

Pressure and Shear – Definitions, Relationships and Measurements

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Abstract:

Shear is a complex phenomenon and yet ever present in wheel chair seating and bed support surfaces. This is an attempt to define the terms and to relate the factors influencing shear and offers suggestions to minimize shear's influence on tissue.

Preamble:

The terms are often used to describe the force that causes deformation and the deformation itself. The definitions given here are from an engineering perspective but specifically address the wheelchair seat cushion or bed support surface environment. Often terms for stress (force) and strain (distortion) are confused, especially when the forces come from different directions. The resulting tissue strain (distortion) may be instrumental in reducing the blood and fluid flow to or from the distorted tissue. Shear is one of the items in the hierarchy of causes pressure ulcers (Taylor³¹). Shear reduces the pressure at which a decubitus occurs in swine by a factor of 6 (from 290mmHg to 45mmHg, Dinsdale³⁵) and since some shear may be necessary to keep people from sliding out of their wheelchair or bed, it is important to understand the cause of shear and how it combines with pressure.

Definitions:

Stress

Stress is force. Stresses in this case are the forces acting on the tissue. Said differently, stress is the force that tends to deform the tissue. Pressure and shear both contribute. The units are the same as for pressure, for example Pascals (N/m^2) or psi. Chow¹⁵ and Bennett¹⁶ defined three types of stress: Compressive Stress, Pinch Shear Stress and Horizontal Shear Stress. Compressive Stress results from purely normal forces (pressure). Pinch shear stress occurs around uneven pressure distributions such as bony prominences. Horizontal Shear Stress (more appropriately called Parallel Shear Stress) results from frictional forces. Ferguson-Pell¹⁹ and Noble¹⁷ used the term normal stress for those forces acting perpendicular to the surface and shear stress for those acting parallel to the skin.

Internal the combination of external forces (normal and shear) are carried by the tissue to the skeleton. The stresses are typically maximized at the bony prominence.

Pressure

Pressure is force per unit area. It is the force distribution normal to the surface. Pressure tends to compress the tissue. The units of pressure are pounds per square inch or Pascals (N/m^2) or mmHg, etc. A pressure distribution (pressure map) is a visual representation of the normal forces between two surfaces. It gives a good picture of where the forces are high and how closely they change from high to low.

Shear

Shear occurs when two forces are in opposing directions such that there is a deformation of the tissue in parallel planes (parallel shear). It also occurs when two forces are in the same direction but of different amounts (pinch shear).

Parallel Shear Stress – Tangential Force Induced Shear Stress

Parallel Shear Stress is a force that exists whenever there is sliding or the potential for relative motion (sliding) between two surfaces. Parallel Shear Stress is proportional to static friction prior to movement and dynamic friction during movement AND proportional to normal force before and during movement. It is opposite in direction to the force trying to make the surfaces move. The total parallel shear force could be thought of as how hard it would be to slide the person off a flat cushion. The localized parallel shear forces will be highest where the normal forces are high. The units of Parallel Shear Stress are Pascals (N/m^2), psi or mmHg. Notice that the units include an area term (per square inch, per square meter). In the case of sliding the person off the flat cushion the area involved is the contact area between the person and the cushion. When sliding a person off their cushion the Parallel Shear Stress acts parallel to the skin/support interface and is proportional to friction but limited by normal force. That is to say that a high normal force can carry a high Parallel Shear Stress but a low normal force requires a high coefficient of friction to carry the same Parallel Shear Stress.

It may be obvious when movement has occurred that there was the potential for shear but shear may also exist where relative movement has not occurred. To the extent that a cushion or bed support surface envelopes the person, it can give rise to Parallel Shear Stress at the periphery. This Parallel Shear Stress occurs because there is a component of the support forces running parallel to the surface due to friction of the cover.

Parallel Shear Stress has in the past been referred to as horizontal shear but since this shear can occur in the vertical direction, for example along the back rest of a wheelchair, it is more appropriately referred to as parallel shear stress.

Pinch Stress - Normal Force Gradient Induced Shear Stress

When forces of different magnitude are applied to neighbouring tissue there is a tendency to move one plane more than another. This is pinch shear stress. The spatial changes in the forces normal to the support surface (pressure gradient) give rise to internal shear forces that are perpendicular to the support surface. Noble¹⁷ defines this as “the shear stress component acting perpendicular to the skin, which is generated by the non-uniformity of the pressure distribution”. Figure 1 (d) shows a cube that is subjected to different normal forces on each side. On the left, the forces are small and on the right the forces are high. This creates a shear stress that tries to distort the cube. This pinch shear stress is perpendicular to and independent of the parallel (tangential) shear stress. Any time the support forces are not evenly distributed, a pinch shear stress is created internally and is not related to relative motion between the two surfaces.

The magnitude of this pinch shear stress is implied by the spatial rate of change of the force distribution (pressure gradient). When forces go from a high normal force, to low, very closely to each other, there is a high normal force gradient. If the force change is gradual across the support surface, there is a low normal force gradient.

