Pressure and Shear

Relating to Deep Tissue Injury

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“Despite the publication of clinical practice guidelines addressing pressure ulcer prevention and treatment by the Agency for Health Care Policy and Research (AHCPFR) within the past decade, the length of stay and cost associated with pressure ulcers continues to rise.”

Maybe...

Keep It Simply Scientific

Homeostasis
The body’s ability to maintain the relatively stable internal conditions even though the outside world changes continuously.
Key Point:

Pressure ulcers are the result of an ischemic event, not a crush injury.

Local control of blood flow by tissues

![Diagram of local control of blood flow by tissues]


Autoregulation

![Diagram of sphincters open and closed]

Active vs Reactive Hyperemia

Reactive Hyperemia
Occurs after the blood supply to a tissue is blocked for a short time with subsequent decrease in oxygen saturation and increase in metabolic waste.

Active Hyperemia
Occurs when the tissue metabolic rate increases.

Reperfusion Injury
Post-ischemic tissue injury caused by highly reactive oxygen-free radicals (Oxidative metabolic injury)

- Pre-existing factors
  Age
  Malnutrition
  Protein/calorie
  Vitamin/mineral
  Cellular Injury
  Hyperinflammatory response

Think of it as an “Aftershock” event

The body is supported by a hard framework

The body is 3-Dimensional
Tissue Tolerance

Pressure Ulcer Stages Revised by National Pressure Ulcer Advisory Panel (NPUAP)

February 2007 – The National Pressure Ulcer Advisory Panel has redefined the definition of a pressure ulcer and the stages of pressure ulcers, including the original 4 stages and adding 2 stages on deep tissue injury and unstageable pressure ulcers. The work is the culmination of over 5 years of work beginning with the identification of deep tissue injury in 2001.

Pressure Ulcer Definition – A pressure ulcer is localized injury to the skin and/or underlying tissue usually over a bony prominence, as a result of pressure, or pressure in combination with shear and/or friction. A number of contributing or confounding factors are also associated with pressure ulcers; the significance of these factors is yet to be elucidated.

Pressure Ulcer Stages Revised by National Pressure Ulcer Advisory Panel (NPUAP)

Pressure Ulcer Stages

Suspected Deep Tissue Injury: Purple or maroon, localized area of discolored intact skin or blood-filled blister due to damage of underlying soft tissue from pressure and/or shear. The area may be preceded by tissue that is painful, firm, mushy, boggy, warmer or cooler as compared to adjacent tissue.

Further description – Deep tissue injury may be difficult to detect in individuals with dark skin tones. Evolution may include a thin blister over a dark wound bed. The wound may further evolve and become covered by thin eschar. Evolution may be rapid exposing additional layers of tissue even with optimal treatment.

Pressure Ulcer Stages Revised by National Pressure Ulcer Advisory Panel (NPUAP)
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Stage I – Intact skin with non-blanchable redness of a localized area usually over a bony prominence. Darkly pigmented skin may not have visible blanching; its color may differ from surrounding area.

Further description – The area may be painful, firm, soft, warmer or cooler as compared to adjacent tissue. Stage I may be difficult to detect in individuals with dark skin tones. May indicate “at risk” persons (a heralding sign of risk).

Stage II – Partial thickness loss of dermis presenting as a shallow open ulcer with a red pink wound bed, without slough. May also be present as an intact or open/ruptured serum-filled blister.

Further description – Presents as a shiny or dry shallow ulcer without slough or bruising*. This stage should not be used to describe skin tears, tape burns, perineal dermatitis, maceration or excoriation. *Bruising indicates suspected deep tissue injury.

Pressure Ulcer Stages Revised by National Pressure Ulcer Advisory Panel (NPUAP)

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Stage III – Full thickness tissue loss. Subcutaneous fat may be visible but bone, tendon or muscle are not exposed. Slough may be present but does not obscure the depth of tissue loss. May include undermining and tunneling.

