Clinical Application of Pressure Mapping

Stephen Sprigle, PhD, PT
Georgia Institute of Techology
Kim Davis, MSPT, ATP
Shepherd Center

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.

NPUAP, 2007

Redistribution of Pressure
Rationale for Interventions

Pressure Ulcer Etiology

Tissue Load

Magnitude and Duration

Interventions:

Support Surfaces
Positioning Devices
Posture

Interventions:

Repositioning
Weight Shifting
Active surfaces

Tissue Load

- Force – can act normal or tangential to tissue
- Pressure = Force / unit area
  - Acts normal to the tissue and causes compression
- Stress is the force per area that deform tissue

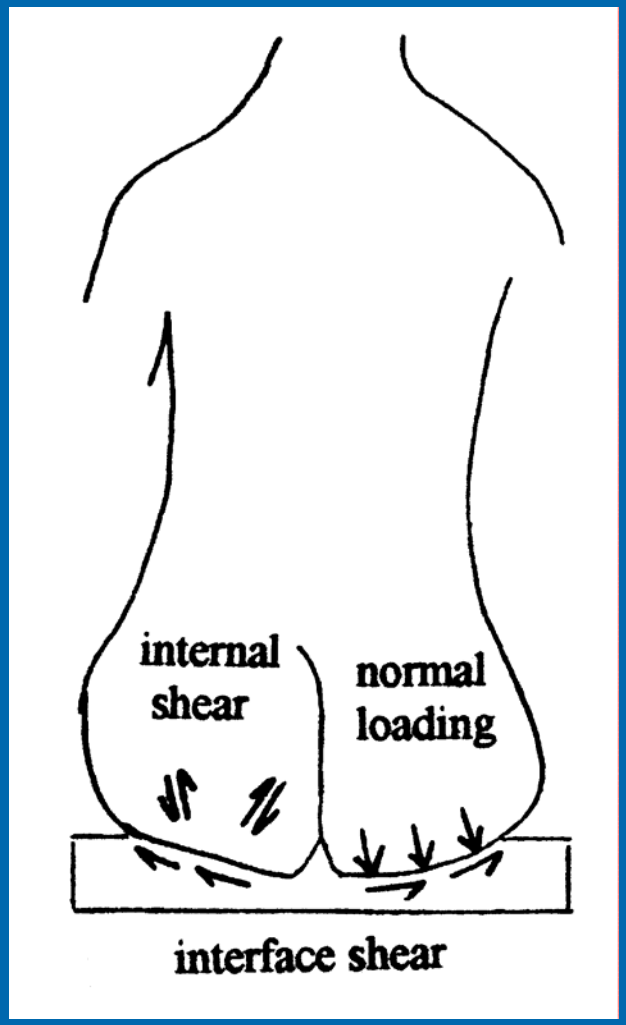
Normal force vs. Shear

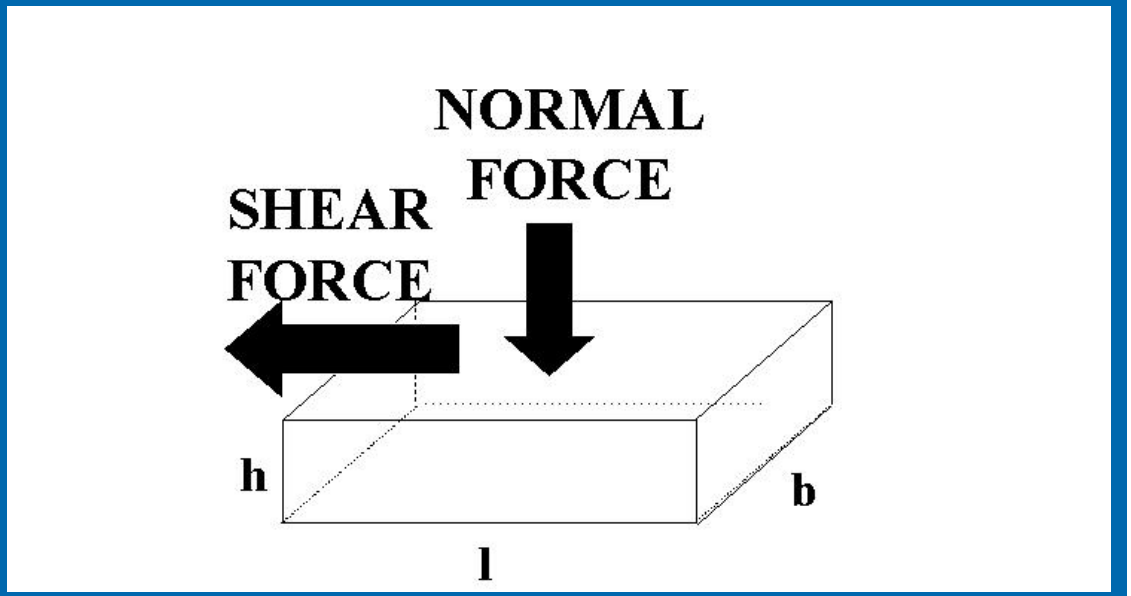
- Normal pressure is a type of stress acting perpendicular to the surface.
- Compression of tissue can also compress blood vessels and inhibit blood flow
- IPM measures only “normal force”
  - Using the area of the sensor, forces are converted to pressures.

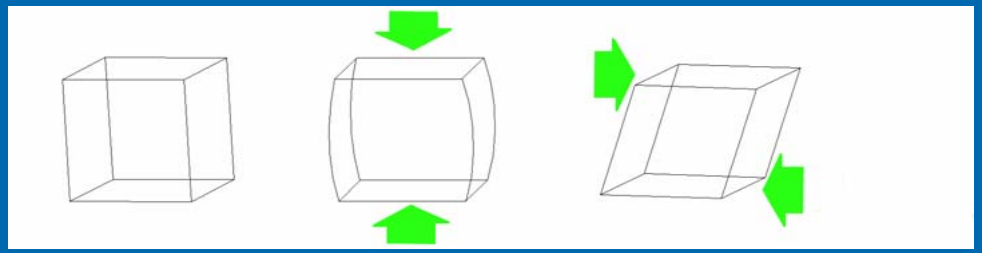
Shear: strain and stress

- *Shear strain* is the deformation of tissue movement of tissues in relation to bony structures; tissue deformation; can separate tissue layers.
- *Shear stresses* also exist:
  - Result from forces acting tangential to surface of tissue or from pressure gradients on the tissue.
- The presence of shear reduces the blood vessels resistance to collapsing;
- IPM devices do not measure shear.

Direction & magnitude of normal and shear forces



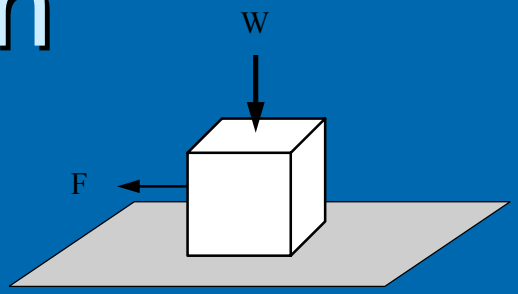




The Science
Shear versus Friction

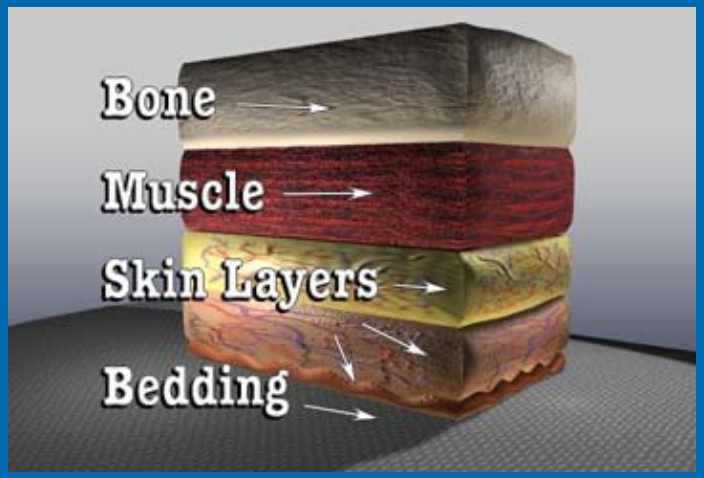
- Terms are used interchangeably, but they are not the same.

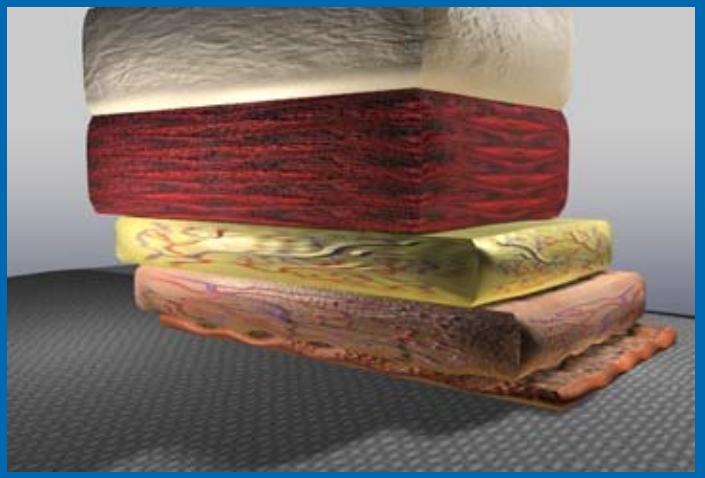
Shear and friction

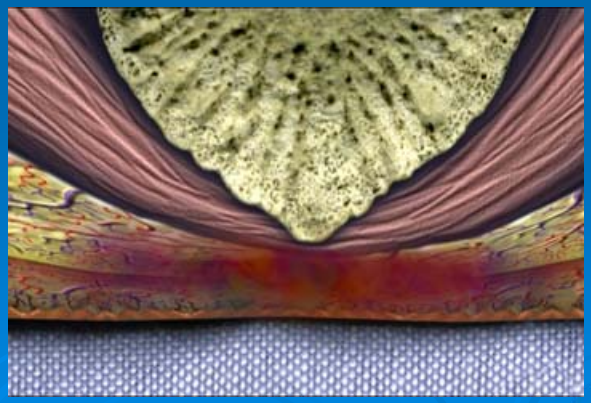


- Friction:
  - contact force that impedes sliding.
  - Clinically, often refers to damaging forces caused by sliding.
  - frictional forces are proportional to normal forces.
- Friction is a type of shear force, but not all shear forces are friction.
- ALL forces on tissue (normal, friction, shear) induce shear *strain* in tissue.
  - Any interaction causing tissue deformation will induce strain.

Shear Strain of Tissue

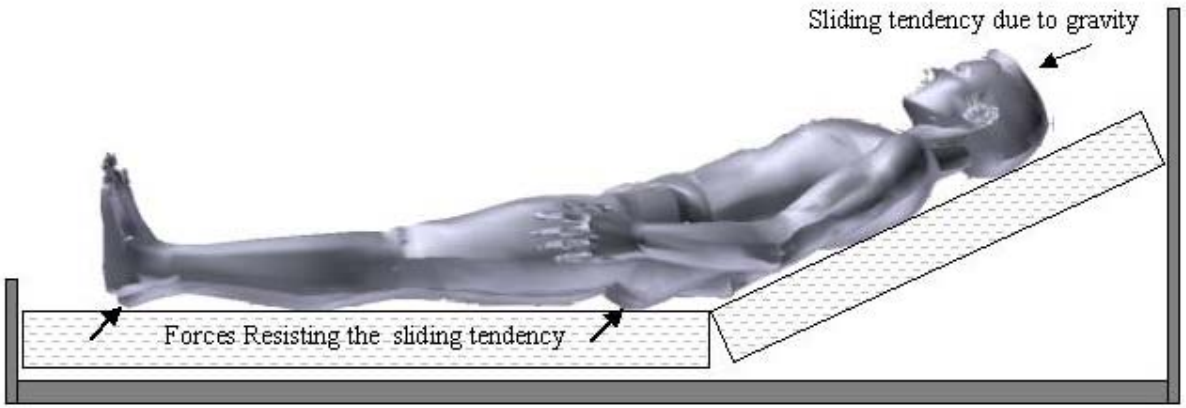




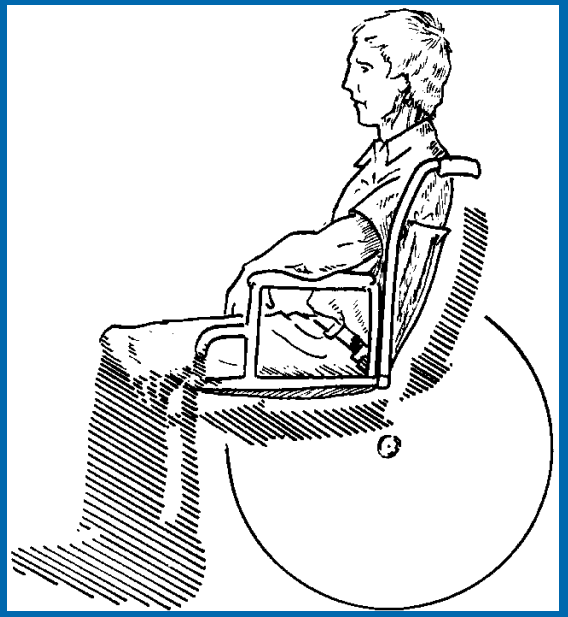


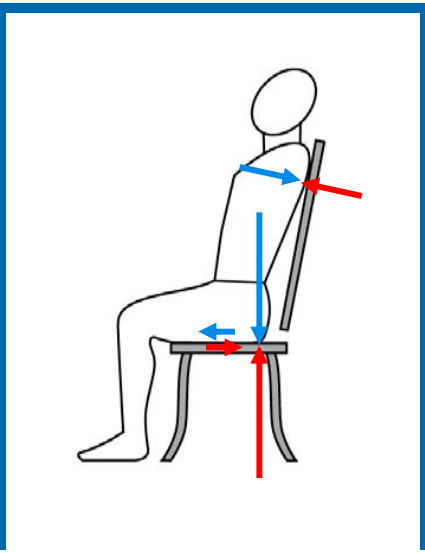
Friction and Shear

Frictional forces due to semi-recumbent position



Sling seat & back upholstery resulting in slumped posture and increased sliding tendency



