REHABILITATION MANUAL 23

FUNDAMENTALS OF WHEELCHAIR SEATING

Editor
FUMIO ETO

NATIONAL REHABILITATION CENTER
FOR PERSONS WITH DISABILITIES
JAPAN

(WHO COLLABORATING CENTRE)

January, 2009

The National Rehabilitation Center for Persons with Disabilities was designated as the WHO Collaborating Centre for Disability Prevention and Rehabilitation in 1995.

Terms of Reference are:

1 To research and develop technologies of primary health care to maintain health condition of persons with disabilities (PWDs), health, medical and rehabilitation services to prevent and alleviate disabilities.
2 To develop technologies for improvement of social skills and promotion of economical independence in collaboration with PWDs.
3 To study and develop social systems for PWDs such as primary health care, social care, etc., in the community.
4 To research and develop affordable assistive products and its service in collaboration with PWDs.
5 To prepare manuals for education and training of professionals in health, medical and welfare services for PWDs.
6 To conduct training programs, conferences and /or seminars on rehabilitation of PWDs for dissemination of technologies and information.

National Rehabilitation Center for Persons with Disabilities
WHO Collaborating Centre for Disability Prevention and Rehabilitation

Rehabilitation Manual 23
Fundamentals of Wheelchair Seating
January 30, 2009

Editor: Fumio ETO

Tsutomu Iwaya, MD., Ph.D., President
4-1, Namiki, Tokorozawa City, Saitama Prefecture, 359-8555, Japan
Tel. 81-4-2995-3100
Fax. 81-4-2995-3102
E-mail: whoclbc@rehab.go.jp

PREFACE

Visual Wheelchairs are an essential mobility device for people who cannot or find it difficult to walk and are also function as a chair at work. Therefore, wheelchair users sit for long periods in a wheelchair. Disabled people and the elderly that need wheelchairs often have various problems with their bodies, such as little to no feeling below their waist, little strength, poor control of their posture, and/or spinal deformities. The danger of developing bedsores through pressure increases by sitting for long periods in the same posture.

Thus here at the National Rehabilitation Center for Persons with Disabilities, we have created a seating clinic for people who use wheelchairs for long periods and assembled doctors, physiotherapists, occupational therapists, wheelchair manufacturers, and researchers of welfare devices. A wheelchair design was decided that matches each person's body and innovations of such things as seats were undertaken to maintain a comfortable sitting position and to make everyday life possible.

The system to maintain a sitting position is called seating but the process to design and create satisfactory seating with several goals is specialized. This manual explains the fundamentals of seating in order for not only specialists but also users and other stakeholders to have a common language to exchange the opinions during the process of the design, creation and adaptation of equipment that maintains a comfortable sitting position. Rehabilitation specialists are working to make seating accessible and help wheelchair users to obtain a better wheelchair.

F. ETO

EDITOR

Fumio ETO, MD, Ph.D.
National Rehabilitation Center for Persons with Disabilities

CONTRIBUTOR

Hideyuki HIROSE, PT, Ph.D. (Eng)
National Rehabilitation Center for Persons with Disabilities

ILLUSTRATOR

Junji MORI

CONTENTS

Preface
Contributor

Introduction 1

Chapter 1.
The Goals of Wheelchair Seating Adaptation 2
1. Comfortable 2
2. Functional 2
3. Physiologic 2
4. Mobile 2
5. Practical 3
6. Cosmetic 3
7. Ease of Care 3

Chapter 2.
Patient's Evaluation and Design of the Seating System 4
1. Sitting Ability Classification 4
2. Lying Position and Sitting Position Evaluations on a Mat 4
2.1 Lying Position Evaluation 5
2.2 Sitting Position Evaluation 6

Chapter 3.
Pressure Ulcers 8

Chapter 4.
The Biomechanics of Posture Support 9
1. What is Force? 9
2. Reaction Force and Friction 9
3. Pressure 10
4. Three-Point Support 11
5. Non-Rigid Support 11
6. Shear Stress and Deformation 12
7. Moment 12
8. Force Transmission 12

Chapter 5.
Seating System 14
1. Support Surface 14
1.1 Tension Adjustable 14
1.2 Planer Support 15
1.3 Pre-Contoured Support 16
1.4 Custom Contoured Support 16
2. Angle Adjustable Solid Seat and Solid Back Support 17
3. Recline and Tilt 17
3.1 Recline 17
3.2 Tilt 18
4. Support of the Occupants Body Segments 19
4.1 Head Support 19
4.2 Trunk Support 20
4.3 Foot Support 21
4.4 Anterior Pelvic Support 21

Chapter 6.
Measuring the Seated Posture 23

Chapter 7.
Actual Seating Adaption 25
1. Procedures 25
2. Simulation 25

Conclusion 26

References 27

Introduction[1)]

This manual was created for professionals that select and arrange comfortable and functional wheelchairs for people who use them for long periods of time. Portable and light wheelchairs have made social activities for persons with disabilities and elderly easier.

Generally, a wheelchair that is not suitable to a user's body length worsens their sitting posture.

And more not to adapt a users range of motion of joints, and siling seats can not keep their posture for long time and make worse them so it is necessary to consider the possibility of developing secondary impairments, such as pressure ulcers and joint contractures. As you know, bedridden makes more disuse syndrom, so many persons with disabilities and elderly have sit in old type wheelchair.

Wheelchair seating, new concept for selecting and arranging a wheelchair, cushion and seating system, spended widely in North America and Europe.

Problems with the user's body are resisting gravity to maintain proper posture and narrowing of direct contact through difficulties with movement and muscle atrophy.

This document highlights the relationship between the body and the wheelchair and explains the process of constructing a wheelchair from a person's physical state. Also it explains the important of kinesiology, biomechanics and skin integrity. As well as the user's physical situation, a wheelchair needs to conform to many goals (Chapter 1), including the user's needs, comfort, and type of care. Thus it is important for the user to try out the wheelchair where they plan to use it to see if it needs adjusting or changing to a different type of wheelchair.

Chapter 1.
The Goals of Wheelchair Seating Adaptation[2)]

Letts[3)] stated that the goals when customizing wheelchair seating were comfort, functionality, physiology, practicality, mobility, and cosmetics. Hirose added ease of care because it is very important in the Japanese care system. To decide evaluation items and methods at the initial evaluation period, and to evaluate the functionality of modified devices, it is necessary to make clear the goals of seating.

