulder vertical distance allows a propulsion-recovery motion (i.e., from rim release to grab position) that does not require excessive shoulder elevation. An unusually tall, short, or atypically proportioned client (e.g., long torso with short extremities or vice-versa) may pose a challenge in determining seat height. In extreme cases it may be advisable to consider non-standard main wheel and/or handrim diameters. One must also consider that the seat cushion typically adds 2 or more inches to the seat height.

Within these limitations, the primary determinant of seat height should be the shoulder-to-wheel vertical orientation. The seat will be very close to optimum height if the elbow flexion angle is approximately 120 degrees when the handrim is grasped at the highest point (Figure 7). Optimization can be achieved by having the client propel the wheelchair at this seat height at 1 inch above and 1 inch below this height. The clinician must observe the elbow angle from a point normal (perpendicular) to the plane of the arm and forearm, because if the client is observed directly from the side, the elbow angle will appear more acute due to the perspective created by internal rotation at the shoulder joint. If this position cannot be attained, then compromises must be made either in rim/wheel diameters or legrest length/angle dimensions.

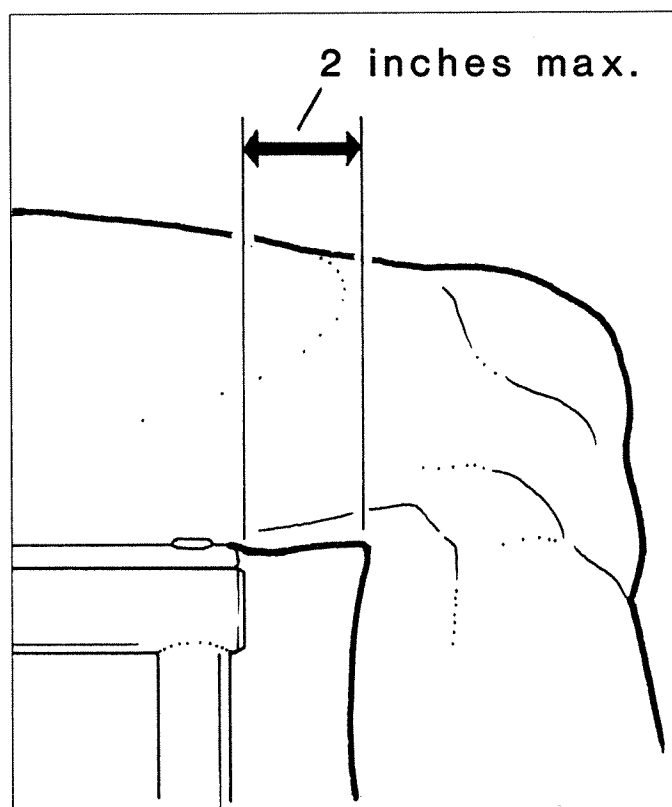


Figure 6.

To assure that the weight is distributed over most of the length of the thigh, the space between the front edge of the seat upholstery and the popliteal crease behind the knee should not exceed 2 inches.

Horizontal (fore-aft) Positioning: Propulsion efficiency is significantly affected by the orientation of the client to the drive wheels. In the standard wheelchair configuration the shoulder axis is approximately 1 to 2 inches in front of the wheel axis. However, for efficient propulsion it should be about 2 inches or more behind the wheel axis. The best position will be determined by trial and error, therefore the client's position of choice is likely to change with experience, as will any apprehension related to decreased stability. For the typical client, the seat post should be from 1/4 to 1/3 of the trunk depth (fore-aft sagittal trunk dimension) forward of the client's dorsal surface (Figure 8). The optimum position will vary slightly based on the degree of disability (e.g., double amputee versus SCI, and quadriplegic versus paraplegic).

*Editor's Note. Also, too much of a seat angle (knees higher than buttocks) can increase ischial/sacral pressure causing tissue compromise.

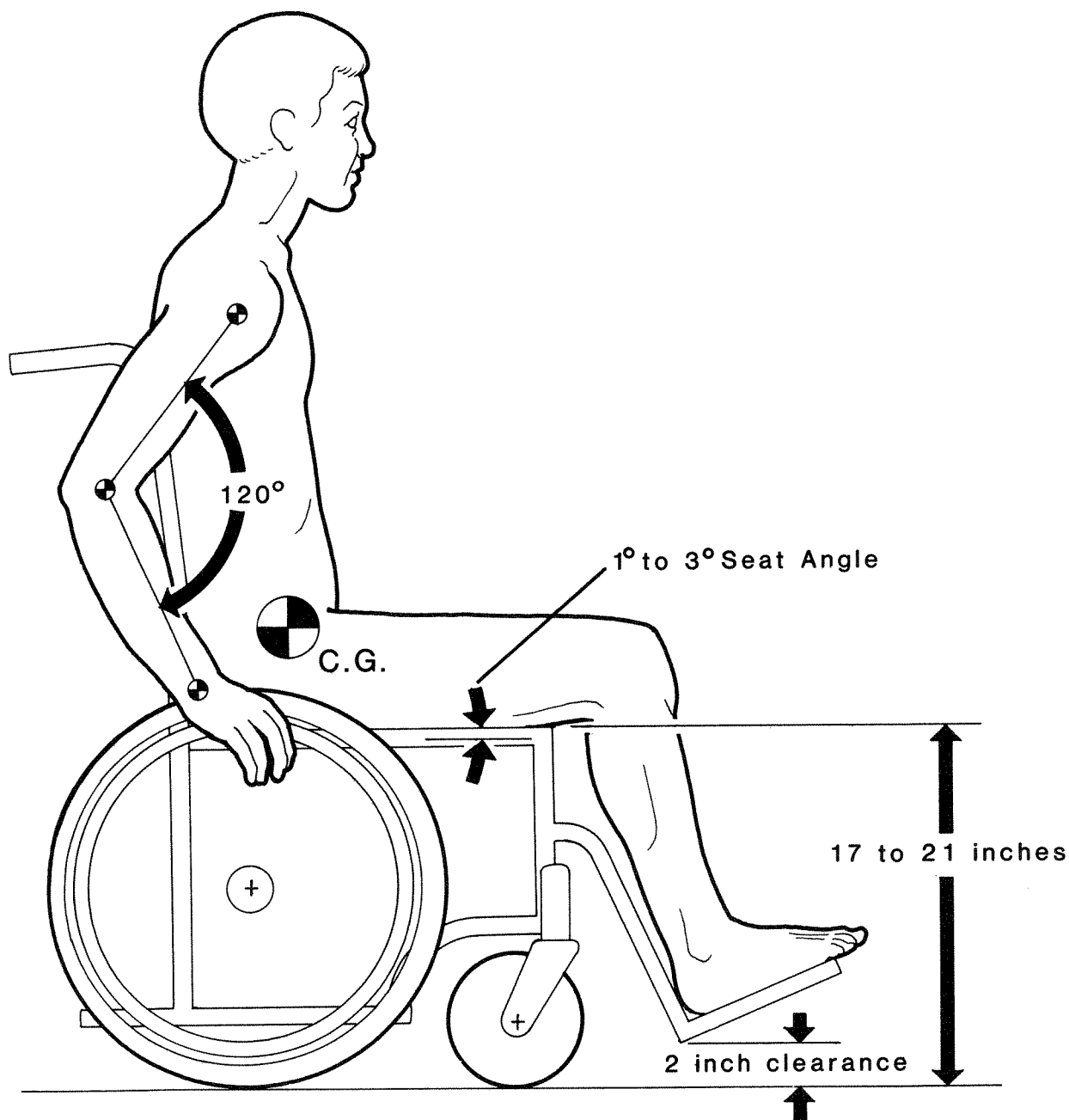


Figure 7.

Seat height and angle have an important influence on posture and propulsion efficiency. The seat will be very close to the optimum height if three criteria are satisfied: 1) the elbow is flexed at approximately 120 degrees when the handrim is grasped at the highest point; 2) the seat angle is between 1 and 3 degrees; and, 3) the footrests clear the ground by 2 inches. All measurements should be made with the cushion in place. Under these conditions, the most common resulting heights at the front of the seat are between 17 and 21 inches.

Back Height: The backrest affects two important functions—trunk support and trunk mobility. The trunk has the largest moment of inertia about the pitch axis of the wheelchair and is therefore the most important body segment to PAC. The impor-

tance of PAC to the client must be balanced with his/her need for trunk support. The functional level of the client should be the major consideration when determining the appropriate seatback height. While it is not likely to be discussed in terms of PAC and

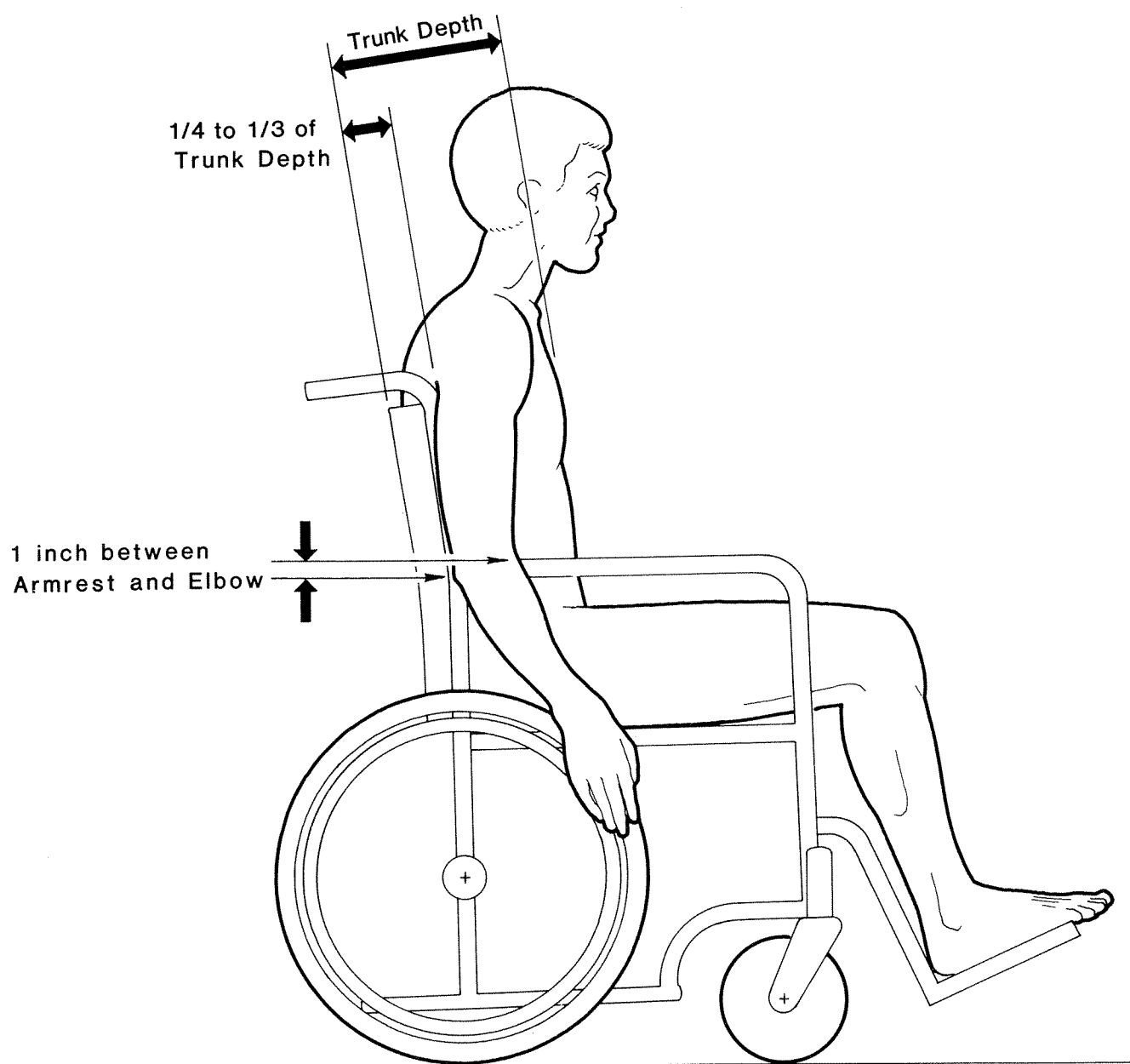


Figure 8.

The metal tubes of the arms and back of the chair can be used as guideposts for measuring optimum fore and aft positioning. The back posts should be one-quarter to one-third of the thickness of the trunk forward of the dorsal surface of the trunk. The top surface of the armrest should be 1 inch higher than the olecranon process of the elbow when the user's arms are pendant and relaxed.

moment of inertia, the popularity of the low seat back is apparent from the numbers of sports chairs with low seatbacks in use. Apparently, there has been no investigation of the potential for spinal deformity with long-term use of low seat backs despite concerns often expressed by clinicians. As this remains a moot issue for the present, most

clinicians are likely to be more comfortable with a conservative approach.

Unrestricted shoulder girdle mobility is essential if the client is expected to propel the wheelchair. This requires that the top edge of the seatback be no higher than the inferior angle of the scapula. A seatback height below the scapula should not be

prescribed for clients without good trunk control (i.e., at least mid-thoracic or lower). In order to provide additional spinal support, a seatback higher than the inferior angle of the scapula can still allow relatively unrestricted shoulder motion if the upper corners are sufficiently rounded or cut out. This condition can be achieved with a solid-back seat which is seldom available except as a custom feature.

Back Width: The seatback width should be compatible with the conditions noted above for shoulder mobility. This dimension should be narrow, consistent with the client's maximum trunk width plus an additional lateral clearance of 1/2 inch between the client's trunk and the seat post. This measurement will usually be taken at the top of the seatback.

Unfortunately, for most wheelchairs seatback width is not a variable, but is determined by the seat-width specification. A probable consequence is a compromise between seat width and back height to attain the desired shoulder mobility. This could be a problem if there is disproportionality between hip width and shoulder width. This situation is most likely to occur with female clients.

An additional consideration is the concavity of the seatback. Since most wheelchairs have a sling back this will be a function of the width of the seatback fabric. Lateral trunk support can be obtained by the "wraparound" effect, but it should be noted that this can affect the seat depth.

Back Angle: This angle, not critical for most clients, is usually fixed. The seat post is perpendicular to the horizontal seat frame, and the apparent angle is a function of the laxity and uniformity of the width of the seat-back fabric. The client's trunk range is usually 2 to 5 degrees behind vertical in a sling back. The only adjustment, other than a reclining back, is in the tension of the seatback fabric. However if a non-standard back angle is required, a cushion insert such as a lumbar support could be used.*

*Editor's Note. Alternatively, some lightweight wheelchairs now have back angles of 8 degrees.

Armrest and Footrest Factors

Armrest Height: In a properly fitted wheelchair the client should not have to depend on the armrests for lateral support. Although the vertical support provided by the armrests can help reduce the load on the buttocks and thighs for a severely disabled client, this is an unlikely consideration for manual wheelchairs users.

In addition to supporting the arms, armrests provide a surface to push against releasing pressure for clients with insensitive skin. In conjunction with side panels, armrests provide protection for the clients' clothing from dirt and interference with the wheels.

The height of the armrest should be 1 inch higher above the floor level than the olecranon process (prominence of the elbow) with the arm pendant as the client is seated in the wheelchair (**Figure 8**). Many clients will not require armrests at all; however, for protection there should be some nominal barrier between the client and the wheel.

Footrest Length: The primary functions of the footrest are to provide support for the foot and shank, thereby reducing the load on the thighs, and maintaining the foot position. There must be at least a 2-inch clearance above the floor surface in order to prevent the bottoming of the footrest on uneven surfaces (**Figure 7**). Other physical constraints include caster clearance (360 degrees of caster swivel is necessary), and minimization of overall wheelchair length.

The load on the foot supports should approximate the weight of the foot and shank segments. Too little load will cause the feet to become dislodged from the supports on bumps or during quick changes in direction of the wheelchair. Too much load will increase the risk of pressure sores on the feet (primarily the heel). The weight of the shank and foot (one extremity) can be estimated as 4 percent of body weight or a value of 6 pounds. This adjustment can be made by grasping the foot and lifting until the heel appears to break contact with the support. This determination can be made by relating the "feel" of a 5-pound weight to the

Table 1.
Effects of Variations from Optimal Dimensions

Variable	Condition	Potential Adverse Consequence(s)
Seat position (fore/aft)	too forward	increased RR, SS; decreased PE, PAC, YAC.
	too aft	reverse of above consequences.
Seat height/axle position	too high or too low	reduced propulsion efficiency and limited mobility; decreased PAC.
Seat height/footrest	too short	increased pressure on both feet (heel) and buttocks (ischial tuberosities) resulting in an increased potential for pressure sores.
	too long	increased pressure on popliteal surface with potential for decreased circulation to leg and foot and greater potential for thrombosis, etc.
Seat width	too narrow	increased pressure on soft tissue with potential for pressure sores; interference with wheel.
	too wide	increased chair width resulting in potentially decreased access; lateral instability with potential for postural deviation (scoliosis); decreased control and PE.
Seat depth	too short	concentration of pressure on buttocks and feet (see Seat height).
	too long	compression of popliteal area (see Seat height).
Back width	too narrow	compression of lateral body surfaces against seat posts.
	too wide	lateral instability which can induce or exacerbate spinal deformity (scoliosis).
Back height	too high	restriction of shoulder mobility resulting in reduced control and mobility; restriction of aft rotation of the trunk resulting in less PAC.
	too low	fore-aft and lateral trunk instability with potential for spinal deformity (scoliosis, kyphosis, lordosis).
Seat angle	too shallow	forward displacement (sliding) which can result in poor posture and potential spinal deformity.
	too steep	concentration of pressure on buttocks; may put too much strain on hamstrings.
Back contour	too flat	reduced lateral support with potential for spinal deformity.
	too concave	not likely to pose a problem but will have an effect on functional seat depth and horizontal seat position.

perceived weight of the foot and shank in the above process. For tall clients, this positioning process may require a corresponding change in seat height and/or legrest angle due to the interdependence of these factors.*

Foot Plate Angle: The foot-to-leg angle should be approximately 90 degrees. This angle is common to most wheelchairs.

CONSEQUENCES OF IMPROPER MEASUREMENT

The further impact of ergonomic factors upon wheelchair performance is illustrated above.

*Editor's Note. Footplates can now be ordered as 'forward-mounted' to accommodate extremely long leg length without raising the seat height from the floor. This will increase overall turning radius.

ACKNOWLEDGMENTS

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Technical Considerations

Powered Mobility and Its Implications

by C. Gerald Warren

Mr. Warren is President of C. Gerald Warren & Associates, a consultant firm in the field of technology applied to rehabilitation. He is also Clinical Associate Professor, Department of Rehabilitation Medicine, and Affiliate Associate Professor, Center for Bioengineering, University of Washington, Seattle, WA. Mr. Warren is a past president of the Association for the Advancement of Rehabilitation Technology (RESNA).

INTRODUCTION

When we examine the factors that contribute to quality of life we see a combination of no less than three: independence, vocation, and recreation. Like legs on a stool, all three need to be present, connected, and of similar length to provide stability. Among those things comprising independence, mobility and communication play the most critical roles, and are functions that are basic to the quality of a person's life.

Homo sapiens have certainly distinguished themselves as the most mobile animals to grace the face of the Earth. For man, mobility is a fundamental part of living. Being able to move about, to explore, under one's volitional control is a keystone of independence. The degree of mobility individuals have is directly related to their level of independence; restricted mobility significantly affects the ability to live a productive life.

Restricted mobility occurs in many forms and to many degrees. It must be looked upon as a functional limitation of an individual rather than as a state or condition related to specific diagnoses. Just as the ability to be mobile varies in able-bodied persons, it also varies among people with disabilities, even within their diagnostic categories. In providing powered mobility, the process must focus on the person, clearly defining his or her restrictions or limitations in function, and then determining how

best to reduce or eliminate those restrictions by integrating powered equipment into their lives. Introducing powered mobility equipment into a disabled individual's life can truly be liberating for that person. For those with no functional capability, it can be the difference between complete dependence and a great deal of independent mobility. For those with marginal capability, it can significantly add to their productivity and quality of their lives.

The powered wheelchair began with the application of automobile starter motors to the tubular cross frame wheelchair with power derived from an automotive battery. The developments that followed all revolved around the basic cross frame tubular chair. As time went on and innovation continued to meet the needs of severely disabled individuals, the cross frame of the wheelchair was removed and the space beneath the seat became available for a variety of equipment. Electronic control systems, communication systems, respirators, recliners, and phrenic nerve stimulators all became part of the support system that could be mounted on a powered wheelchair. By the mid-1970s, where the resources were available, severely disabled individuals were seated on a "pile of parts" which they were able to control and so achieve a significant level of independent mobility. Concurrently, the "make America accessible" plan was implemented and the domain of wheelchair users, particularly those using powered equipment, expanded dramatically.

As sophistication in the design and variety of accessories and seating systems grew, so did the pile of parts. In 1982, new concepts were brought together at the VA-sponsored workshop on special adapted wheelchairs and sports chairs, Wheelchair III (1). As a result of this conference, many recommendations were made for research and development focusing on efficiency of the equipment, noise factors, braking systems, and ride quality. In addition, a philosophy evolved regarding the esthetics or the cosmetics of a mobility system. This originated the concept of a powered chassis to which seats and accessories were added in an orderly, modular form.

In the 1980s it is not uncommon to see individuals who are completely dependent in their mobility functioning at very high levels, using an appropriate and well-integrated mobility system to independently pursue their vocational, social, and leisure goals. The key to a successful implementation of a powered mobility system does not, however, lie in the technology itself—it relies primarily on the needs and desires of the disabled individual to maintain or increase the quality of his/her life. The application of powered mobility equipment must be part of the total rehabilitation program. It must be integrated into the total plan which is directed at specific functional outcomes.

The most obvious benefactors of powered mobility are persons who are completely dependent (i.e., without the equipment they are unable to move in their environment). In some clinical settings, these are the only people who are considered as candidates for powered mobility equipment. There are, however, many manual wheelchair users and marginal walkers who can gain considerable functional benefits from the use of powered equipment. These “marginal” ambulators do move in their environments independently, but they may be greatly restricted in rate and distance due to their limited capability.