Further description – The depth of a stage III pressure ulcer varies by anatomical location. The bridge of the nose, ear, occiput, and malleolus do not have subcutaneous tissue and stage III ulcers can be shallow. In contrast, areas of significant adiposity can develop extremely deep stage III pressure ulcers. Bone/tendon is not visible or directly palpable.

Stage IV – Full thickness tissue loss with exposed bone, tendon or muscle. Slough or eschar may be present on some parts of the wound bed. Often include undermining and tunneling.

Further description – The depth of a stage IV pressure ulcer varies by anatomical location. The bridge of the nose, ear, occiput and malleolus do not have subcutaneous tissue and these ulcers can be shallow. Stage IV ulcers can extend into muscle and/or supporting structures (e.g. Fascia, tendon or joint capsule) making osteomyelitis possible. Exposed bone/tendon is visible and directly palpable.

Pressure Ulcer Stages Revised by National Pressure Ulcer Advisory Panel (NPUAP)

Pressure Ulcer Stages Revised by National Pressure Ulcer Advisory Panel (NPUAP)

Unstageable – Full thickness tissue loss in which the base of the ulcer is covered by slough (yellow, tan, gray, green or brown) and/or eschar (tan, brown or black) in the wound bed.
Pressure Ulcer Stages Revised by National Pressure Ulcer Advisory Panel (NPUAP)

The staging system was defined by Shea in 1975 and provides a name to the amount of anatomical tissue loss. The original definitions were confusing to many clinicians and lead to inaccurate staging of ulcers associated or due to perineal dermatitis and those due to deep tissue injury.

The proposed definitions were refined by the NPUAP with input from an on-line evaluation of their face validity, accuracy clarity, succinctness, utility, and discrimination. This process was completed online and provided input to the Panel for continued work. The proposed final definitions were reviewed by a consensus conference and their comments were used to create the final definitions. "NPUAP is pleased to have completed this important task and look forward to the inclusion of these definitions into practice, education and research", said Joyce Black, NPUAP President and Chairperson of the Staging Task Force.

Clinical Ramifications of Deep Tissue Injury

Can develop within 2 to 6 hours

May take 3 to 7 days to be clinically recognized

Complicates admission and discharge procedures

The Effects of Extended Bedrest

(Microgravity)

- Blood volume
- In red cell mass
- In muscle strength and work capacity
- In maximum cardiac output
- Loss of calcium, phosphate and mass from bones

"Most of these same effects also occur in people who lie in bed for an extended period of time."

Pressure Ulcer Development

Pathophysiology

- Mechanical stress (Gradient pressure or shear)
- Soft tissue distortion
- Change in velocity of character of blood flow
- Margination of intravascular cells
  - Intravascular coagulation
  - Decreased Oxygen
  - Anaerobic metabolism
  - Ischemia
  - Necrosis
  - Inflammatory Response

Homeostatic Imbalance
The Culprit

Body Weight
(Skeletal Press)

Tissue at Risk
(Viscoelastic tissue)

Support Surface
(Media – Container Design)

Competition for Space

Know the effect of the support surface on the soft tissue at risk

Mechanical Stress
- Pressure
  - Gradient pressure
  - Non-gradient pressure
- Shear

Soft Tissue Strain
- Distortion
- Volumetric
Know the effect of the support surface on the soft tissue at risk

Mechanical Stress
- Pressure
  - Gradient pressure
  - Non-gradient pressure
- Shear

Soft Tissue Strain
- Distortion
  - Volumetric

Unequalized Weight Distribution

Know the effect of the support surface on the soft tissue at risk

Mechanical Stress
- Pressure
  - Gradient pressure
  - Non-gradient pressure
- Shear

Soft Tissue Strain
- Distortion
  - Volumetric

Flotation Therapy
(Equalized Weight Distribution)

Soft Tissue Distortion

What is it?
Shape Deformation
Soft Tissue Distortion

What causes it?
Tangential Force/Area = Shear
Gradient Pressure = Vertical Shear

Soft Tissue Distortion

What does it cause?
1. Vessel crimping
2. Ischemia
3. Tissue injury

Necrosis

Volumetric Support

What is it?
Proper soft tissue skeletal anatomical alignment
Volumetric Support

What causes it?
Symmetrical
Perpendicular Support

Volumetric Support

What does it cause?
Maintains homeostasis of soft tissue

Newton’s 3rd Law
For every force exerted on one body, there is an equal, but oppositely directed, force acting on some other body.