Some of these goals contradict themselves. For example, by correcting spine deformity the user's comfort level decreases or the degree of adhesion between the body and the device increases and caregivers are unable to put their hand down the back for transferring it and therefore care often becomes difficult. Having all stakeholders involved, including rehabilitation specialists and caregivers, is the most basic concept in the process of creating the best wheelchair.

1. Comfortable

It is the period of time spending in a wheelchair without pain and uncomfortability. If posture needs to be corrected, it is necessary to change posture slowly over time.

2. Functional

It refers to the ability to functionally move arms, legs, and head, and also to swallow. Supporting the user's trunk often makes it possible for the user to move their arms and legs freely.

By keeping their trunk stable through a seating system, it can make it easier to move the wheelchair and to eat for wheelchair users that find it necessary to support themselves with their hand in a sitting position.

3. Physiologic

Losing the seated posture can lead to pressure ulcers, aggravate spinal deformity, and decrease breathing function. Maintaining a physiological seated posture can prevent this. It is also important to control the pathorogical tone of cerebral palsy.

4. Mobile

Moving by oneself with one's arms or legs, moving with assistance, moving with a motorized wheelchair, and transferring from a bed all need to be considered.

For example, hemiplegia sufferers that move in a wheelchair by using their legs lose their posture and suffer posterior pelvic tilt from the use of their hamstrings.

5. Practical

As seating system with various functions is difficult to fold and is heavy, the situations it can be used for are limited. It is important that it is used as a chair. In much the same way for sandals and sports shoes, it is necessary to use a wheelchair that emphasizes seating functions for sitting for long periods as a "chair" and a foldable wheelchair for moving for short periods.

6. Cosmetic

Being restrained to a chair by a band or looking up at someone while in a hunched back position gives people a bad impression. For elderly wheelchair users, the back can be arched from a hunched back and in wheelchairs with a small depth one's face looks downward so when talking to someone standing up one must look upward. Straightening one's back moves one's face upward. Looking at each other face to face gives one dignity.

7. Ease of Care

Correct seated posture makes care easy. By attaching a seating system to increase body maintenance can make it difficult for caregivers to put a hand down the back making care difficult.

Chapter 2.
Patient's Evaluation and Design of Seating System

Until now dimensions were at the center of wheelchair manufacturing and what sort of posture should be taken was unclear. By conducting the following evaluation, what kind of wheelchair configuration should be selected, the dimensions and at the same time what angle should be chosen, and what sort of support should be used can be decided, thereby helping one to surmise what sort of problems may occur when one sits in the wheelchair.

1. Sitting Ability Classification

The Hoffer[4)] sitting ability classification is a reliable[5)], easy evaluation method and can be used to select a broad selection of posture support device functions.

The following 3 levels are determined as the user sits with his/her feet touching the platform:

Hands free sitter: The user can sit steadily without their hands touching the platform.

Hands-dependent sitter: The user can sit steadily with their hands touching the platform.

Propped sitter: The user cannot sit without assistance.

Seating system is not needed with a hands free sitter and wheelchair is modified to match the user's body dimensions with the purpose of preventing secondary legions.

A hands-dependent sitter uses a stabilizing or supporting solid surface for the seat and back, and a lateral support is also necessary. Through this, it frees up the hands that were supporting the trunk and the user can improve the functional activities by their hands.

A head support device and a space in tilt mechanism are necessary for a propped sitter. Through this, physiological issues, such as pressure ulcers and spinal deformity can be addressed while the movement area out of bed in daily life can be secured.

2. Lying Position and Sitting Position Evaluations on a Mat[5)]

This section will explain how to evaluate the lying position and the sitting position on a mat. The mat evaluation is carried out to find the best posture in his/her physical situations and obtain information regarding the support position and the support surface.

2.1 Lying Position Evaluation

Look at the movement of the head, trunk, and legs, and measure the body. If the user has a hunched back, evaluate from the lateral position.

(1) Hip Joint

The hip joint related with angles between back and seat supports.

Firstly, start bending your hips from about 45 degrees with 90 degrees being the goal. Then maintain a mild lumbar lordosis position. From that position, bend both hip joints. If there is pain or a limit to how much the hip joint can bend, posterior pelvic tilt will occur from bending. Then put a towel or a hand underneath the lumbar region and support the small lumbar lordosis (Figure 1). Pressure can be felt on the hand that is under the lumbar region. The angle between the back and thigh at the foot position that posterior pelvic tilt begins is the angle of the seat and back of a wheelchair (seat and back angle: reclining angle).

Figure 1 Hip flexion position in a lumbar lordosis state with the pelvis inclined

(2) Knee Joint

The knee joint is related to leg support to seat surface angle. Actually it affects angle between seat and foot plate line in wheelchair, related with knee joint itself and tight hamsrings. Most cases for the elderly and disabled people have tigh hamstrings. If there is contraction of the hamstrings, with the hip joint fixed at a certain angle extending the knee joints makes the hamstrings taut and posterior pelvic tilt occurs. Bending the knees relaxes the hamstrings, maintaining pelvic anterior inclination and lumbar lordosis.

With a wheelchair seat, move the foot support toward the rear. Bending your knees relaxes the hamstrings and makes it easy to move the pelvis to a neutral position or forward.

If the trunk is stable in a sitting position, bend your knees and you can get into a posture to move your pelvis into neutral position and activate upper limb movement. If the trunk is not stable in a sitting position, you can stabilize your trunk by moving your pelvis backwards with your knees in an extended position.

(3) Ankles (Figure 2)

The ankle angle is related to foot support to leg angle. Extend the ankles as much as possible without straining and the soles of the feet should contact as wide an area as possible on the sole support board. The 90 degree angle between the leg pipe and the foot support on a standard wheelchair is perfect for use by users that can attain an ankle dorsal arc foot position of 0 degrees. For users with equinus, the direct contact surface of the soles and the sole support board is small and the soles can develop pressure ulcers easily.