Strain

Strain is distortion. Tissue strain (distortion) in this case is the deformation of the tissue that results from the applied forces.

The distortion associated with pressure is compression. Shear strain results from the combination of strains (distortions) induced by both parallel (friction related) and pinch (normal force gradient related) shear stresses.

Elastic Modulus

The pliability of the tissue is called its elastic modulus. Muscle has a high modulus, fat and skin have a low ones. Elastic modulus is defined as the ratio of Stress to Strain; the ratio of the force to the associated distortion. This means that if you have to push hard to distort the tissue (like muscle) it has a high modulus but if a small force distorts the tissue (like fat) then it has a low modulus. Because different tissues deform differently with the same force, the intersections of differing tissues have shear stress along the boundary. This is especially true for the interface at the bone.

Friction

Friction causes the force between two surfaces moving across one another. Friction is the mechanism by which shear forces are applied to the skin. This gives rise to shear stresses and shear strains within the tissues.

Friction is the force that tries to prevent the movement between two surfaces. Friction is always opposite to the direction of movement or intended movement. It is friction that prevents movement when an external force is applied and it is friction that causes the heat and abrasions that result from that movement. The amount of friction is limited by the amount of normal force and stickiness of the surfaces. Friction comes in two types static and dynamic.

Static Friction

Static Friction is the force that exists prior to movement between two surfaces as they try to move but before they actually move.

Dynamic (Sliding) Friction

Dynamic or sliding friction is the force that exists between two surfaces during relative movement (during sliding) and it is lower than static friction.

Coefficient of Friction

Coefficient of Friction is a measure of the stickiness of the combined surfaces. It is the ratio of the static or dynamic friction force to the normal force.

$$C_{sf} = F_{sf} / N \quad \text{and} \quad C_{df} = F_{df} / N$$

C = coefficient of friction

Sf = static friction

Df = dynamic friction

N = normal force

Said differently: It is the force required to initiate movement (or maintain movement) divided by the force pressing the two surfaces together. A low coefficient of friction describes surfaces that together are slippery and a high coefficient of friction describes two surfaces tend to stick to each other. Two different surfaces will have two different coefficients but they will combine to give an overall coefficient of friction for the pair. These same surfaces will have different coefficients of friction depending on the temperature and humidity.

The coefficient of dynamic friction is measured routinely for fabrics by dragging a known weight across a flat surface. The coefficient of static friction is measured by tipping the surface until the weight starts to slide down the surface.

Ref: ASTM C1028: Coefficient of Friction measurement by drag sled.

ASTM F1679: Coefficient of Friction measurement by inclined plane.

Relationships:

Relationship between Static and Dynamic Friction

Dynamic (sliding) friction is always lower than static friction, therefore, as forces are applied to try to move two surfaces with respect to each other, there is first a high force required to overcome the static friction and then a lowering of that force as the coefficient of friction drops to that of dynamic friction. The force remains low until the two surfaces cease relative motion (stops sliding). Once relative motion has stopped it is possible to again reach the higher forces necessary to overcome the static friction.

Both the static and dynamic coefficients of friction may increase as the patient sweats. A pressure relief at the end of the slide may eliminate remaining frictional forces.

Relationship between Parallel Shear Stress and Pinch Stress

Both parallel and pinch stresses (forces) cause strain (distortion). In cases where these forces cause distortion in the same direction they are additive. In other cases these forces may tend to cancel out each other's distortions. For example a parallel shear stress in one direction may be additive to pinch distortion but in the opposite direction it will reduce the pinch distortion. See fig 1(e)

Relationship between Pressure, Parallel and Pinch

Pressure is thought to limit blood flow to, and also trap waist products in, a region. Blood flow restriction occurs when pressure is above a threshold value related to capillary closure. Entrapment is related to a threshold value for the lymph system and may also be related to muscle activity. Shear is additive to pressure and reduces blood flow volume to increase the risk of sores. Cellular distortions maybe at the heart of these influences and since Pressure, Parallel and Pinch stresses all cause distortions it is reasonable to assume that they can all combine to limit blood flow and lymph system waste removal.

Although the support forces are applied at the surface they are spread out though the tissue and ultimately carried through the bone. The less tissue there is to spread out the stresses or the more compliant the tissue is at the bone the higher the stress is at the bone interface.

Although the units of measurement are the same for pressure parallel and pinch, (mmHg, psi) the methods of measurement are different and it is difficult of combine the numbers. However, reducing high pressures, reducing the coefficient of friction where the pressures are highest, and reducing the pressure gradient will improve any situation.

Friction and the associated parallel shear are needed to keep the patient from sliding out of the cushion or bed but not wanted where the pressures or pressure gradients are high and can potentially combine with these frictional forces to exacerbate tissue strain.