The marginal manual wheelchair user is someone whose disability includes upper body weakness and who depletes energy levels by propelling a manual wheelchair for more than very short distances (such as those with mid- to low-level quadriplegia). The resulting fatigue often compromises other aspects related to the quality of their life. This situation can occur simply because the options to be gained by using a powered system were not considered during the prescription process. While such

individuals should use manual equipment for needed exercise, recreation, and as a back-up in circumstances where transportation or access is restricted, everyday mobility may be less stressful with a powered system. In some instances, the use of manual wheelchairs can be equated to use of knee-ankle orthoses by individuals with paraplegia. For some, it soon becomes apparent that they would be better off using a lightweight manual wheelchair.

These considerations illustrate the importance of realistically assessing the functional objectives of an individual and, when indicated, encouraging the use of powered equipment. This can provide the marginal manual wheelchair user with an appropriate rate of ambulation as well as a means of conserving his/her personal energies for activities other than mobility. The same considerations apply to the person with marginal ability to walk independently. Individuals with peripheral nerve disease, obesity, limb deficiency, or advanced age, all become candidates for a form of powered mobility when the rate and/or range of their ambulation significantly restricts the quality of their lives.

The use of powered mobility for children has become more prevalent in recent years, but not without controversy. In the early 1980s, the concept of early mobility for severely disabled children emerged and was based on the logic that the pattern of development of these individuals should approximate that of able-bodied children. The intervention was focused on reducing the limitations in the areas of social, cognitive, perceptual, and functional development that were induced by lack of mobility. Clinical application of powered mobility for very young children spurred the wheelchair industry to respond with new equipment. Research and development programs were established to provide disabled children with mobility at a time that would closely coincide with the development of mobility in able-bodied children.

There are two main concerns regarding powered equipment for young children: safety applications, and the potential adverse effects on the physical development of a child who is provided early use of powered mobility. However, from clinical experience, it is becoming clear that providing appropriate mobility to very young disabled children benefits their total development pattern and has a significant impact on their potential to be more productive individuals.

GENERAL CONSIDERATIONS IN SELECTING POWERED MOBILITY EQUIPMENT

The assessment that leads to the decision about which equipment to purchase or recommend is most important. This assessment must integrate the individual's functional needs, life plan, and available resources. The process is similar to that of a small business deciding to purchase a new vehicle. Good decision-making would call for careful analysis of all the functions the vehicle should perform for the business. Then, depending on the needs identified by the company, attention would be focused on the type of vehicle indicated—say, a compact car or a tractor trailer. Next, it would be necessary to determine how the vehicle would fit into the company's total business plan by balancing functions to be gained with purchase cost. Finally, it would be necessary to answer the question: can and how will this acquisition be paid for?

When applied to a recommendation for the purchase of a wheelchair, this kind of approach requires that a team of clinicians assist the client in the process of evaluation. In projecting a realistic outcome, the client must be knowledgeable about the equipment, and be able to reconcile the cost of achieving the objectives while maximizing the available resources.

Because of the expense involved, the most difficult part of the delivery process may be establishing a payment source and the needed level of funding. Third party payers often reel at the cost of providing powered mobility and its accessories. They have also historically witnessed the fact that the intended or desired outcome has frequently not been achieved. Such experience naturally leads them to be cautious, or at least conservative, in their approaches to funding powered mobility. This is a difficult position to try to reverse.

The conservative position of the third party payers has been precipitated by the fact that the market for durable medical equipment has been supply (vendor) driven. The only way to regain the confidence and support of the funding agencies is through modification of the service delivery process to make it more demand driven. This can only be done by having clients and clinicians make appropriate decisions about the equipment that is needed to realize a reasonable functional outcome.

This outcome can be achieved by clearly defining the client's needs, being informed about and selecting the most appropriate equipment, and effectively utilizing all available technical, clinical, and financial resources.

EQUIPMENT FOR THE MARGINAL WALKER

The design of equipment used by the marginal walker is usually 3-wheeled or scooter-like. This design provides excellent mobility without the "stigma" of a wheelchair and it is easy to mount and dismount. It is often used to compensate for a person's inability, for whatever reason, to comfortably and safely travel distances outside the home. It is not usually selected for exclusive in-home use because canes, walkers, or grab bars and rails are more suitable for moving over short distances.

The first consideration for equipment selection is whether it will be used indoors, outdoors, or both. Equipment used exclusively indoors, at home, or in institutional or vocational settings, may not need to have the stability, power, distance, or durability requirements that outdoor use demands. However, the vigor and functional needs of the users should influence the selection of indoor equipment. For example, the equipment for a geriatric individual to use going from bedroom to dining room to therapy facilities in a retirement home would differ significantly in function and cost from that used by a young person with bilateral above-knee amputation who was a shop supervisor in a large industrial setting. In some cases, a choice of low performance or high performance equipment may have to be made, or, in cases where adequate resources are available, two types of equipment may be selected. Equipment used for high performance indoors is often suitable for the low performance requirements of outdoor use (i.e., on relatively flat, uniform surfaces with moderate distance requirements).

The selection of equipment for outdoor use is influenced most by the surfaces upon which it will operate and the distances required to travel. Climatic conditions must also be considered because performance of powered drive mechanisms are affected significantly by moisture and temperature. Other considerations for this type of equipment are:

seating for posture and trunk stability; ease of mounting and dismounting; portability in ease of assembly and disassembly; and the weight and size of individual components which may need to be lifted and stored in a car trunk.

The following case study illustrates how needs assessment and proper prescription can restore functional independence for an individual with marginal walking capabilities.

Case #1: Jackie M.

Jackie M. is a 28-year-old female, diagnosed at age 14 with Kugelberg-Welander's disease. She has a history of progressive motor weakness. At this point in her life she is able to walk short distances on smooth surfaces with the use of a cane. Jackie is a large individual whose joints are being jeopardized with ambulation and she is at high risk of fractures or joint trauma due to falling. Though weak, she has good positional control of her upper extremities and her hand dexterity is excellent. She cannot, however, stand from a seated position independently.

Jackie is employed as a clerk-typist, full-time. She is currently experiencing a number of problems at work which are directly related to her impaired mobility. She requires assistance getting in and out of the building and rising from her chair at her work station. She is reluctant to ask for assistance and therefore does not use the bathroom as often as she should. As a result she experiences periodic urinary tract problems. Jackie is unable to meet part of her job requirement—moving to various locations around the workplace. Her employer will be relocating to a carpeted facility, which will make it nearly impossible for her to walk at all.

Jackie's functional need made her an excellent candidate for a 3-wheeled mobility device with a pivoting and elevating seat. It was found that she could independently come to the standing position if the seat could be elevated to 34 inches and located adjacent to a 54-inch high solid surface for her to lean on.

Providing her with this equipment makes Jackie independent in the workplace. The installation of a 54-inch shelf in the lavatory makes it possible for her to carry out her bladder functions (which she performs standing). Now, Jackie only needs transfer assistance from her husband when entering or departing her work facility.

EQUIPMENT FOR THE MARGINAL MANUAL WHEELCHAIR USER

Many people interpret the change from a manual wheelchair to a powered wheelchair as an admission or "indictment" of greater disability rather than as an option for increased capability. It is often difficult to accurately assess or recognize the secondary functional options that are realized when a person chooses to use a more efficient and effective form of mobility. Often the perceived loss of physical prowess can be obviated by introducing the person to wheelchair sports. The questions must be asked: What else might be achieved if the form of mobility saves the wheelchair user's expense of energy? How much more work could get done? How much more "up time" could the individual have? How much more productive could that time be?

It is also important to consider the complications and expense that are introduced by incorporating powered mobility into a person's life. The cost of providing and maintaining a powered system is approximately three times that of a manual system. Some people who would like to use powered equipment do not, simply because the expense of the initial purchase combined with the need for suitable transportation far exceeds available resources.

If they do use powered equipment, marginal manual wheelchair users also need manual equipment for back-up and convenience. Some individuals use the powered equipment only in fixed locations and use the manual chair when traveling by car. Others, where resources are available, use an appropriately equipped van.

It is not uncommon to find an individual who moves from powered equipment back to manual equipment. This can occur when the gains intended by the use of a powered chair is overridden by the benefits of practicality or convenience offered by using manual equipment.

A careful assessment of the individual can result in a mobility plan that incorporates both powered and manual chairs. Based on functional needs, the powered equipment can range from light duty equipment for use in a work place to full-sized heavy duty high powered equipment for use in long range indoor and outdoor mobility.

People in this ambulation category generally have good upper extremity control and moderately

good trunk balance. They often desire high performance equipment, which is available through some of the major manufacturers, but can also be found in kits which modify a chair to provide greater acceleration and top speed.

There is a population of disabled individuals who can use a hybrid approach to their mobility needs by combining manual and powered wheelchair equipment. Selecting the appropriate types of equipment for these individuals relies heavily on insightful analysis of their functional needs, looking particularly at how the use of powered mobility will impact their total lifestyle. The key to implementing such a program for an individual lies in identifying the functional or productivity gains that can be achieved and weighing them against the costs involved in providing that equipment given the client's resources.

The case study below describes how one person combined the use of manual and powered systems in order to concentrate his energies on being productive at work, while maintaining a more independent image for leisure-time activities.

Case #2: Russell G.

Russell G. is a 20-year-old male with complete quadriplegia at C 6-7. He completed a comprehensive rehabilitation program and had been discharged ambulating with a lightweight wheelchair equipped with pegged hand rims. He wanted to use the manual wheelchair in order to maintain and improve his upper extremity condition. Russell independently transferred in and out of an automobile, laboriously loading and unloading the wheelchair.

Eighteen months after discharge he was sponsored by the Division of Vocational Rehabilitation to attend a computer training program specifically for disabled individuals. The demands of the program began to take a toll on his stamina, and during the course he would on occasion allow an ambulating student to give him a push from his car into the facility and/or to and from the lunch room (over low pile carpet).

Suggestions that he consider using a powered wheelchair continued to be rejected because Russell perceived that using a powered wheelchair would be an admission of greater disability. Then, on field trips to potential employers he began to realize the impracticality of pushing the distances required to get from the parking facility into the building and to

his workplace. There were also considerable distances to be travelled within the building, such as to meetings and to the lunchroom. To efficiently accomplish these tasks (related solely to his mobility and not to his job function) it would require excessive effort in his manual chair.

He eventually engaged in planning the move into a powered wheelchair system. Russell relocated his residence close to a wheelchair-accessible bus line that connected with his employment location. He now uses his electric wheelchair to go to and from work. But he continues to use his manual wheelchair for all other social and recreational activities. The manual wheelchair also serves as a backup when he encounters difficulties and/or breakdown with his electric wheelchair.

EQUIPMENT FOR THE SEVERELY DISABLED INDIVIDUAL

People in this category are unable to independently transfer and/or are severely limited in their ability to control mobility equipment. They must rely completely on their equipment for any level of independent mobility. With the proper equipment, it is possible for someone capable of only one or two body motions to control a wheelchair. The use of pneumatic switches makes it possible for a person with only control of pressure in the oral cavity to operate powered equipment with a sip and puff control. Once fitted with the appropriate system, many people can have sufficient mobility to achieve high levels of independence. It is not uncommon now to find people in the workplace who have little more than breath or head control. These people can be assisted into their wheelchair in the morning, provided with minimal assistance throughout the day with feeding or leg bag evacuation, and at the end of a very productive day can be assisted from the wheelchair to their bed. Many such individuals are engaged in activities related to their education, vocation, and social leisure time.

Providing equipment for these individuals requires a highly integrated approach taking into consideration the physical requirements of the person's environment, the seating and positioning of the individual, the selection of the optimal control method, and the integration of accessories and associated equipment. Determination of a mobility

system for an individual in this category is, as in all other wheelchair prescription cases, based on the anticipated functional needs and life objectives that will be pursued.

The first step in the process is to select the basic powered base. The characteristics of additional powered equipment—such as recliners, communication, and/or life support systems—must also be considered. This places further requirements on the mobility system for both power and the space to accommodate this equipment.

The next consideration is seating. The individual must be provided with a seating system that will both position him/her for optimal control of the equipment and also maximize the length of time the person is able to remain seated in the wheelchair, which involves the factors of fatigue and tissue protection. Determining the best positioning and posture of the individual in the wheelchair is a highly specialized process that requires a well coordinated team approach. Proper seating is often fundamental to an individual's ability to operate the control system. This is particularly true for individuals who are cerebral palsied or head injured for which the processes of seating and control must be performed together.

The factors in seating a severely disabled person to maximize "up time" are tissue protection, lower extremity circulation, and threshold of fatigue. Tissue protection in persons with insensitive tissue requires a seating surface that provides optimal distribution of the pressures. However, the redistribution or unweighting of the load-bearing surfaces is an effective complementary method of assuring maximum protection.

For the individual who is unable to perform reliable pressure relief manually, powered reclining or tilting of the seat may be necessary. Powered reclining mechanisms allows the individual to independently redistribute or decrease the pressure on the weight-bearing surfaces and to rest residual trunk and respiratory musculature. The recline function is often combined with elevating legrests and can assist in control of lower extremity fluid pooling. Many such users have demonstrated a secondary function of the recliner: using the motion to reposition themselves in space in a limited form of body language.

People who use reclining equipment have frequently complained that repeated reclining shifts

their bodies out of the normal stable position, causing a loss of sitting balance and poor positioning. Sliding or stretching during the recline can also cause unwanted spasticity and repeated reclining can wrinkle and bunch clothing, which of itself can cause uneven pressure distribution.

The reason for these difficulties arises from the early design of the wheelchair, which used a simple hinge joint to attach the chair back to the frame. In reclining a wheelchair with a standard hinge the person tends to slide down the back of the seat. During elevation of the chair back, shear forces between the person and the back usually prevent the person from sliding back up to the original seating position. The sliding occurs because the location of the pivot points of the chair differ from the axis of rotation of the person's body during the recline (2).

Many manufacturers now incorporate mechanisms into the recline system of wheelchair mechanisms that are designed to eliminate sliding either by allowing the chair back to slide with the person by tilting the entire seat, or by using mechanisms that cause the chair back to follow the path of the person. Studies have shown that the average displacement during recline is 11 centimeters. Chairbacks that provide a non-shear feature must accommodate displacement of approximately this magnitude as the chair back goes through the recline cycle (**Figures 1a and 1b**).

A similar displacement problem can exist at the knee because the axis of rotation of the chair and the knee joint may not coincide. The problem here is less severe, however, because the low mass of the legs lets them slide without difficulty. A more common problem is encountered with the incorrect length of the legrests. If they are too short, excessive pressure can be applied on the bottom of the feet when the legrest is elevated. Pressure on the feet and accommodations made by adjusting the length of the legrest on the chair should always be checked when using a system for reclining or elevating the legs.

The use of non-shear reclining systems can significantly increase the up time of an individual and make it feasible and safe for that person to spend an entire functional day in a powered wheelchair.

Control of a powered wheelchair can be achieved by harnessing any reliable motion an individual may have. Motion in a plane can be used

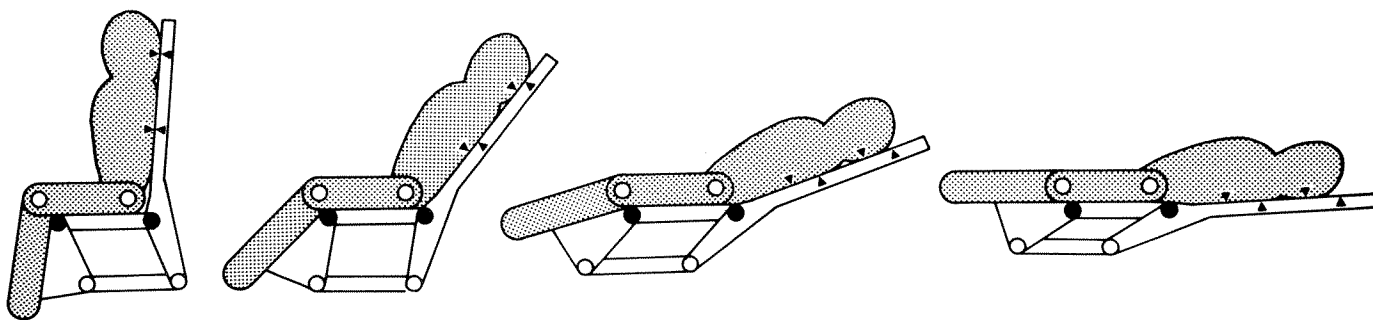


Figure 1a.

Back displacement produced in a typical wheelchair. Reprinted from C.G. Warren *et al.*: Reduction of back displacement wheelchairs. *Arch Phys Med Rehabil* 63:447-449, 1982.

to control a joystick and provide proportional control. Limited unidirectional motion can activate single switches which can be electronically interpreted to perform a variety of functions. It is possible to drive a wheelchair, slowly, with the use of a single switch. Voice recognition, whereby a person speaks commands to control the chair, has been used; however, this approach has not been widely accepted due to cost, complexity, and reliability of operation.

The numerous sites that can be used for wheelchair control are shown in **Figure 2**. Proportional control can be achieved using conventional joysticks when gross hand motion is available. When motion is limited, "short throw" joysticks needing only 3/16 of an inch displacement of the sticks still result in full amplitude signal from the wheelchair controller. This approach can make fingertip control, chin control, and, in some cases, lip or tongue control possible.

Switching control of the wheelchair is made feasible by the use of acceleration control circuitry. A sip and puff regimen uses a hard puff or sip on a straw connected to pneumatic switches to control the chair's forward and reverse and stopping functions. A soft sip or puff on the same straw activates switches that control the turning rate. Single-switch control of a chair is also possible, whereby the functions are scanned and selected with a single switch (**Figures 3a and 3b**). Such operation is necessarily slow, but it does provide independent mobility for the severely disabled individual who may have no other alternative.

Recently, microprocessors have been integrated into wheelchair control systems that allow the custom programming of performance features. Once

a person's motor capabilities have been analyzed with regard to rate and degree of control and a physical interface defined (i.e., the method by which the person will activate the system), the control features can be custom-tailored to make the machine respond appropriately.

When a severely disabled individual begins daily activities there are many accessories on board the

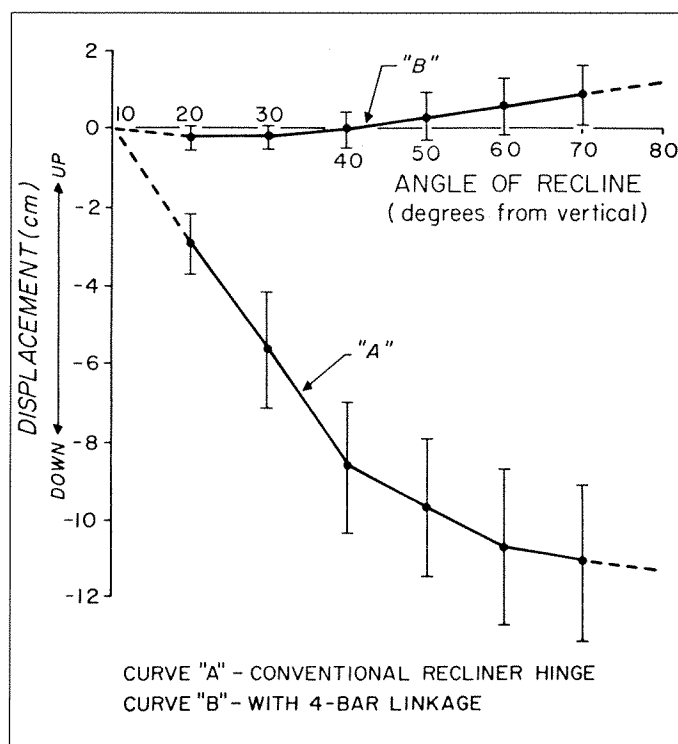


Figure 1b.

Average curve of back displacement versus recline angle for a sample of quadriplegic subjects. Reprinted from C.G. Warren *et al.*: Reduction of back displacement in wheelchairs. *Arch Phys Med Rehabil* 63:447-449, 1982.

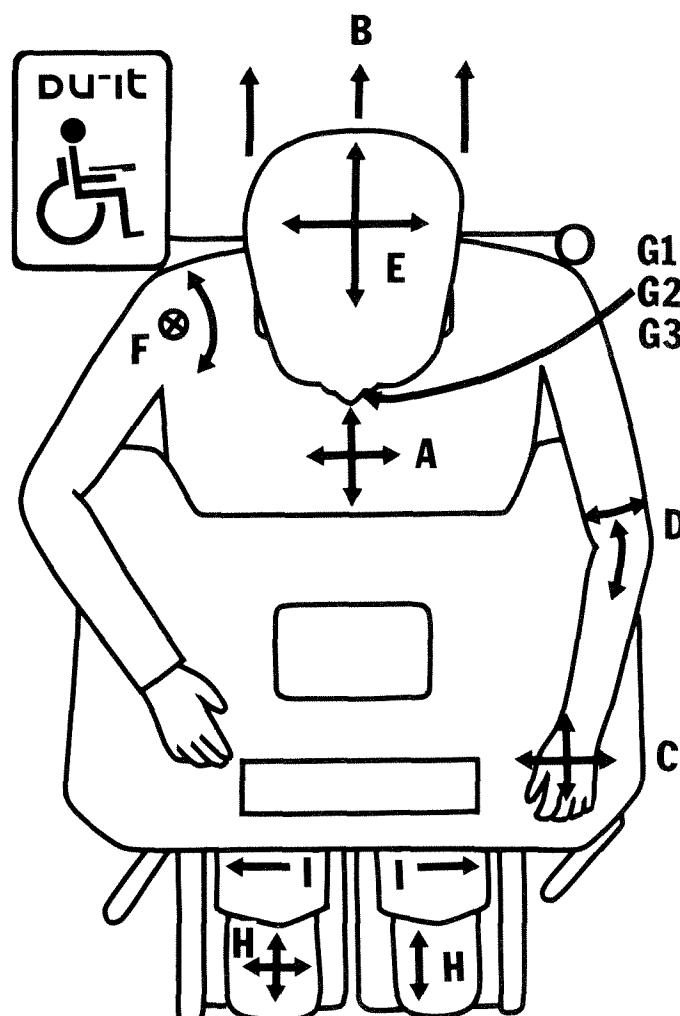


Figure 2.