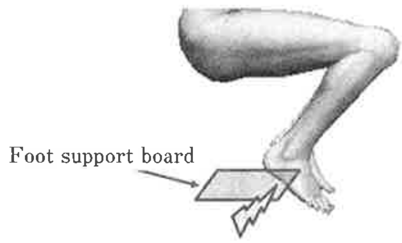

Figure 2 Contact between foot and foot support board on a standard wheelchair in the case of equines

(4) Spine and Pelvis

By setting the sternum line and abdominal line, which will be mentioned in chapter 6, in a lying position and measuring the angle and each length the range of motion of the distance between the pelvis, the lumbar spine, and the distance between the lumbar spine and the thoracic spine can be evaluated. The goal is to have the physiological posture in symmetry with the alignment of the spine and pelvis in frontal plane. Moreover, confirm the possibility of and existence and remediation of the limit of range of motion.

2.2 Sitting Position Evaluation

The user sits on a hard platform like the one a physiotherapist uses and puts both soles flat on the floor. The evaluator marks the position of the back and with both hands checks the anterior superior iliac spine. Then (tucking the user's pelvis in from the right and left on both sides of the thigh) support the pelvis horizontally and support the patient's thoracic with both hands from the side. At that point, add support force from as horizontal as possible. The reason for that is support from lateral support devices comes from the side and to add support force that controls the rotation is difficult.

The evaluator adjusts the support force and regions by his/her hands, obtains an appropriate spine alignment, and checks the added force and support position for the best upper extremity movement (Figure 3).

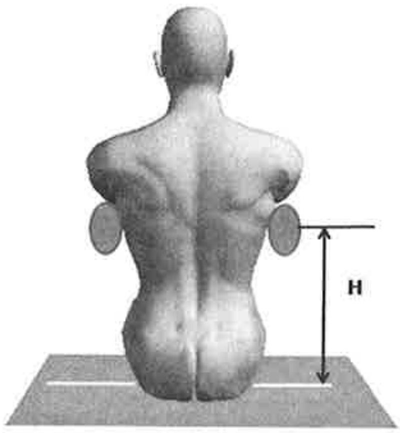

Figure 3 Support the thoracic from both sides and if the trunk is appropriately supported, the height of the hand at H is the height of the lateral support.

If strong support force is required to maintain the trunk alignment, the skin at the support area can be scarred and hurt easily. The way to counter that is to expand the support area and decrease the burden on the skin. Alternatively, to get comfort, we decrease support force and allow the deformity of body alignment.

Chapter 3.
Pressure Ulcers

As a result of ischemia from pressure on skin and soft tissue for long periods of time, necrosis or dead skin is generated and pressure ulcers occur. In order to evaluate the risk of pressure ulcers, the Braden scale[6] is recommended.

Use pressure redistribution cushions or mattresses for patients who are at risk of pressure ulcers.

The thickness, material, shape and the adjustment functions of pressure redistribution cushions are all factors to prevent pressure ulcers. Thickness of cushions is an important factor in selection of pressure redistribution ability. If there is a risk of pressure ulcers, choose a wheelchair cushion with a thickness of about 10cm. If there is no risk of pressure ulcers, then choose it with a thickness of about 5cm. Thick cushions might make the seated posture unstable so one has to be careful.

As for materials, there are several options, including plastic foam, gel, and air. The advantages of plastic foam are that it is reasonably priced, light weight, and easy to maintain. The disadvantage of it is that it is brittle and degenerates easily in two or three years. The advantage of gel is that it lowers the shear force, and the disadvantages are that it is heavy and cannot be made thick. Air is light and easy to be made thick. Fewer functions will be available with cushions that have less adjustability.

For shapes, there is a square block type and a contour type with the shape of the buttocks. Block type cushions perform to a certain level regardless of the way the user sits from front to back and from side to side. With the contour type, the user should sit in the intended position within the shape. If the user sits on it ignoring the contour shape, there will be higher risk of pressure ulcers.

When choosing cushions, the user needs to consider the risk of pressure ulcers, the adjustability of the cushion, how the user sits, and whether the user might move around with the cushion.

With the cushion that is to be used, the user observes the skin where it contacts the seat surface at the time the user wishes to sit and after seating. If the user confirms redness and presses the redness area with their fingers, if the skin color becomes white or the redness disappears within 30 minutes, there will be minimum risk of getting pressure ulcers.

Chapter 4.
The Biomechanics of Posture Support[9)]

Many problems generated by sitting occur as the head, trunk muscles, bone structure, and ligaments cannot support the weight of the head and trunk. On earth, human bodies are always under the influence of gravity. To understand the mechanisms that support bodies against gravity the essential biomechanical knowledge will be explained here.

1. What is Force?

Force has both magnitude and direction. When a box is placed flat, the force pressures the box into a vertical direction and functions as power to crush the box from above. When a box is place on a slope, the force in the longitudinal direction decreases. Using this principle, one can prevent the trunk alignment from collapsing by reclining the back (Figure 4).

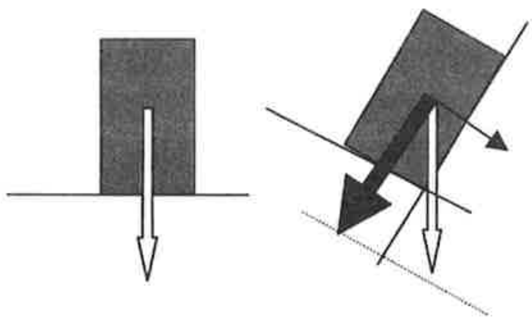

Figure 4 The Reclining effect

The white arrows show the force in a vertical direction. When placing a rectangular box vertically on the floor, gravity works as a force to crush the box (it puts pressure on the box in a vertical direction). When placing a box so that it touches the floor at right angles and lean it back (the right figure), the force (the white arrow) separates into two forces (the black arrows) and push onto two contact areas. The greater the angle of gradient of the box, the less force there is to crush the box.

2. Reaction Force and Friction

When placing a stick against the floor and wall, the stick receives a reaction force from the wall and friction from where it touches the floor and the stick maintains the resting state by the balance of these two forces (table 5, left). When leaning the stick flush against the wall, the stick slides off as the reaction force and friction do not balance (Figure 5). The same phenomenon happens when reclining backwards. When reclining backwards, the user has to be careful so as to not slide off by tilting the sitting position using the tilting mechanism (Figure 6).