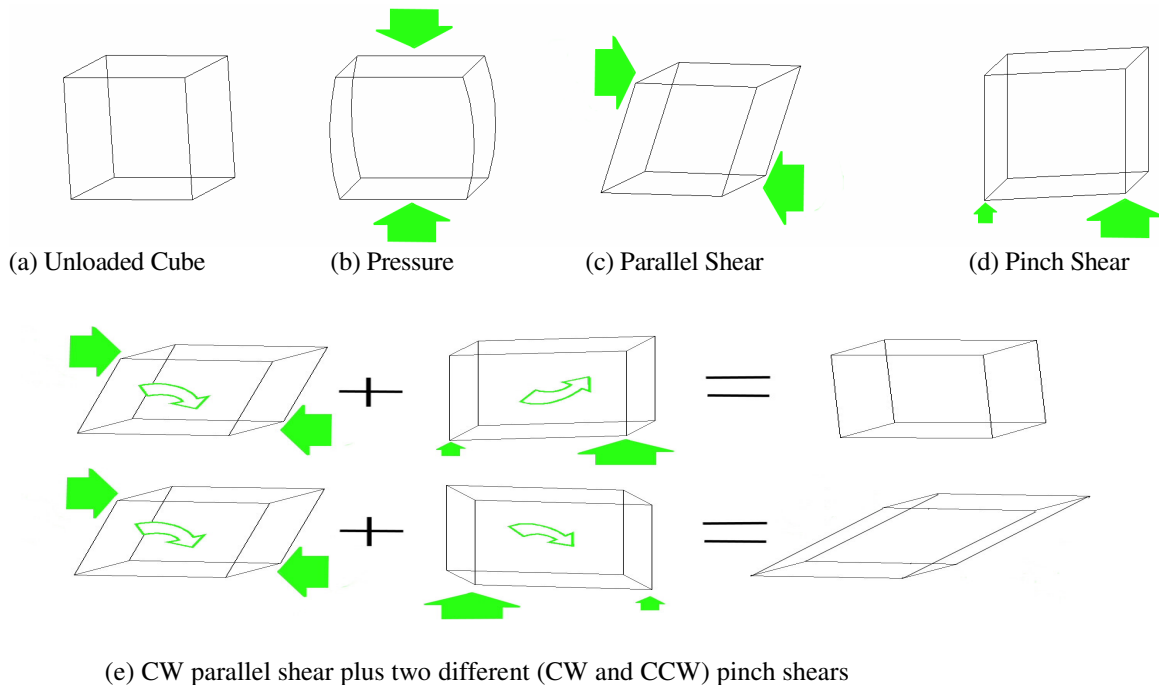


Fig 1. Cube subjected to various forces

Combined Shear Stress Measurement

The measurement of internal stress/strain requires the combination of both omni directional shear force sensor (to measure the parallel shear force), and an array of normal force sensors to measure the pinch shear force (pressure gradient). Since patients are at risk where pressures are highest and since high shear forces can also be transmitted where the normal forces are high (or the coefficient of friction is high), the highest potential for combining their influences occurs near the point of maximum normal force (typically near a boney prominence). Knowing the parallel shear and pressure gradient it is possible to estimate the maximum possible internal shear stress (typically at the soft tissue bone interface).

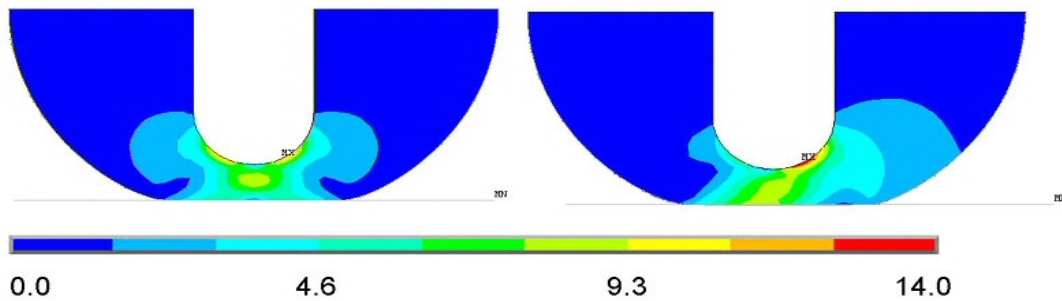


Fig 2. Finite Element Calculation of Internal Stress. In the figure above the white U in the center represents the ischial tuberosities. The blue represents homogeneous tissue. As the combined pressure and shear increase, the colors change from blues thru green yellow and finally to red at the bone tissue interface. Figure on the left shows no shear. Figure on the right includes shear. Note the maximum combined stress is one the right side of the boney prominence. (Courtesy of Dr. Makoto Takahashi. Hokkaido University).

Summary:

1. Shear stress is the force that tries to make things slide. Shear strain is the distortion that results.
2. Friction tries to prevent sliding.
3. No friction, no shear. No pressure, no shear.
4. Where pressures are high, the potential for parallel shear is high. Make sure that spot is slippery.
5. Near high pressures, the potential for pinch shear is high. Make sure the gradient is low.
6. Pressure, parallel and pinch stresses can combine. Do what you can to minimize them or keep them apart.

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