Wheelchair control system. By positioning a switch or sensing device at some anatomical location, signals can be derived which might be employed to operate a wheelchair. This listing represents potential control sources; controllers have been implemented to use many of these sites:

A. *Chin control.* Worn as a collar, device requires very small travel (1/4 inch or less) to produce proportional control.

B. *Headrest control.* By pushing straight back against the headrest, a forward signal is produced. By rocking the head to the left or right against the headrest, turn signals are generated. A separate switch needs to be activated to reverse the sense for backward motion.

C. *Joystick.* This operates using standard joystick format.

D. *Arm/elbow control.* Movement of the elbow outward and/or sliding of the arm forward and backward might be used for activation of switches or proportional signals.

E. *Head control.* Direct use of forward/backward and left/right movement of the head is employed.

F. *Shoulder position.* Elevation and depression (or slump) provide forward/backward signals while protraction/retraction

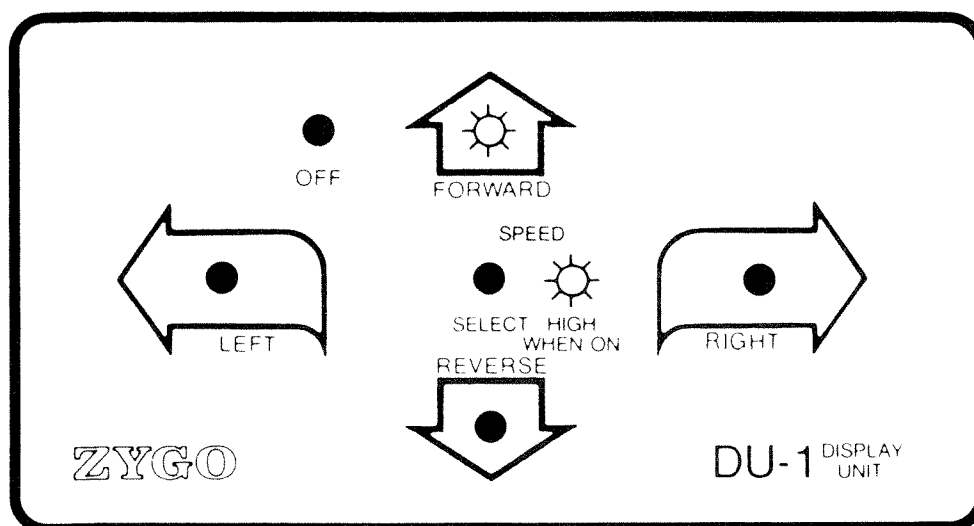
of the shoulder provide the left/right signals.

G. 1) *Pneumatic (puff/sip) control.* This system uses hard puffs and sips to control forward and backward velocities, while soft puffs and sips introduce proportional turns; 2) *Spoken control.* A computer can analyze the words spoken and use them to "drive" the wheelchair; 3) *Mouth, tongue, lip control.* A head-mounted chin-controller element can make use of small movements to provide proportional control.

H. *Foot control.* A rocker plate could yield all four signals for wheelchair direction, or "gas pedal" type controls might be used.

I. *Knee control.* Thrusting the knee inward or outward can provide control signals.

(Courtesy of DU-IT Control Systems Group, Inc., Shreve, OH 44676)

**Figure 3a.**

Display for single switch scanning.

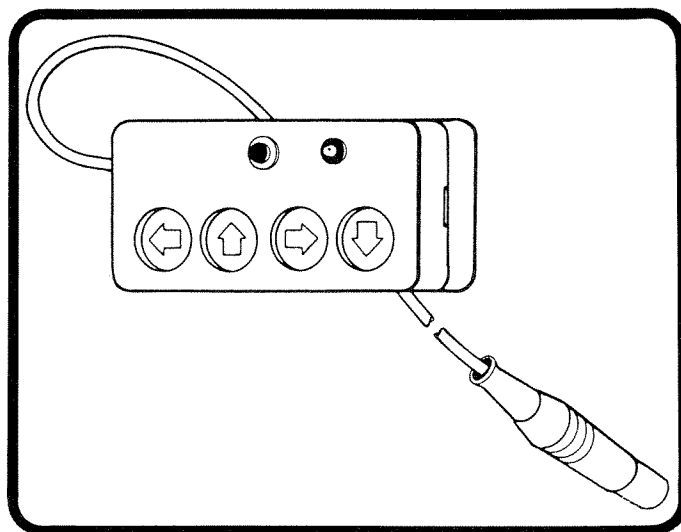
(Courtesy of ZYGO Industries, Inc.)

wheelchair that may require control. Accessories may include headlights, flashing lights, horns, alarms, tape recorders, fans, recline functions, telephone, and remote control actuators. The variety of functions on the chair are selected through a switch that controls a scanning display of the functions available. A second set of switches or a joystick is then used to select a desired function. Since most individuals who use this type of equipment are not capable of operating more than one control mechanism at a time, the functions are usually performed in serial.

Besides operating the wheelchair accessory equipment, the control systems also incorporate remote control communication with environmental systems through radio frequency or infrared beams. Usually, the individual operates the features of an environmental control system through the same control mechanism that is used for all other features of the wheelchair. Such a system enables the person to have remote control of anything switchable in his or her environment, such as the telephone, intercom, door latches, lights, AC receptacles, radios, television, and computer (**Figure 4**).

The survival rate of spinal cord injured people who are respirator dependent has increased markedly because of the improved evacuation procedures at accident sites and the specialized care now provided for severely disabled individuals. Those

who require life support systems, such as respirators and/or phrenic nerve stimulators, now can have them mounted on board their wheelchairs. The critical nature of these life support systems requires that they be coupled to an emergency alarm system that can sense difficulty or malfunction and summon assistance if needed. Commercial paging technology can be applied, where a simple sensor detects the malfunction and a paging system transmits a signal to a receiving station to summon assistance.

**Figure 3b.**

Direct select switches for directional control.

(Courtesy of ZYGO Industries, Inc.)

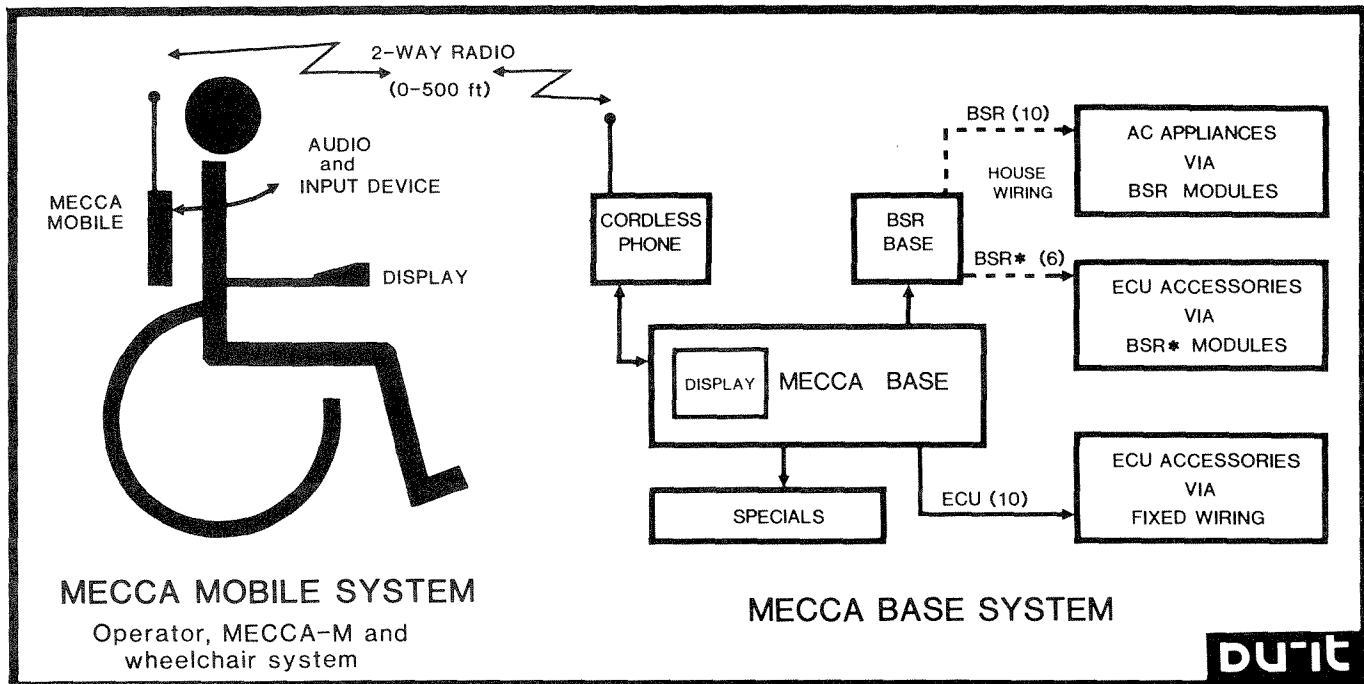


Figure 4.

Environmental control unit (ECU) utilizing cordless telephone technology. The MECCA system fully integrates into DU-IT wheelchair systems. This approach permits nearly all functions of the system to be located anywhere in the household. It places both the selection and control processes as well as all of the telephone functions with the user in his wheelchair.

(Courtesy of DU-IT Control Systems Group, Inc., Shreve, OH 44676)

This type of equipment requires lift-equipped vehicles for transportation. The most critical issue in transporting such individuals is adequate hold-down mechanisms in the vehicle. These mechanisms must securely hold the wheelchair frame to the vehicle, and the individual must be secured to the wheelchair. It is essential to remain aware of the fact that the wheelchair itself can constitute a mass 2 to 3 times that of a person, and thus on impact it can become a formidable missile inside a vehicle.

The following case study demonstrates how a person with a progressively disabling condition has been able to continue his daily activities through the use of a specially-equipped powered mobility system.

Case #3: Bill T.

Bill T. is a 39-year-old male, diagnosed with Charcot-Marie-Tooth disease, a progressive hereditary neuropathy. The disease had progressed to the point where he was using a standard powered wheelchair with a low back, swing-away legrests, and detachable desk arms. He used a lift-equipped

van with a translating driver's seat to which he transferred from the powered wheelchair.

Bill was employed full-time by a state agency as an administrator of a major social service program. This position required him to spend a significant amount of time in and out of his office, driving 15,000 miles a year.

Deterioration of his condition led to a more generalized weakness, which in turn affected his posture, his ability to do pressure-reliefs, and in particular his transfer abilities. He began experiencing persistent swelling in his lower extremities. His level of fatigue became extremely high. By the end of the day an independent transfer could take him up to 5 minutes. He found it necessary to retire immediately after his evening meal. His general health and well-being were deteriorating to the point where he began to miss work.

A request to the Division of Vocational Rehabilitation for post-employment services resulted in an evaluation focused on his mobility and transportation system. It was recommended that he use a powered reclining wheelchair with elevating legrests

and non-shear hinge mechanism operated through a wheelchair accessory control system. This system also allows Bill to mount on the wheelchair a tape recording system for dictation and note-taking. The powered recline system allows him to sit in a relaxed posture and perform pressure reliefs while in meetings and at his desk talking on his speaker phone. Bill now has a great deal of flexibility finding ways to rest during the work day. The elevating legrests significantly improved the pooling of fluids in his lower extremities.

In addition, the van was modified to include a drop pan and hold-down system in the driver's position so that he could operate his vehicle from his wheelchair. This eliminates what had been a very difficult transfer activity. It also adds to his safety since his wheelchair is now secured whereas in the past it had simply been parked with brakes on while the van was in motion.

This implementation not only significantly improves Bill's effectiveness in the workplace but also has had a tremendously positive impact on the quality of his life by increasing his daily up time by 3 and a half to 4 hours.

PEDIATRIC POWERED MOBILITY

In recent years increased attention has been paid to the mobility needs of motor-impaired children (3,4). Proponents of powered vehicles for very young people present strong reasons for introducing powered mobility to children at a time in their developmental pattern that coincides as closely as possible to when they would have begun independent mobility as an able-bodied child. The application of powered mobility can be as young as 24 months.

This is a marked departure from the previously held concept that powered mobility should only be provided to adults because the value of providing this equipment to children was offset by issues of safety and physical development. Moreover, it is certainly true that with powered systems there are higher costs, transportation problems, and accessibility issues. However, recent research clearly points to the advances that can be achieved in social, cognitive, perceptual, and functional developments of the child when early mobility is achieved.

Introducing powered mobility equipment for use by a child must be done through a comprehensive evaluation of the child and family that is performed by clinicians who understand how to maximize the potential benefits of the equipment to the child's life. There is a variety of equipment with many options now on the market, such as 3-wheeled vehicles, carts and buggies, and a miniature version of the standard powered wheelchair.

Many systems are available for the child with limited functional control. Selecting and interfacing the control system with the child's abilities is one of the most crucial aspects, and should be done in conjunction with choosing the proper seating system. Proper positioning of the child is critical in achieving both operational success and safety.

All aspects of the child's growth and development need to be considered and incorporated into the process. The evaluation must also consider the devices that will be used in conjunction with the mobility system, such as augmentative communication, environmental control, and computers used in the educational process. Of particular importance is integrating the control of each piece of equipment to assure that it can be effectively operated with as few restrictions as possible. As with any child, there is the ever-present concern for safety as independent mobility is explored. The disabled child learning to use powered mobility just presents a different set of circumstances.

ELEVATING AND STANDING MOBILITY DEVICES

In some vocational, educational, or perhaps even domestic settings, an individual might benefit from either elevating himself to various heights or moving around in a vertical position. For example, an individual may have to perform desk or keyboard activities on the job and may also have to perform customer service related activities at a 42-inch counter. An elevating wheelchair seat will facilitate these tasks.

There also is equipment on the market that will enable a person to be restrained in a standing position and use a joystick to drive the powered platform upon which he/she stands. One such piece of equipment also allows the individual to bend at

the waist and/or to move from standing to a nearly prone position. Such equipment, however, is not for everyone. But, it is appropriate in circumstances where a needed function demands a capability that can only be provided by such equipment.

RECREATIONAL EQUIPMENT

There are many types of all-terrain vehicles that are hand-controlled or that are easily adaptable to hand controls. These vehicles can provide a tremendous social leisure outlet for many disabled individuals. Such vehicles have also been used in vocational settings to move individuals through terrain completely non-negotiable by standard powered mobility equipment. This kind of equipment can provide opportunities for activities ranging from competing on semi-professional race track circuits to hiking, hunting, fishing, or just taking a leisurely "walk in the woods."

Organized competitive activities for powered wheelchair users have been conducted on an *ad hoc* basis in many parts of the country, usually in conjunction with a sports wheelchair event. As interest in powered wheelchair competitive events increases, it is hoped it will precipitate the type of design development that occurred with manual wheelchairs and the resulting growth of sports and recreational activities.

CONCLUSION

The goal and responsibility of the prescriber of a wheelchair must be to restore to the greatest degree possible the individual's ability to pursue the three quality of life factors: independence, vocation, and recreation. In some instances, this is best accomplished by providing the option of using both a manual and a powered wheelchair. Giving a person the advantage of both options may make the difference between self-reliance

and dependence on others. It can determine whether or not a person is able to travel between home and work or school without the assistance of others. It can greatly affect the quality and degree of participation in many leisure activities, such as going out for a "walk" to the grocery store or just around the neighborhood. Distances that seem short or a bit of brisk exercise to an able-bodied walker may cause total fatigue to those who must push themselves in a manual wheelchair. These are considerations that should not be overlooked by the prescriber.

Clearly, the powered wheelchair is not a symbol of further disability but a means to move about freely while preserving vital energies for productive pursuits. This message must be conveyed to everyone whose disability requires the use of a wheelchair to carry out all or some of the everyday functions of living. However, the attitude that powered mobility is only for those with severe disability is a concept widely held by both disabled individuals and the general public. It need not be and should not be. Clinicians and other professionals who prescribe wheelchairs have an opportunity to dispel this myth and, at the same time, improve the quality of life for many wheelchair users.

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Future Developments

Seeking Information about Wheelchair Evaluation: A Call for Action

by Samuel R. McFarland, MSME

Mr. McFarland was Director of the Rehabilitation Engineering Program at the National Rehabilitation Hospital in Washington, DC, and Director of the Rehabilitation Engineering Center on Evaluation of Rehabilitation Technology, funded by the National Institute on Disability and Rehabilitation Research. He was a charter member, board member, and editor of the newsletter of the Association for the Advancement of Rehabilitation Technology (RESNA).

When seeking evaluative information for our common consumer purchases, we rely on direct experience, advertising, sales pitches, or published consumer's buying guides. Will that work when selecting wheelchairs? If you rely solely on your own experience, you will probably continue to prescribe the same wheelchair brands and types you have been using. If you depend on your local supplier for advice, you can expand your options only as fast as he expands his product line. However, if you seek objective information from published, formal wheelchair evaluations—you will either have to wait or become an activist—because such information is not well organized in this country. At present, there is no single national center for wheelchair evaluation in the United States.

Wheelchair manufacturers do conduct evaluations of their own products (and prospective imports) in order to find out about product safety, service life, and market acceptability and some of the information they gather could be useful for prescription purposes. However, it is proprietary and not available to purchasers or prescribers. Also, they usually work through selected dealers and with clinicians who volunteer information.

On the other hand, if the information were to come directly from the supplier, or even from the clinician working with a specific supplier, objectivity of the source might be questioned.

In the U.S., the champion of objective evaluation for products used in health care is the U.S. Food and Drug Administration (FDA). Its job is to protect the consumer of a medical product from injury or disease that might result from the use of the product. In the mid-1970s, the FDA recruited a panel of experts to put together a list of rehabilitation devices and to classify each product according to its suspected potential for causing injury. Wheelchairs were assigned to one of five groups and each group was assigned one of three classifications (1). The only type of wheelchair that was classed as high risk (Class III, Premarket Approval) was the type that climbs stairs. The very fact that the product will be used on stairs, therefore susceptible to falling, is substantial argument for inferring a high potential risk of user injury. Of the other four types of wheelchairs, only the prescription-based powered wheelchair seemed, to the classifying panel, to have presented safety risks, such as loss of operator control, electric shock, and exposure to battery acids. Such risks were, however, deemed amenable to reduction through the judicious development and application of performance standards. But the FDA has not been developing standards, preferring instead to encourage and support the development of such standards by groups of experts in the field. In the case of wheelchairs, that unfinished work has been ongoing for several years under the sanction of

the American National Standards Institute (ANSI) and RESNA. Their efforts are nearing completion and are reported in this publication.

After reviewing the standards, the search for objective evaluations of wheelchairs will take you to local suppliers to see which chairs are available in your area. If you feel the selection is at all limited, ask the suppliers why they do not carry certain other brands. Then check with other clinicians, either in your own area or through your professional society, to see if they would be interested in forming an evaluation committee. Awareness of need creates demand for satisfaction. Also, search the technical journals for articles that report on wheelchair applications for special cases or populations.

If you are an activist, or are thinking that you should become one, you may want to initiate some evaluation activity through the local chapter of your professional organization, or on a national basis. You will not be plowing unbroken ground, since exemplary information and techniques are reported in a few special publications, and new research and demonstration programs are available. Special workshops focusing on wheelchairs were conducted by Moss Rehabilitation Hospital in the late 70s. "Wheelchair I" and "Wheelchair II" (2,3), identified many of the clinical and user experiences that were available at that time. Even though the data are now outdated, it is easy to see that the identification of problem areas led to initiating research and standards development which has spun off improvements in wheelchair design and performance. A similar workshop, "Wheelchair III" was conducted by the VA Rehabilitation Research and Development Service in 1982, and had similar beneficial effects on the development of improved powered wheelchairs (4).

Laboratory testing and qualification of wheelchairs is now beginning. Methods for objectively gathering and presenting experiences of active wheelchair users still need development. Perhaps the independent living centers can work on developing a user-experience network similar to the parochial data-gathering effort that was active at the Center for Independent Living in Berkeley during the mid-1970s (5).

Whether the evaluative data we seek is technical, clinical, or user-experience based, the fact

remains that there is no central place for that information to be stored and shared. Although it is too early to report on its format or relative success, there is promise of the development of such a source for wheelchairs, as well as other products, for use in rehabilitation. The National Institute on Disability and Rehabilitation Research has awarded a five-year cooperative agreement to the National Rehabilitation Hospital, Washington, D.C., to establish such a data-gathering and reporting resource. The Rehabilitation Engineering Center for "Evaluation of Rehabilitation Technology" will seek to collect information on methods, resources, and evaluation by researchers, clinicians, and users. A partnership with ECRI, a Pennsylvania company involved with testing and reporting on health care products, is designed to acquire evaluative data and disseminate it to people who need it.

The process of evaluation is under way, but the resources for conducting evaluations and getting the results to the rehabilitation professionals who need this information are still very limited. As you gain new insights into the variety and potential of new products, we hope you will join in the quest for establishing a way of gathering and sharing information to help in evaluating and selecting wheelchairs, as well as many other products intended to minimize disability.

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Future Developments

Current Directions in Wheelchair Research

by Colin A. McLaurin, ScD

Prior to his retirement, Dr. McLaurin was Project Director and Research Professor of Orthopedics and Rehabilitation at the Rehabilitation Engineering Center, Department of Orthopedics and Rehabilitation, University of Virginia Medical Center, Charlottesville, VA.

INTRODUCTION

Over the past several years, there has been increasing interest in the wheelchair among inventors, design engineers, and the general public. This is probably because the wheelchair has come to symbolize the person with handicaps. For example, the national symbol for handicapped access is an abstract image of a person in a wheelchair. It is a tangible and understandable object, and in recent years has become the focus of a great many ideas and suggestions for improvement.

