TECHNICAL SPECIFICATION

ISO/TS 16840-14

First edition
2023-05

Wheelchair seating —

Part 14:
Concepts related to managing external forces to maintain tissue integrity

Sièges de fauteuils roulants —

Partie 14: Concepts liés à la gestion des forces externes pour maintenir l'intégrité des tissus

Reference number
ISO/TS 16840-14:2023(E)

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Foreword

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The procedures used to develop this document and those intended for its further maintenance are described in the ISO/IEC Directives, Part 1. In particular, the different approval criteria needed for the different types of ISO documents should be noted. This document was drafted in accordance with the editorial rules of the ISO/IEC Directives, Part 2 (see www.iso.org/directives).

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This document was prepared by Technical Committee ISO/TC 173, *Assistive products*, Subcommittee SC 1, *Wheelchairs*.

A list of all parts in the ISO 16840 series can be found on the ISO website.

Any feedback or questions on this document should be directed to the user's national standards body. A complete listing of these bodies can be found at www.iso.org/members.html.

Introduction

The influence of pressure on the health of skin tissues has been acknowledged for some time: what used to be called "bed sores" or "decubitus ulcers" became renamed "pressure ulcers" in Europe and "pressure injuries" in much of the rest of the world. However, in recent years, greater awareness of other extrinsic factors affecting the health of skin tissues has led to increased reference to the more general term of tissue integrity. The current pressure injury definition from the 2019 International Guideline Prevention and Treatment of Pressure Ulcers/Injuries[1] highlights this new understanding. Pressure injury is referred to in Reference [1] as “localized damage to the skin and/or underlying tissue, as a result of pressure or pressure in combination with shear.” “The tissue damage occurs as the result of intense and/or prolonged exposure to sustained deformations in compression (perpendicular to the tissue surface), tension or shear (parallel to the tissue surface), or a combination of these loading modes. The tolerance of soft tissue for sustained deformations differs by tissue type and may also be affected by microclimate, perfusion, age, health status (either chronic or acute), comorbidities, and conditions of the soft tissues”.

The current NPIAP/EPUAP/PPPIA Guidelines[1] note the changing views on pressure injury staging. Stages 1 and 2 are described as “partial-thickness tissue loss” and having the strongest connections to superficial microclimate (temperature, humidity, altered pH due to incontinence), shear, and friction effects. Stage 1 and 2 pressure injuries are also described as ‘outside in’ skin damage[2]. Stages 3 and 4, Unstageable, and Suspected Deep Tissue Pressure Injury are categorized in the Guidelines as “full-thickness skin and tissue loss”. Deep tissue injury is an ‘inside out’ skin damage, which usually originates in deep soft tissues subjected to external pressure and shear forces and subsequent deformations around the bony prominences[2]. Suspected deep tissue injury is one of the most challenging pressure injuries for accurate identification: it can present as an intact non-blanchable red, maroon, or purple discolouration that can quickly evolve to reveal a full tissue loss[3]. Current guidelines advise clinicians not to think of the numbered stages as linear progression of the wound towards improvement/healing or worsening, but rather use the stage descriptions to note the maximum depth of a wound at a single point in time[3].

While the characteristics of an ideal microclimate (skin temperature and humidity) are still being researched, it is recognized that there are strong connections between microclimate and friction, and hence surface and internal tissue loads. This is relevant for all pressure injuries, not just the superficial ones[1].

It is the materials closest to the skin, be they clothing, continence products, and/or the materials in the cover of the support surface that the person is sitting or lying on that often have the most impact on microclimate, friction, and shear effects on the surface of the skin.

Stage 3 and 4, Unstageable and Suspected Deep Tissue, Pressure Injuries affect the deeper layers of the skin and around bony tissues and are currently thought to derive from the effects of external pressure, external shear forces, and the resulting internal shear stresses and strains.