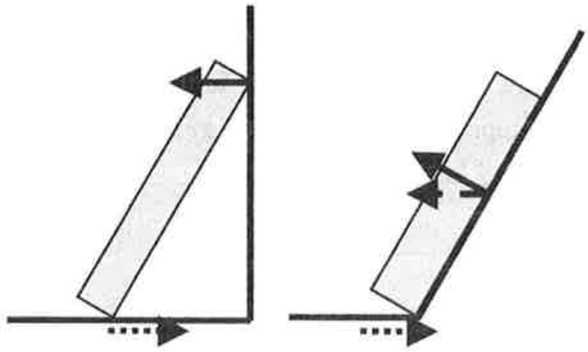

Figure 5 When placing a stick against wall, a force (reaction force: solid arrow) pushes the top of the stick horizontally and against this friction (the dotted arrow) pushes against the direction it is sliding in. When the gradient angle is small the stick remains stationary. However, when the gradient angle is large, the stick starts sliding off.

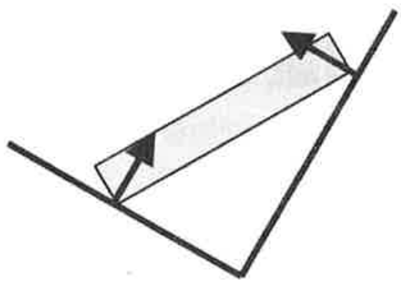

Figure 6 When inclining the whole stick while maintaining the relationship between the stick, wall and floor, the stick does not slide as the friction against the floor increases.

3. Pressure

Pressure is a load that is divided by the contact area that receives the load (Pressure = Load / Contact Area). Even though the loading force does not change, pressure increases when the contact area becomes smaller, and the possibility of pressure ulcers increases when the pressure becomes high. For people whose muscles around the spine that have atrophied, such as the elderly or those with spinal cord injuries, the backbone protrudes. Pressure ulcers occur when leaning on the back support device as there will be a high pressure on the protruding spine.

Load on the buttocks while in the sitting position is not concentrated on the protruding part, such as in the case of ischial tuberosity, but dispersed to where it touches the seating surface. To take the weight of the load by the whole area that is touching the surface is called total contact.

4. Three-Point Support

When placing a hard stick on an area and supporting it from two directions and one point that is between the two points from the opposite side of the two directions, the stick remains stationary and can be fixed (Figure 7). For examples, in order to stabilize the head and neck collapus, supports from the front and back, sides, and a downwards direction are necessary. The chest region can be stabilized maximum by supports devices from the front and back, and from the sides.

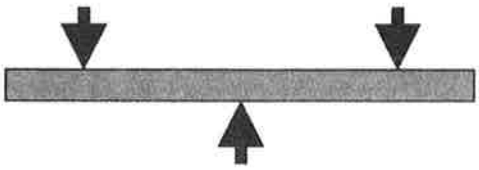

Figure 7 The principle of three-point support

5. Non-Rigid Support (Figure 8)

Substances that aren't hard (non-rigid), such as balloons filled with water, cannot be stabilized even if supported from three points. In this case, something that wraps the whole substance to a fixed position (total contact) is necessary. When securing the trunk, the chest region can be treated as rigid, but the abdominal area must be treated as non-rigid. Healthy people can support their bodies by using the abdominal and back muscles and increasing the intra-abdominal pressure so the body does not collapus. For those whose abdominal muscles or back muscles are weak, such as the elderly or people with spinal cord injuries, the abdominal area needs to be supported over a wide area from the sides to control the aligments of the body.

Figure 8 Non-rigid support (A balloon filled with water needs to be held over a wide area)

6. Shear Stress and Deformation

When the soft part of a living creature takes force, horizontal direction force (shear stress) and vertical direction force (stress) works on the soft part. Shear stress changes the square soft part to a parallelogram. This phenomenon is called deformation.

7. Moment

To support weight (supporting point), the distance from the supporting point to the point that is supporting weight (action point) takes torque (Moment = Length × Weight).

The supporting point that supports the weight of the head is on the cervical spine alignment. The distance between the cervical muscle that supports the head and the working point is short and the head is supported by little muscle strength. If the cervical spine becomes inflective and the head falls forward, the distance between the supporting point at the cervical spine and the working point (barycentric position of the head) will become larger, and a large amount of torque is generated and a large force will be required to support the head area (Figure 9).

To support the sitting position, choose and arrange the parts that support the trunk first and then that reconcile the alignment between the trunk and the cervical spine.

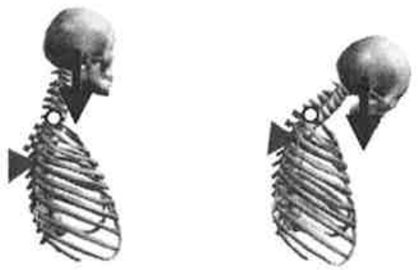

Figure 9 When the cervical spine is inflective, the barycenter of the head (black arrow moves forward and is moving away from the cervical spine supporting point (the circle mark in the above figure). As a result, more muscle at the spinal cord (red dotted line arrow) will be required. The weaker the muscle is, the more inflective the cervical spine becomes.

8. Force Transmission (Figure 10)

Force that corrects deformations or supports posture must be transmitted appropriately to bones in the body. Even though adding force to soft tissue, such as fat, enough corrective or fixed force cannot be transmitted to bones. In order to transmit the force of chairs or wheelchairs to bodies, the materials of the seating surface or the supporting devices of wheelchairs need to be solid. As a material to stabilize the sitting position, sling sheet is not appropriate. Also, it does not help to correct deformations by fixing cushions or towels with a Velcro band.

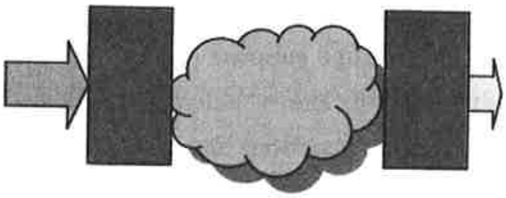

Figure 10 Force cannot be transmitted through soft materials (cloud in the middle).

Chapter 5.
Seating System[11)]

The configuration for the seating system on a wheelchair are divided into structures for sitting such as posture support devices and recline and tilt mechanics, a frame structures for driving into the wheelchair, such as tires or hand rims, and structures for ease of use (folding function) and the strength (Figure 11).