In contrast, the major manufacturers of wheelchairs have been rather conservative in introducing new ideas and have instead been content with minor product improvements, particularly with regard to powered wheelchairs. The exception has been the production of the sports-type wheelchair, which was first conceived and developed in response to competitions in racing, basketball, and other sports for athletes with disabilities. Sports-type wheelchairs for general use were first introduced by new companies such as Quadra and Motion Designs, but are now offered by all major manufacturers. The revolution in lightweight wheelchair design and styling is a credit to the spirit and vitality of the people behind this movement, many of whom have disabilities.

However, problems of liability and the rather low overall market demand has contributed to a conservative attitude among manufacturers. Al-

though the amount of research done by wheelchair manufacturers is not public information, it is doubtful that much effort is being devoted to this area by them. Some universities are appropriately staffed and equipped to carry out research on wheelchairs, paving the way for greater innovations in component design.

For example, a major research effort at the University of Virginia Rehabilitation Engineering Center has focused on the basic principles associated with the functional and structural characteristics of wheelchairs. These include ergonomics of propulsion, rolling resistance, seating configuration, structural analysis, controller design, motor efficiency, and battery capacity. Research efforts, such as those at UVA, are providing the theoretical framework which will result in designs that will meet the needs of disabled users for specific activities.

The definition of the user population and their activities, both customary and desired, needs to be known. To date, there has been very little research in this area, but some information can be obtained from surveys conducted by the University of Virginia (1) and the Paralyzed Veterans of America (2).

FUNCTIONAL CHARACTERISTICS

The primary purpose behind research is to improve the functional characteristics of a wheel-

Table 1.
Distribution of Subjects in Anthropometric Survey, 52 Clients

Diagnosis	Number of Clients		Range of Age	Mean Body Weight
	Male	Female	Years	Kg.
Cerebral Palsy	7	11	2-22	58.1 ± 29.9
Muscular Dystrophy	3	2	10-54	88.1 ± 45.3
Spina Bifida	3	3	15-20	104.2 ± 17.4
Paraplegia	9	1	19-53	165.0 ± 46.2
Quadriplegia	4	3	20-45	143.1 ± 37.1
Arthritis	2	2	64-79	142.9 ± 38.7
Other	0	2	28-50	104.0

chair. These can be divided into two categories: 1) seating comfort, and 2) mobility.

Seating Comfort and Support

Much has been said about the inadequacies of the sling seat, but very little has been documented to support this opinion. However, it requires little observation to note that just minor differences in wheelchair seating, usually only width and depth, can hardly accommodate the range of sizes, disability types, personal attributes, and activities that exist in the user population. It is the first duty of researchers to establish information regarding these individual requirements, and such work is underway. This topic is discussed in more detail by Ferguson-Pell elsewhere in this publication.

Perhaps the most basic work is the collection of anthropometric data for wheelchair users. The RECs at Memphis and Virginia have been collecting such data for several years now, and hopefully more centers will contribute to this compilation (3). Information completed from 52 subjects for 7 disability groups is shown in **Tables 1 and 2** (4). A report of anthropometry for cerebral palsy (5) compiled by the Memphis REC includes nineteen seated dimensions for ages 2 to 55 years. Relaxation and functional activities for persons with cerebral palsy also have been studied at Memphis to determine the most appropriate seating angle, and these studies will be expanded to include other disabilities.

In addition to the anthropometric data, more needs to be known about the ideal shapes for

support surfaces for various parts of the body. For this purpose, a shape-sensing device has been developed and is in use at UVA. Probes projecting through a cushion in the seat and back of an adjustable chair automatically record the shape in a computer. By using cushions of different density, the tissue characteristics can also be deduced. Corresponding pressure readings and related work with magnetic resonance imaging (MRI) are providing the necessary information for determining the ideal shapes and cushion characteristics for seats and other support surfaces. This shape measurement technique is now used to produce numerical data for the automatic shaping of custom contoured cushions that are currently under evaluation. Since seating requirements may vary with activities, some form of adjustment while seated (like those done for automobiles) may be indicated.

Mobility

To a considerable extent, mobility is dependent upon seating, as it is one of the ergonomic factors. (Ergonomic factors are more fully described by Brubaker elsewhere in this publication.) Mobility also depends upon the rolling characteristics of the wheelchair.

One of the most important factors contributing to propulsion efficiency is mechanical advantage, since it determines if muscles perform at optimum speed and force. Experimental models have been built with a geared transmission in the hub, allowing two or more ratios between the handrim and the drive wheel. Lever or crank drives, or handrim drives that are separate from the drive wheels,

provide a simpler means for obtaining an optimum mechanical advantage through a bicycle-type chain and sprocket transmission (Figures 1a and 1b). Since levers have been shown to be more efficient than handrims, their use in wheelchairs can be expected to increase in the future. The main disadvantage of levers—the difficulty in achieving the control and maneuverability associated with handrims—appears

to have been overcome by recent designs. In any event, the lessons learned by studying propulsion with handrims, levers, or other means will have significant impact on the future design of wheelchairs.

Equally important are the rolling characteristics of the wheelchair itself. At one time, hard rubber tires were prescribed for low resistance, but studies

Table 2.
Statistical Analysis of Anthropometric Survey, 50 Clients

Linear Measurements	Dimensions in Centimeters											
	Cerebral Palsy		Muscular Dystrophy		Spina Bifida		Paraplegia		Quadriplegia		Arthritis	
	Mean	S.D.	Mean	S.D.	Mean	S.D.	Mean	S.D.	Mean	S.D.	Mean	S.D.
1. Sitting Height	63.5	± 9.9	68.7	± 12.0	68.9	± 6.0	84.0	± 6.0	89.9	± 9.0	77.7	± 6.2
2. Shoulder Height	40.6	± 6.7	46.5	± 8.7	45.9	± 4.9	56.7	± 5.0	61.9	± 8.4	53.2	± 4.2
3. Elbow Height	17.7	± 5.1	17.3	± 7.6	17.0	± 4.8	19.1	± 4.8	25.5	± 7.4	20.0	± 4.9
4. Elbow to Knuckle of Small Finger	26.6	± 6.1	31.0	± 3.9	31.3	± 2.2	36.9	± 1.8	41.1	± 14.0	31.9	± 3.3
5. Back to the Kneecap	44.1	± 11.3	52.1	± 10.8	49.0	± 2.5	58.8	± 4.5	59.7	± 2.7	59.1	± 3.6
6. Back to Underside of Knee	37.6	± 9.6	45.8	± 9.6	42.1	± 1.8	50.3	± 4.3	51.5	± 4.0	50.7	± 3.8
7. Ground to Underside of Knee	58.7	± 5.8	63.6	± 9.0	54.1	± 2.0	54.6	± 3.9	53.1	± 3.5	50.5	± 10.4
8. Ground to top of Knee	66.6	± 6.2	72.4	± 8.3	63.0	± 2.3	65.2	± 4.8	63.9	± 4.0	62.4	± 13.7
9. Ground to heel	26.9	± 11.2	27.4	± 15.1	28.0	± 7.2	7.1	± 4.0	12.2	± 9.4	11.9	± 7.7
10. Shoulder Width	31.2	± 6.9	35.5	± 10.4	42.6	± 7.2	44.2	± 3.2	44.0	± 7.4	37.6	± 4.8
11. Chest Width at Axilla	23.5	± 4.3	26.0	± 8.7	32.0	± 4.6	35.2	± 4.0	34.5	± 5.1	29.9	± 2.9
12. Waist Width	20.0	± 3.6	26.7	± 4.8	30.1	± 7.0	32.5	± 5.6	30.6	± 6.6	32.7	± 6.0
13. Hip Width	24.8	± 5.7	32.6	± 10.7	37.2	± 6.0	41.1	± 6.7	40.3	± 4.8	41.8	± 4.1
14. Width at Knees	26.4	± 5.9	25.2	± 11.6	31.1	± 7.2	31.2	± 10.4	26.0	± 6.8		
15. Foot Length	18.7	± 4.4	22.9	± 1.6	18.8	± 2.0	26.3	± 2.9	26.5	± 1.6	25.4	± 4.0
16. Leg Length	33.3	± 7.9	39.8	± 7.7	34.3	± 1.8	51.4	± 7.1	47.4	± 3.9	45.4	± 6.8
17. Acromian Width	24.1	± 4.4	35.6	± 4.5	34.4	± 4.0	39.5	± 4.4	39.2	± 3.3	34.8	± 3.8
Angular Measurements												
Angles in Degrees												
< 6 – Angle of Seat Surface to Horizontal	18.5°	± 13.4°	8.3°	± 9.9°	2.7°	± 3.8°	2.5°	± 1.6°	2.1°	± 2.4°	6.5°	± 7.9°
< 1 – Angle of Back Surface to Horizontal	110.7°	± 16.9°	109.3°	± 12.6°	96.2°	± 6.4°	103.7°	± 4.9°	106.6°	± 7.2°	103.0°	± 12.9°
< 16 – Angle of Post. Leg Sur. to Horizontal	107.8°	± 11.8°	105.8°	± 3.0°	124.7°	± 9.6°	106.°	± 3.5°	114.°	± 12.5°	107.°	± 12.7°
< 15 – Angle of Foot to Horizontal	15.6°	± 8.5°	14.0°	± 6.6°	6.2°	± 11.7°	14.9°	± 6.6°	17.0°	± 15.5°	22.5°	± 18.4°
< 4 – Angle of Forearm to the Horizontal	11.2°	± 16.8°	76.0°	± 50.5°	2.3°	± 5.7°	-4.3°	± 12.5°	6.6°	± 11.7°		

on a treadmill have shown that it may require about four times the effort to propel hard rubber tires than that required for high pressure pneumatic tires. Some synthetic, non-inflatable tires show results nearly as good as high pressure pneumatic tires but with limitations in comfort. This may indicate the need for some type of suspension which could provide comfort as well as the durability associated with the new synthetic materials. Theories have been put forward by Kauzlarich regarding the optimum design of such tires for easy rolling (6). Since smaller wheels such as those used in casters have a rolling resistance greater than large wheels (roughly inverse to the size) the weight of the user and wheelchair should be kept over the large wheels. This also provides better balance for performing wheelies and other maneuvers.

Other factors that affect rolling resistance are alignment and caster flutter. One degree of misalignment can double the rolling resistance. (However, camber—the tipping inward of wheels at the top—has little or no effect.) Frames must be made that maintain correct alignment under any load. Caster flutter, a long standing and widely experienced problem, has now been thoroughly analyzed and there is no longer any excuse for this annoying and dangerous problem (7). One device recently developed, that weighs less than an ounce, effectively dampens any flutter for speeds up to 12 kph and beyond. The design utilizes cone shape wedges and a compression spring mounted in the caster housing (**Figure 2**). The spring forces the cones against the caster stem, effectively damping flutter for all reasonable speeds.

With the advent of sealed bearings, only the tires, irregular surfaces such as carpets and hills, or the wind will limit progress. It has been shown that carpets increase resistance by as much as four times with typical tires, but little is known about tire design for use specifically on carpets, grass, or similar surfaces. The biggest energy consumers for the wheelchair user are hills, but other than reducing the weight little can be done without resorting to innovative propulsion systems. A lever drive with variable gear ratios and an anti-back up device is an example. Wind resistance has been measured in a NASA low speed tunnel, indicating that a head wind of 20 mph can increase the drag force on level terrain from 1.5 to 9



Figure 1a.

Lever Drive Wheelchair in Operation. In this prototype, the rear wheels are driven by the lever through a clutch and bicycle chain. The clutch is engaged by moving the levers inboard, allowing the wheelchair to be driven forward or backward by a similar motion in the lever. Propelling the wheelchair is like rowing a boat. The clutch is released at the end of each stroke by outboard motion of the lever, similar to lifting the oars from the water. The clutch also acts as a very effective dynamic brake and the chain drive allows the selection of a speed ratio suitable for the strength of the user.

pounds (8). This information could be used in designing a propulsion system optimized for all conditions.

To summarize, theoretically it is possible to increase the power available in the arms and shoulders by a factor of three, over that available in a conventional wheelchair. It is also possible to decrease by a similar amount the power required to move the wheelchair. This has already been achieved, in part, by the introduction of sports-type wheelchairs for everyday use. Research results are providing the necessary information for designing a machine with optimum features for a given person and intended activities.

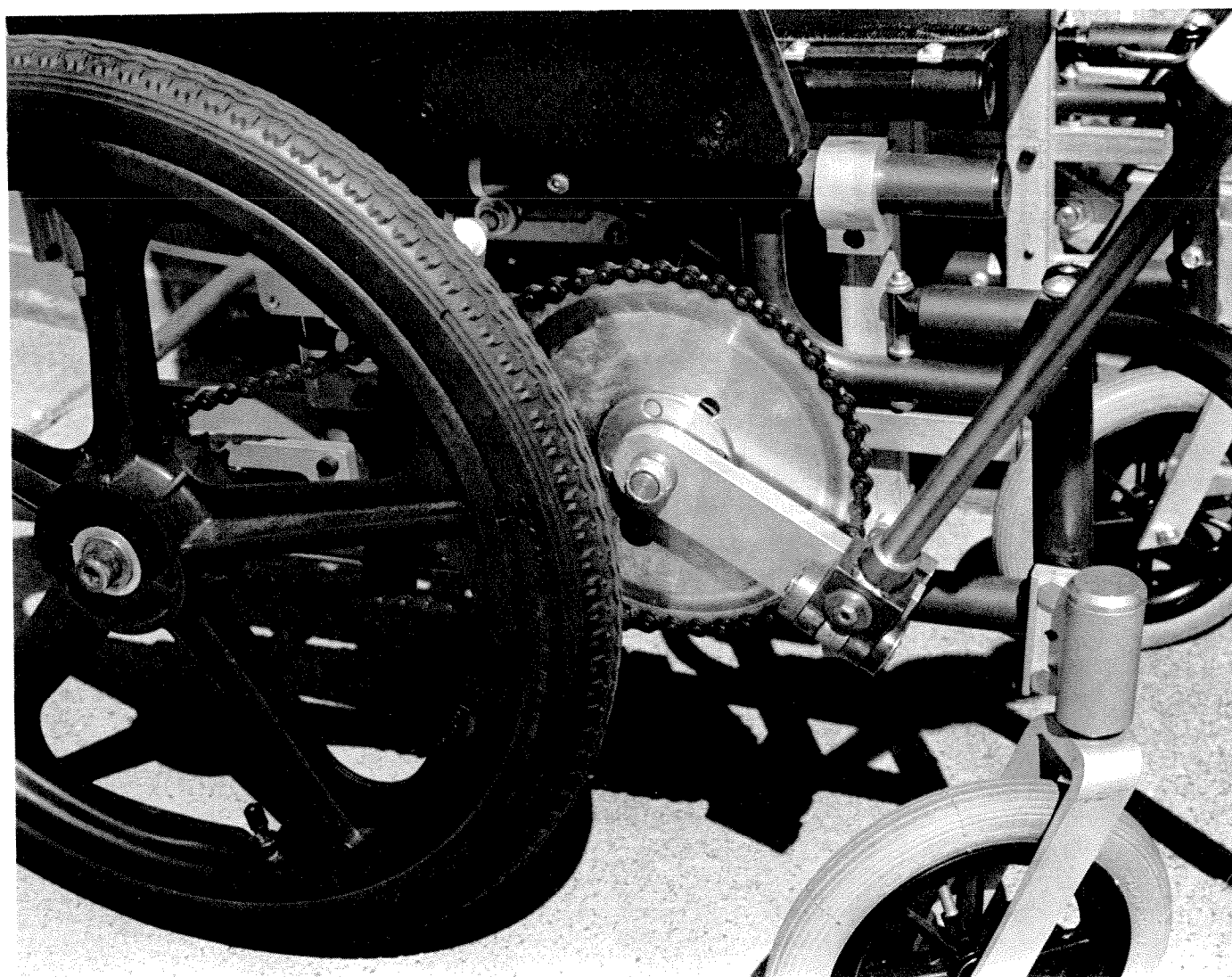


Figure 1b.

Lever Drive Wheelchair in Operation. Detail of the clutch assembly. The front sprockets serve as the clutch plate in a recent prototype of the lever drive system. The system has been designed to be retrofitted to commercial wheelchairs.

MANUAL WHEELCHAIRS: THE EFFECT OF RESEARCH ON COMPONENT DESIGN

Much like bicycles, wheelchairs are an assembly of components with varying and optional characteristics that include a frame, seat, foot and armrests, wheels, tires, brakes, and drive systems.

Frame

Tubular construction will probably be the mainstay for some time to come. Material options such as aluminum alloys, titanium, and carbon fibers all have their own characteristics. No matter what material is used, stress analysis systems, some simple

enough to conduct on a personal computer, are now available that allow designers to ensure adequate strength where needed. An example is the tube adjacent to the caster, which has been shown in analysis and testing to be a highly stressed point. By simply replacing the round tubing with square tubing at this point, the strength is increased by about 38 percent.

Plastics are being used more and more in frame design. Reinforced plastics such as carbon-epoxy tubes, or composites that can include panels with foam or honeycomb cores, are light and strong. Production cost estimates show that side frames can be produced in quantity for as little as \$15, because

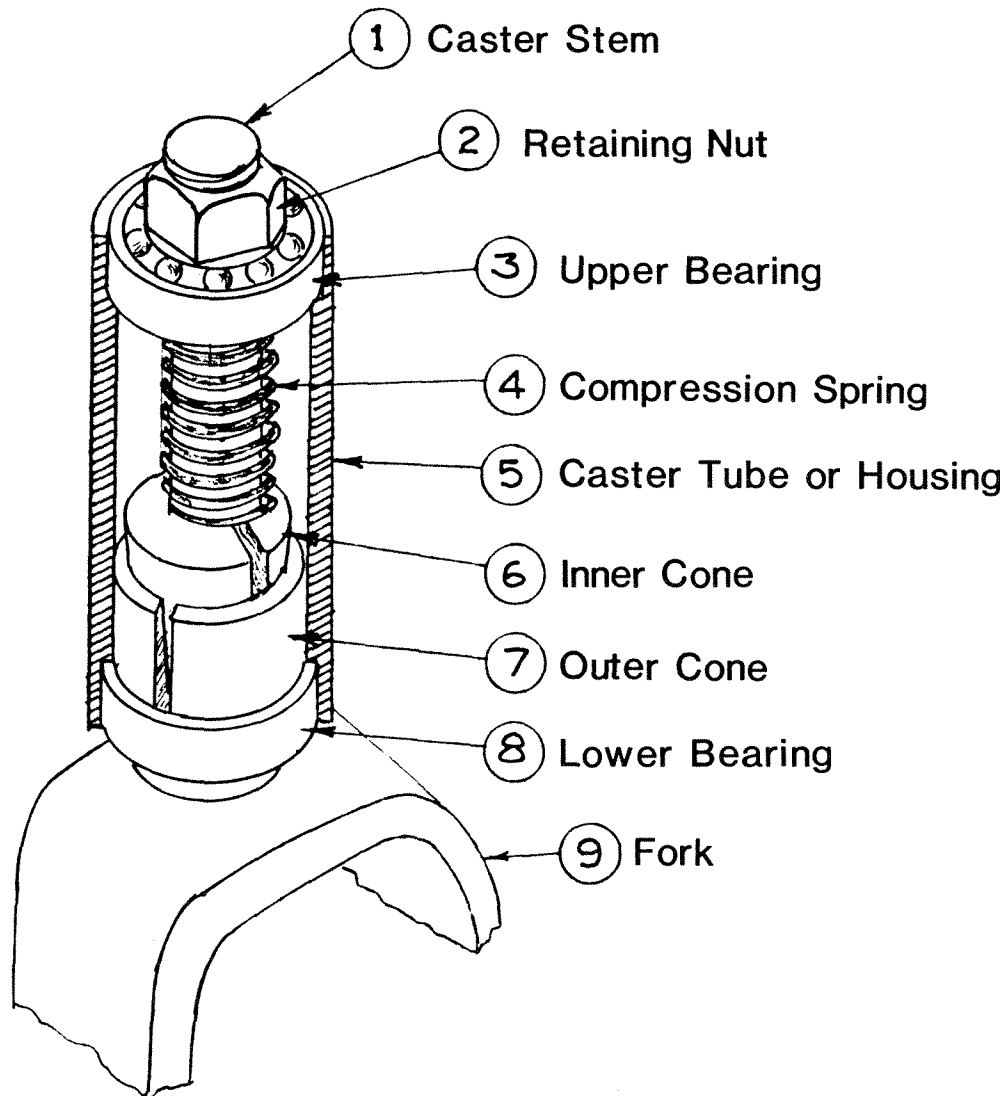


Figure 2.

University of Virginia Shimmy Damper. The cutaway drawing shows the three components of the friction type damper in a typical installation. The spring (4) forces the inner cone (6) into the outer cone (7). This causes the inner cone to press against the caster stem (1), thus producing friction to damp rotational oscillation. Both the inner and outer cones are split so that they are free to move radially. Parts (1) caster stem, (2) retaining nut, (3) upper bearing, (5) caster tube or housing, (8) lower bearing, and (9) fork are existing parts of a typical wheelchair.

these parts are made in a one-step process requiring no further finishing.

Frames should adjust to suit the individual. Experimental plastic models have shown how the front and back position over the wheels, the seat angle, and the seatback angle can be adjusted with simple tools and with little weight penalty. These adjustments should become a part of routine wheelchair prescription. Ideally, it should be possible for the user to make adjustments such as front and back

positions without leaving the seat, as has been demonstrated in experimental models.

Seats

For simplicity, sling seats will probably continue to be used routinely. But the variety of plastic and composite panels being developed suggest that more consideration be given to rigid seats which provide firm and predictable support for the seat cushion, a prerequisite for so many users. In the

past, rigid seats have been flat, but the use of contoured shapes opens up new possibilities for comfort and support, with or without a cushion. Current research is determining the required shapes and sizes for such seat panels.

Lightweight Frame with Adjustable Seat Systems

No wheelchairs are commercially available that reflect the design and development of seats having the optimum support characteristics determined by research, plus the light weight and foldability required for wheelchair use. This is a considerable

task, if one is to remain within the fiscal restraints of the market. A prototype developed by the author is shown in **Figures 3a and 3b**.