Both short-term high pressure and long-term moderate pressures can be harmful for soft tissues. Internal muscular, adipose, and dermal tissue deformations are linked to a multitude of damaging effects: partial or total occlusions of microvascular and lymphatic network, tissue ischaemia, direct cell deformations with cytoskeleton distortions and breakdown, cellular DNA damage, tissue inflammation and necrosis, pH changes in interstitial fluids, altered orientation of collagen fibres, and subepidermal separation[2][4][5][6].

Combined effects of shear and pressure can be more damaging than effects of pressure and gravity forces alone. These effects can be ameliorated or exacerbated by the materials and construction of support surfaces.

The accompanying effects of shear strain alongside the pressures introduced by the effects of gravity creating areas of pressure on the body, have a more damaging effect on the tissues themselves, than pressure alone.

Frequently the terms discussed in this document are misused or confused in general usage. This document has been created to aid in understanding the differences between the defined extrinsic elements and their respective effects on human tissues.

Wheelchair seating —

Part 14:
Concepts related to managing external forces to maintain tissue integrity

1 Scope

This document describes common terms related to forces and their effects as experienced by human bodies and their support surfaces. It provides further information on concepts around how these forces affect the human body's response to postural support systems, and particularly highlights the impact of the interface between tissues and postural support devices (PSD) on the maintenance of tissue integrity. It provides a general introduction to biomechanical concepts, phenomena, and vocabulary. This is intended to facilitate effective understanding and sharing of information between a range of disciplines/stakeholders involved in providing equipment to manage tissue integrity.

Representative stakeholders include people with a disability, occupational therapists, physical therapists, biomedical engineers, nurses, medical and para medical personnel, device manufacturers, and other professionals facilitating development, provision, and access to seating and mobility equipment.

This document does not provide detailed information that is currently available in physiological text books or scientific literature.

2 Normative references

The following documents are referred to in the text in such a way that some or all of their content constitutes requirements of this document. For dated references, only the edition cited applies. For undated references, the latest edition of the referenced document (including any amendments) applies.

ISO 7176-26, *Wheelchairs — Part 26: Vocabulary*

ISO 16840-1, *Wheelchair seating — Part 1: Vocabulary, reference axis convention and measures for body segments, posture and postural support surfaces*

3 Terms and definitions

For the purposes of this document, the terms and definitions given in ISO 7176-26 and ISO 16840-1 and the following apply.

ISO and IEC maintain terminology databases for use in standardization at the following addresses:

— ISO Online browsing platform: available at https://www.iso.org/obp

— IEC Electropedia: available at https://www.electropedia.org/

3.1
perpendicular force
force occurring at 90° to an element's surface

Note 1 to entry: It is measured in newtons (N).

3.2
shear force
F_s
force occurring parallel with an element's surface

Note 1 to entry: It is measured in newtons (N).

3.3
pressure
p
force per unit area in a direction perpendicular to the surface

$$p = X / A$$

where

p is the pressure (MPa);

X is the perpendicular force (N);

A is the area (mm^2);

1 MPa = 1 000 kPa.

Note 1 to entry: It is measured in pascals (Pa) or equivalent units.

3.4
shear stress
τ
shear force divided by the area of the element's surface to which the shear force is applied, parallel with the slope or plane in which it lies

$$\tau = F_s / A$$

where

τ is the shear stress (MPa);

F_s is the shear force (N);

A is the area (mm^2);

1 MPa = 1 000 kPa.

Note 1 to entry: It is measured in pascals (Pa) or equivalent units.

3.5
axial strain
normal strain
ε
change of dimension due to the action of pressure

Note 1 to entry: Axial strain is dimensionless.

EXAMPLE Compressive effects from pressure are illustrated in Figure 1.

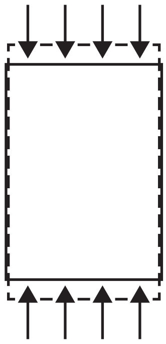


Figure 1 — Axial strain effects from the compressive effect of pressure

3.6
shear strain
γ
change in the shape of an element due to the action of shear stress

Note 1 to entry: Shear strain is dimensionless.