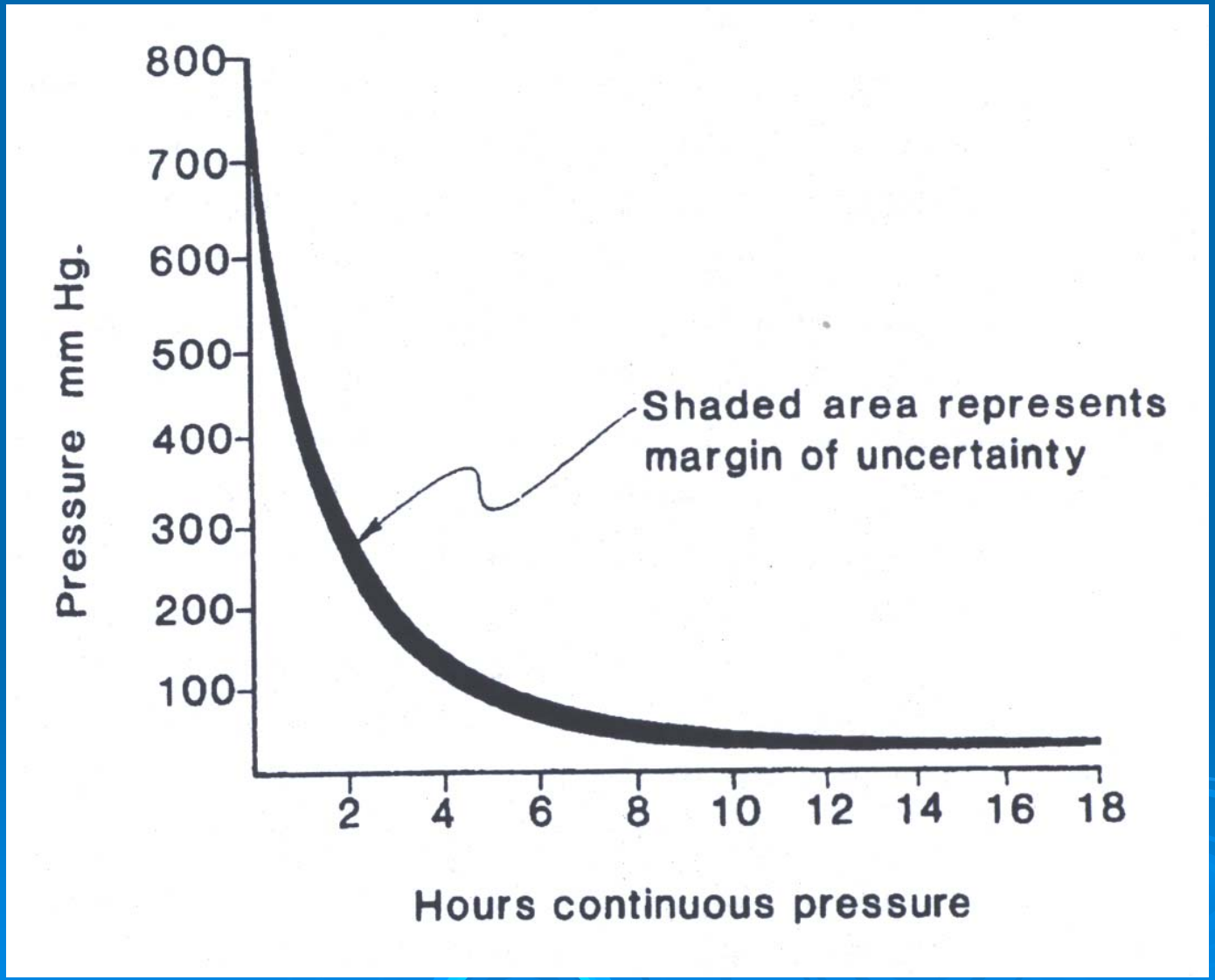


Anytime a backrest is used, friction must exist to keep a person seated

The Science
Amount and Duration of Load

- Inversely proportional.
- The greater the load, the shorter the time the tissues can withstand before damage occurs (Kosiak, 1959).

Reswick & Rogers, 1976



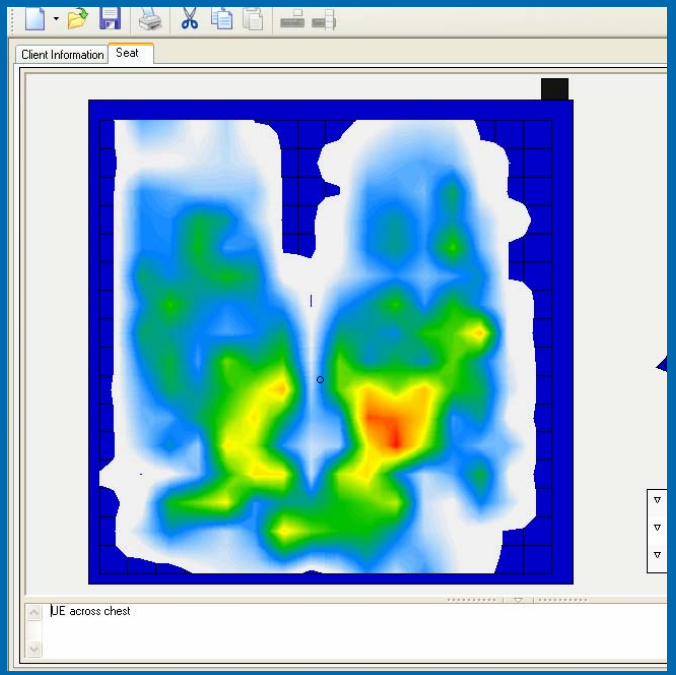
The Clinical Objective
Load redistribution

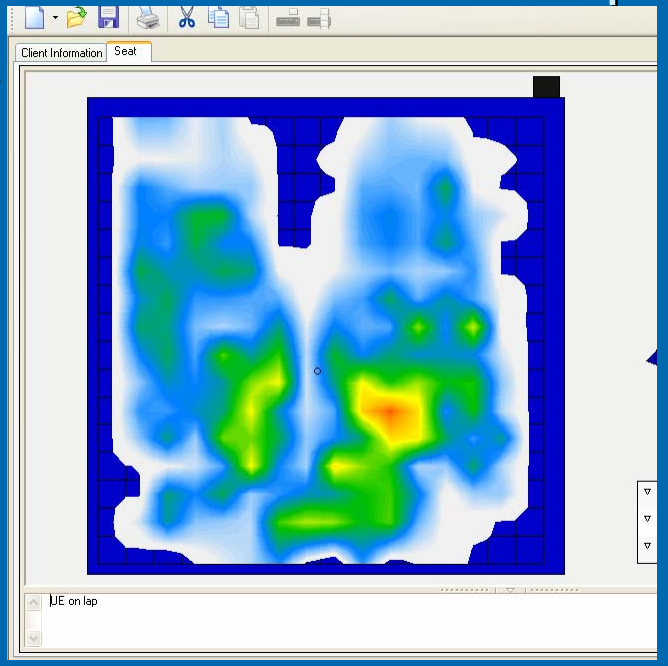
- Distribute load over maximum area.
- Reduce loading on ‘at-risk’ sites
- Extends beyond the seat to footrests, armrests, backrest and headrest.
- The forces on the seat represent ~2/3 of total body weight (represents upper body weight).

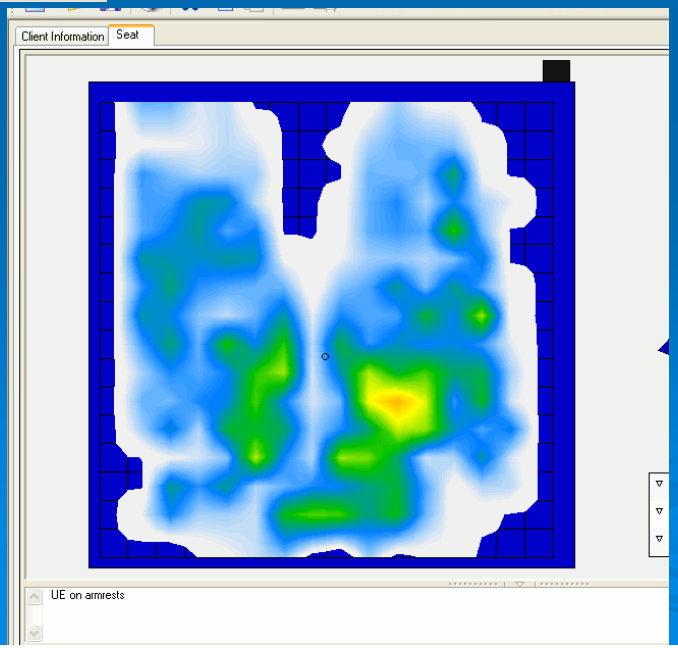
UE's across chest

Arm position changes load on seat

UE's on lap



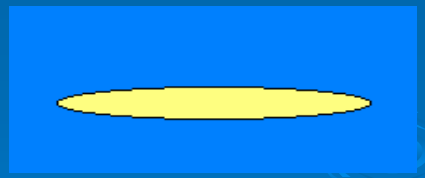




UE's on armrests

Mat technology- sensors

- Resistive
  - Conductance changes in proportion to load
- Capacitive
  - forces compress the 2 conductors together
- Pneumatic
  - internal air pressure changes as load applied externally
- Hydraulic
  - similar to pneumatic



Mat Comparison

	Sensor type	Sensing area (cm)	# of sensors	Resolution (Center spacing)
FSA	Resistive	43 x 43	256	2 cm
Tekscan Conformat	Resistive	47 x 47	1024	1.4 cm
Xsensor	Capacitive	45 x 45	1296	1.25 cm

Sensor Characteristics

- Accuracy
- Range
- Creep
- Hysteresis

Accuracy

- A measure of error
  - Difference between the *measured* value and the *actual* value
- When using IPM technology, one never knows the *actual* value
  - Errors of ≈ 10% are to be expected
- Mat accuracy is established during calibration

Range

- The minimum to maximum pressures that can be measured by a sensor
- IPM used in seating
  - 0-200 or 300 mmHg
- Some systems
  - Report only up to max calibration value
  - Extrapolate above calibration limit

Accuracy varies over range
At low values ..

- *electrical noise* dominates pressure value
- Constant error: Given noise of 5mmHg…
  - If apply 5mmHg, mat reads 10mmHg
  - If apply 150mmHg, mat reads 155mmHg
- Relative error: increases with magnitude
  - Might desire full scale error or ½ scale

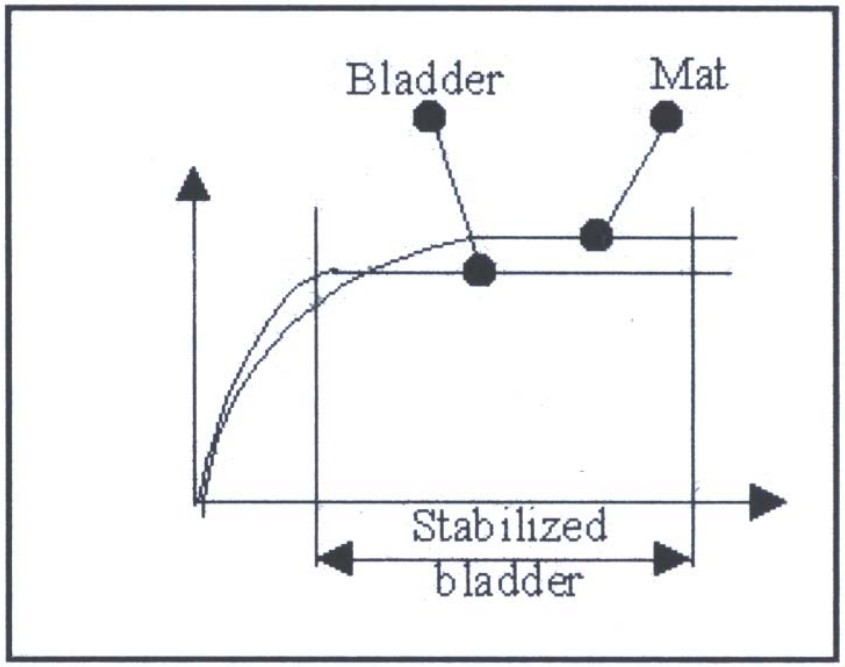
Accuracy varies over range
At high end of scale…