Footrests and Armrests

Previously, footrests were one of the most cumbersome and vulnerable parts of a wheelchair. With the development of sports wheelchairs, new approaches to designing footrests were introduced. Combining the support required in prescription wheelchairs with swing-away footrest features and simplicity in design of sports chairs, calls for more ingenuity than research. But the current enthusiasm

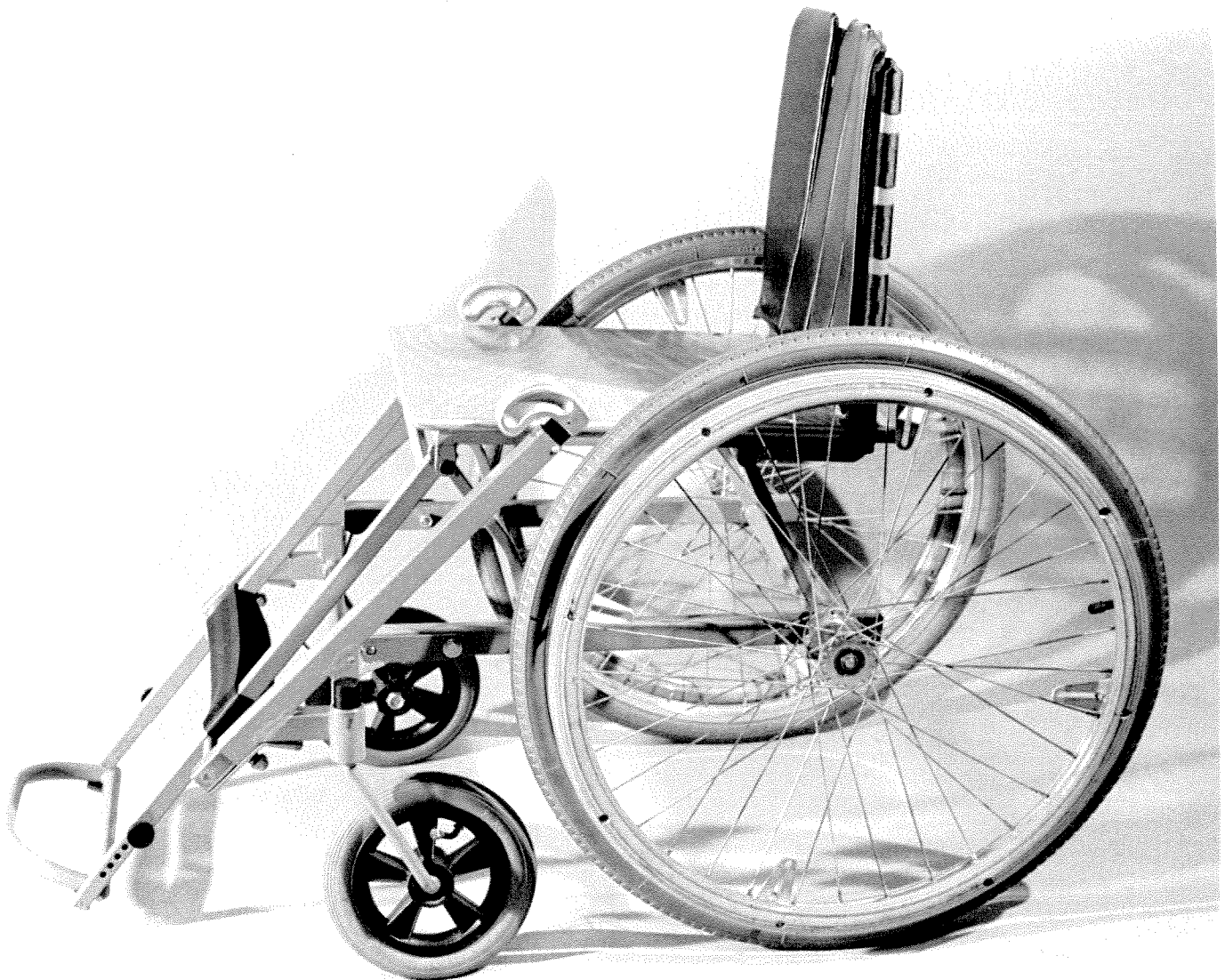


Figure 3a.
University of Virginia Adjustable Seat Wheelchair: Extended.

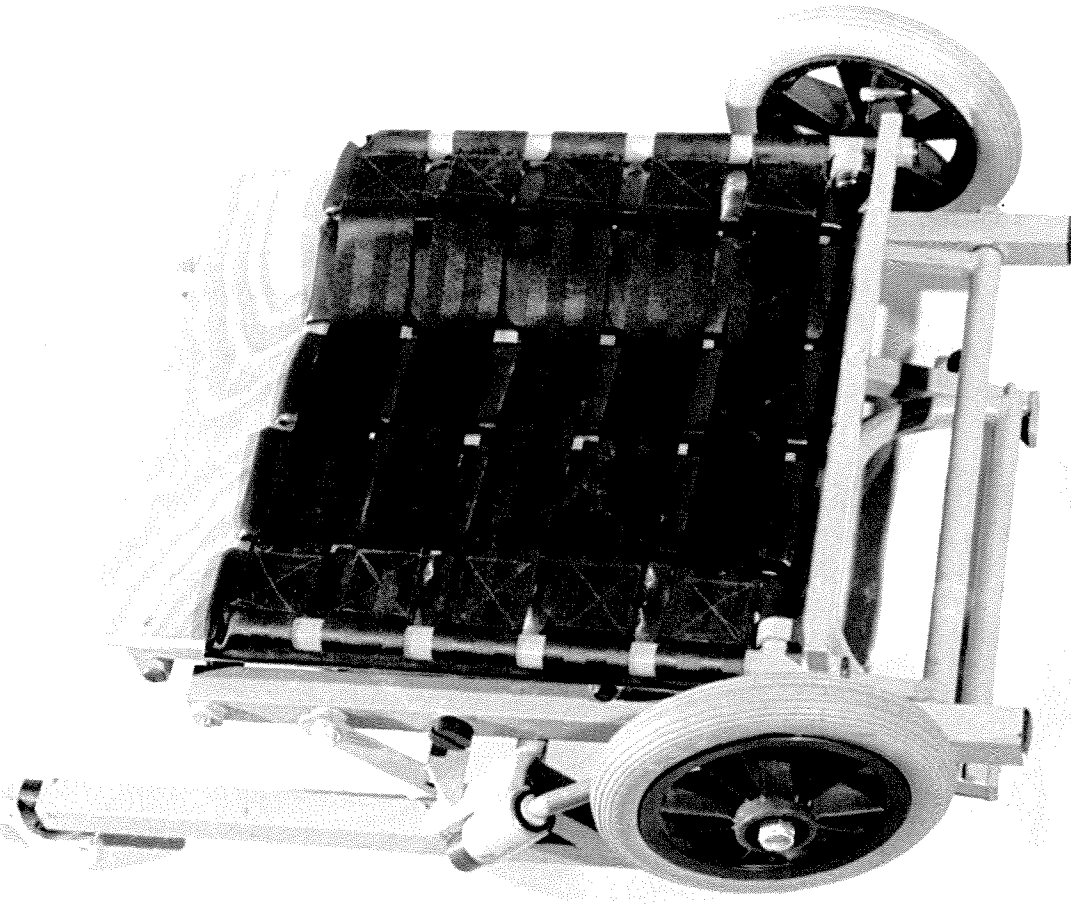


Figure 3b: Folded. This wheelchair has a frame geometry that allows the user to move the seat forward or backward through a range of 5 inches while seated. The handles at seat level just forward of the main wheels control clamps inside the frame tubes that secure the wheelchair in the selected position. The handles also provide a firm reaction point for pushing or pulling the seat to the desired position. With the wheels removed, using customary quick release axles, the wheelchair folds to a compact configuration.

for improvement, demonstrated by users and entrepreneurs, insures that new, better solutions will be sought. As with armrests, we now see examples of fold-away designs replacing the old plug-in, removable models.

Wheels

Although wire-spoke wheels are difficult to improve on from the viewpoint of strength and weight, one can expect an increasing use of mag-type wheels, probably made of reinforced plastic. The use of computer analysis allows the design of wheels for optimum strength and light weight, but the main advantages are in durability and minimum

maintenance. Sealed precision ball bearings are replacing the cone type of wheel bearings for most uses.

Tires

Non-pneumatic tires made from urethane or other synthetics minimize maintenance and increase tire life span. They also approach the light weight and low rolling resistance of high-pressure pneumatic tires. However, to provide a ride comparable in comfort to pneumatic tires, some type of suspension, such as rubber mounting between the frame and wheels, may be required. The characteristics of this suspension are yet to be determined, although

some work is being done in this area. Several spring casters are already on the market, but the amount of springing (spring constant) has not provided comfort without bounce, nor has it reduced stress on the frame. This is a problem that remains open to analytical and experimental study.

Brakes

A recent survey* has shown that paralyzed veterans would like their wheelchairs to be equipped with running brakes that, like a bicycle or automobile, allow the user to control the speed of the vehicle on hills and in coming to a stop (9). Drum-type brakes, like those used on bicycles and some wheelchairs in Europe, are a satisfactory solution that is available; it is up to the American manufacturers to respond.

Drive Systems

Although there are proven functional advantages to alternate drive systems, the inherent simplicity of the rim drive has an undeniable appeal. Current efforts in demonstrating lever drive possibilities should be viewed as indicators rather than comparative examples. The considerable interest in lever drive systems that has been generated in the last two years should give rise to one or more commercially available models, either as a complete wheelchair or as an add-on accessory.

POWERED WHEELCHAIRS

In December 1953, G.J. Klein at the National Research Council in Ottawa issued a report titled "A Wheelchair Electric Drive for the Use of Quadriplegics" (10). The system consisted of two geared motors driving each main wheel independently through a rubber faced pulley wheel, powered by two 12-volt batteries, controlled by a joystick operating through relays, all mounted on an Everest & Jennings manual wheelchair. The powered wheelchair in common use one third of a century later follows this same configuration and still retains a remarkably similar list of components. However, a closer examination reveals significant changes in design and construction. The frames have been

made more sturdy and the wheelbase lengthened. Pneumatic tires have replaced hard rubber, mag type wheels have replaced the wire spoked wheels, and belt drives are used instead of friction pulleys. Pulse-width modulation now provides variable speed control, replacing the on-off clatter of the solenoids. Deep-discharge batteries provide longer cycle life than the automotive type and with the other features contribute a better overall performance than that found in the 1953 version.

In spite of these many improvements, for the most part the powered wheelchair is still a modified manual wheelchair. There are some exceptions. Wheelchair III, a workshop held in San Diego in March 1982 (11), addressed this problem and recommended that the powered wheelchair be based on a powered chassis upon which could be mounted a standard or custom seat and any accessories that might be needed by the user. The history and implications of this new approach to powered mobility are discussed in more detail in Chapter 6.

Some recently introduced models reflect this trend. One example is the Fortress Scientific which not only has a demountable seat, but the chassis itself can be readily separated into separate parts for lifting into the trunk of a car. Another example is the Besam, with the drive wheels in front and a seat which has powered legrests and backrest as an option. Both of these wheelchairs have abandoned the manual wheelchair frame concept and built the wheelchair from scratch, an approach that offers much more scope in improving function, comfort, durability, and appearance.

In assessing how the advantages inherent in this new approach might materialize, it is prudent to examine the possibilities in the component parts. By separating seating from the chassis, it becomes possible to provide a variety of standard seats or to fabricate custom seats that satisfy the needs and wants of particular users. Several automotive bucket seats are now available for wheelchairs offering comfort, adjustability, support, and style that goes far beyond the conventional. These seats, however, are bulky and heavy. Cost and weight are the prime concerns restricting the introduction of powered adjustments for support as demonstrated in the Besam model.

The powered chassis, once independent from the anthropometric and ergonomic considerations of seating, becomes purely an engineering problem,

*Survey based on 168 responses to a questionnaire published in the March 1985 issue of *Paraplegia News*.

and can more readily utilize up to date engineering technology in all of its parts. At present there are no apparent breakthroughs in energy storage. The deep-discharge lead acid battery is still the best solution, but the use of tubular positive plates, as has been demonstrated in Europe, can lead to a cycle life of 2,000 discharge cycles or more. Although more costly initially, they could conceivably last the life of the wheelchair. Recent improvements in chargers and battery monitors ensure a more efficient and reliable energy source, further increasing battery life and avoiding the chance of being stranded with a "flat" battery. Motors represent a long standing technology which offers little hope for improvement, except that a motor with the correct specifications can offer improvements in performance and efficiency. Motors other than permanent magnet, such as series wound motors, may offer some advantages in starting torque and are readily available in production. Pancake motors with a large diameter, low speed, and high torque are attractive but as yet are not available with specifications suitable for a wheelchair.

More important than the motor is the drive train which connects the motor to the drive wheel. Although pulleys and toothed belts will continue to be used, enclosed gearing is a more logical choice for trouble free operation. A transmission that permits a change in gear ratios could do much to improve the overall efficiency, range, and performance. A recent and very innovative automatic transmission called the Resatran has been demonstrated by Reswick (12). It is doubtful if such devices could be developed economically for wheelchair use, but if they were already in use in some other application their use in a powered chassis should be seriously considered. Motor controllers play an equally important part in determining the overall performance. The customary pulse width modulation robs the motors of some of the efficiency experienced with direct current. Power transistors are not yet available in a size suitable for wheelchair power requirements and have exhibited considerable intrinsic losses. As an alternative a voltage converter under investigation by Inigo holds some promise in providing a reliable, compact, and efficient means of controlling motor speed and torque (13).

Wheelchairs that embrace the powered chassis concept show changes in wheels and tires. Typically, the drive wheels are smaller than conventional and the caster wheels are larger. All tires are pneumatic, with wider treads for better off-pavement traction. Some models are made with the drive wheels in front and the casters in the rear. This provides more foot room and better traction over obstacles, but is inherently unstable requiring velocity feedback in the control system to avoid fishtailing. The use of some form of suspension to keep all wheels on the ground and to improve riding characteristics is also indicated.

The joystick will probably continue as a basic interface between the man and the machine, although it is far from ideal for many users. Head, voice, chin, and breath control will continue as alternative means, but all of these may benefit in the future from micro-computers that can provide a modicum of automatic control, relieving the operator of all but the grossest decisions. There are many possibilities for the future of these systems, but to be useful and effective, intimate cooperation between the electronic experts and potential users will be required. As in all other aspects of the powered wheelchair, simplicity and reliability are overriding considerations in an application where low volume, reasonable cost, and high liability govern the marketplace.

SPECIALTY ITEMS AND ORPHAN PRODUCTS

A variety of special purpose wheelchair designs have been developed in recent years. Some, such as the 3-wheeled scooter popularized by Amigo, have become a viable alternative for many users, but most fill a very limited need which makes economic development an unlikely venture.

Wheelchairs in this category include stairclimbers, both manual and powered, stand up wheelchairs, omni-directional powered wheelchairs, and all-terrain models. Specialty needs, particularly for children, include seating systems with multi-adjustments to provide comfort, function, and posture support. Some of these may be classified as orphan products and be eligible to receive subsidies to encourage manufacture. Others can be considered little more than curiosities, satisfying the special desires of only a few people.

SUMMARY: THE FUTURE

Emerging from the recent advances in wheelchair technology and the availability of inexpensive imported wheelchairs, is a marked distinction between commodity, or occasional use wheelchairs, and prescription-type wheelchairs that serve as an integral part of a user's lifestyle. Continued development of the prescription chair is needed to meet the varied requirements of persons with different disabilities, abilities, needs, and activities. Seating comfort is perhaps the greatest need, and only recently have models become available that offer any adjustability. Mobility in confined spaces is another requirement that needs attention. Propulsion systems other than handrims, such as levers, are receiving wider attention. Ease of transferring to and from various situations needs to be addressed.

Further development in material and structural design can reduce the cost and increase durability for the lightweight chair. Mag-type wheels that are as light as wire spoke wheels are one example of a possible technical improvement. Another example are the trouble-free tires with good ride and low rolling resistance.

The power base concept is taking root and with it the promise of greater reliability and overall performance. Seating options for a power base offer many possibilities, from simple lightweight folding seats to fully adjustable power seats. Custom contoured seating using CAD-CAM is a real possibility in the next few years.

Controls for powered wheelchairs are still in the early stages of development. Smooth, accurate control of the dynamic aspects of the wheelchair in all situations is the goal for all types of inputs and should be pursued.

At the present time, the wheelchair manufacturing industry itself seems to be undergoing a period of rapid change with many new ideas, designs, and concepts presented to a small but diverse clientele. One can expect a sorting out in the next few years, with the more practical innovations becoming the standards for the future.

It is hoped that this future includes a marketing system that allows a customer to choose from a variety of components that can be assembled to provide a machine that suits the size, function, and

appearance desired, as well as the prospect of immediate delivery. Providing a suitable, reliable product without delay and at a reasonable cost should be the main goal of research in the wheelchair industry.

ACKNOWLEDGMENTS

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Future Developments

Wheelchair Standards: An Overview

by Colin A. McLaurin, ScD and Peter Axelson, MSME

Peter Axelson is President of Beneficial Designs, Inc., Santa Cruz, CA, and succeeded Dr. McLaurin upon his retirement as Chairman, ANSI/RESNA Wheelchair Technical Advisory Group.

A series of wheelchair standards are currently in the final phase of approval by the American National Standards Institute (ANSI). These standards have been under development for several years, working closely with the International Standards Organization (ISO) so that the ANSI standards will be essentially the same as those in the other participating countries.

The development of standards has been a long and tedious process involving participation from many disciplines and interests. The ANSI Technical Advisory Group (TAG), organized by RESNA, operates under a grant from the Veterans Administration, with a secretariat at RESNA.

The main purpose of these standards is to provide the user and prescriber with the knowledge and assurance that a product measures up in durability and performance. The standards are of value to the manufacturer on an international basis because it enhances their position in foreign markets and restricts the sale of imports that do not meet these standards. The standards define test procedures that are useful to the Veterans Administration and other national purchasing agencies in establishing acceptance criteria for domestic or imported products.

The ANSI TAG has a diverse membership consisting of users, manufacturers, engineers, testing

authorities, therapists and distributors. As each of these professionals may have differing requirements, considerable discussion and testing is required in order to reach a decision. It is then followed by the drafting and redrafting of documents particularly within the ISO since language also plays a part in arriving at understandable and unequivocal statements. Throughout the entire process, there is one paramount concern and that is that the standards do not restrict innovation by specifying a particular material or construction. The standards are therefore Performance Standards that establish means by which durability and performance may be measured. In some cases levels of acceptance may be recommended, in others only the disclosure of the results is required.

ISO standards must undergo a rigorous procedure which includes a majority vote from all participating and observer countries that are involved. At the national level, the ANSI/RESNA TAG is developing standards that will be adopted as U.S. standards once they have been subjected to public comment and have been approved by ANSI's Standards Review Board. The standards, once they come into effect, are voluntary standards, not law. ANSI is strictly a private, non-government, institute. It is in the interest of manufacturers to adhere to the standards so that they may be so labeled. Any wheelchair that does not carry the ANSI label will be at a real disadvantage in the market place.

Portions of this material previously appeared in *Caliper*, Vol. XLII, No. 1, 1987, pp. 20-22, published by the Canadian Paraplegic Association.

Currently there are 17 standards under consideration. Four of these are general in nature covering terms and definitions, overall dimensions, test dummy specifications and the procedure for measuring the coefficient of friction of test surfaces. The dummy is a simple design used to load the wheelchair in a manner equivalent to typical users. Four dummies are used with overall weights of 25, 50, 75 and 100 Kg representing children, small adults, average adults and large adults, respectively. The results of tests that include the use of dummies must always include the weight of the dummy(s) used.

One other general test concerns burning; hazards associated with cigarettes and matches igniting upholstery. The test procedures are adapted directly from those already in use for furniture.

The nature and status of selected standards are as follows:

Nomenclature, Terms, and Definitions (Final)

This national standard defines the basic elements of wheelchairs (manual, electric, and others) and gives terms and definitions for these elements in an illustrated glossary. It also illustrates the dimensions commonly used to describe wheelchair physical characteristics.

1) Static Stability (Final)

This applies to manual and powered wheelchairs and refers to the tipping angle of the wheelchair with and without locked brakes when loaded with the appropriate dummy. The tipping in the forward, rearward and lateral directions is determined plus any other direction that may be more critical. The standard will not include acceptance levels, but requires the disclosure of the test results so that the consumer or prescriber may make an informed choice.

The mean value of the test results of other wheelchairs in the same category will be included in the disclosure. Since some wheelchairs have adjustable wheel or seat positions, the maximum and minimum values are recorded.

2) Dynamic Stability of Electric Wheelchairs (Final)

This standard is concerned with the stability of an electric wheelchair when turning at full speed.

3) Efficiency of Brakes (Final)

This test is concerned with the ability of wheel locks to hold the wheelchair and dummy on a slope. The stopping distance from maximum speed both on the level and on a 5-degree slope is measured on powered wheelchairs. It also applies to wheelchairs with mechanical brakes that are sometimes used on European wheelchairs.

4) Energy Consumption of Electric Wheelchairs (Final)

In this test, the energy consumption is recorded over a standard course that includes turns and slopes. From the test results, the theoretical range can be calculated for indoor and outdoor conditions based on the nominal capacity of the battery(s).

5) Overall Dimensions, Mass and Turning Space (Final)

The overall dimensions are self explanatory and include the folded position with and without demountable parts such as footrests. The turning space includes the smallest turning radius and the narrowest corridor in which the wheelchair can reverse direction with a single backing operation.

6) Maximum Speed and Acceleration of Electric Wheelchairs (Final)

The maximum speed is determined on a level surface loaded with the appropriate dummy or a person of the same weight. The maximum acceleration requires the use of the dummy to ensure consistency. The acceleration is measured by an accelerometer mounted on the dummy and filtered to eliminate all frequencies higher than 30 Hz. The results indicate the wheelchair performance but are also concerned with the comfort and stability of the user under maximum acceleration.