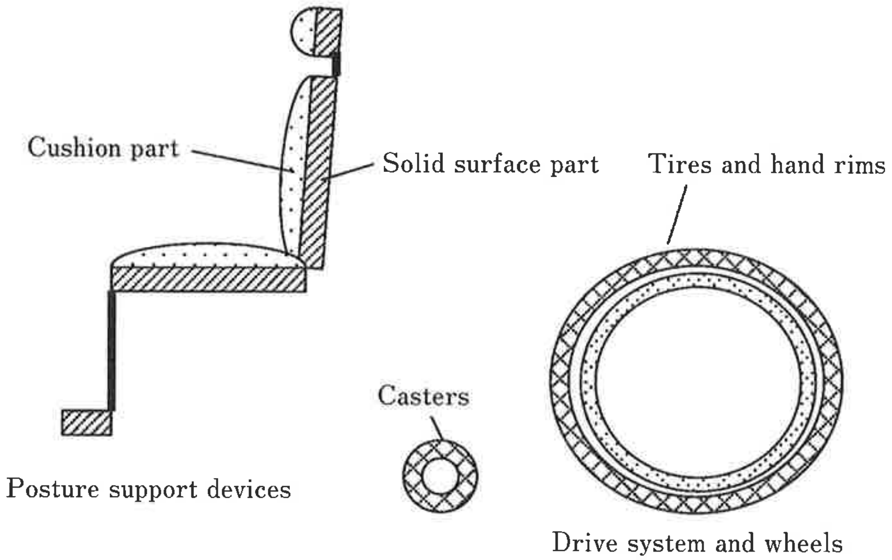

Figure 11 The configuration of seating system on a wheelchair

The chair part can be divided into the solid board part to support bones, and the cushion part to protect soft part tissues from pain by excess pressure and at the same time prevent pressure ulcers. This board part and cushion part become the interface with body, and becomes the sling seat part for standard wheelchairs. The chair part is composed of pads to not only support seating and the back, but to also stabilize the trunk from the sides and to support extremities, and by belts to support the body from the front or topside.

Furthermore, both the hooks that connect the chair part and the wheel part can adjust the position, and tables that are used to support the upper body have important roles in the seating system.

1. Support Surface

1.1 Tension Adjustable (Figure 12)

There is a tension adjustable single seat and a seat that is composed of several length-adjustable belts. If there are several belts that are intended to allow adjustment to create a contoured surface, it can be adapted to the shape of the back or trunk. The advantages are that it is light, foldable, and easy to handle. However, compared to the board seat, the supporting function is weak, and there is a high possibility for users with muscle atrophy to experience pressure ulcers as the pressure is focused.

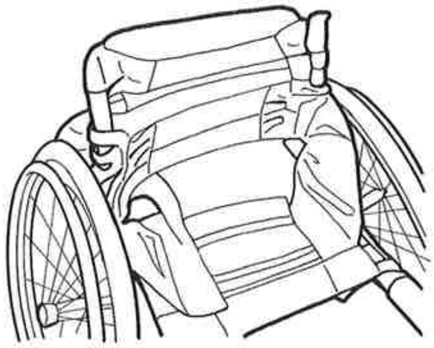

Figure 12 Sling seats and back composed of several tension adjustable belts

1.2 Planer Support (Figure 13)

It holds the supporting areas that were made with a flat board or slightly arced board.

Many cushions are flat and can easily be equipped with various kinds of pads. This type does not change shape and is support for users who are capable of maintaining a symmetrical sitting position. The user can expect high supportability and a stable sitting position will be maintained. Contact doesn't change even if the body moves slightly.

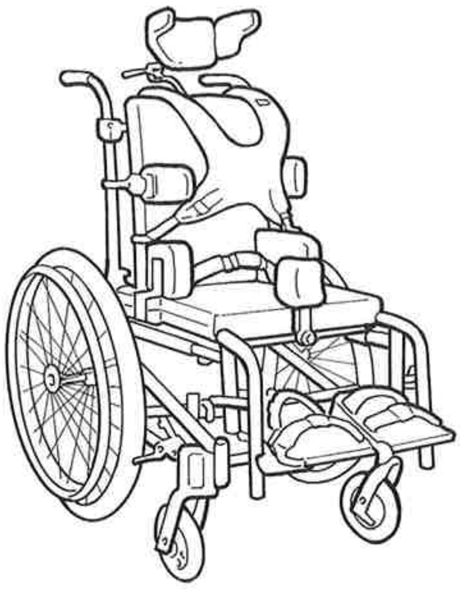

Figure 13 Planer support

1.3 Pre-Contoured Support (Figure 14)

Total contact is possible as the shape of the trunk and buttocks adjusts to fit the user, and the support devices are designed to reduce the load, stabilize posture and give support. A certain amount of deformation can be fixed by adding a pad to the seat and back. The intended function cannot be applied when the user's body moves.

Figure 14 Pre-contoured support

1.4 Custom Contoured Support

Made with moldable material such as polyurethane foam, it can be molded to match the user's body. It is enhanced for growth and any physical changes but it needs to be re-made when it no longer matches the user's body. One disadvantage is that it can be sticky in summer (Figure 15).

Figure 15 Custom contoured support

2. Angle Adjustable Solid Seat and Solid Back Support

A hard board seat that supports the buttock and the trunk, it is used for the purpose of supporting the pelvis, femurs and spine, and stabilizing the seated posture. It can be fixed to the hooks on the wheelchair's frame. There are also versions that can be removed from the frame when it is folded. The hook's length and position can be adjusted on the inclined (Figure 16), and the seat's height, depth, and angle can be adjusted. The height, position, and angle for the solid back support device can also be adjusted.

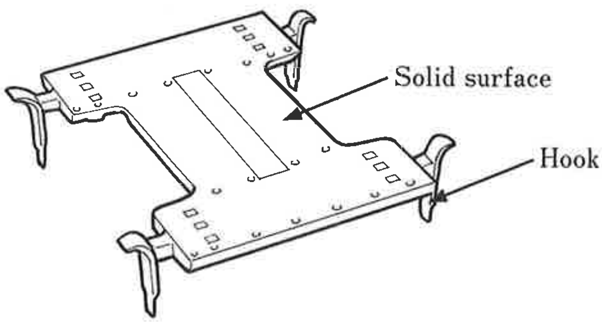

Figure 16 Angle adjustable seat

3. Recline and Tilt[13,14]

Recline is to change of the back support angle from an upright sitting position toward a supine position without moving the seat. The tilt is to change of the seating orientation in the sagittal plane while maintaining the seat to back support angle. Normally, the back and seat angle on a wheelchair is fixed so to change the angle, there is a static mechanism that adjusts the angle or position of the hooks or the wheelchair's back frames. There is also a dynamic mechanism that can change the angle manually or electrically anytime.