- Due to **saturation**
  - If mat calibrated to 200mmHg, a sensor value of 200 could equal 200, 201, or 2001mmHg.
  - This should be considered if you decide to calibrate to a lower max value (e.g. 100mmHg if working with pediatric clients).
- Due to **extrapolation**
  - Extrapolated values more error-prone than interpolated ones

Choosing range

- Choose sensors that reflect the range of interest
  - E.g., blood pressure sensors range to 300 mmHg (or 5 PSI, or 40 kPa)
- IPM- calibrate to capture the range of interest
  - Adult Seating: typically 200+ mmHg
  - Bed lying: 100 mmHg

Creep



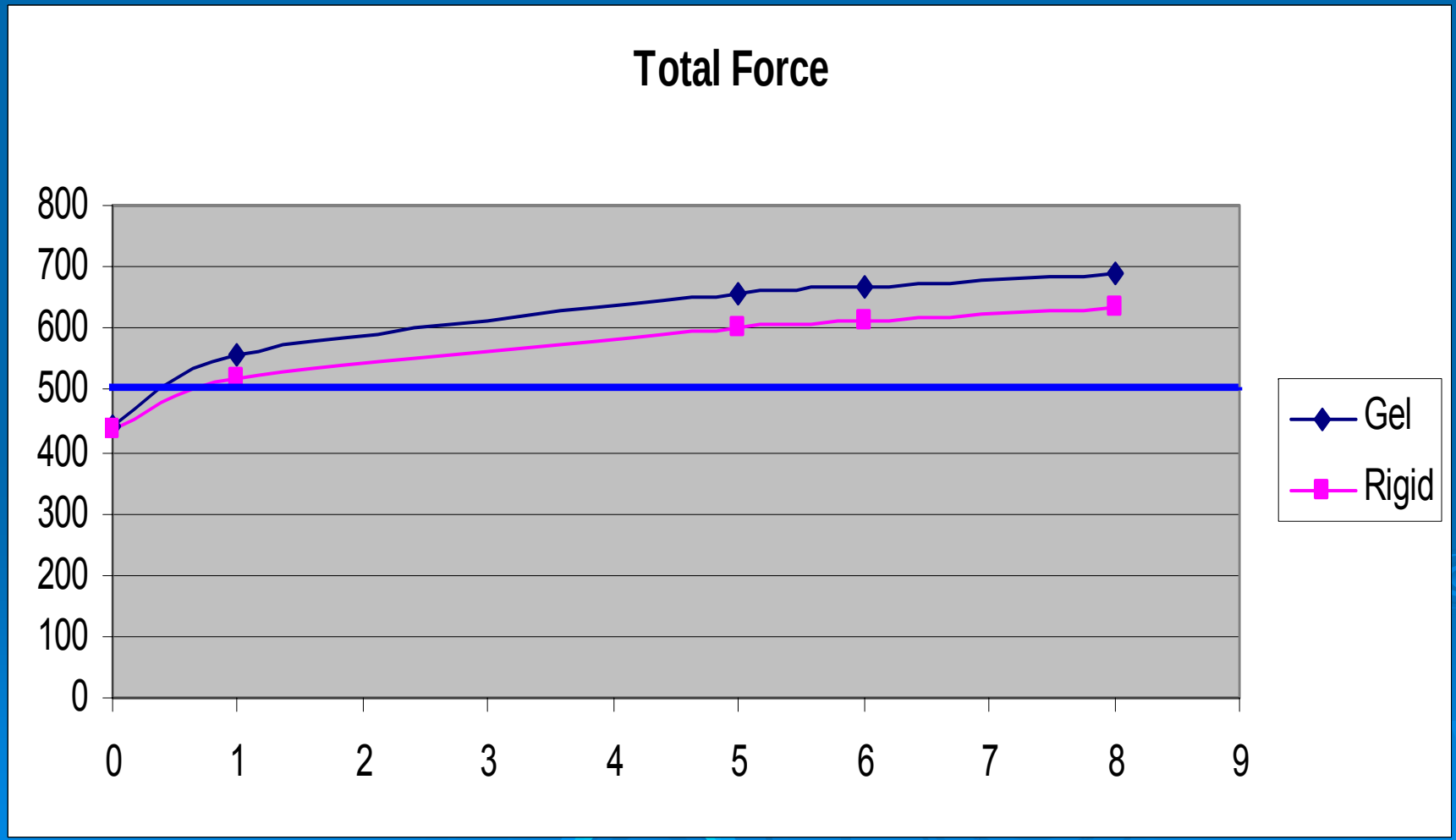
- Mat creep is the slow increase in pressure over time with constant load applied.
- Creep due to **mat, cushion and tissue** have to be acknowledged.
- Creep helps determine how long to wait until to take a measurement

Figure: Nicholson, et al (2001)

Mat creep:
apply 500N load using buttock models

Time frame	Changes in total force		Changes in peak pressure	
	Gel	Rigid	Gel	Rigid
between 0-1 minute	26%	18%	26%	19%
between 1-5 minutes	18%	15%	21%	26%
between 5-8 minutes	5%	5%	7%	8%
between 1-8 minutes	44%	36%	50%	51%

Mat creep:
does this change your opinion?

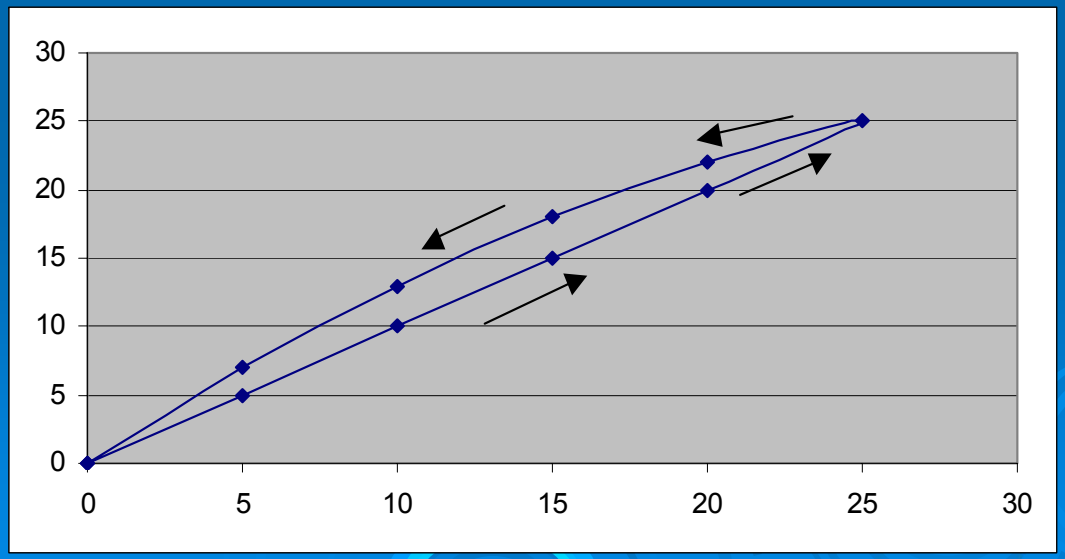


Mat creep

- Decide how long to wait until to collect data
- Adjust calibration parameters to monitor creep for approximately that time period
  - E.g., if default creep accommodation is 60 secs but you take data at 300 secs, try to alter the calibration defaults

Hysteresis

- Characterizes energy loss during the loading and unloading of a sensor
- Mat and cushion both have hysteresis
- Unweight cushion and mat entirely between readings that you want to be independent
- Always select hysteresis correction in software



IPM myths, facts, & utility
Taking data

Interface Pressure Mapping (IPM)

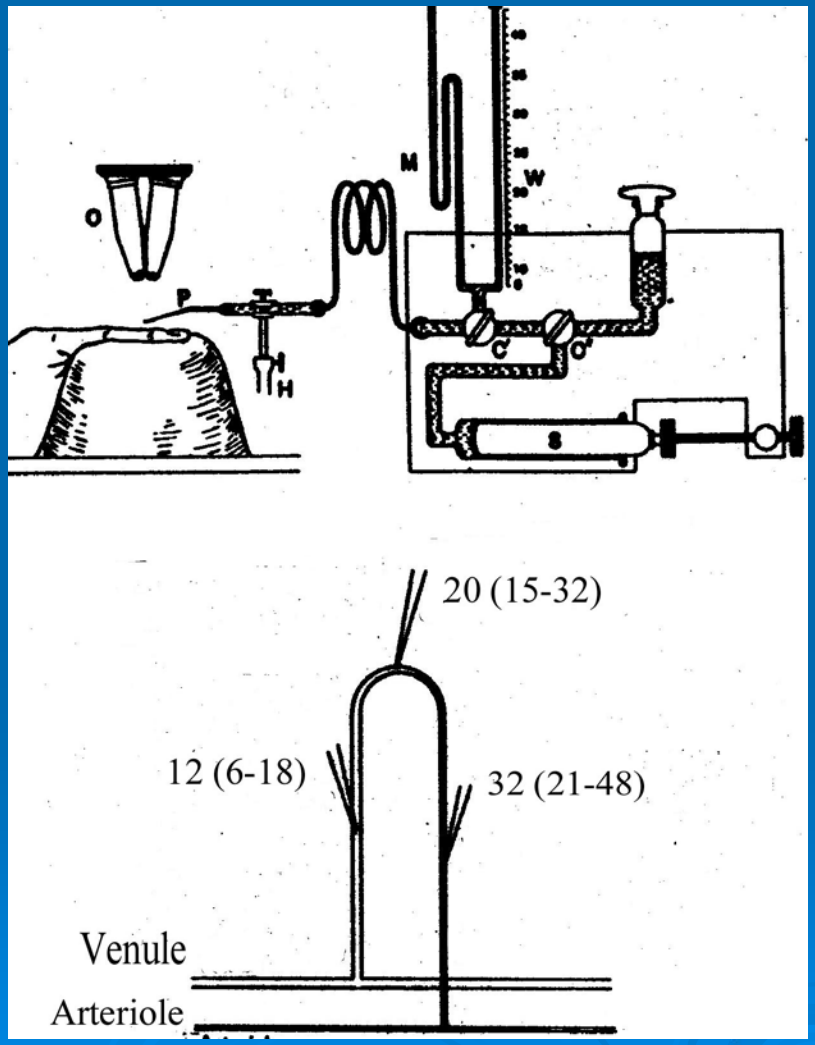
- IS:
  - A great clinical assessment tool and a great comparative tool.

- IS *NOT*:
  - A substitute for clinical decision making. (Best to use to *rule out* cushions vs. to select)

Pressure Myth #1

- Myth: any load exceeding 32 mmHg is harmful.
- Study which measured the pressure within the capillary loop of a fingernail bed (Landis , 1930).
- Landis' protocol did not include inducing occlusion.

Landis, 1930- *Heart*



Pressure Myth #2

- You must tilt at least 55 degrees in order to sufficiently unweight the buttocks for a pressure relief.
  - Depends on the person, their posture, the seating set-up, etc.

Cautions
Snap shot

- Remember that clinical IPM provides just a snapshot in time.
- Not representative of client's range of postures, activities (transfers), other surfaces, e.g. toileting, showering, transportation, etc.
- Using remote or movie mode can capture more representative IPM data.

Cautions:
Validity

- Does IPM measure tissue risk?
- Remember that it measures what's happening between the body and the cushion, at the *interface.*
- We don't know how well that correlates to what is happening inside the body.
- Current research trend to study tissue deformation vs capillary occlusion.

IPM- is it worth it?