7) Seating Dimensions (Under Development)

This proposed standard is still under development. It is based on loading the wheelchair with a specified loader gauge to form the upholstery into the shape it would assume in normal use. From this position, 26 measurements are recorded on the dimensions of the seat, backrest, footrests and armrests. For ergonomic reasons, the position of the seat with respect to the handrim or other propulsion device is included. The loader gauge, based on a design used in the

European furniture industry, will be available in child and adult sizes.

8) Static Impact and Fatigue Strength (Under Development)

This is one of the few instances where minimum levels of performance are recommended. The actual test values are based on dummy size, and the test results must state which dummy was used, indicating the weight of the person for whom the wheelchair is suitable.

The static test consists of applying a load to various parts of the wheelchair.

The impact testing has several parts. For testing casters, footrests and other parts subject to impact against curbs and potholes, the wheelchair is loaded with the appropriate dummy and crashed into the obstacle at a pre-determined speed. The seat and backrest are tested by dropping a soccerball fitted with 25 kg of lead shot on specific areas and in specific directions. The wheel and axle assemblies are tested by dropping the wheelchair loaded with the appropriate dummy from a prescribed height so as to land on each wheel separately. The test simulates the stresses incurred when rolling off a curb. The handrims are tested with a weighted pendulum which simulates the accidental striking of the handrims on a door frame.

The fatigue test is conducted using a two-drum test machine. The wheelchair is positioned on the test machine so that the front and rear wheels will run on the drums.

The wheelchair loaded with the appropriate dummy is secured by the axles while the drums are rotated at a speed corresponding to about 1 meter per second. Fastened to each drum are slats, one-half $\times$ 1 and one-half inches. The number of cycles satisfactorily completed is then disclosed.

The order of testing is specified and one wheelchair must be used for all tests. The disclosed values include the static forces applied, the velocity or dropheight of the impact and the number of fatigue cycles completed without structural failure.

9) Climatic Tests for Electric Wheelchairs (Final)

There are two parts for this test. One involves the use of a water spray, simulating heavy rain, to

determine any safety hazards or performance deficiencies under these conditions. The second part tests the wheelchair's performance after exposure to hot and cold conditions. The temperature range for operating conditions is from -20 degrees C to $+50$ degrees C and for storage at temperatures from -40 degrees C to $+65$ degrees C.

10) Obstacle Climbing for Electric Wheelchairs (Final)

This test determines the ability of a powered wheelchair to climb a step or curb both from a standing start and from a run of 0.5 meters.

For the test, the simulated step is progressively increased from 20 to 200 mm (3/4 inch to 8 inches) and the maximum heights recorded. As in other tests, the dummy size is specified, although a person of the same weight may be used.

11) Test Dummies (Final)

This part of the ANSI/RESNA national wheelchair standard outlines the construction of test dummies of nominal mass 25, 50, 75, and 100 kg (55, 110, 165, 220 pounds). The dummies are intended for tests in which the wheelchair is required to be loaded.

13) Coefficient of Friction of Test Surfaces (Final)

Several test procedures for wheelchairs require that the coefficient of friction of the test surface be within specified limits.

This part of the standard specifies a method for determining the coefficient of friction of a test surface that has a rough texture, such as unfinished concrete.

14) Power and Controls (Under Development)

This standard embodies a series of tests to ensure electrical safety, controller performance, and safety from unintentional access to hazardous areas and pinch points.

15) Disclosure Requirements (Under Development)

This standard specifies the information that is required to be disclosed in the user manuals,

product literature, and other documentation related to wheelchairs.

91) Burning Behavior (Under Development)

This standard specifies a procedure for determining the ignitability characteristics of a wheelchair's upholstered surface.

93) Overall Dimensions (Final)

This standard defines the maximum dimensions recommended for manual and powered wheelchairs. This standard serves as a reference for environmental designers to enable wheelchair-accessible hotels, buses, trains, etc., to be designed (28 inches wide, 51 inches long, and 43 inches high).

APPENDIX

Types of Wheelchairs

Reprinted from *Wheelchairs: A Prescription Guide*, by A. Bennett Wilson, Jr. and Samuel R. McFarland. Charlottesville, VA: Rehabilitation Press, 6-18, 44-46, 1986.

THE BASIC WHEELCHAIR

The configuration and dimensions of the adult basic chair are shown in **Figure 10**. The dimensions and components that must be specified in a prescription of a wheelchair are:

Seat: Dimensions, type
Back: Dimensions, type
Arms: Type, dimensions, in some cases
Footrest: Type
Legrest: Type
Wheels and Tires: Type and size of wheel, type and size of tire, type of driving rim
Casters: Type and size

Other considerations are weight, amount and type of use expected, upholstery material and color, and seating inserts.

Seat Width and Depth

Chairs are regularly available in widths ranging from 10 inches to 22 inches in 2-inch increments.* Chairs with seats 24 inches wide are available but they do not fold. Wider chairs can be obtained by special order. The seat depth and height from the

floor vary with the width approximately as shown in **Table 1**.

Selection of the proper seat width is important to comfort and stability. A seat too narrow is not only uncomfortable, but access to the chair is made difficult. Furthermore, the chances of pressure sores developing is increased. A seat that is too wide encourages the user to lean toward one side, thus promoting scoliosis and increased pressure over the buttocks on one side. In addition, a seat wider than is necessary makes propulsion more difficult.

A seat that is too shallow reduces the area in contact with the seat and causes more pressure on the soft tissues in contact with the seat than is necessary. Furthermore, the footrests do not support the feet and legs properly, and balance of the user is affected.

A seat that is too deep, or longer than it should be, can restrict circulation in the legs, and causes the patient either to sit with his legs extended or to slide forward in the chair.

Seat Height

The height of the seat above the ground of the basic adult chair is 19 1/2 - 20 1/2 inches. The tall person will require a seat that is higher and deeper; a shorter person will require a seat that is lower. Usually these requirements can be met by a stock chair; if not, properly dimensioned units can be had

*Dimensions given here for seat width and depth relate to space available to the occupant and are not overall dimensions for the chair or its components.

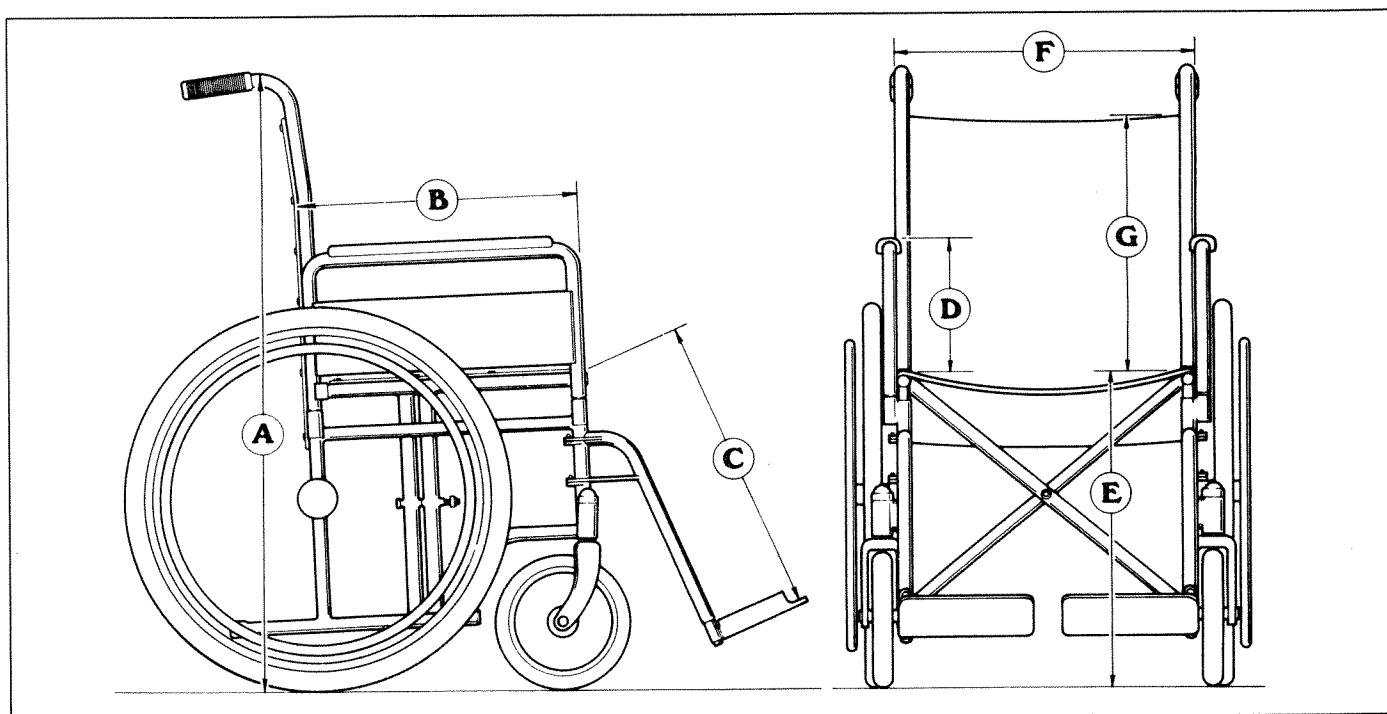


Figure 10.

Dimension ranges for the basic adult wheelchairs from major U.S. manufacturers. a) Overall height: 36 - 37"; b) Seat depth: 16 - 17"; c) Footrest support (adjustment range): 16 1/2 - 22"; d) Armrest height from seat rail (adjustment range): 5 - 12"; e) Seat height from floor: 19 1/2 - 20 1/2"; f) Seat and back width: 14 - 22"; g) Back height from seat rail: essentially as required.

on special order. Obviously, the cushion or seating system to be used will affect the end result.

Seat Type

Seat types available from wheelchair manufacturers are sling, or hammock, made of a flexible material, and solid seats which are generally removable (Figure 11).

The sling seats are by far the type used most. A solid seat installed so that folding is still possible is

available, or a removable solid wooden seat may be purchased or made, when such a seat is indicated for posture control or some other reason.

For many patients, especially those with lack of sensation in the buttocks and legs, special cushions or inserts are required.

Cushions and inserts should not be considered as "add-ons" but as an important part of an overall mobility system. While cushions and inserts are used to obtain the lowest pressures possible over the soft

Table 1.

Height from floor	Width	Depth	Designation
19½	10	8	pre-school or tiny tot
19½	12	10-11½	child's or tot's, high
16½	12	10-11½	child's or tot's, low
21	14-14½	11½	growing chair
17½-20½	14-16	11-13	growing chair
18½	16 ¹	14	junior or slim adult
19½	16-16½	16-17	narrow adult
19½-20½	18 ²	16	adult
		17	tall adult
19½-20½	20-22	16	wide adult

¹ at least one manufacturer supplies 14 and 15 in. as well.

² at least one manufacturer supplies 14, 15, 16, and 17 in. as well.

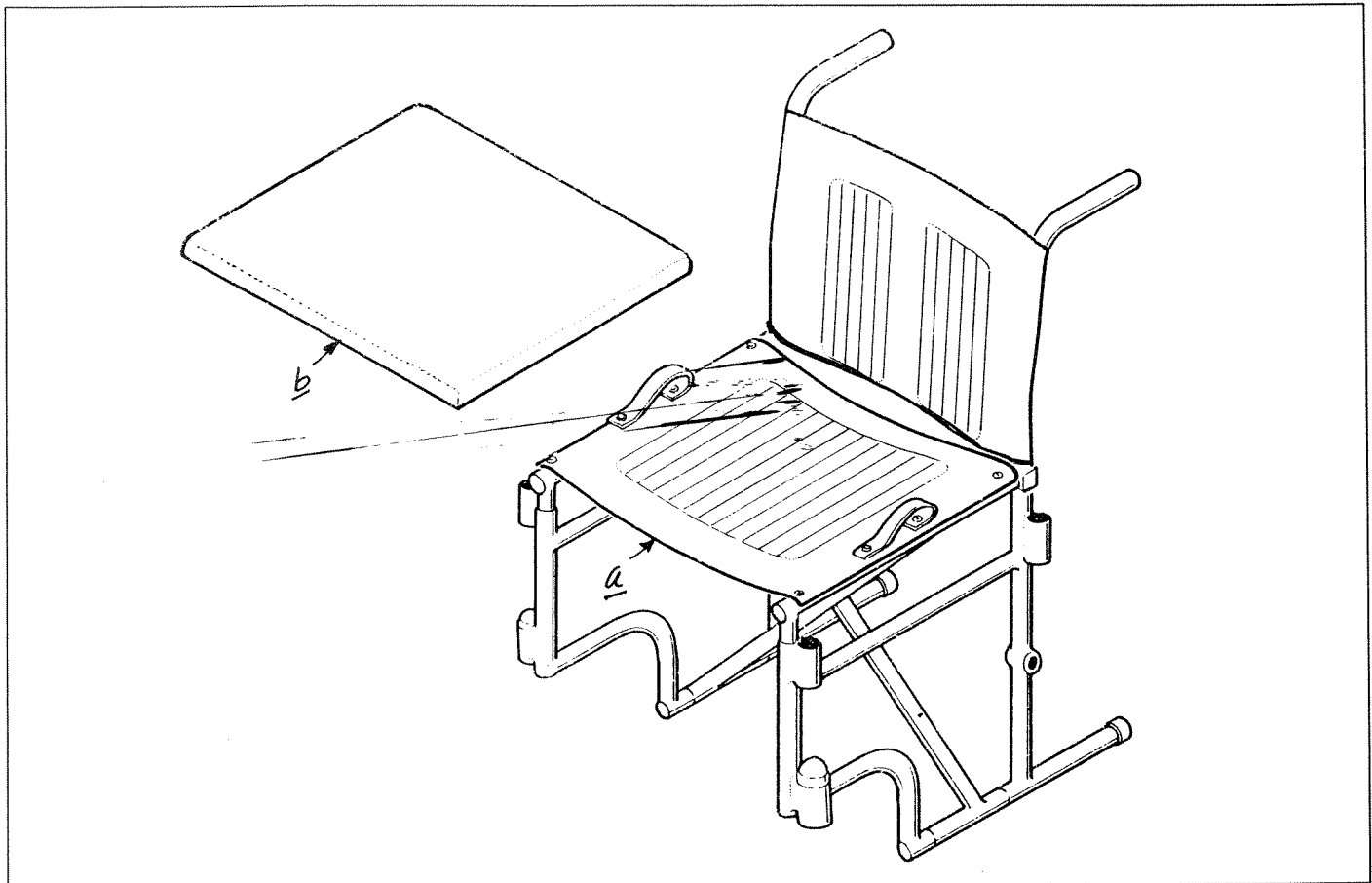


Figure 11.

Seat types: a) Hammock or sling; b) Solid.

tissues in contact with the seat to reduce the chance of pressure sores, they can also be used to great advantage to place the user in the best position for operation of the wheelchair or for simply maintaining the user in the best position for other functions.

Cushions and inserts are covered in more detail in a separate chapter.

Backrest

The backrest of the basic chair is made of a flexible material stretched between the two side frames which are fixed with respect to the seat. The height of the backrest of the adult chair from the seat is 16 - 16 1/2 inches. Shorter heights can be ordered. Backs of different heights which are interchangeable are available for some models. The backrest should be high enough to provide support without inhibiting motion, and not so low that the scapulae can hang over the back of the chair and cause discomfort.

For patients that have to enter the chair from the rear, backrests with a vertical zipper or snap fasteners for easy opening are available (**Figure 12**).

Solid inserts are available for the backrest when that type of support is required, usually for people with cerebral palsy. Also available are cushions that support the lumbar area. In the prescription process, it must be remembered that both solid backs and lumbar supports move the patient forward with respect to the other parts of the wheelchair.

Patients who cannot sit fully erect or otherwise need to be able to adjust the attitude of the back can be provided with a semi-reclining back that can be adjusted to 30 degrees with the vertical (**Figure 13**). For those patients that require respirators, a backrest that can be reclined to 90 degrees with the vertical is necessary. The fully reclining feature has slight additional advantage in that the patient can be transferred between bed and wheelchair somewhat easier, although the upper part of the wheel presents

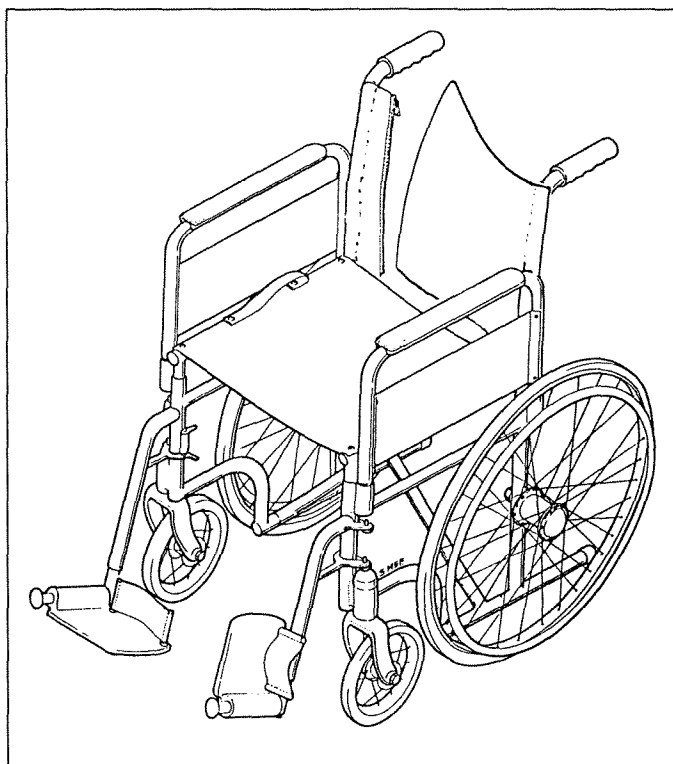


Figure 12.
Backrest: zippered opening.

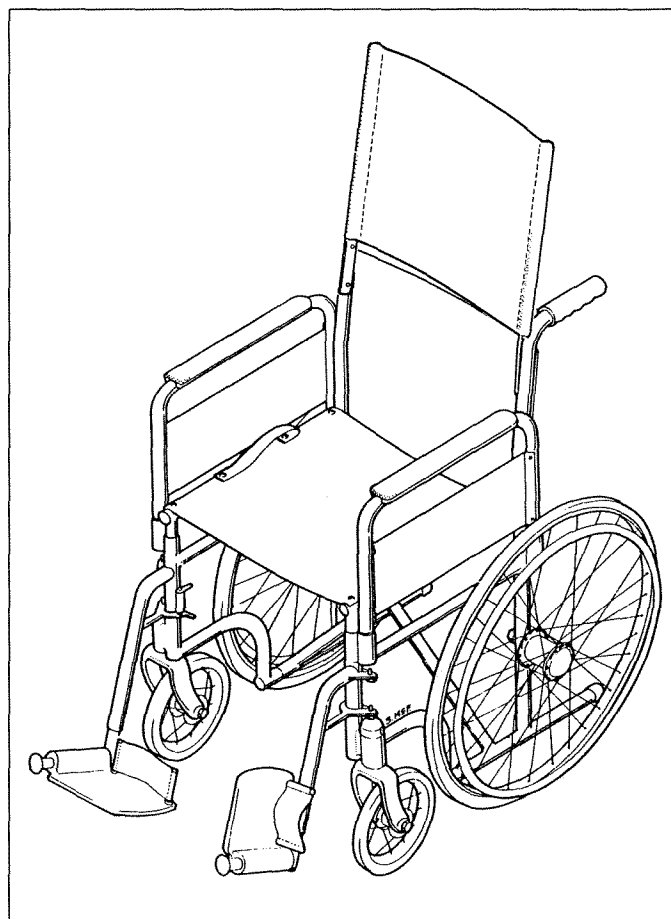


Figure 14.
Backrest or "headrest" extension.

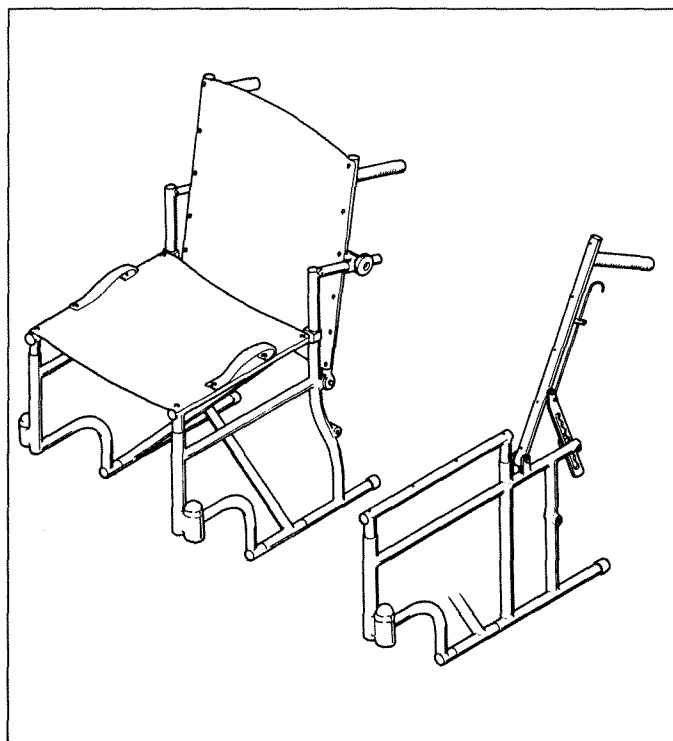


Figure 13.
Reclining backrests: a) Partial; b) Full.

an obstacle. A longer wheelbase is necessary for maintenance of adequate stability when the backrest is in the fully reclined position. One design accomplishes this by coupling the reclining mechanisms with the driving-wheel mounts so that the wheelbase is lengthened as the seat is reclined. Thus, maneuverability is not sacrificed when the back is in the upright position.

The backrest on the reclining chairs is lengthened usually by an extension (**Figure 14**), which is removed when the chair is to be folded.