Note 2 to entry: See Figure 2.

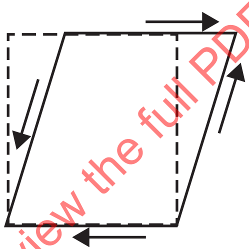


Figure 2 — Shear strain effects

3.7
shear modulus
G
ratio of shear stress to shear strain

Note 1 to entry: It is measured in pascals (Pa).

3.8
friction
force resisting the relative motion of two objects with surfaces in contact

3.8.1
static friction
friction force resisting the initial relative motion

3.8.2
dynamic friction
friction force resisting the motion while motion is in process

4 Effects on human tissues from interaction with a support surface

4.1 General principles

When any surface comes into direct contact with a user's body, then there will be a number of effects:

a) the skin surface is subject to complex pressure distributions;

b) the pressure distribution gradient at the interface surface, and friction forces, induce internal tissue deformation;

c) tissue deformation from the skin to the bony prominences produces an overall tissue displacement with respect to the unloaded tissue condition;

d) tissue deformation comprises internal axial strain and shear strain:

   1) axial strain and shear strain induce modification of internal blood and lymphatic circulation;

   2) blood vessel occlusion can lead to cellular death due to lack of oxygen and nutrients;

   3) high levels of cell strain can lead to cellular death due to disruption of the cytoskeleton.

e) there is modification of thermal exchange;

f) there is modification of moisture exchange;

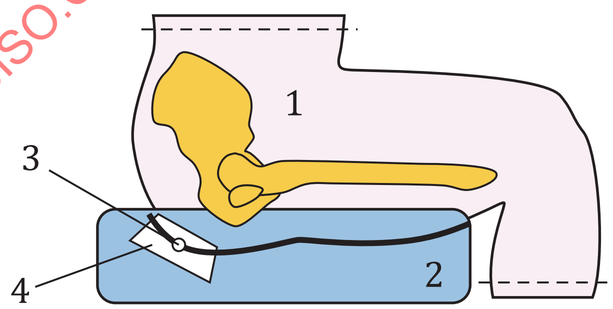
g) there is influence on the posture adopted by the body.

4.2 Phenomenological description

4.2.1 General

When a person sits on a seat cushion, there are two primary objects in contact with each other, as shown in Figure 3: the human body (key 1) and the cushion (key 2). There can be multiple interfaces between these two primary objects (e.g. clothes, cushion covers, sheets, continence products, etc).

Gravitational forces applied to the static human body are transmitted to the cushion through a contact surface whose complex shape can depend on the stiffness and shape of the human body and of the cushion. At any location of the contact surface (key 3), a tangential plane can be ideally defined (key 4).