- Evidence suggests that evaluation leads to better outcomes
- IPM is an evaluation tool and offers information not otherwise available
- However, no evidence exists to suggest that IPM leads to better outcomes

Brienza, et. al, 2001

Study of IPM vs. PU incidence in elderly

- Relationship between people with high IP values (for peak and average of highest 4 pressures) and the formation of PU.
  - but results unable to relate loading at a site with PU occurrence at that site (ulcers didn't always occur at the peak and not always caused by sitting)

Taking measurements How best to use IPM:

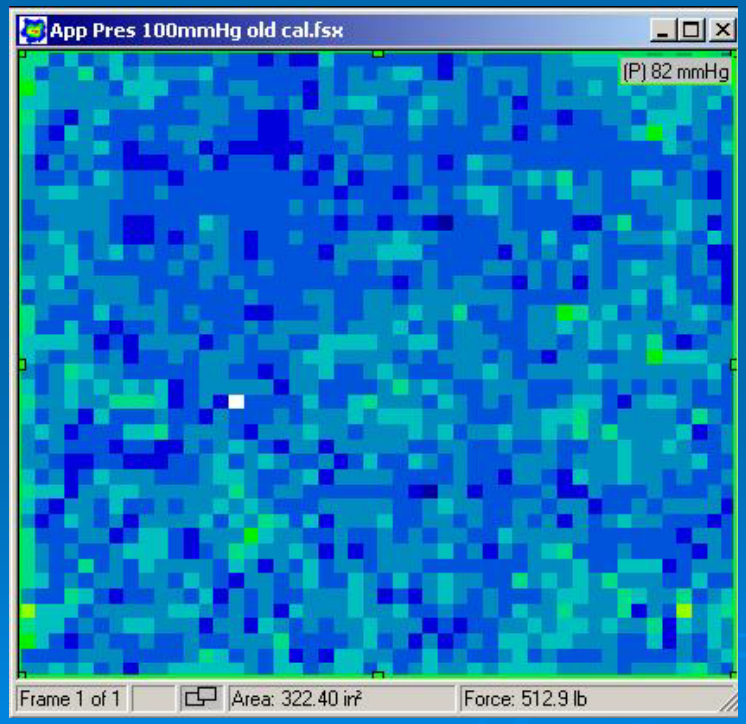
- Calibration
- Alignment
- Error identification
- Metrics and measures
- Reproducibility

Calibration

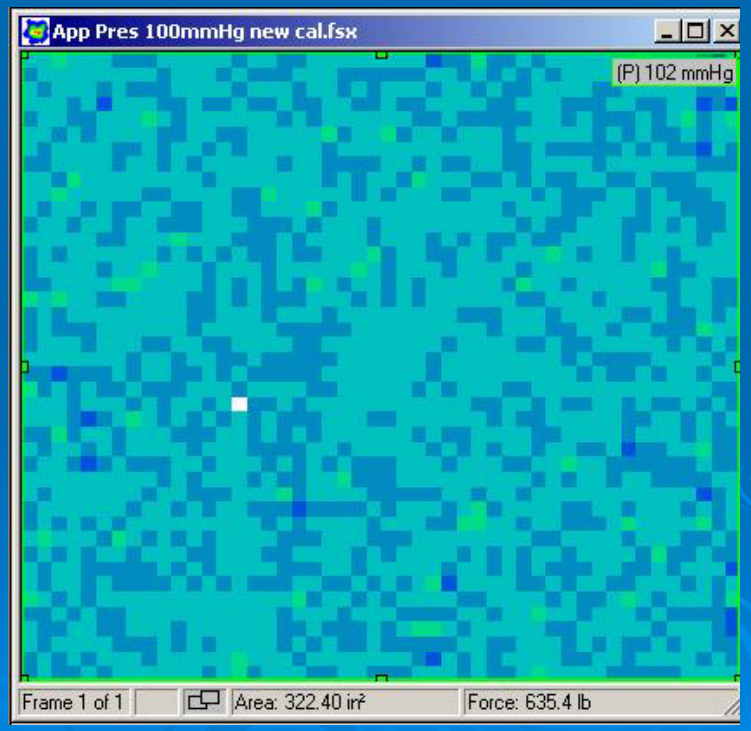
- Correlates the load to the output readings.
- All systems must be re-calibrated periodically.
- Calibration minimizes error and effects of creep and hysteresis.
- While # of uses between calibration is probably most telling, time between calibration is more clinically-friendly.
- 1x per month minimum.

Calibration check- in jig
100 mmHg applied

3 months of use
Avg: 82 mmHg



New calibration
Avg: 102 mmHg



FSA Calibration Jig

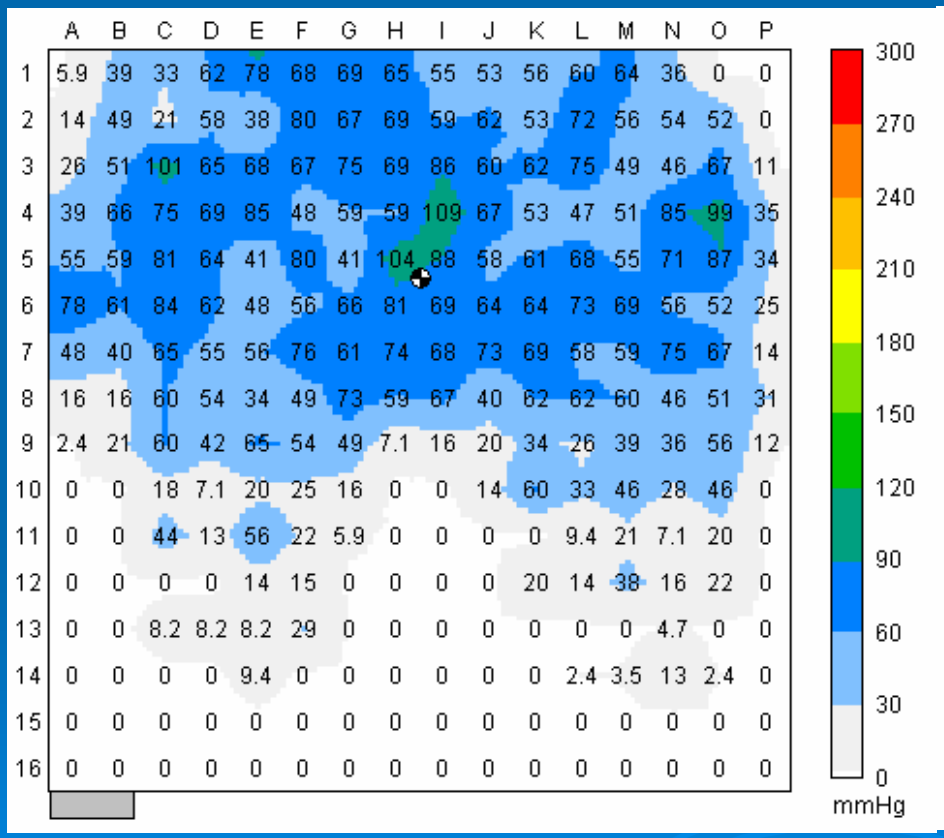
Calibration range

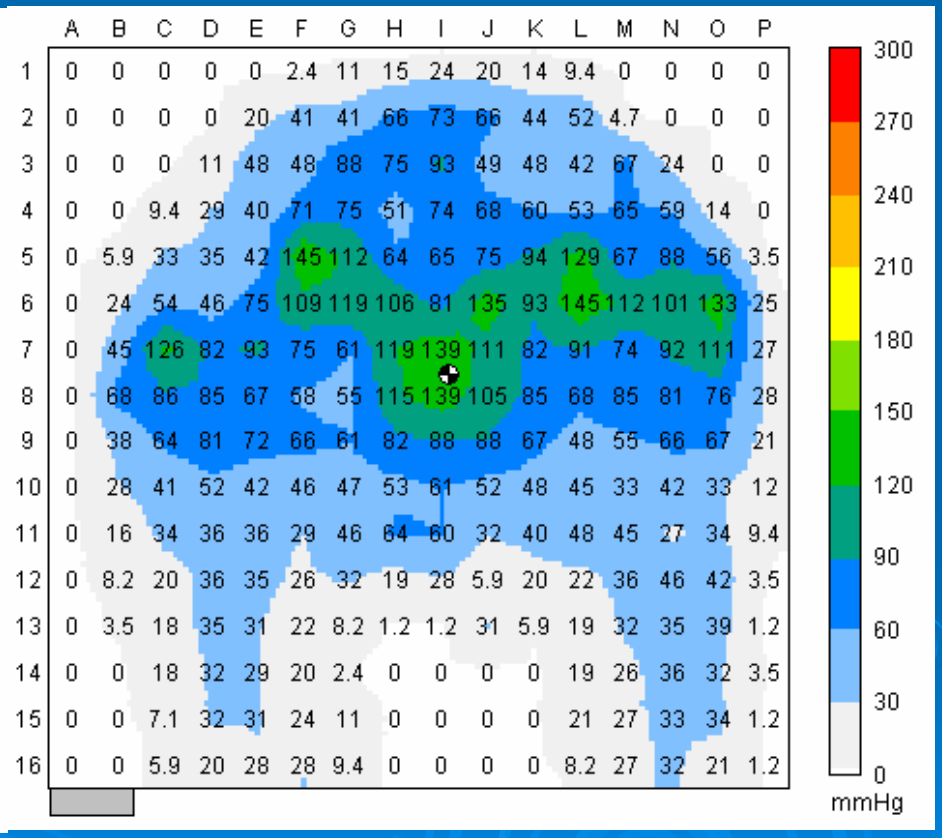
- Calibration range affects accuracy
  - Values <10 mmHg are not accurate or important
  - Peak values may be less accurate due to saturation or extrapolation
- Clinical question:
  - Do you want to know actual high pressure values?
    - If yes, then must calibrate to a value exceeding measured peak pressures
  - Why would anyone answer ‘no’?
    - If I decide ‘everything over 175 mmHg is bad’, then why would I care if the pressure were 176 or 576?

Alignment
Capture the butt

- The entire butt profile should be captured on the mat, versus hanging off the back edge, sides.
- Try to have rear row clear.

Alignment
(get the entire butt on the mat)



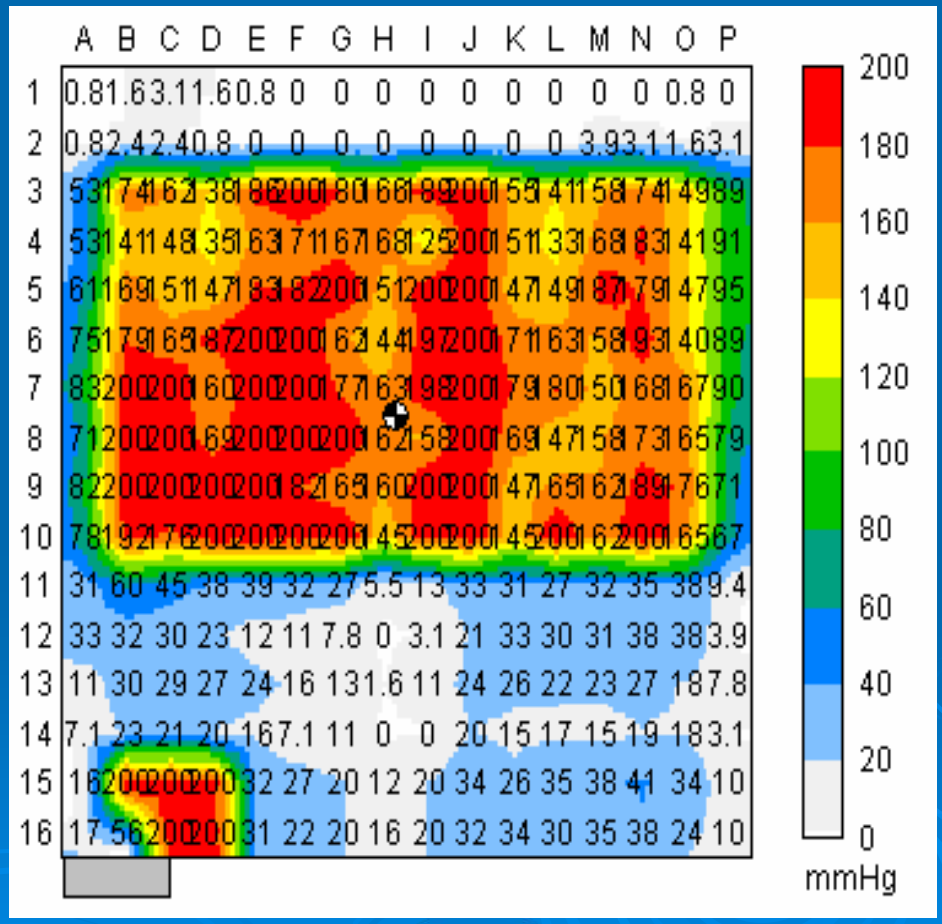


Error Identification

- Does it look like a butt?

Real or error?

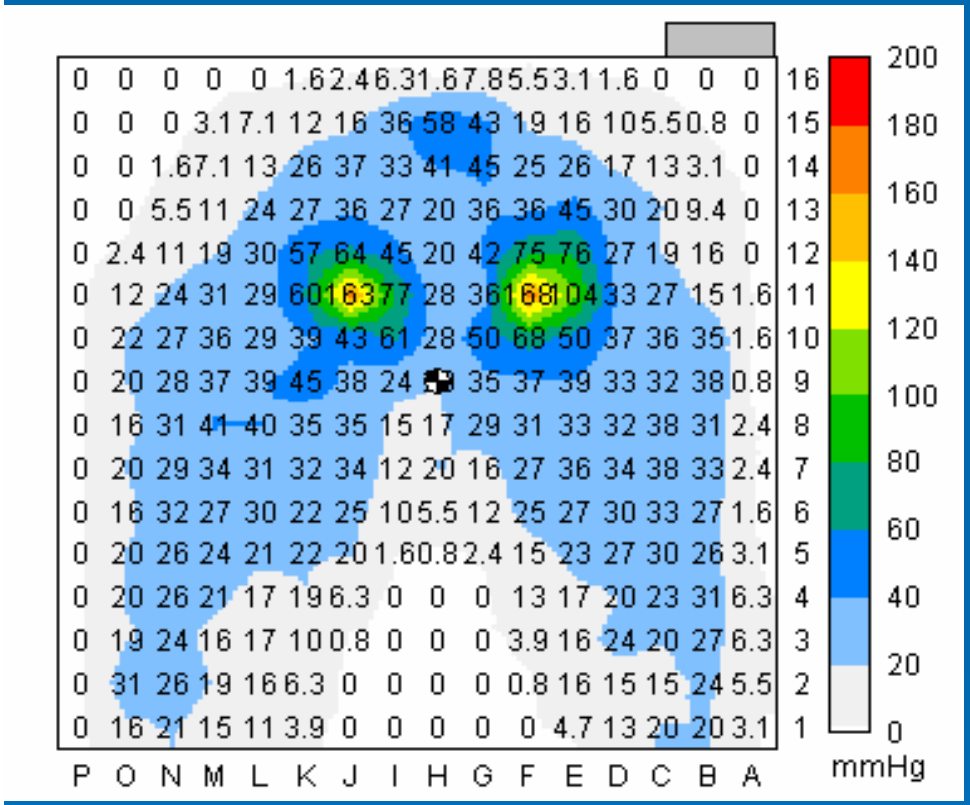
- Buttocks do not impart a rectangular load profile.