Arms

The lightest chairs have fixed arms (or none at all), but an overriding factor in wheelchair prescription is transfer into and from the wheelchair, especially when the patient is unable to stand for a brief period. For this reason, most patients require arms that can be removed easily.

Chair arms not only provide support for the patient's arms in a resting attitude, but also provide lateral support and a reaction point for the hands when the asensitive patient elevates his body at regular intervals to prevent restriction of circulation and thus pressure sores.

Both removable and fixed arms are available in full-length and desk models; both of these styles are available with the height either fixed or adjustable (**Figure 15**). The height of the arms above the seat of the basic adult chair is usually 9 inches. Many models can be had with higher arms at 1-inch intervals on order. The thickness of any seat cushion to be used must be taken into account when specifying the height of arms.

The desk models are foreshortened to permit the user to get closer to a desk or table top. The removable desk arm is by far the most popular type. The full length models are indicated when the forepart is needed to support the arms of the user in rising from the chair or when lordosis, obesity, or some other physical factor makes it necessary to use the front part of the arm for support while the patient is in the sitting position.

The standard removable desk model can be reversed to provide this feature.

Adjustable removable arms have an adjustment range between 5 and 12 inches above the seat.

The simplest type of removable arm design adds nearly 2 inches to the overall width of the basic chair. When this is a disadvantage the wrap-around, or space-saver, arm is used. The single functional disadvantage in the wrap-around design is that the desk model arm cannot be reversed.

The armrests are cushioned and upholstered in nearly every instance and custom features are available on the more expensive models.

Front Rigging

Front rigging is the collective term for footrest and legrests (**Figure 16**). Footrests consist of a support bracket with swing-away mechanism, and pivot-and-slide-tube to which the footplates are attached. Legrests consist of an elevating support bracket with swing-away mechanism, pivot-and-slide-tube with foot-plate, and calf pad to support the back of the leg when elevated.

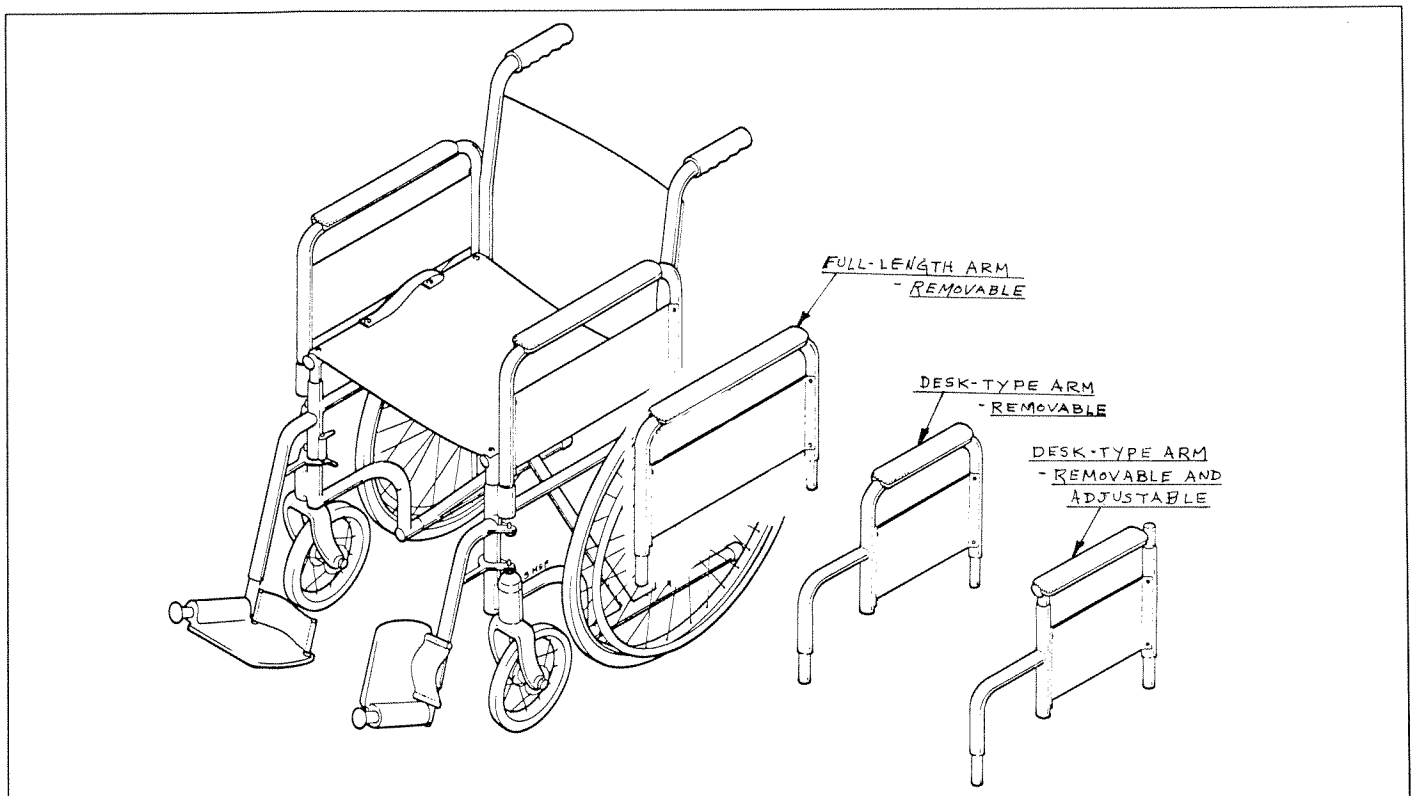


Figure 15.

The basic wheelchair and the most popular types of arms: a) Removable full-length; b) Removable desk-type; c) Removable, adjustable desk-type.

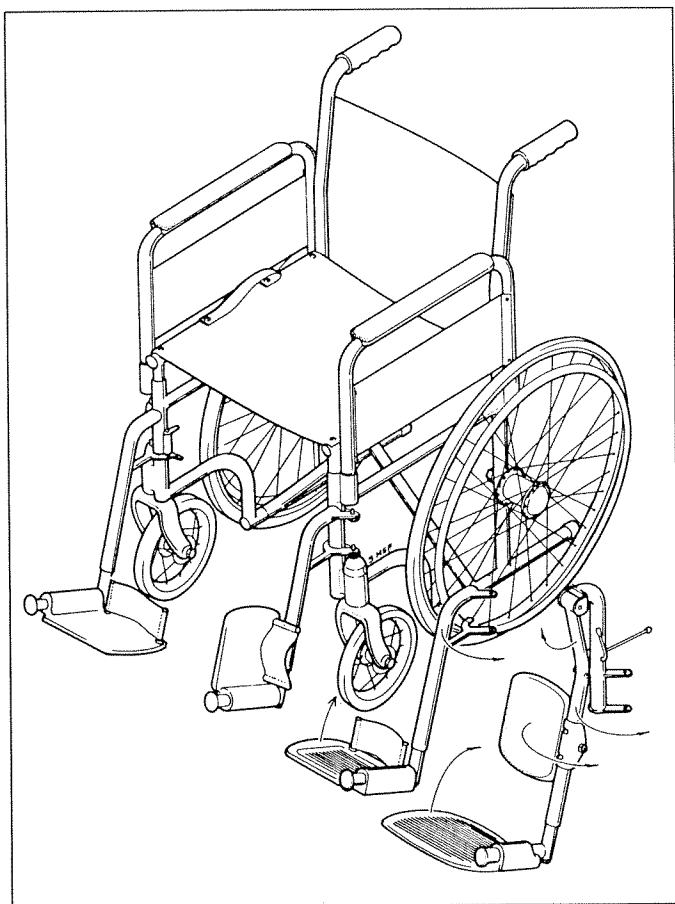


Figure 16.

The basic wheelchair with some variations of footrests and legrests. Shown is the detachable type that can be pivoted away from the center line of the chair to afford better entry and exit and to permit the chair and occupant to get closer to a desk or counter. Also shown is the legrest for support for the leg when elevated. The distance between footplate and chair is adjustable.

The obvious function of the footrests is to keep the feet off the floor. Not so obvious is that footrests hold the posterior aspect of the distal thighs of paralyzed patients at a height above the front edge of the seat so as not to restrict circulation.

Footrests can be fixed or can be detached from the wheelchair for those occasions when their presence is restrictive, such as maneuvering in a small bathroom.

Detachable footrests and front rigging that can be pivoted about the vertical axis to aid entry and exit and to permit the chair and occupant to get closer to a desk or counter are available.

The distance between the footplate and the front edge of the seat can be adjusted. This

adjustment is critical with respect to the distribution of the loads over the thighs and buttocks. The foot-plates can be swung up 90 degrees so that they are vertical to the floor to permit easy access to the chair by patients who can stand.

Elevating front riggings consisting of adjustable footrests and legrests are available for those patients with conditions, such as edema, arthrodesed knee, and leg in a cast, that require that one or both legs be elevated. Legrests also provide better support for persons with long legs.

Wheels and Tires

The basic chair has two 24-inch diameter rear wheels and two 8-inch diameter caster wheels in the front (**Figure 17**). Overall length without the front rigging varies between 30 5/8 and 32 inches, depending upon model and manufacturer.

The standard rear wheel for many years has been a wire spoke wheel, but wheels of cast metal alloy and wheels of cast plastic have been made available recently to overcome the maintenance problems inherent in the wire wheel design, yet not weigh any more.

Three types of tires are available in several widths and tread types as shown in **Table 2**.

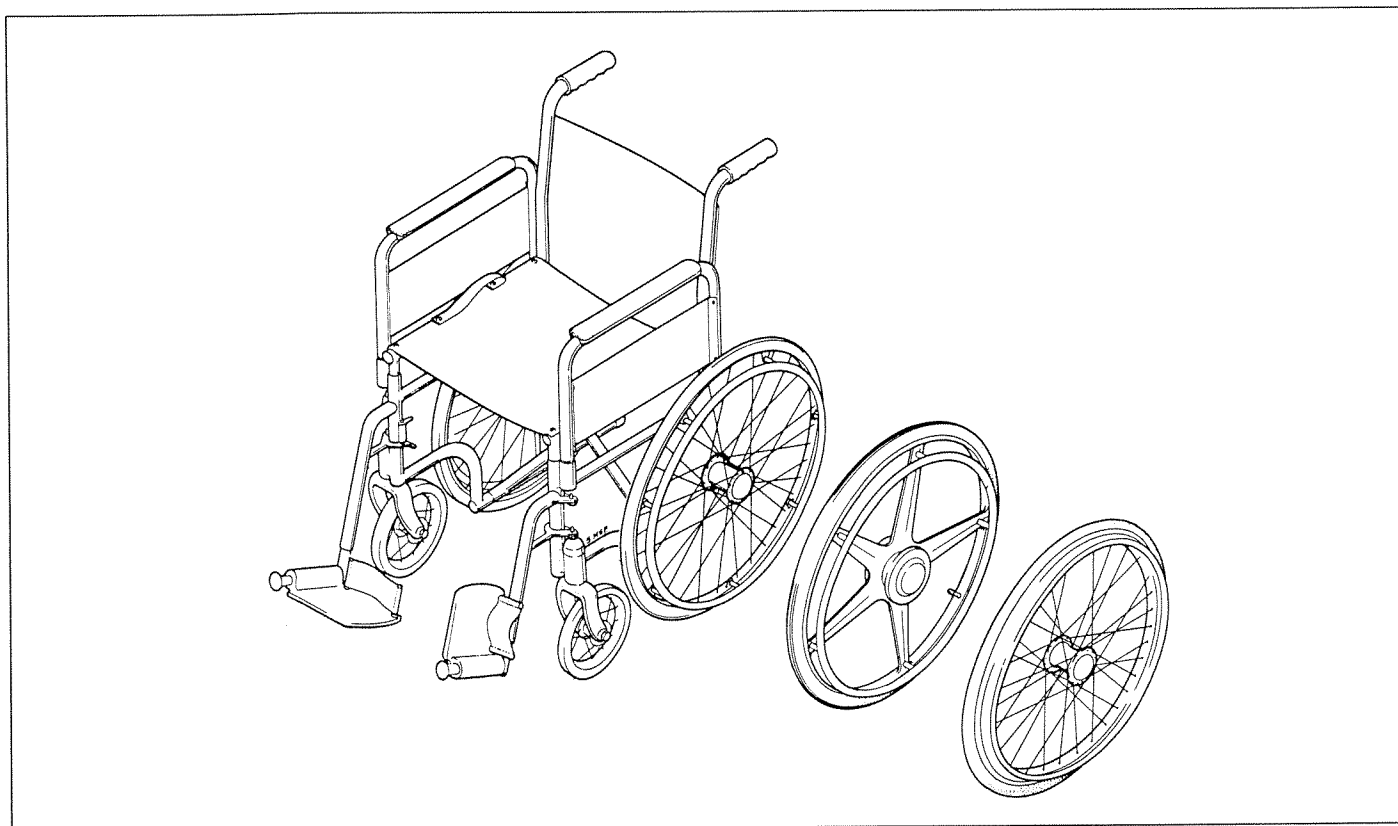
Pneumatic tires provide a more cushioned ride and the shock absorber action tends to prolong the life of a wheelchair when kept inflated properly.

Handrims

Handrims are attached to the driving wheels of wheelchairs to permit control without soiling the hands. The standard handrim is a circular steel tube. For users who have problems gripping the smooth surface of a metal ring, there are available vinyl coated rings and a variety of knobs and projections that can be added to the ring (**Figure 22**).

Casters

Casters make steering possible and are available in two diameters: 8 inches and 5 inches. Pneumatic, semi-pneumatic, and solid tires are available (**Figure 18**). The 8-inch diameter wheel with solid rubber tires is standard on the basic chair, and is suitable for use on smooth surfaces and indoors. The semi-pneumatic and pneumatic tires provide shock absorption, and, thus, are more suitable for rough surfaces and outdoor use. The 5-inch model is available only with solid tires, and is used on

**Figure 17.**

Basic wheelchair with standard 24-inch diameter wire-spoke wheel and 2 options: a) The cast magnesium wheel; b) A wheel with special built in handrim.

children's chairs and in special circumstances on adult chairs and basketball chairs, when more maneuverability is desired.

Parking Locks

Most users need some means of securing one or more wheels to keep the chair from rolling down inclines or to provide stability during transfer to and from the chair. Two types of parking locks are available for the large wheel (**Figure 19**): toggle and lever. Selection depends upon user preference which is usually based on the residual function of the upper limb and hand. These devices are designed

strictly as locks to hold the chair in place and should never be used to slow down a chair because the abrupt stop that would be provided can cause the chair to overturn.

Pin type locks are available for retaining a caster in the trail position and to prevent swiveling during lateral transfer. Extensions are available so that users with limited function can operate the locks.

Amputee Chair (Figure 20)

Because the center of gravity of a bilateral amputee in the seated position, even with artificial

Table 2.

Type	Width	Spoke Size	Tread Type	Purpose
Pneumatic	1 ¼"	.105	smooth	general purpose
	1 ¼"	mag. wheel	smooth	general purpose
	1 ¼"	.105	treaded	for soft, sandy, or rough terrain
Semi-Pneumatic				
Solid	⅞"	.080	smooth	indoor use
	⅞"	mag. wheel	smooth	sturdier, less maintenance

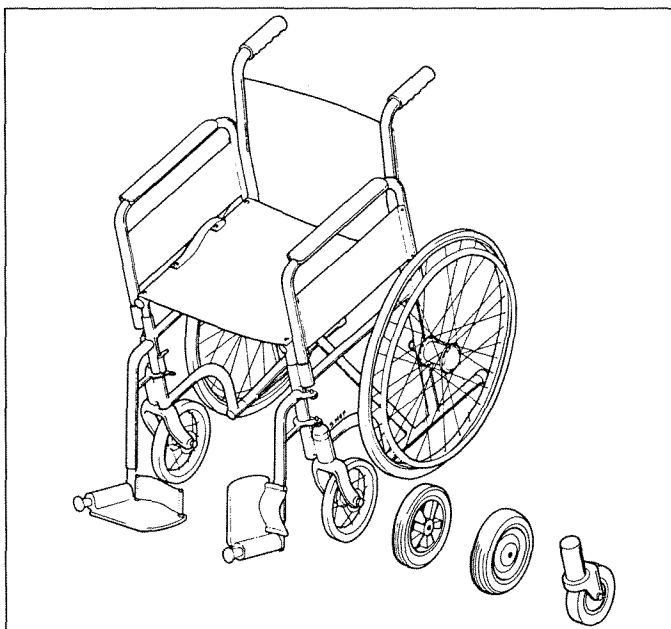


Figure 18.

Basic wheelchair and optional casters available. Shown on the chair is the standard 8-inch diameter wheel with solid rubber tire. Next in order are: the 8-inch wheel with semi-pneumatic tire; the 8-inch wheel with pneumatic tire; a 5-inch diameter wheel with solid rubber tire.

legs, is at least an inch further to the rear than is the case with most other patients, it is wise to provide a chair in which the rear wheels are moved

toward the rear if the proper degree of stability is to be attained. The distance used in most chairs is 2 inches. As a result, the turning radius is increased slightly, but this is offset when the front rigging is removed for amputees not wearing artificial legs.

Footdrive Chair (Figure 20)

For those patients who have good use of at least one leg, such as hemiplegics, the so-called footdrive, or hemiplegic chair, where the seat is about 2 inches lower than standard and specially adapted front riggings are used, is available to permit efficient use of the leg.

The use of 22-inch diameter wheels will effectively lower the seat 1 inch.

Indoor Chair (Figure 20)

When the large driving wheels are placed at the front and the casters are placed at the rear, the overall length of the wheelchair can be reduced and the feet can be placed parallel to the floor. Known as the indoor chair, this configuration is seldom prescribed because the disadvantages almost always outweigh the advantages. Although it can be maneuvered in smaller areas than the basic chair, it is more difficult to propel and to negotiate curbs and steps, and is generally not as handy.

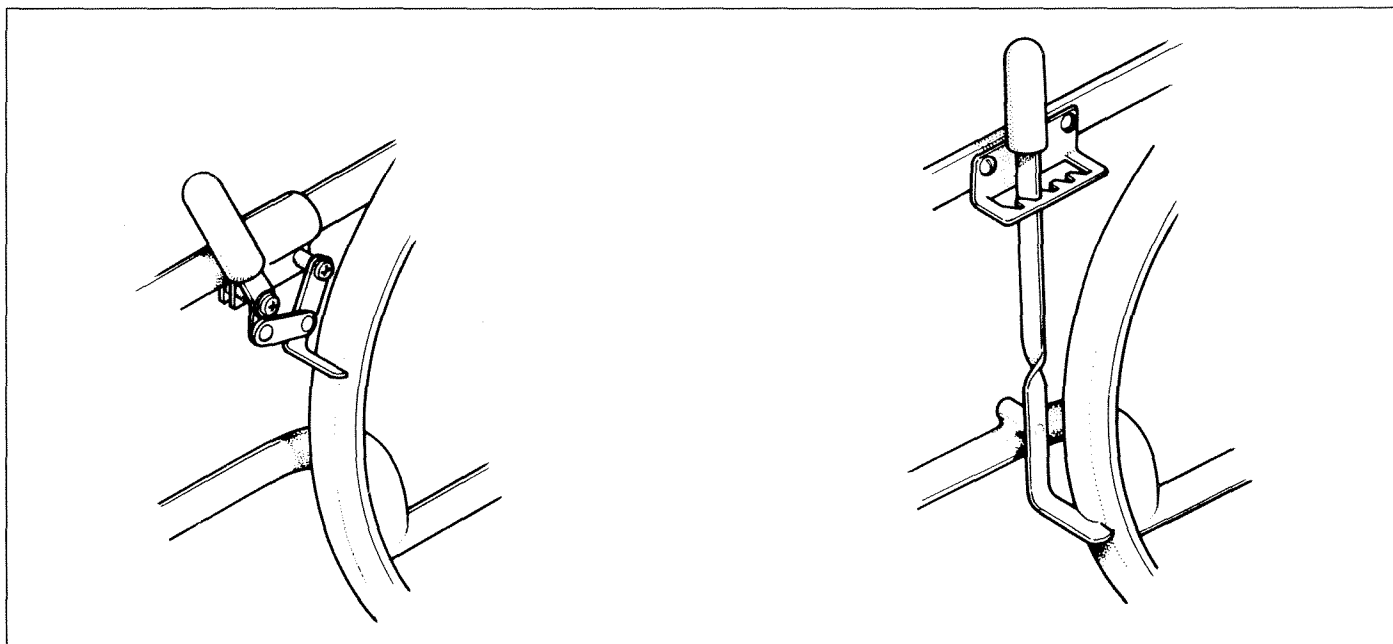


Figure 19.

Two types of parking brakes: left, toggle type; right, lever type. Variations of these 2 types of brakes are available.

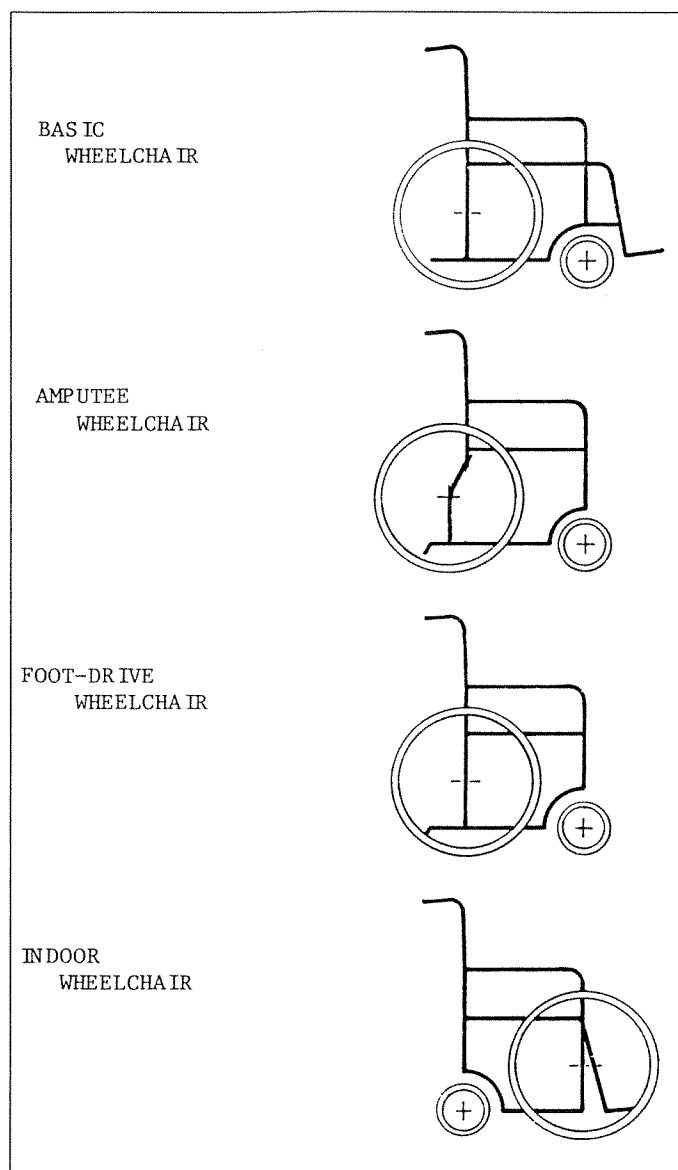


Figure 20.