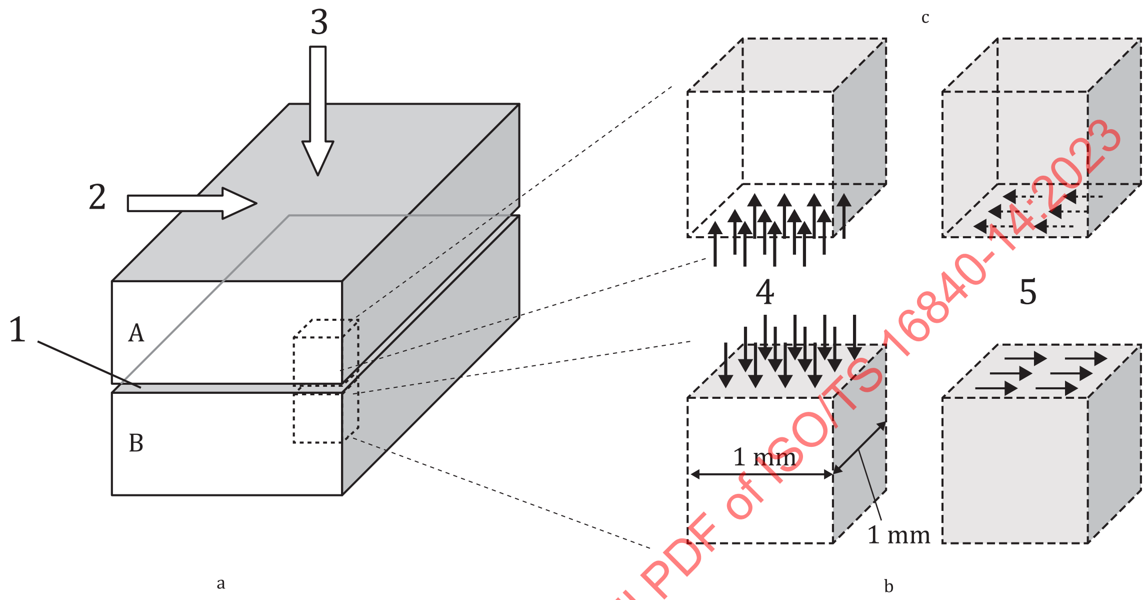
Key

1 human body
2 cushion
3 contact surface
4 tangential plane

Figure 3 — Human body in contact with a cushion

4.2.2 Pressure and shear

With reference to a given plane, two types of forces can be defined. The force at right angles to the plane is a perpendicular force. The force parallel with the plane is the shear force. This is described in part a of Figure 4 where the two objects are simplified as Object A and Object B. In Figure 4, the two objects are in contact at a common flat surface with an area A.



Key

1 contact surface
2 shear force
3 perpendicular force
4 pressure
5 shear stress
A object A
B object B

NOTE Object A can represent the skin of a seated person and Object B a support surface under a seated person.

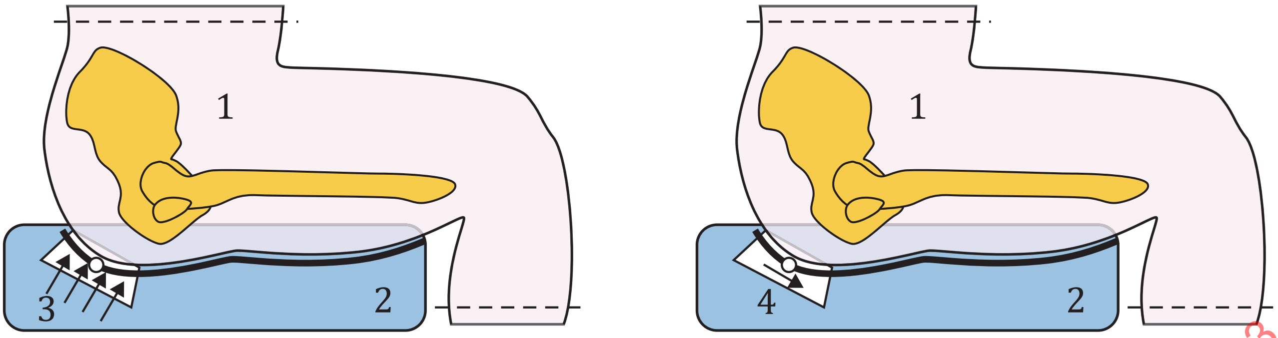
[a] Forces acting on Object A and transmitted to Object B.

[b] Pressure and shear stress acting on the upper surface of a unit volume of Object B at the Object A-Object B contact surface.

[c] Pressure and shear stress acting on the lower surface of a unit volume of Object A at the Object A-Object B contact surface.

Figure 4 — Forces and stresses acting between two objects.

When the perpendicular force is distributed over the contact surface of area A, the pressure can be quantified. When the shear force is distributed over the contact surface of area A, the shear stress can be quantified, as described in parts b and c of Figure 4. These quantities can be extended also at any location of a curved contact surface, as local forces per unit area referenced to the local tangential plane (see Figure 5).