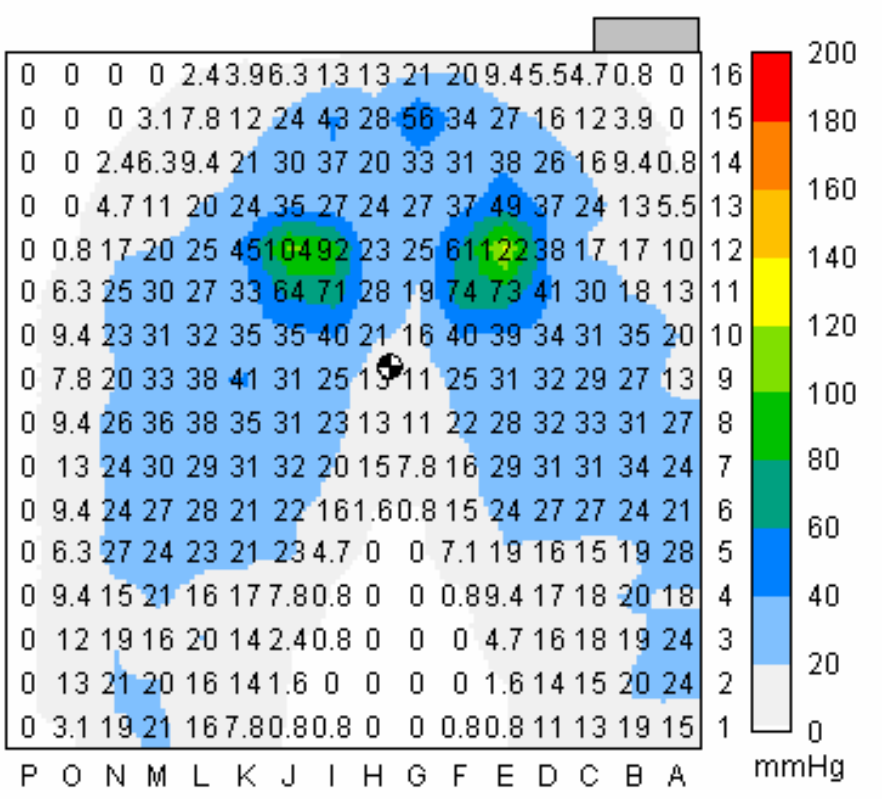


Repeatability of IPM
Peak Pressure

- Single sensor peak pressure - poor repeatability (Sprigle et al, 2003)

Repeatability at ischial tuberosities





Same subject; same cushion, same posture
60 second pressure relief between measurements.

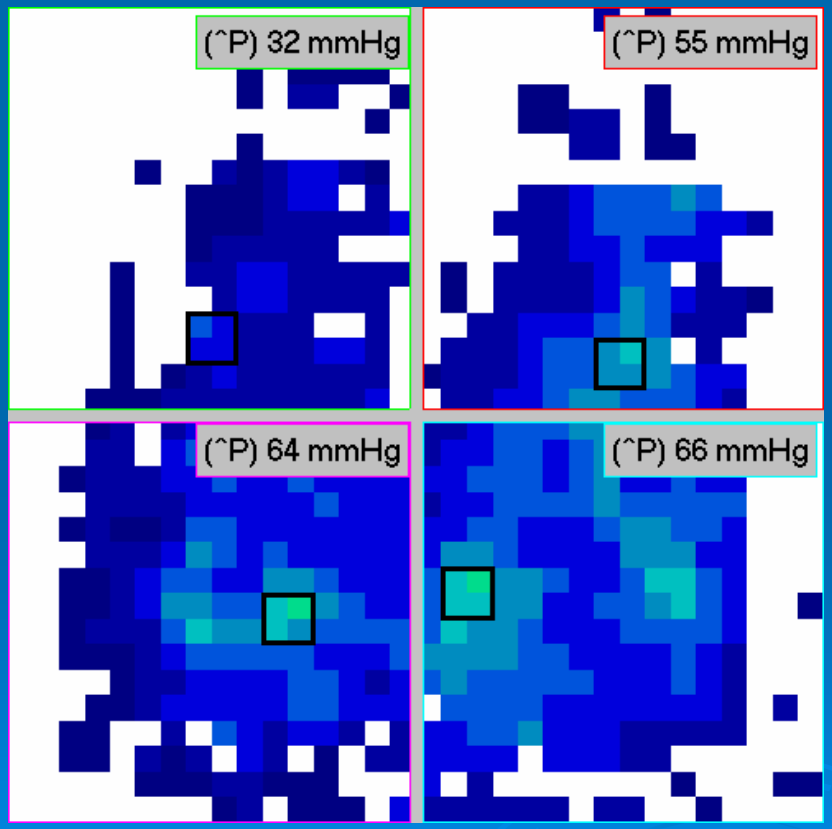
Reliable variables

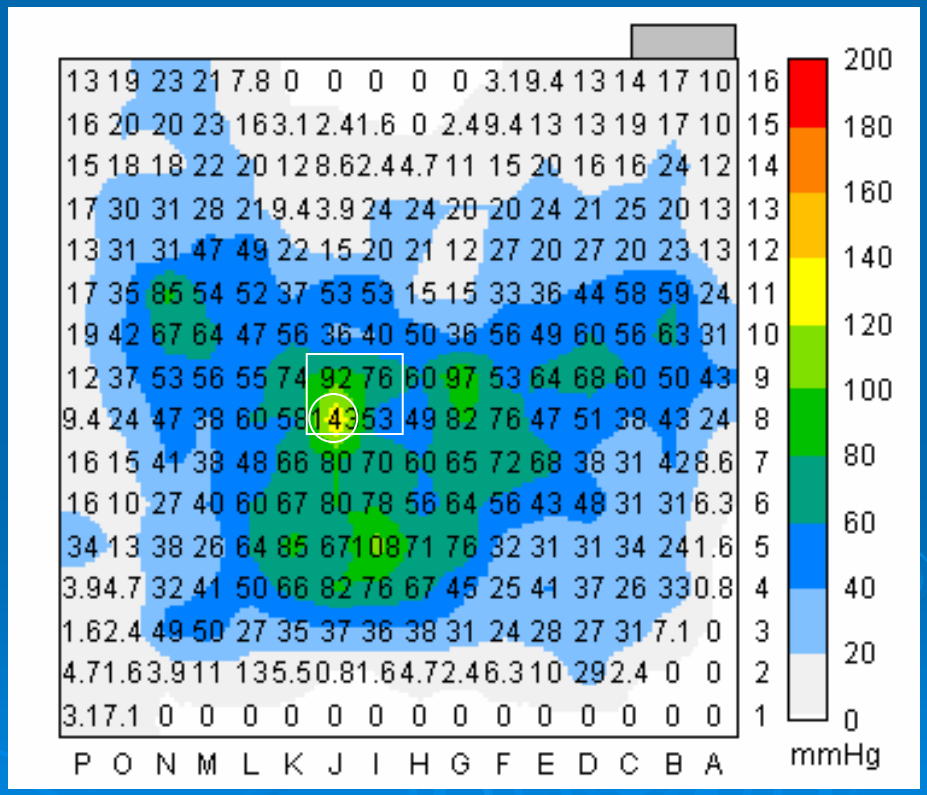
- Peak Pressure Index
  - Peak and surrounding values
- Average Pressure
  - Harder to distinguish differences
- Contact Area
  - Requires calculation in some software
- Dispersion Index
  - Ratio of IT/Sacral loading to total loading

Peak Pressure Index (PPI)

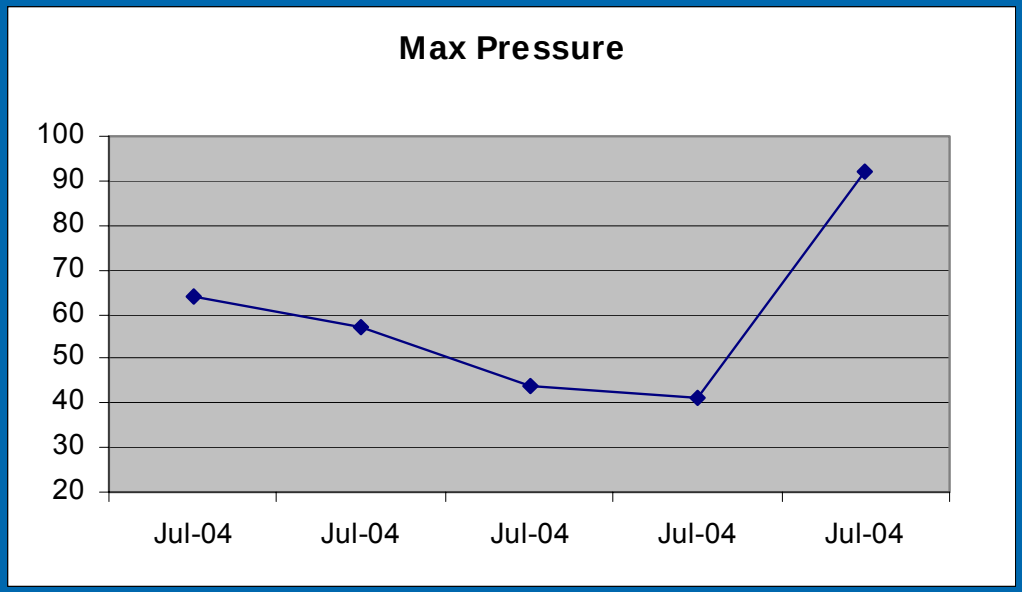
- Average of the peak value + the surrounding cells which make up 9-10cm^2 (size of an IT or other bony prominence).
- This is 4 or 9 cells, depending on spatial resolution (# of sensors/mat area).

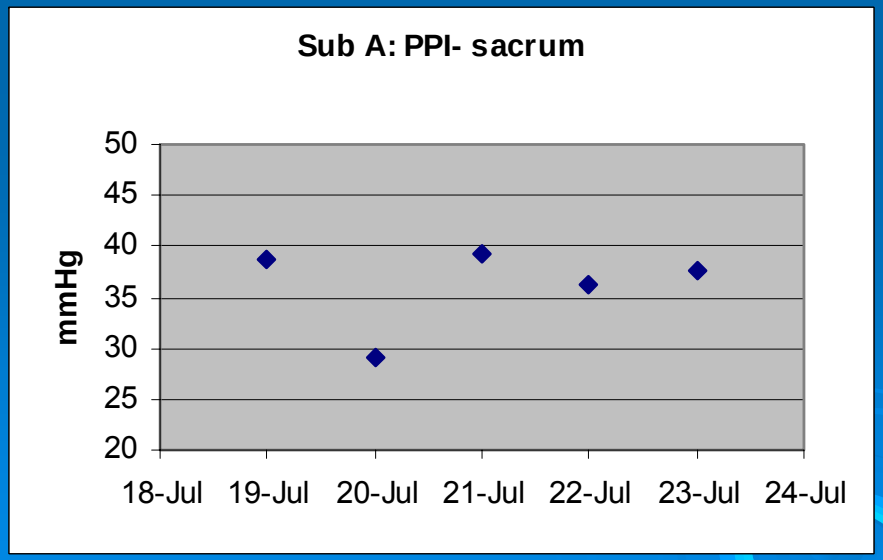
Peak Pressure Index- average of peak and surrounding values

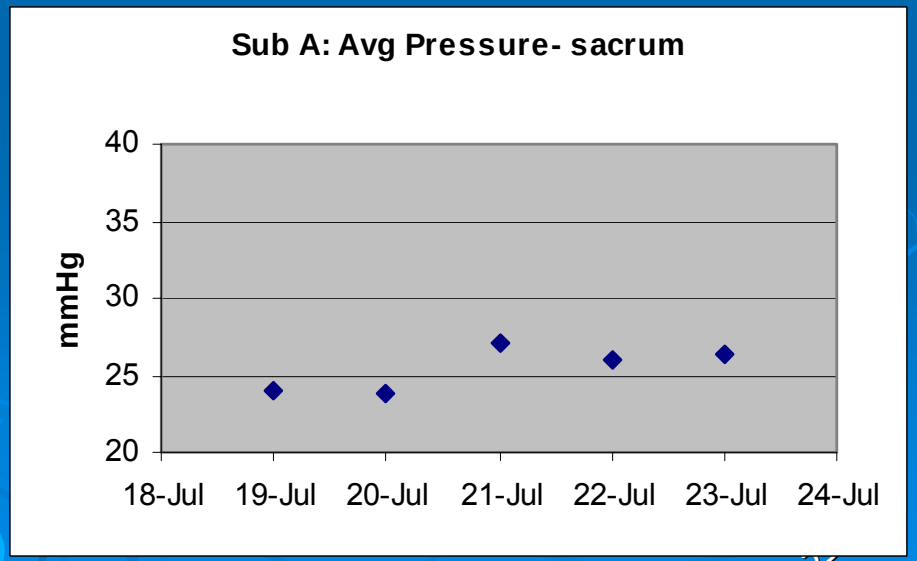




Repeatability: Sacrum in bed

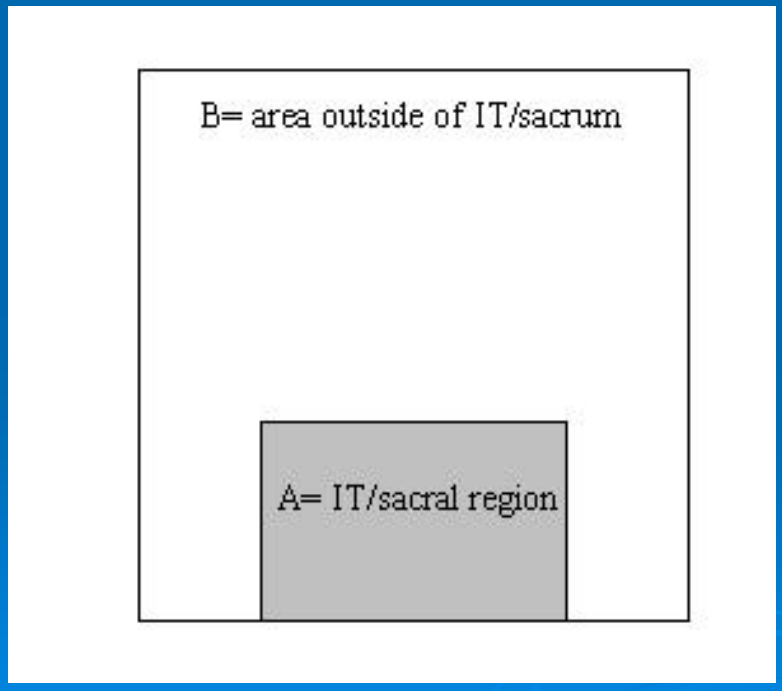






Dispersion Index

DI= A/(A+B)