*Schaum’s Outline of Theory and Problems of College Physics,
Eighth edition. Bueche PhD, Frederick J., Distinguished Professor at Large, University of Dayton.*
Definition of Force

A push or pull exerted on a body. It is a vector quantity, having magnitude and direction.

-Schaum’s Outline of Theory and Problems of College Physics. Eighth edition. Bueche PhD, Frederick J., Distinguished Professor at Large, University of Dayton.
**Pressure**  
Load perpendicular to the plane of interest.

**Shear**

**Friction**  
Load parallel to the plane of interest.

Tendency of two objects to stick together
Frictional forces act to oppose relative motion between surfaces that are in contact. Such forces act parallel to the surface.

Frictional force equation:

\[ F_f = \mu N \]
Gradient pressure
(Unequalized)

vs.

Non-Gradient pressure
(Equalized or Volumetric)
Understanding the PreShear Vector
3-Dimensional

Magnitude

Plane of Interest

Direction

Vertical Shear

Vertical Shear
Pressure Ulcer: Mechanical stress induced ischemic necrosis of three-dimensional soft tissue predominantly of nutritionally and mobility impaired individuals due to placement on a support surface.

Pressure ulcer definition according to Dr. Spahn.
Support Surfaces:
How do I choose?

Unintended Consequences

"It is recognized that the word ‘pressure’ comes from physics and describes a force perpendicular to an area"
AGREE

"In the pressure ulcer community, we have interchanged the word ‘force’ in the physics language to mean load or weight on a bony prominence"
DISAGREE
Unintended Consequences

The Confusion

“Attempts to reduce pressure on a bony prominence must be directed at the other part of the equation – area”

Agree...but

Support Surface Resultant Stress

\[ \text{Support Surface Resultant Stress} = \frac{\text{Force} \times \text{Area (contour)}}{\text{Contouring}} \]

Greater: What Direction
Less Strain
Less Strain

Support Surface Resultant Stress

\[ \text{Support Surface Resultant Stress} = \frac{\text{Force} \times \text{Area (contour)}}{\text{Contouring}} \]

Greater: Contouring
Less Strain
Less Strain
Support Surface Resultant Stress

\[ \text{Resultant Stress} = \frac{\text{Force}}{\text{Area}} \]

(Magnitude & Direction)

(Amount)

Contouring  Non-Contouring

The body is 3-D, not 2-D!

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Which media provides the best volumetric support?

- Contouring
- Gradiency
  (Three-dimensional weight distribution)

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Important!

4 inches of the support surface immediately adjacent to the body determines the body’s response to the support surface.

- Media
- Container Design
Basic scientific principles relating to mechanics and physics explain the effects of various support surfaces

- Basic physics
  - 200 BC
    - Archimedes
  - 17th Century
    - Boyle
    - Pascal
    - Newton
    - Hooke’s
      - Young’s Modulus
      - Shear Modulus
      - Bulk Modulus

- Physical properties of media
  - Static (non-powered)
    - Gas
      - minimal molecular bonding
    - Liquid
      - moderate molecular bonding
    - Solid
      - strong molecular bonding
  - Dynamic (powered)
    - Fluid
      - Gas

SOLID VS. FLUID
History of Medical Foam Usage

1960 – Egg Crate
1970 – Foam Overlay (Patterned)
1980-1990 – Foam Replacement Mattresses
1990-Present – Therapeutic Foam Mattress