Key

1 seated person
2 cushion
3 pressure
4 shear stress
a Pressure on a tangential plane at the contact surface (exerted by the cushion on the skin).
b Shear stress due to pressure and friction on a tangential plane at the contact surface (exerted by the cushion on the skin).

Figure 5 — Relationship between pressure and shear stress on a tangential plane at a contact surface

4.2.3 Friction

With regard to the contact surface of the two bodies, friction produces shear stresses at the local tangential plane, depending on

a) the amount of pressure between the two surfaces,

b) the nature of the two surfaces, and

c) the environmental conditions at the contact surface.

As shear forces on one of two objects attempt to create relative motion between their two surfaces, this creates static friction initially, which will increase the shear stress forces at the surfaces, leading to increased shear strain under the surfaces. When the shear forces reach the point where one surface starts to move relative to the other surface, the friction moves from static to dynamic friction. The result will be decreased shear stress at the surfaces, leading to less shear strain beneath the surfaces, but abrasive damage can still occur as the surfaces move over each other.

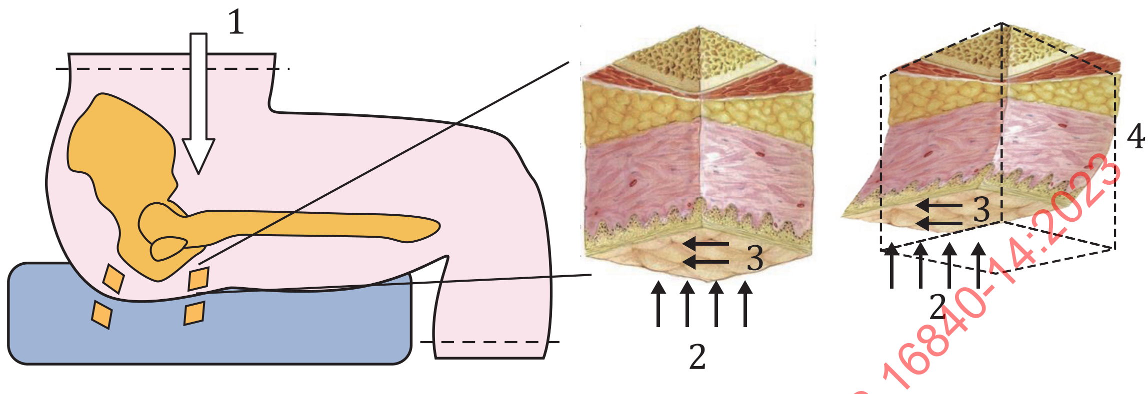
4.2.4 Distribution of strains

Focusing on the deformed shape of the two objects in contact, a complex distribution of strains (deformation) is created inside the human body's soft tissues and inside the cushion, even where only a perpendicular force is applied to the cushion (as compared with its upper nominal surface when unloaded). The heterogeneity of the human tissues in combination with the presence of bony prominences produces complex distributions of strains across the soft tissue layers inside the body.

These deformations can be classified as shear strain, when changes in shape occur (see Figure 2), or as axial strain, when only dimensional changes occur (see Figure 1 for an example of compression under pressure). They usually occur together.

Shear strain, together with axial strain, is responsible for the damage to soft tissues at different depths of the skin layers (epidermis, dermis, fat, connective tissue, circulatory vessels, muscles), due to blood vessel occlusion and to cell strain. Mechanisms causing this damage continue to be under scientific evaluation.

Simply sitting on a cushion produces complex strain distributions inside the body soft tissues and inside the cushion. Different shear strains occur in the different tissue layers (see Figure 6).