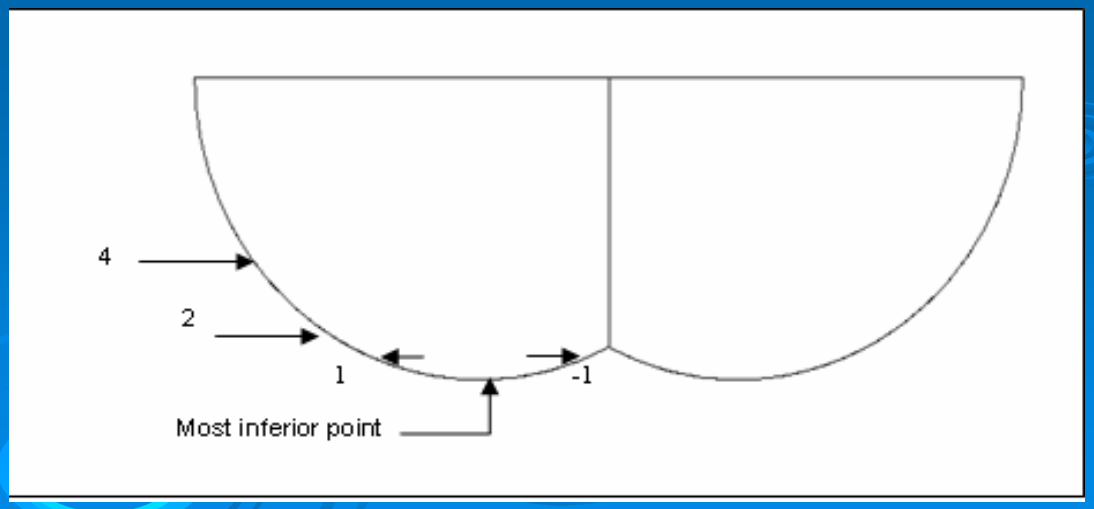


- Based upon the theory that redistributing load away from ITs is a good idea
- Some evidence suggests that DI>.50 are bad
- Clinical challenge: identification of areas

Impact of IP Mat on IP measurements
Impact of cushion type on IP measurements

Instrumentation

- Rigid Buttock Model
  - 36 cm wide with 11 cm ischial spacing
- 5 points of interest
  - Most inferior point (IT), 1, 2, and 4 cm superior to the IT
- Custom FSA Individual Pressure Sensors
  - active area = .3in^2 each
  - 2 mounted per site



Methods

- 5 Mat Conditions
  - No Mat
  - XSensor Seat System
  - FSA UltraThin Seat System
  - Tekscan 5315
  - Tekscan Conformat
- 7 cushions with different design features:
  - Action XAct – Foam/Gel
  - J2 Deep Contour – Foam/Viscous Fluid
  - Ottobock Cloud – Foam/Viscous Fluid
  - Star – Air
  - Tempermed – Viscoelastic Foam
  - Flat 3” thick HR 45 foam
  - HR 45 foam segmented into 2”x2” squares extending 1” into the 3” block

Variables

- Magnitude- relative to *no mat* condition
  - 1) $$Total-1\ to\ 1\ Ratio=\frac{[(-1cm)+(IT)+(1cm)]test}{[(-1cm)+(IT)+(1cm)]no\ mat}$$
- Envelopment
  - Ideal envelopment would result in even pressure across the model
  - *Parity:* a measure of the equality of the two sensors 1 cm from the IT.
    - Closer to 0 indicates greater envelopment.

$$Parity=\frac{(1cm)-(-1cm)}{(1cm)+(-1cm)}$$

Results - Magnitude

Mat	Total -1to1 Ratio
Conformat	**0.8390**
FSA	**0.6095**
Xsensor	**0.7781**
5315	**0.5133**

- Presence of each mat resulted in ***reduced*** pressure on the buttock model

$$Total-1\ to\ 1\ Ratio = \frac{\left[(-1cm)+(IT)+(1cm)\right]test}{\left[(-1cm)+(IT)+(1cm)\right]no\ mat}$$

Results - Envelopment

Mat	Average Parity	Change from No Mat
No Mat	-0.1171	--
Conformat	-0.1257	-0.0086
FSA	-0.8024	**-0.6852**
Xsensor	-0.2386	**-0.1214**
5315	-0.8167	**-0.6995**

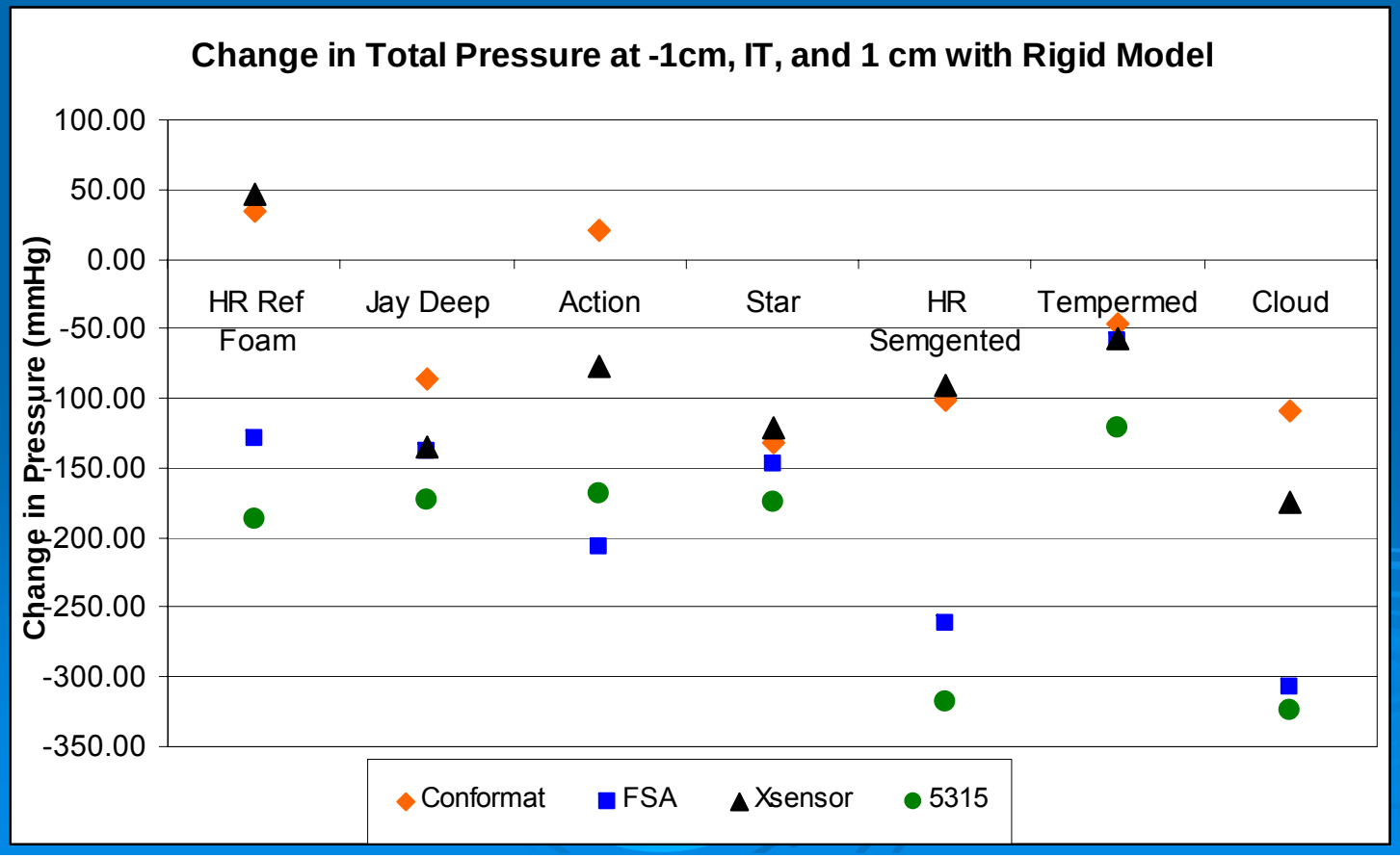
- Envelopment decreased after mat introduction, meaning that the two pressure values were less similar
- Envelopment of the Conformat was not different from buttock envelopment without a mat present.
  - 3 other mats resulted in a significant change in envelopment

Red values are statistically significant, p<.05

$$Parity = \frac{(1cm) - (-1cm)}{(1cm) + (-1cm)}$$

Interaction between mat & cushion type

- IP mats have different effects on IP magnitude depending on the cushion being tested



Discussion

- Mats impact loading
- Mat thickness is not an important factor
- Measured pressure decreased in 95% of test trials with rigid and gel buttock models.
  - This is most clearly seen in the medial region.
- Cushions have varying levels of creep and time dependency
  - Elastic foams and air react quickly.
  - Viscoelastic foams and viscous fluids (Jay), react slower.
- Be consistent within clinical measurements

Using IPM to judge pressure redistribution

- Interpretation
- Areas of risk
- Matching pressures to anatomical locations
- Symmetry
- Answering the question: “is this cushion good enough from a pressure standpoint?”

IPM Clinical Interpretation

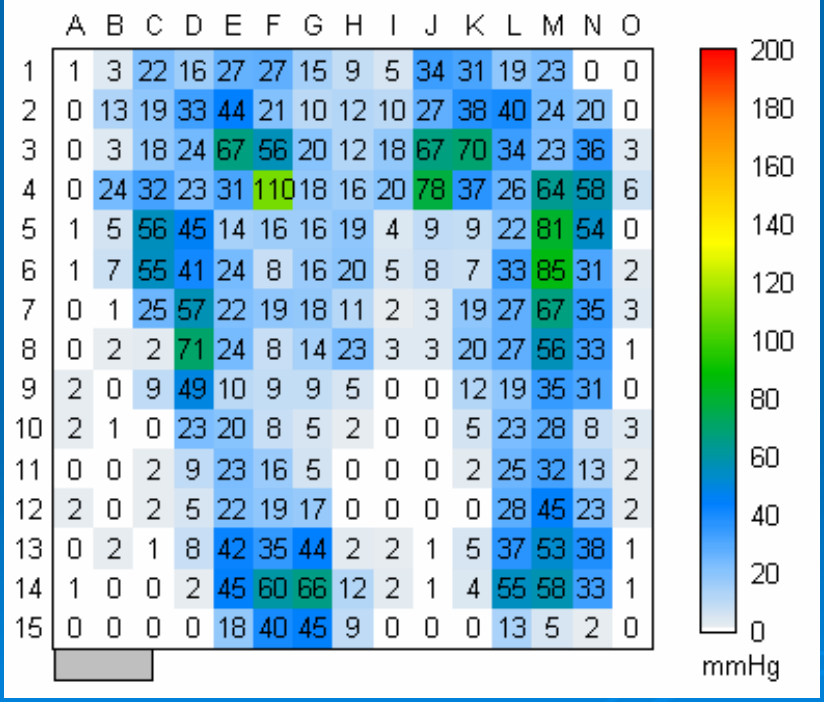
- **1st thing: rule out mat error**

1. Entire columns or rows wrong.
2. Evident over or under-reading.
3. Flashing sensor (fluctuates between very high and low value when client is static)
4. Diagonal hot spot (likely a wrinkle)

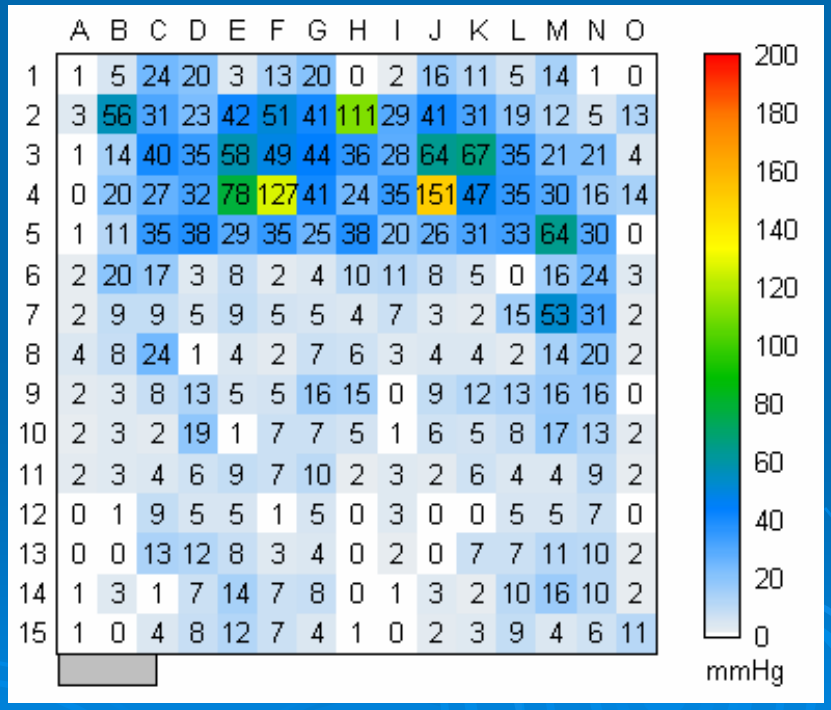
TIME TO RE-CALIBRATE???