I. Stacked Glued Foam
II. Viscoelastic Foam
III. Foam on Air
IV. Foam on Foam

Manufacturing

A. Polyall (Formula)

Ten sided cells
Elastic cells
Windows (Open cell)
Urethane (Ether Based)
Manufacturing

A. Polyall (Formula)

Compressed

10 Sided Cell

B. Technique

- EPA Regulation changed approximately 5 years ago
- Blowing techniques (Chemical)
  - a. Freon
  - b. Methylene Chloride
  - c. CO₂

Manufacturing

B. Technique

- VPF (Variable Pressure Foaming)
  - a. Mechanical
Manufacturing

C. Blowing vs. VPF
- Cell Wall Consistency
- Bun consistency
- Stiffness
- Environmental Affect

Manufacturing

C. Blowing vs. VPF
- Durability
- Environmental Affect
  - UV Light
  - Hydrocarbons
  - Temperature
  - H2O

Manufacturing

B. Blowing vs. VPF
- Durability
  - Elasticity Loss (10%)
    - 20% Early
Formula Causes
IFD (Stiffness) → Softener (Reduces Stiffness)

(Chemical)
Freon
Methylene Chloride
CO₂

(Mechanical)
VPF

Reduces Stiffness and Reduces Strength of Cell Wall
Reduces Stiffness but Maintains Strength of Cell Wall

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<table>
<thead>
<tr>
<th>Foam Type</th>
<th>Air Release Time</th>
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<tbody>
<tr>
<td>Closed Cell</td>
<td>NONE</td>
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<tr>
<td>Open Cell</td>
<td>MODERATE</td>
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<tr>
<td>Viscoelastic</td>
<td>VERY SLOW</td>
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<table>
<thead>
<tr>
<th>Foam Type</th>
<th>Memory</th>
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<tbody>
<tr>
<td>Closed Cell</td>
<td>COMPLETE</td>
</tr>
<tr>
<td>Open Cell</td>
<td>MODERATE</td>
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<tr>
<td>Viscoelastic</td>
<td>GOOD</td>
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### Compaction Time

<table>
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<tr>
<th>Foam Type</th>
<th>Compaction Time</th>
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<td>Open Cell</td>
<td>MODERATE</td>
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<tr>
<td>Viscoelastic</td>
<td>SLOW</td>
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</table>

### Indentation (Push Back)

<table>
<thead>
<tr>
<th>Foam Type</th>
<th>Indentation (Push Back)</th>
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<tbody>
<tr>
<td>Closed Cell</td>
<td>GREAT</td>
</tr>
<tr>
<td>Open Cell</td>
<td>MODERATE</td>
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<tr>
<td>Viscoelastic</td>
<td>LEAST</td>
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### Recovery Time

<table>
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<tr>
<th>Foam Type</th>
<th>Recovery Time</th>
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<tr>
<td>Closed Cell</td>
<td>NONE</td>
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<tr>
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<td>MODERATE</td>
</tr>
<tr>
<td>Viscoelastic</td>
<td>SLOW</td>
</tr>
<tr>
<td>Foam Type</td>
<td>Conclusion</td>
</tr>
<tr>
<td>--------------</td>
<td>----------------------------------------------------------------------------</td>
</tr>
<tr>
<td>Closed Cell</td>
<td>No Medical Usage</td>
</tr>
<tr>
<td>Open Cell</td>
<td>Medical Usage, but creates pressure and shear</td>
</tr>
<tr>
<td>Viscoelastic</td>
<td>Medical Usage, but creates pressure and shear and limited by creating a difficult mobility media</td>
</tr>
</tbody>
</table>
Static Fluid

FLotation
(Pascals Principle)

Air: Contouring
Volumetric Support

Confusion

Contouring
vs.
Flotation

Contouring ≠ Flotation
What’s the difference between the different types of fluids?

- Static
  - Density
  - Viscosity
- Dynamic

Dynamic vs. Static Fluid

“A fluid is, by definition, a substance in which there is no shear stresses when at rest. All substances in motion have shear stresses acting in addition to the normal stresses.”