Key

1 perpendicular force

2 pressure

3 shear stress

4 shear and axial strain

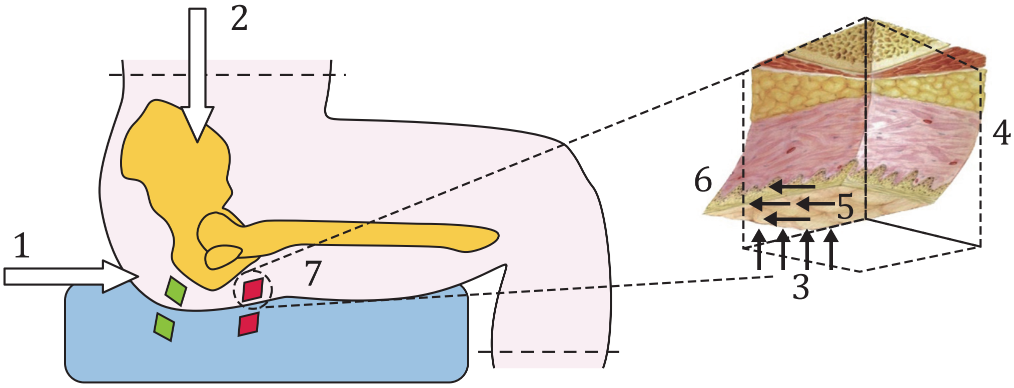
a Before perpendicular force applied.

b After perpendicular force applied.

NOTE Complex strains are developed inside the cushion as well as the skin tissues.

Figure 6 — Example of body tissue strains resulting from contact surface stresses when sitting on a cushion

When an additional shear force is applied to the part of the body in contact with the cushion (key 1 in Figure 7) (e.g. by certain construction of a cushion, or by a person's action of sliding forward), additional shear stresses are produced at the contact surfaces: this changes the tissue internal strain distributions and can produce an increase of shear strain at certain locations (red blocks, Figure 7) resulting in increased risk of tissue damage as well as a reduction of strain levels at other locations (green blocks, Figure 7).



Key

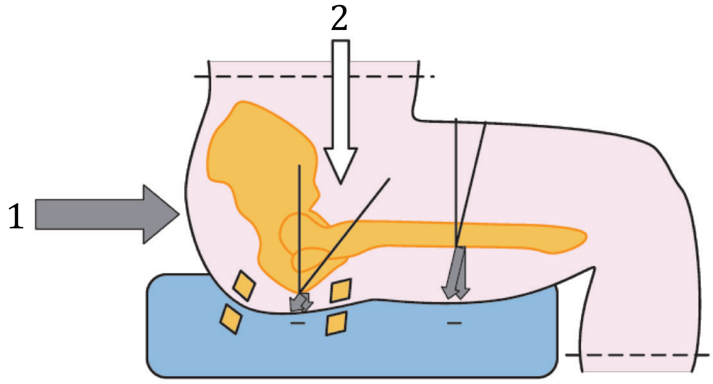
1 shear force
2 perpendicular force
3 pressure
4 axial strain
5 increased shear stress
6 increased shear strain
7 increased tissue damage risk

Figure 7 — Alterations of shear strain effects arising from the application of an external shear force

A further element of relevance can be the shear modulus of the support surface, in that the harder a material is, the higher will be its shear modulus value. As the shear modulus value rises, this indicates that a much greater amount of force or stress is required to strain or deform it along the plane of the direction of the force. The implication is that if the support surface has a lower shear modulus than the skin tissues on the support surface, the support surface will take up the greater percentage of shear strain or deformation.

4.3 Clinical implications of support surface cover selection

Skin and underlying soft tissue thickness over bony prominences such as ischial tuberosities, coccyx, and sacrum, tend to be less than in other areas such as under the femurs along the thighs. Shear forces on the tissues therefore have less thickness under the bony prominences to dissipate the shear strain. The cells in this less thick tissue will thus undergo greater individual distortion than the cells within the thicker soft tissue regions when subjected to the axial and shear forces generated following contact with denser surfaces (e.g. bone, seat cushion, back support, etc.) (see Figure 8).



Key

1 shear force

2 perpendicular force

NOTE Difference in skin and underlying soft tissue thickness under the ischial tuberosities and femur are indicated in the figure.