3.1 Recline (Figure 17)

To decide the seat to back support angle of the wheelchair, the angle (reclining angle) obtained in the evaluation mentioned in 2.1 (1) is fundamental. Enlarging the size of the reclining angle of the back of the wheelchair (leaning the back of the chair back) has the effect of stabilizing the trunk.

For people with low blood pressure and people who get tired easily sitting, a wheelchair with a dynamic reclining mechanism is recommended. The center of rotation when a reclining wheelchair's back and seat angle change, and the impact of the center of rotation of the hip joint don't match so every time the angle is changed the user's posture changes rubbing the skin, which can lead to pressure ulcers. The body's position must therefore be adjusted. There is also little change in the burden placed upon the buttocks.

Figure 17 A reclining wheelchair

3.2 Tilt (Figure 18)

For wheelchairs that have a dynamic tilt mechanism that allows a change in angle for the whole wheelchair, posture (relative to gravity of the body) can be changed without changing attitude (head, trunk, relative position of limbs). Changing the angle of the entire wheelchair changes the way gravity affects the body and the weight that pressured the pelvis can be divided over the back. By doing this, the user can expect such improvements as preventing the colapusing trunk, taking pressure off the buttocks, increased blood flow to the lower extremities, and preventing the user from falling out of the wheelchair. On the other hand, by tilting the whole chair, the head needs to be supported. To prevent the head from falling backwards, various negative effects will occur, such as the wheelchair will become larger, arm reaches on a desk will be restricted, it will be difficult for the user to move around under their own power, and the degree of body restraint will increase. The user can use the tilt mechanism by one self or asistant to tilt the chair when they want to use their arms on a desk so as lessening the restriction on their arm movements.

Figure 18　A wheelchair with a tilt mechanism and posture support devices

4. Support of the Occupants Body Segments

There are various devices, including pads and belts, used to support posture and various parts of the body, like the head, neck, shoulder, trunk, lumbar, sacral,, upper arm, pelvis, upper leg, lower leg, medial knee, knee, ankle, resion from the anterior, posterior, medial, lateral, superior, inferior, and circumferential in a seating system. The major body support devices and the methods are shown below.

4.1　Head Support (Figure 19)

If head support is necessary, it is first necessary to support and secure the trunk. If one attempts to support the head when the trunk is unstable, the head will get tucked into the neck. Therefore, alignment of the neck is important.

If cervical spine alignment can be maintained against the gravity, the head can be controlled with the planer back support in Figure 13. If not, support methods through head biomechanics need to be considered.

The head is spherical in shape so to keep it in a stable position four supports are necessary. The devices that can be supported are the mastoid process, the external occipital protuberance, the temporal surface, and the forehead. If the support devices touch the auricle, it will make it difficult for the user to hear and pressure ulcers may result so one must be careful that the support devices don't touch the auricle.

Figure 19 Head support

4.2 Trunk Support

The chest region can be supported by the back from behind and also from the side and the front.

The trunk is divided with thoracic and abdominal or lumbar regions. The back and lumbar support devices support the trunk from backside. The lateral trunk support (Figure 20) device supports the rib cage in lateral and lateral side of the pre-contoured back support (Figure 14) devices support the lower rib cage and abdominal region in lateral. Anterior trunk support (Figure 21) is used to support the trunk at sternal region for backward.

Lateral thoracic support changes the supportable posture depending on the way it is attached to support the back. The positioning of some support devices can be finely adjusted and others are foldable for when they are moved (Figure 20: lateral trunk support).Its fundamental to support the anterior thoracic at the sternal region (Figure 21).

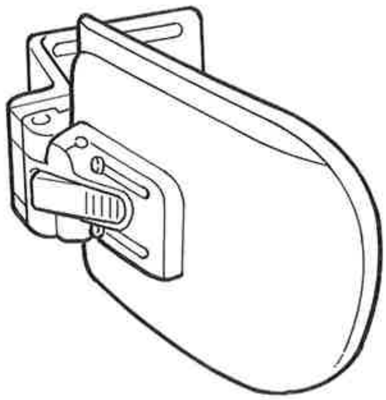

Figure 20 Swing-away lateral trunk support

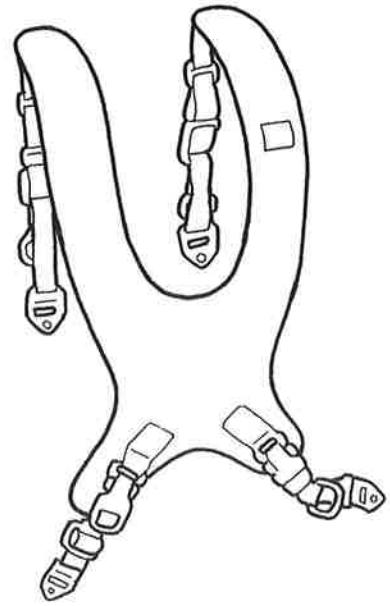

Figure 21 Anterior trunk support

4.3 Foot Support (Figure 22)

For foot support parts, there are functions to support feet, lower legs, and a part of the thigh. When the distance between the seat surface and the foot support device is short, the load on the buttocks increases and abduction/external rotation of the thigh occurs. Ideally, it is necessary to have functions that are flexible in 3 ways for the ankles: dorsi-flexion/plantal-flexion, inversion/eversion, and adduction/abduction (Figure 22, Left).

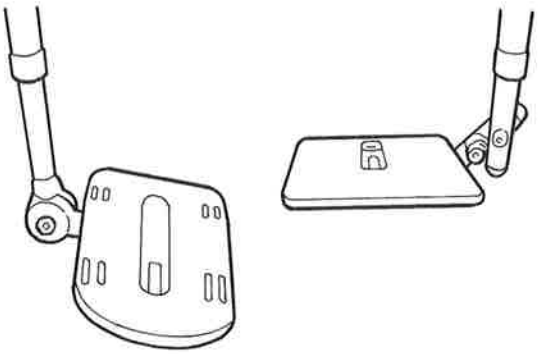

Figure 22 Angle adjustable foot support

4.4 Anterior Pelvic Support

With sagittal plane, the back is supported a pelvic from the back, the seat is supported it from below, and the anterior superior iliac spine is supported it from the front with pelvis support belts that can maintain the skew angle 45 degree from both sides (Figure 23). In the case that a horizontal pelvis position cannot be maintained even with the frontal plane adjusted for a sitting position and back support, supports from the sides are necessary.