Besancon, Robert M., The Encyclopedia of Physics, Third Edition

Dynamic vs. Static Fluid

“In motion, the normal stresses in a fluid are not equal in all directions, but the average of the normal stresses is employed and called pressure as an extension of the concept of pressure which arises in fluid statics.”

Besancon, Robert M., The Encyclopedia of Physics, Third Edition
Dynamic vs. Static Fluid

“Many fluids, e.g., tar, waxes, oil, honey, bread dough, and many other synthetic polymers, have both normal stress and shear stress components which depend on the recent deformation history as well as on the current rates of deformation.:

(See RHEOLOGY)

Besancon, Robert M., The Encyclopedia of Physics, Third Edition

Why Static Air?

As the media thickens and become more viscous, the less you will shrink into the product and the more you will have tissue distortion due to increased shear forces due to resistance to flow.

Why Static Air?

Volume of body sinks into static air chamber compressing and displacing volume of air in chamber until pressure in chamber* is enough to support weight of body (Bouyancy Principle, Boyle’s Law and Newton’s Third Law) in perpendicular, non-gradient fashion. (Pascal’s Principle)

*Intra-chamber pressure
How full do I fill my bathtub?
Container Design
1. Durable
2. Pliable
3. Accommodate physical properties of media (displacement)

Dynamic Fluid
Proper Inflation Management

Dynamic Fluid
Alternating Pressure

Dynamic Fluid
Alternating Pressure
Physical Properties of Media

<table>
<thead>
<tr>
<th>MECHANICAL STRESS</th>
<th>SOFT TISSUE STRAIN</th>
</tr>
</thead>
<tbody>
<tr>
<td>Gradient Pressure</td>
<td>Non-Gradient</td>
</tr>
<tr>
<td>Pressure &amp; Shear</td>
<td>Pressure</td>
</tr>
<tr>
<td></td>
<td>Distortion</td>
</tr>
<tr>
<td></td>
<td>Volumetric</td>
</tr>
</tbody>
</table>

Solid           | X      | X      |
Static Fluid    |        |        |
(Non-Powered)    |        |        |
Air             |        | X      | X      |
Water           | X      |        |        |
Sol             | X      |        | X      |
Powered Air     | X      |        | X      |

REMEMBER!

All containers are solids and their design and construction determine the effectiveness of the internal media.

Interface pressure readings measure only the pressure at the skin surface.

(length x width)
Pressure mapping is a form of interface pressure readings.
A 3-dimensional approach is needed to accurately assess the effectiveness of a support surface.

(length x width x depth)

Soft tissue contact with a support surface will result in either volumetric support or distortion (shearing).

CT scans help us visualize soft tissue changes.
**Why CT and MRI Scan Studies?**

Since
The body reacts to a support surface in a
stress to strain relationship
and
The type and design of support surface dictates
the type of stresses applied to the body
and since
There is no device available to measure
the interface pressure-shear vector
then
Visualizing the strain of the soft tissue enables
clinicians to evaluate the stresses delivered by
various surface types to the soft tissue at risk.

**Contouring**

**Static Air**    **Foam**
CT SCAN Findings

- Reliable, non-invasive, and reproducible
- Coincides with animal and biomedical research.
- Define and visualize soft tissue distortion around the body prominence (wedge effect)
- 3-4 inches of the support surface next to the body dictate the resultant stresses to the soft tissue
- No support surface alone can protect the Ankle-heel complex at all times

Clinical Implications

Must understand the pathophysiology of deep tissue injury

Since deep tissue injury can occur in as little as 2 hours, use of protocols, including support surfaces and lower extremity devices, must be used immediately on all surfaces at all times

Clinical recognition of deep tissue injury can take 3 to 7 days.