Figure 8 — Relative effects of shear strain on less thick tissues under a bony prominence (e.g. ischial tuberosity) as compared with deeper tissues (e.g. under the femur along the thighs)

The selection of the support surface materials adjacent to the skin covering the bony prominences is important: if the support surface covering can move with the skin at this point, then there will be less shear strain on the adjacent tissues. On the other hand, the support surface cover adjacent to the thicker layers of skin will need to have higher friction elements to prevent the user from sliding off the surface – however, the greater depth of skin (e.g. as indicated in Figure 8 under the femur along the thighs) is more appropriate for distributing the shear strain over a greater number of cells, thereby giving a reduced shear strain to each individual cell.

4.4 Measurement of pressure distribution and shear

4.4.1 Pressure mapping

Some pressure mapping devices have software that depicts not only the actual pressures measured at each sensor, but also a gradient view which shows the rate of change of pressure from one sensor to the next. The greater the gradient, the greater the likely shear strain occurring in the tissues between one sensor's area of detection and the next, at the surface of the skin.

4.4.2 Shear sensors

A shear sensor detects force and direction of external shear forces that occurs locally between the sensor and the adjacent surfaces (e.g. the cushion surface, garment, skin, etc.) to which it is applied. A unit of measure is generally newton, and under appropriate circumstances pascal could be used.

When using a shear sensor, certain limitations should be considered (see Annex A).

4.4.3 Pressure and shear modelling

Although not offering direct measures, modelling with finite element analysis has been developed as a cost-effective way to model in three dimensions the friction, shear, and pressure effects of the human body's interaction with a cushion.

Annex A
(informative)

Considerations around the use of shear sensors

A.1 Effects on the measurement from the sensor itself

The thickness and flexibility of the shear sensor should be considered. For precise measurement, the sensor should be sufficiently thin to avoid effects to the measurement by the sensor itself. The sensor also should be flexible enough to follow the shape of the measured object(s), and to avoid the effects of the sensor itself, as well. When using a thicker shear sensor, higher force values tend to be shown where that sensor is placed[13][14].

NOTE When using a thick shear sensor, embedding the sensor into the object(s) can decrease the effects of the sensor itself.

A.2 Slipperiness of the shear sensor surface

The 'slipperiness' of the shear sensor surface should be considered. There are two types of shear measurement by a shear sensor, one is measurement with no slip between the sensor and the object(s), and the other is measurement with slip. When measuring with no slip, it is appropriate to fix the sensor to the object(s), and to make slipperiness of the surface of the sensor low.

When measuring the shear force between a wheelchair cushion and a body with no slip, it is appropriate to fix the sensor to a cushion by a double-faced tape, and to cover the surface of the sensor with a fabric that is thin and has a high coefficient of static friction. In this case, note that when the slipperiness between two objects is very high, and between either object and the sensor is very low, the sensor can easily break.

When measuring the shear force with slip, the surface features (i.e. the coefficient of dynamic friction) of the sensor must be same as that of the object(s).

When the sensor is placed between an Object A and an Object B, the coefficient of friction of the side of the sensor which contacts Object A should be same as that which contacts Object B, and vice versa.

When the sensor is fixed to either object (e.g. Object A), the surface feature of only the other side (i.e. the surface that contacts Object B) should be considered.

A.3 Actual sensing area of a shear sensor

To compare the test results, pascal should be used as the unit of measure. The unit of measure of a raw data from the sensor is usually newton: to convert it to pascal, the raw data shall be divided by the actual sensing area of the sensor. The actual sensing area is where the force is being applied. Thus, for example, when part of the sensing area is not in contact an object, the actual sensing area becomes smaller. Otherwise, the actual sensing area is equal to the sensing area of the sensor.

A.4 Cabling

To take the raw data from a sensor, usually a cable is used to connect the sensor to an external circuit. When the cable is in contact with an object, a pull force on the object might occur. To minimize this adverse effect, one method to consider is using a flexible/stretchable cable. Another method to consider is to cover the sensor cable area with lubricant materials to minimize friction from the cable. Embedding a cable into an object is one way to minimize the adverse effect.