In order to stabilize the pelvis, there are methods to secure the thighs with a belt to the seating support, or place a fixture (a sub ASIS bar) between the anterior superior iliac spine and thighs.

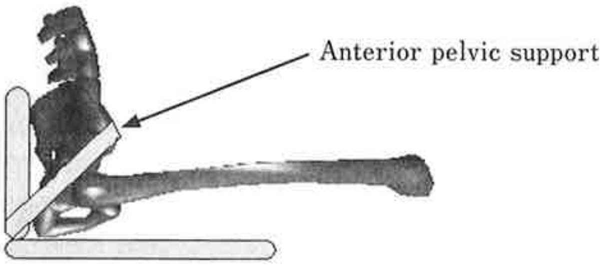

Figure 23 Pelvis support

Chapter 6.
Measuring the Seated Posture

In order for users to objectively evaluate the adjustment result of the seating system, it is necessary to measure seating posture quantitatively. The ISO (International Organization for Standard) made a standard to measure the seated posture of wheelchairs[12].

It is essential to support good posture when using a seating system, beds or mats, and wheelchairs. To measure dimensions of a seated person and seating system, the anatomical axis system, wheelchair axis system, and support surface axis are set as the coordinate system. On each coordinate system, the places and angles of each part of the body are measured in three-dimensions based on the designated measurement origin, which are the frontal plane, sagittal plane and transverse plane. The wheelchair coordinate system is normally used.

The origin of the seated anatomical axis system is the center point of where both the left and right hip joints are connected. For the wheelchair axis system, the origin is the center of the axle on both sides, and for the support surface axis, the origin is the seat posterior center point. Make the frontal, sagittal and traverse three-dimensional projection of each origin to describe the limb segments positions and angles. Based on a clockwise direction rotation angle, a 0 angle 0 time 360 ° measurement convention is used (Figure 24).

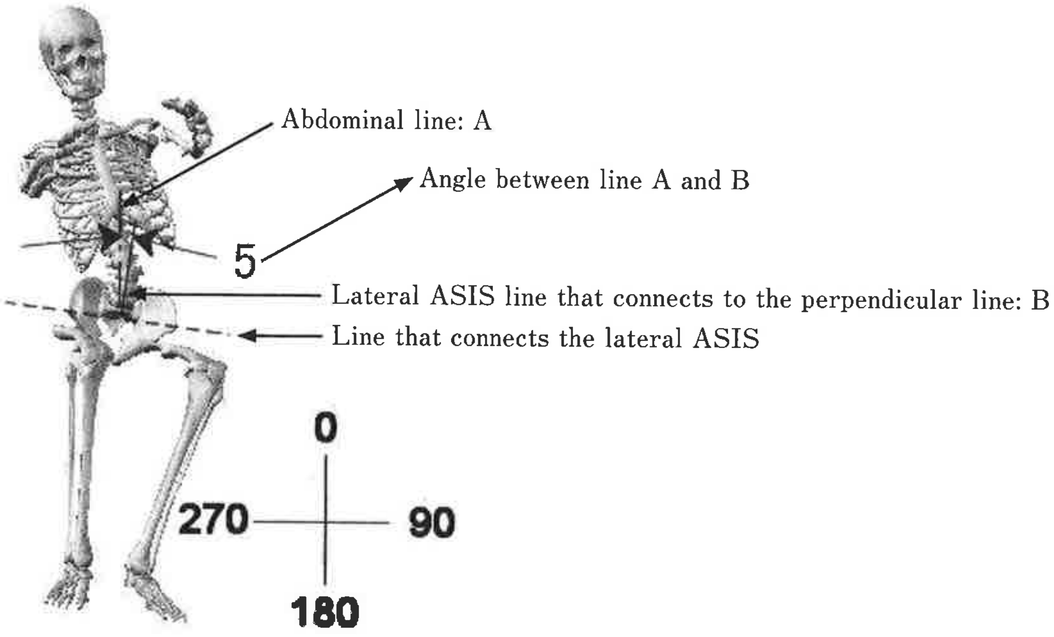

Figure 24 The measurement and angle of the pelvis gradient at the frontal plane

In order to show body segments, major nodal lines were defined by connecting two anatomical landmarks by a segment line.

At the head, the frontal head line (the line passing between the right and left eye corners), Sagittal head line (the line perpendicular to the line passing through the tragion and eye corner), transverse head line (the line perpendicular to the line connecting the right and left Tragions at the midpoint of this line) are defined. At the cervical region, the neck line (the center parts of both mastoid bone, the center of line that connects C7 and the superior margin of the sternum, and the lines that connect them) are defined as each frontal neck line and sagittal neck line. For the trunk, the sternum line (the line passing through the upper sternal notch and the lower sternal notch), abdominal line (line passing through the lower sternal notch and the ASIS midpoint) are defined (Figure 25). In particular it has been confirmed that the sternum line is related to the alignment of the thoracic vertebra, and the abdominal line is related to the lumber vertebra at both sagittal and frontal planes[15].

Note: Sometimes it is difficult to measure the cervical region by the ISO clinical practice. Therefore, the approximate points are suggested here[16].

By measuring the length of these nodal lines and the angle of these two nodal lines it becomes possible to express the posture as the group of numbers, and through seating adaptation it becomes possible to record objectively how posture was transmuted.

In order to evaluate the impact of seating adaptation, it is necessary to investigate the comfort and safety of the users (if the system is used safely), functionality (if the upper body can move more freely; if mobility capability was increased), practicality (if the system can be used widely in daily life), physiologically (if the system has a function to prevent pressure ulcers; if it is easy to breathe; if there are no difficulties in eating and evacuating), and if life functions are improved other than these measurements.