Support Surface Selection is a modifiable event.
Please Remember

- No support surface can protect the ankle/heel region from pressure ulcers at all times

Not because they are bad products

This occurs because of:

- Recumbent Physiologic Changes
- Hemodynamics
- Anatomy of the Region

ALL SUPPORT SURFACES SHOULD:

- Redistribute weight equally in a 3-dimensional manner.
- Minimize pressure, shear and friction injury.
- Assist in moisture and temperature control.
- Minimize surface contamination and bioaerosol spread.
- Be easy to clean.
- Aid in patient transferring and mobilization.
- Be compatible with multiple surfaces.
- Be cost effective.
Why Follow Protocols

ALL SUPPORT SURFACES SHOULD:

- Fulfill regulatory requirements.
  - Flame retardant
  - Bio-compatibility
  - Antimicrobial
  - FDA regulations
  - Good manufacturing processes (i.e. ISO)
- Address safety and comfort of the patient.
  - Low-profile design (i.e. height, entrapment)
  - Pliable but durable
  - Latex Free

3. Addressing the Problem
Clinical Protocols for Pressure Ulcers Should Address:

- Cognition
- Mobilization & Ambulation
- Nutrition and Hydration
- Moisture and Incontinence
- General Medical Co-Morbidities (Medication Use)
- Existing Pressure Ulcers (Deep Tissue Injury)
- Previous Pressure Ulcers (Closed Stage III, IV and Unstageable)

A separate risk scale must be used for prevention and treatment of pressures on the ankle, foot and heel due to the fact that support surfaces alone cannot adequately address this problem, foot drop or lateral rotation.
Pressure and shear relief on all surfaces must be addressed (i.e., OR tables, wheelchairs, geri-chairs, transportation carts, etc.)

Overlay Advantages:
May be utilized during patient repositioning and transfers for caregiver ease
May be utilized on multiple surfaces (i.e. mattress, transfer cart, etc.)
May be used throughout the continuum of care (i.e., unit to unit, facility to facility, facility to home)

FACTS

- Protocols decrease incidence by 50% \(^1\)
- Usage of pressure-reducing devices alone can cause an increase in incidence. \(^2\)

Clinical Protocols

Nutrition
Mobilization
  Ambulate
  Turn
  Passive Range of Motion
Support Surface
  Bed, Chair, Cart, Emergency Room, Operating Room
Lower Extremity Protection
Incontinence Care
Wound Care
Continuum of Care

Treatment of other general medical conditions

Summary
If the body is 3-dimensional then Deliverance of gradient pressure and shear mechanical stresses by the support surface (solids, gels, and powered fluids) will Cause soft tissue distortion, change in velocity and flow pattern of the circulation, causing endothelial damage resulting in ischemia and possible infraction of the soft tissue at risk (pressure ulcer) thus Selection of these types of media must be evaluated by scientific facts and soft tissue strain visualization (CT or MRI scanning) since pressure mapping is 2-dimensional and unreliable in defining causation of the soft tissue distortion

Conclusion
If the body is 3-dimensional then Volumetric support (flotation) is needed to maintain proper tissue orientation then A static fluid media (gas, liquid, sol) is needed to float the body in a flexible container that is properly filled or inflated and Static air is preferred to liquid or sol because it has less density and no viscosity

Flotation Therapy
“Equalized distribution of the body’s weight”
Nature’s Flotation

Do No Harm!

Hippocratic Oath

Clinicians are held accountable to proven clinical standards of care

Understand the underlying problem
Do not impair the body’s autoregulatory mechanism (Homeostasis)
Product selection should be based upon scientific facts, not marketing materials

Clinicians are held accountable to proven clinical standards of care

Increased expenditure does not always guarantee better outcomes.

Summary

1. Recognizing the Problem

↑ $ ⇑ Clinical Outcomes

Maklebust J. An update on horizontal support surfaces. Ostomy/Wound Management 1999; 45(1A (Suppl)):708-775.


If clinical outcomes are equal, choose the most cost-effective product.

Caution
Cost effectiveness does not always mean “the cheapest.”

In Summary – “The Six ‘R’s”
- Re-think
- Review
- Re-group
- Re-train
- Respond
- Reward