Interpretation of Interface Pressures
The hardest part

Avg= 22 Peak = 110

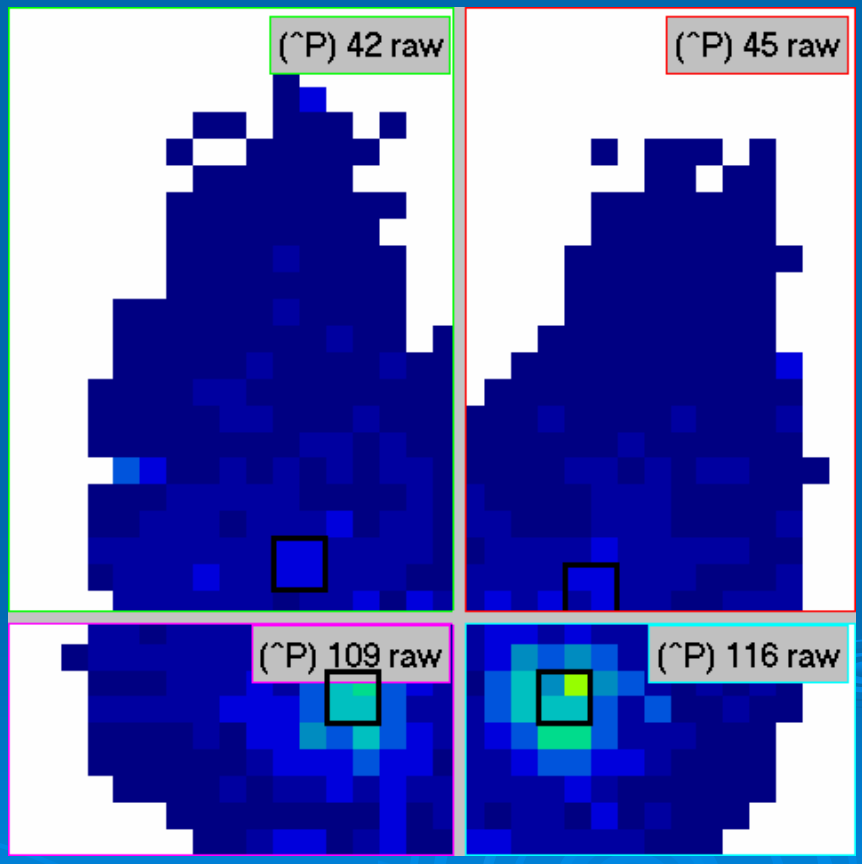


Avg= 16 Peak = 151

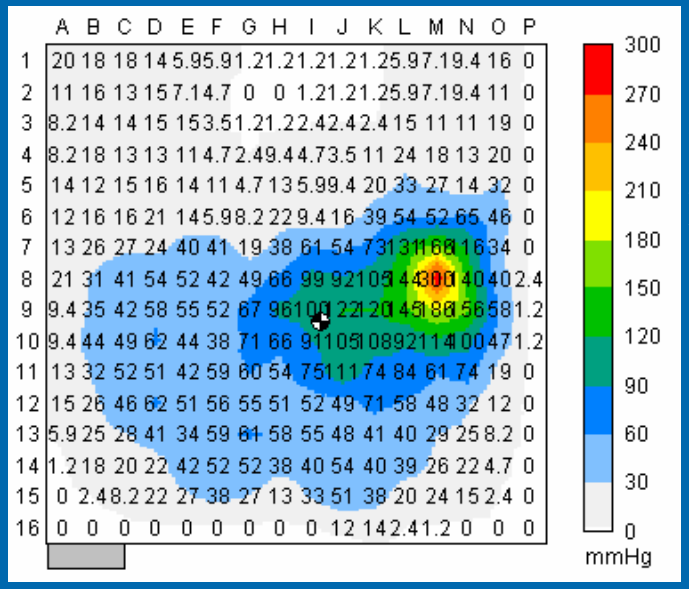


Focus on areas of interest

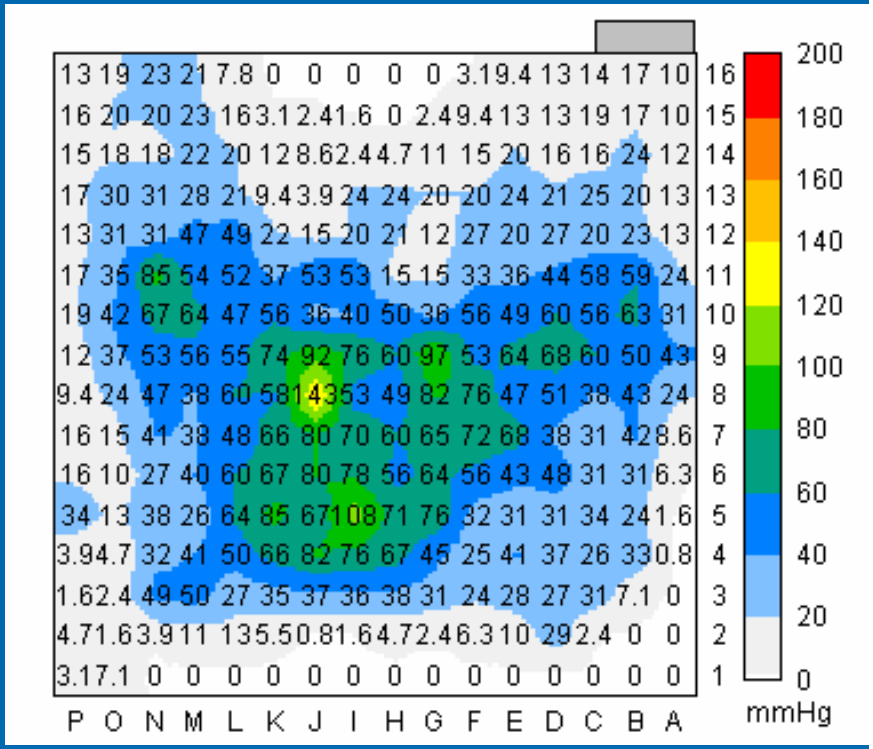
- Bony prominences are at greatest risk
  - However, eval will inform specific risks
- Learn software's capabilities to provide you with the data you desire