Sideview schematic showing differences between: a) Basic chair; b) Amputee chair; c) Foot-drive chair; d) Indoor chair.

One-Hand Drive Chair (Figure 21)

For people who have use of only one arm, such as hemiplegics and unilateral arm amputees, the wheelchair can be equipped with a system that permits operation from one side. The driving wheels are interconnected so that either or both can be controlled from one side through a dual set of handrims. When one handrim is moved independently of the other, only one wheel is driven; when both rims are grasped in the hand and moved together, both wheels are driven.

Lever drives are also available for one-hand operation, but in present designs the lever can be restrictive in certain situations.

ACCESSORIES

A great number of accessories are available to meet special needs. Some are available from the manufacturers of wheelchairs, while some ingenious devices are available from other sources. Some of the accessories available and used most frequently are described below.

Special Handrims (Figure 22)

Handrims can be provided with projections of various designs to make it easier for patients with hand deformities to propel the driving wheels. Special handrims for replacement on the original equipment to provide more function are also available.

Trays and Desks (Figure 23)

A variety of trays and desks are available for eating and working. Some are made of plywood,

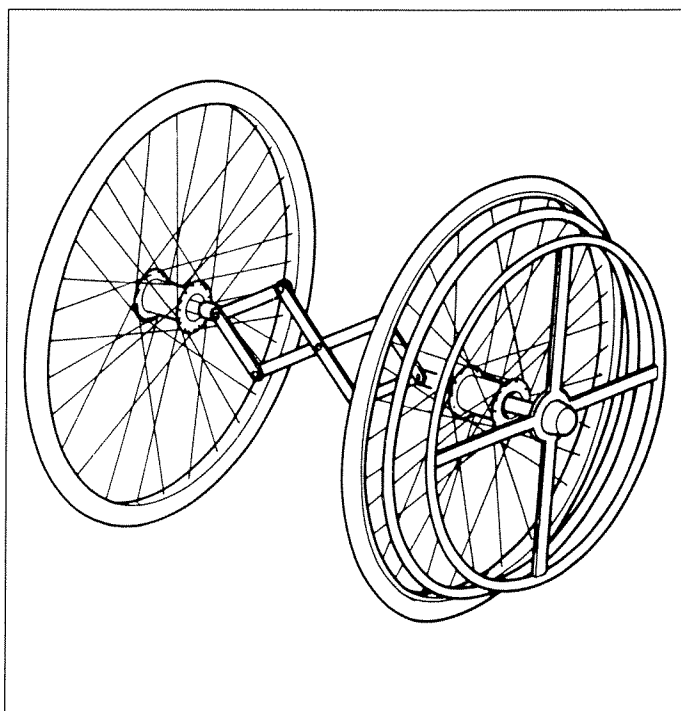


Figure 21.

Mechanism for a 1-hand drive chair.

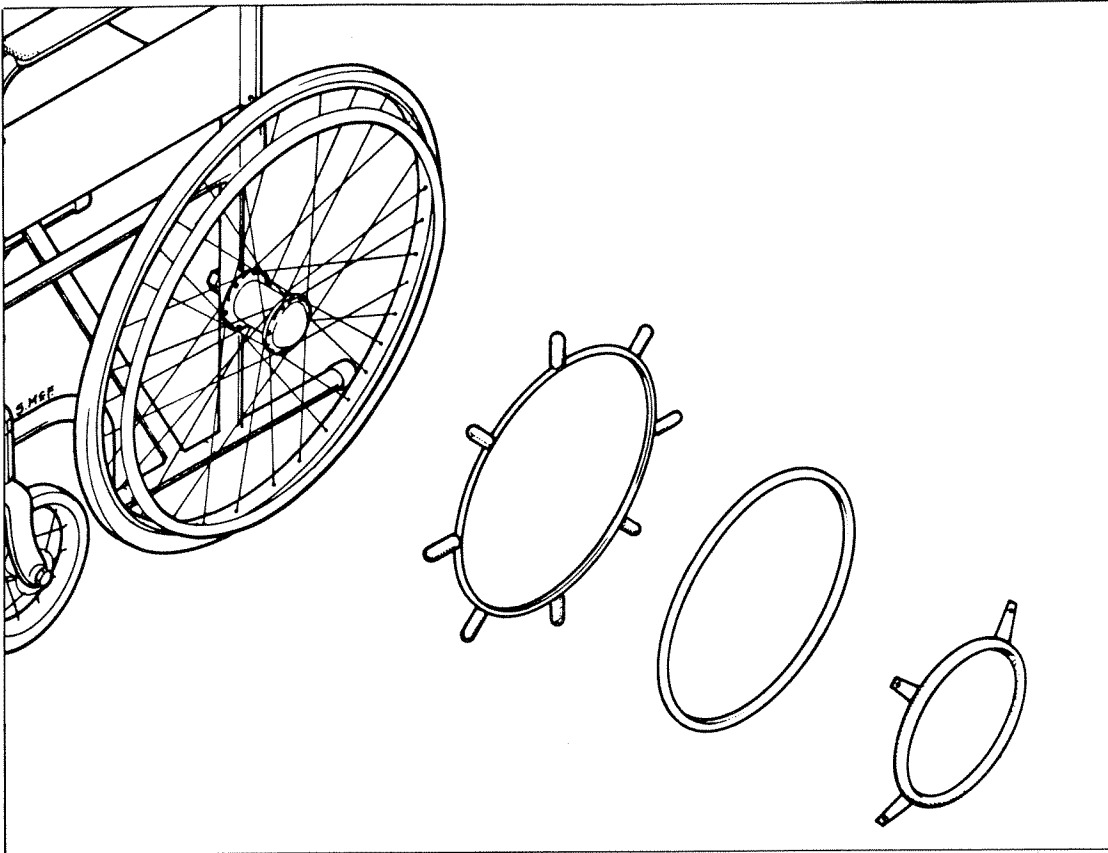


Figure 22.
Several types of
handrims.

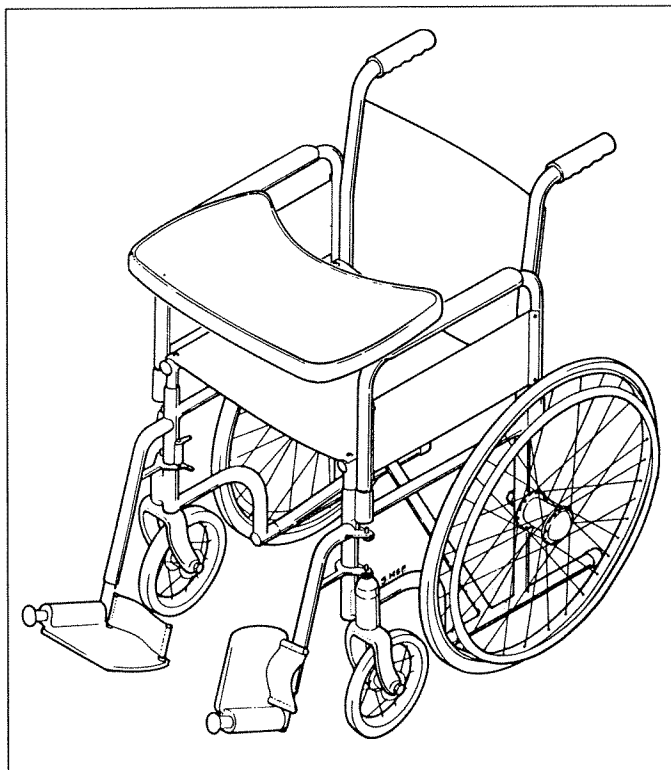


Figure 23.
Typical tray in place on wheelchair.

others of plastic, transparent and opaque; some are adjustable in several ways; some are designed for special purposes.

Restraining and Positioning Systems (Figure 24)

A number of belts and pads are available for holding severely disabled patients in proper position in the wheelchair.

Anti-Tipping Devices (Figure 25)

Detachable extensions for the lower rail of the wheelchair can be used to prevent the chair from tipping backward. One design uses wheels at the end that will come in contact with the floor upon tipping, thus avoiding a sudden deceleration.

Anti-tipping devices are also available for attachment to the front rigging to prevent tipping forward.

Narrowing Device (Figure 26)

A device is available that permits a wheelchair to be made narrower temporarily by a few inches by applying through a crank and gear mechanism the

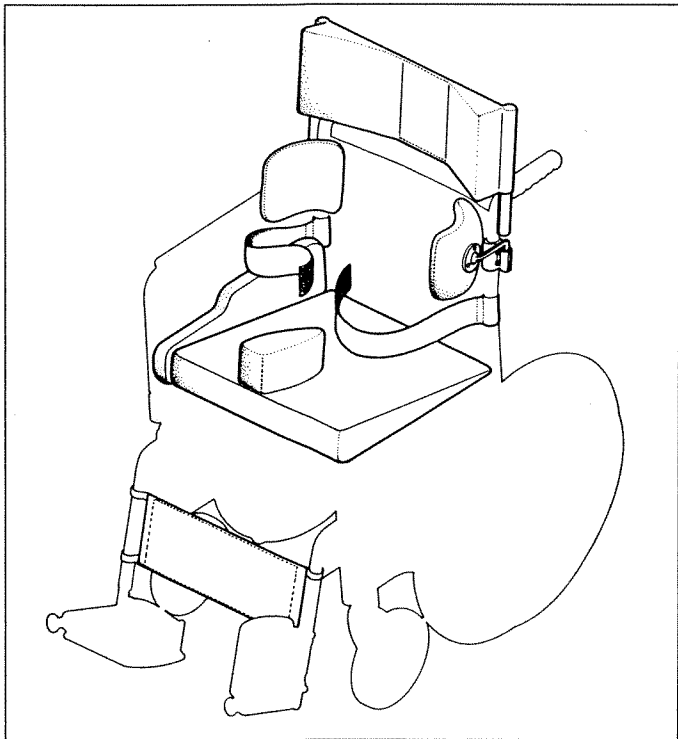


Figure 24.
One type of restraining and positioning device.

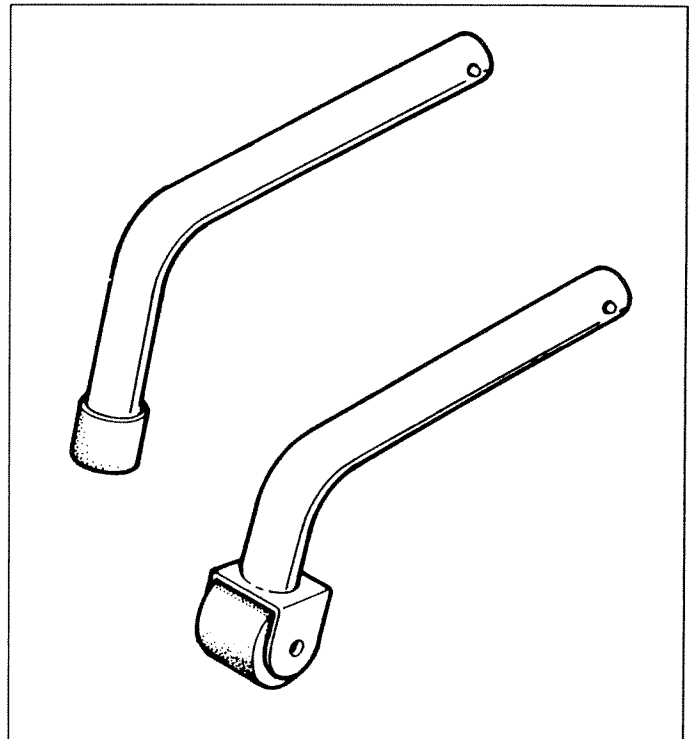


Figure 25.
Two anti-tipping devices that fit over end of lower rail of the frame. The model shown in the lower part contains a wheel that prevents scraping.

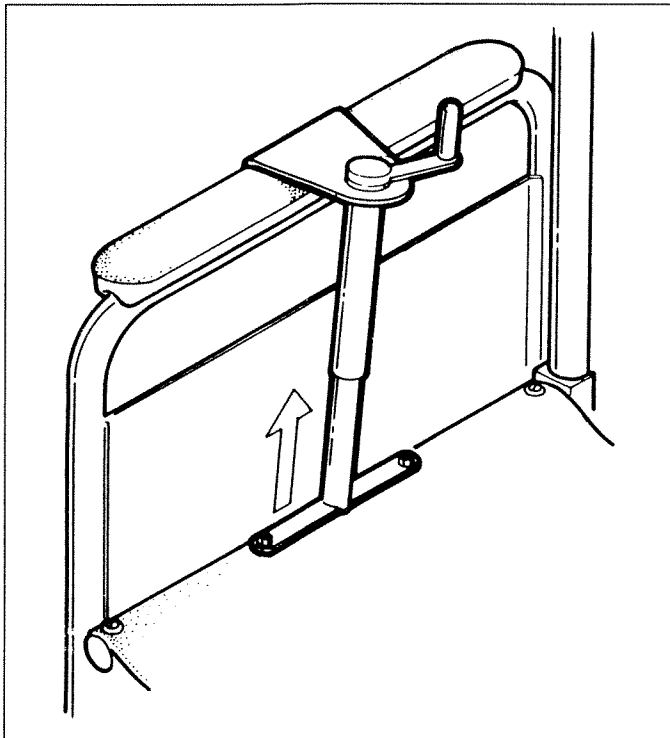


Figure 26.
View of narrowing device. The wheelchair is made narrow by turning the crank which causes the chair to start the folding action.

force necessary to begin the folding process. The narrowing device is generally left in place, but the crank handle is removable for storage.

New accessories and refinements of present designs are continuously being introduced for general use. Advertisements and announcements of new commercially available chairs and accessories are published in one or more of the following periodicals:

Accent on Living
P.O. Box 700
Bloomington, IL 61702

Paraplegia News
5201 N. 18th Ave.
Suite 111
Phoenix, AZ 85015

Sports 'n Spokes
5201 N. 18th Ave.
Suite 111
Phoenix, AZ 85015

SPORTS CHAIRS

Since the introduction of wheelchair basketball shortly after World War II a constant stream of modifications and refinements have been made to the basic wheelchair to meet the need of the so-called wheelchair athletes. Development of the lightweight, high-performance, sports chair (**Figure 39**) has led to racing among wheelchair users and has made tennis from wheelchairs practical and enjoyable. These chairs have also been found useful in non-competitive recreation such as camping and mountain climbing. Some of the lessons learned in developing and using sports chairs have resulted in improved performance and quality of prescription wheelchairs just as automobile racing has led to improvements in the family car. At the same time

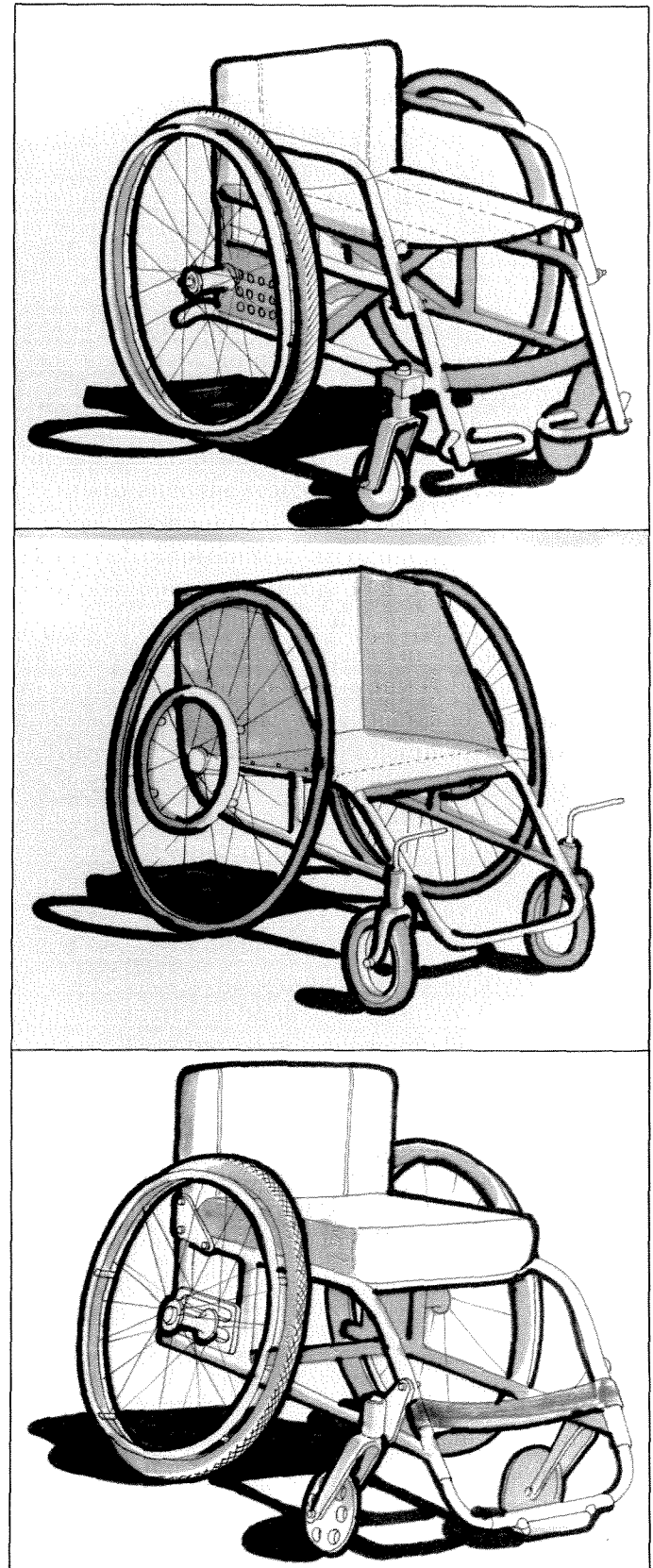


Figure 39.
Three designs of sports chairs.

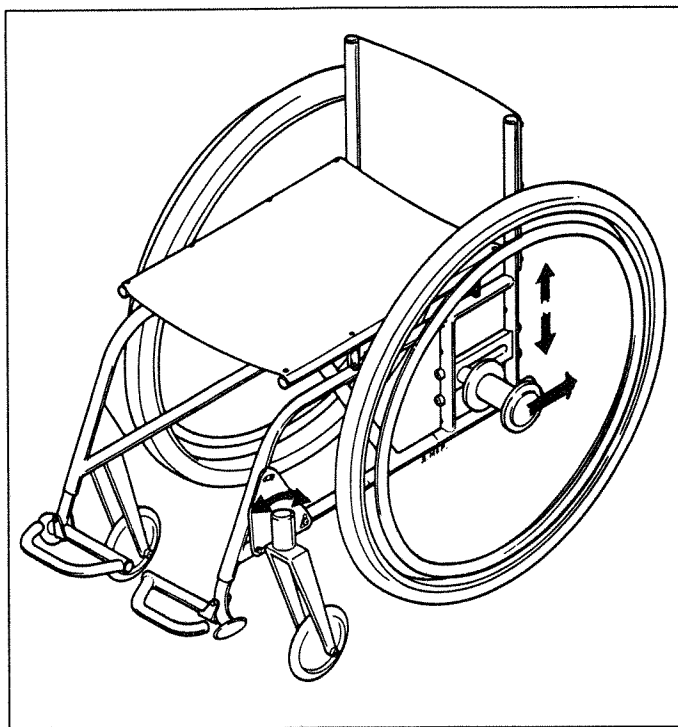


Figure 40.

Schematic showing adjustability often found in sports chairs that permit an optimum relationship between position of the user and the wheels.

many of the people who have been using conventional wheelchairs are now using the so-called sports chairs full time.

Like the basic prescription wheelchair, the sports chair has evolved through a series of refinements to where the general configuration of the

most used chairs is strikingly similar. At least 14 manufacturers at this time offer 1 or more models. Most use 24-inch diameter wheels; some use 27-inch wheels. Weight varies from 16 to 38 pounds due mainly to material selection and whether the chair can be folded or not. A number of designs incorporate provisions for folding. The others use wheels that can be disconnected (and connected) quickly without tools to make transportation easier.

Nearly all use 5-inch diameter front casters except one manufacturer that uses 4-inch wheels. Two make 8-inch casters available as an option. All have a feature that permits a choice of rear wheel axle position with respect to the frame. Only a very few offer armrests.

Many active wheelchair users prefer to use a sports type chair all the time, and in many instances options that make regular use practical are offered. Many models have adjustable features, and most manufacturers will provide a chair with dimensions to suit a given individual. Most manufacturers offer one or more types of arms.

A feature found on most sports chairs, but not on other types is the easy adjustability of wheelbase and seat height afforded by the positioning plate for the rear wheels. In many models the position of the caster wheels can also be adjusted (**Figure 40**). Such adjustability, of course, permits the user to be seated in a position which puts the muscles in the upper limbs and shoulders in the optimum arrangements for maximum biomechanical efficiency.

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