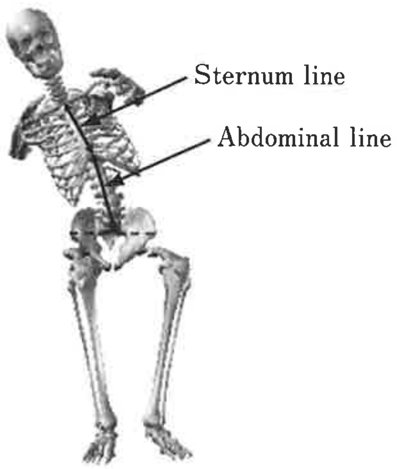

Figure 25　Sternum line and abdominal line

Chapter 7.
Actual Seating Adaptation

1. Procedures

A seating system is made after processing the general evaluation to decide a seating system, assembling and manufacturing device, and adaptation evaluation. At the first evaluation process, needs for wheelchair and seating system including time how many hours a day the user wants to sit in it, activity what does the user want to do in it, risk of pressure ulcer, the living environment in home, car, school and office he/she spend all day, and possible care situations and places that the user might use the adaptation are estimated, the information about the parts that are used for the devices are collected and then its designed. At the device assembling and manufacturing process, the parts are selected, assembled and adjusted in adaptation process. In order to make devices that are suitable for the user's characteristics, it is ideal to make a trial device to simulate the impact (to be mentioned later).

At the adaptation evaluation stage, the functionality of "individual level" - which are if there are any physiological problems (if there is pain, the user might be forced to adopt an unnatural posture; if there is any possibility of pressure ulcers; if the user can breathe and swallow without difficulties); if the seat is comfortable to sit in it for the hours he/she needs; if there is any restriction for the users to be able to do the activity he/she wants (move their hands and legs are evaluated.) The "social level" , such as practicality, safety, mobility, care, and physical aspects, when the device is used at home, school, work places and other facilities are also evaluated. Moreover, there are disadvantages, such as the possibility of falling off the wheelchair and the fact that living space becomes smaller when using a wheelchair and/or a posture support device. It is important to evaluate these negative aspects.

It is important to exchange opinions between all the related stakeholders, such as users, families, caregivers, and rehabilitation staff, when deciding a device and the position of posture support, the materials and positions for the supporting parts. For example, a device made based on the opinion of physical therapist who is keen to correct the spinal deformation might limit the upper body's movement and it might distract the improvement of the upper body that an occupational therapist is aiming to do. It is necessary to seek the related stakeholder's opinions for device manufacturing and adaptation judgment.

2. Simulation

In the process of device manufacturing, it often happens that other support parts and supporting parts need to be changed when selecting the support part and supporting parts, assembling and adjusting them. By adopting an adjustable wheelchair with adjustable seating system in the individual and social levels and confirming the effect before deciding the final design, it enables the creation of better adapting devices possible.

Taylor[17] states that it is important to simulate the posture and foot position in open areas, and it is impossible to obtain enough information about the muscle stress or actual weight by evaluation on mat only. She also said that it becomes possible to know how to accept the initial posture and the function changes depending on the posture by simulation, and simulation improves communication between the therapists and the manufacturers.

Conclusion

I have explained the biomechanics, kinematics, and pressure ulcers which are the base of a seating system. In reality, other factors, such as the condition of the user or the age of the users (children, growing period, and elderly people), come in to play as well. It is important to show evidence for these factors.

Moreover, it is also essential to consider that motorized wheelchairs and communication devices are a part of assistive technology, and seating in particular can be the first step of the total measures to improve QOL.

Wards used in this document are refered to ISO 7176-26 Wheelchairs-Part 26 Vocabulary, 2007.

Finally I'd like to thank Kelly Waugh of the Dept. of Physical Medicine and Rehabilitation, School of Medicine, University of Colorado, Denver, for her invaluable advice on this document.

References

1 Hallenborg SC. Wheelchair Needs of the Disabled, Therapeutic Considerations for the Elderly, Osa Littrup Jackson ed. ChurchilLivingstone,USA,1987,p.93-111.

2 Hirose H, Kinose T. Seating for the Elderly(Japanese), Miwa-Shoten, 2006,p.80-87.

3 Letts RM. General Principles of Seating, Principles of Seating the Disabled, CRC Press,USA, 1991, p.440-441.

4 Hoffer MM: Basic considerations and classifications of cerebral palsy. In American Academy of orthopaedic Surgeons: Instructional course lectures. Vol.25, St Louis,The C.V. Mosby Co,1976.p.97-98.

5 Koga H, Hirose H, et al. Reliability and validity of the sitting scale by Hoffer (JSSC), Rehabilitation and engineering,24 （2） , 2009,p.92-96.

6 Minkel JL. Mat Evaluation, Seventeenth International Seating Symposium,2001, p.115-117.

7 Braden BJ, Bergstrom N. A conceptual schema for the study of the etiology of pressure sores. Rehabil Nurs, 12 (1), 1987, p.8-16.

8 National Pressure Ulcer Advisery Panel:Pressure ulcers prevalence, cost and risk assessment:consensus development conference statement. Decubitus,1989, p.24-28.

9 International Association for Enterostomal Therapy: Dermal Wounds: pressure sores, J Enterost Ther, 15,1988, p.4-17.

10 Hirose H. Seating Support and Biomechanism (Japanese), Society of Biomechanisms . 31(1), 2007,p.8-11.

11 White AA, Panjabi MM. Clinical Biomechanics of the Spine, J.B.Lippincott, 1978, p.348-349.

12 Bergen AF, Presperin J, Tallman T. Positioning for Function, Wheelchairs and other assistive technologies, Valhalla Rehabilitation Publications, Ltd. NY,1990.

13 ISO16840-1(2006), Wheelchair seating-Part1: Vocabulary, reference axis convention and measures for body segments, posture and postural support surfaces.

13 Sprigle S and Sposato B. Physiologic effects and design considerations of tilt-and-recline wheelchairs, Orthopaedic physical therapy clinics of north America, 6(1), 1997,p.99-121.

14 Ward DE. Prescriptive Seating for Wheeled Mobility, Vol.1,Theory, Application, and Terminology, Health Wealth International,USA,1994,p.102.

15 Hirose H. Development of clinical methods for measuring geometric alignment of the thoracic and lumbar spins of wheelchair-seated persons. JRRD, 42(4). 2005, p.437-446.
16 Hirose H, et.al. Measurement of body positions and postural support devices according to ISO16840-1. 23rd International Seating Symposium,2007,p.65-67.
17 Taylor SJ: Evaluating the client with physical disabilities for wheelchair seating. Am J Occup Ther, 41,1987,p.714.