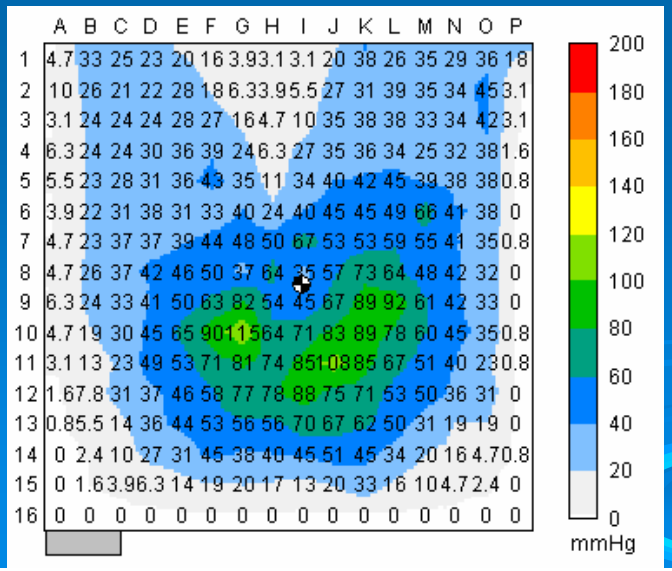


Palpate to match values to prominences



Fairly easy

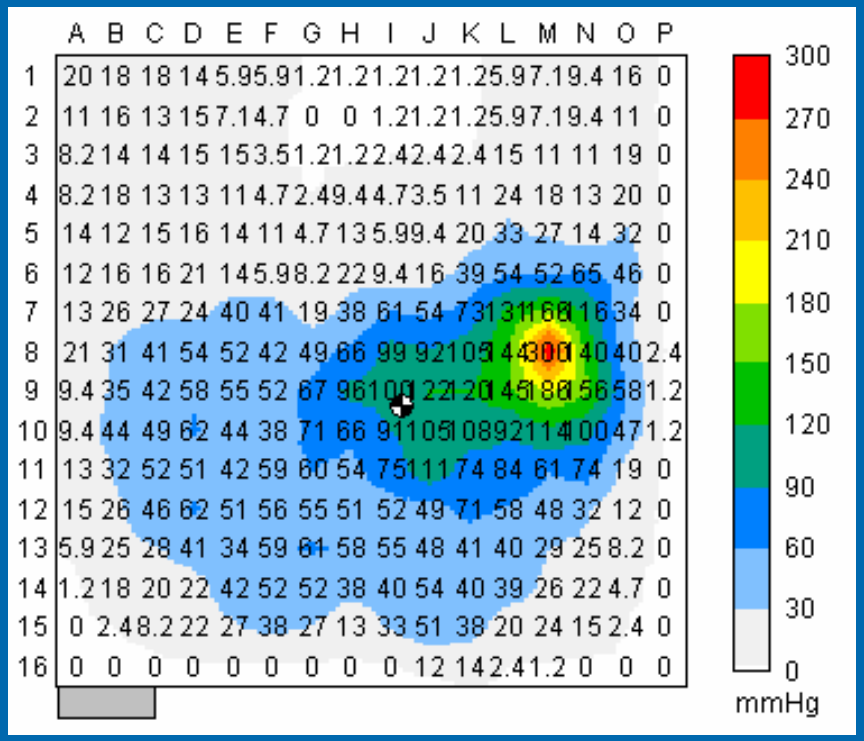


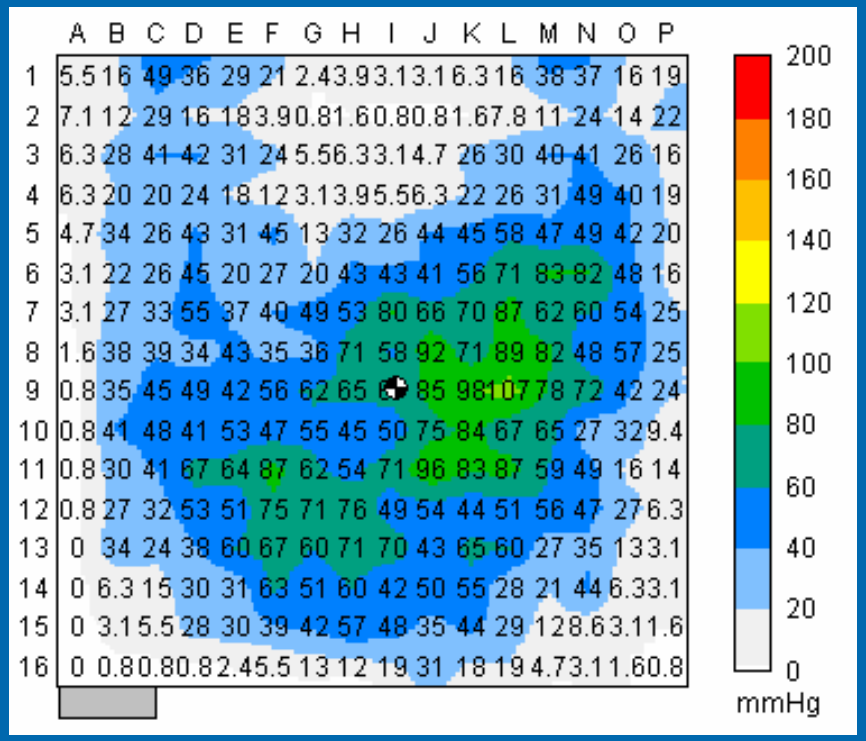


Not so easy

difficult

Symmetry → Posture





Same person- different cushions

IPM can be used to corroborate palpation

Generally, asymmetric postures are bad for tissue

Correct or accommodate- cushion on L was doing neither

This person had a fixed asymmetry, & cushion needed to accommodate

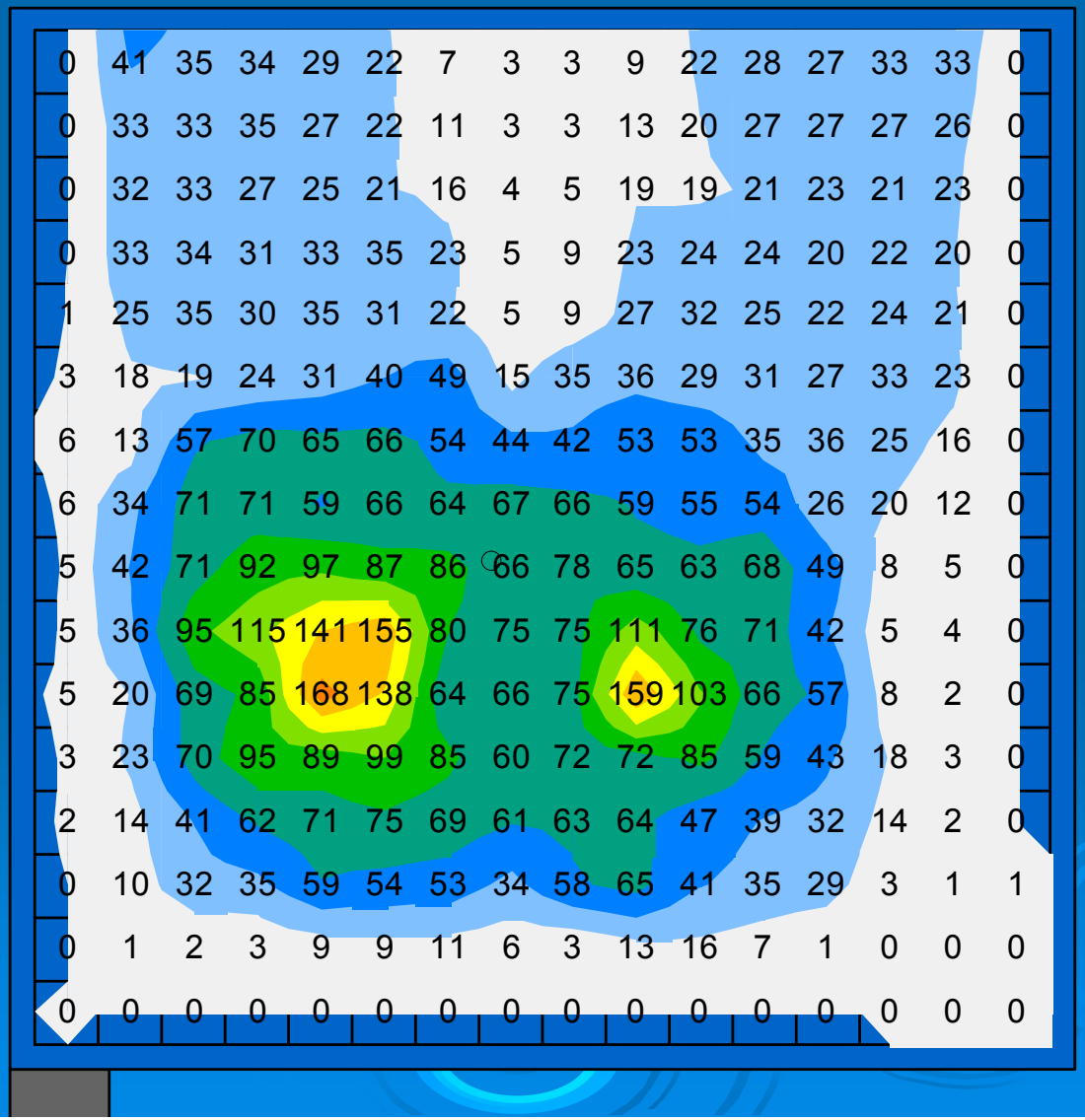
IPM Clinical Interpretation
Avoid high gradients

- Gradient – how quickly sensor values rise and fall.
- Results from a poorly enveloped or off-loaded bony prominence.

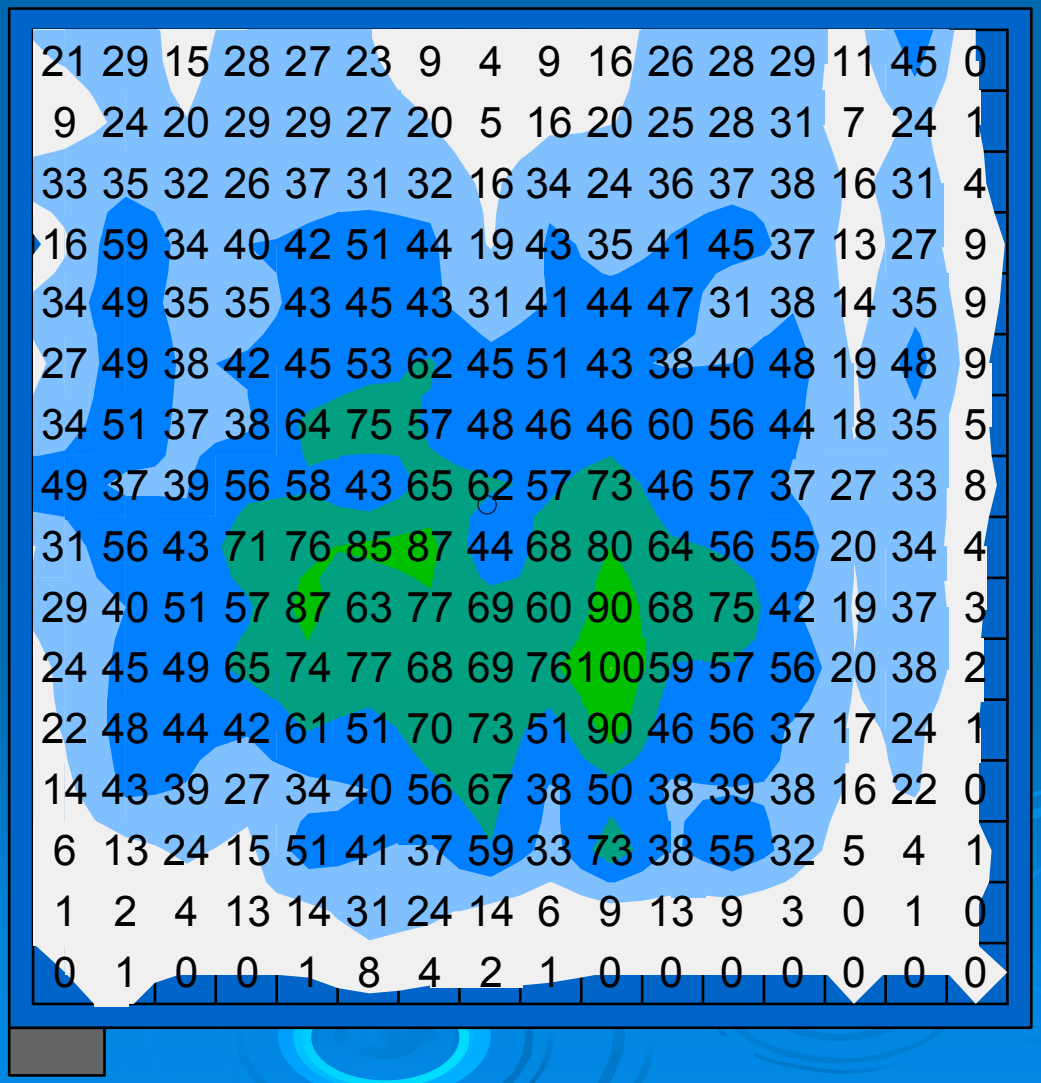
IPM Clinical Interpretation
Envelopment

- Capability of a support surface in deforming around and encompassing the contour of the human body.
- An enveloping cushion should have the ability to encompass and equalize pressure about irregularities in contour due to buttock shape, objects in pockets, clothing, etc.

High gradients around @risk sites



Envelopment

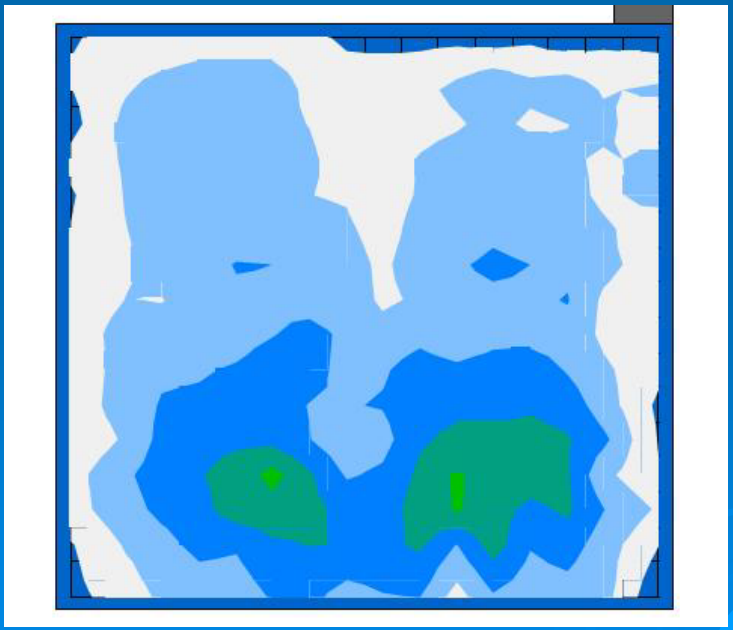


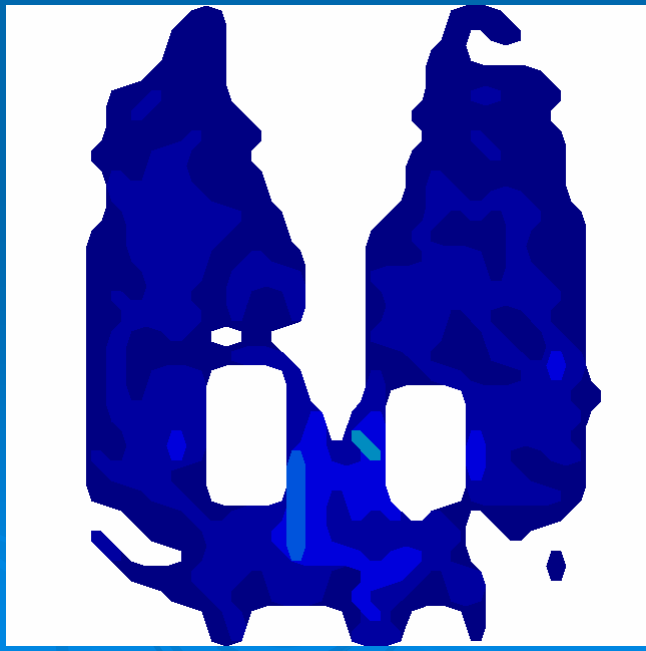
IPM Clinical Interpretation
surface area

- Maximize surface contact area, especially if envelopment is the goal.
- If redistribution via off-loading is the goal:
  - make sure IPM reflects sites intended to be off-loaded (e.g. ITs)
  - Make sure off-loading to other areas is safe (not to other at-risk sites)

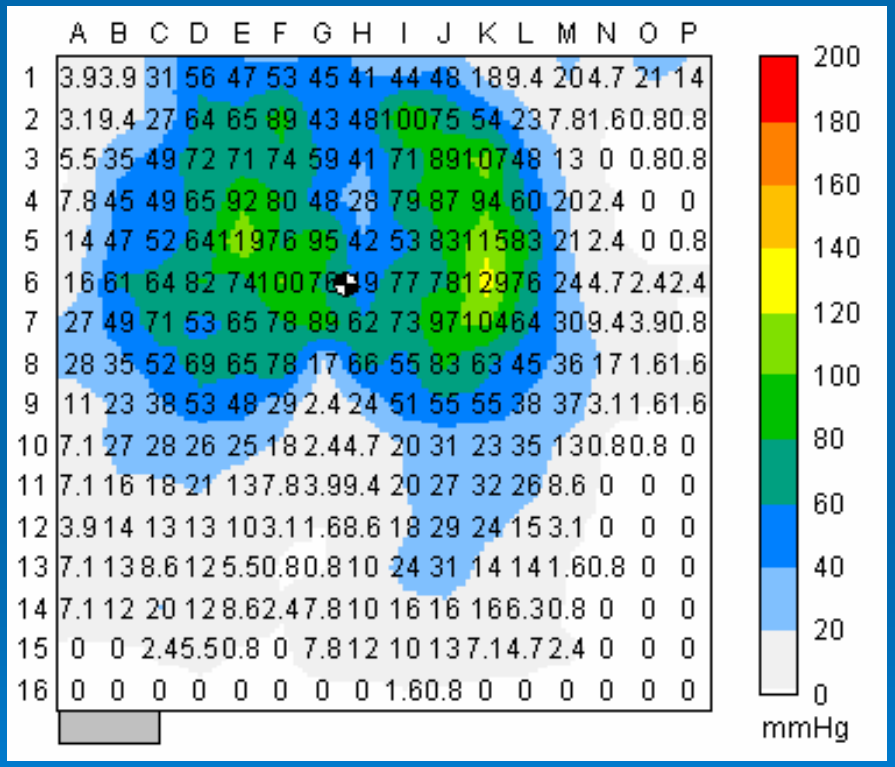
Interface pressure distribution

- IP should reflect intended cushion design

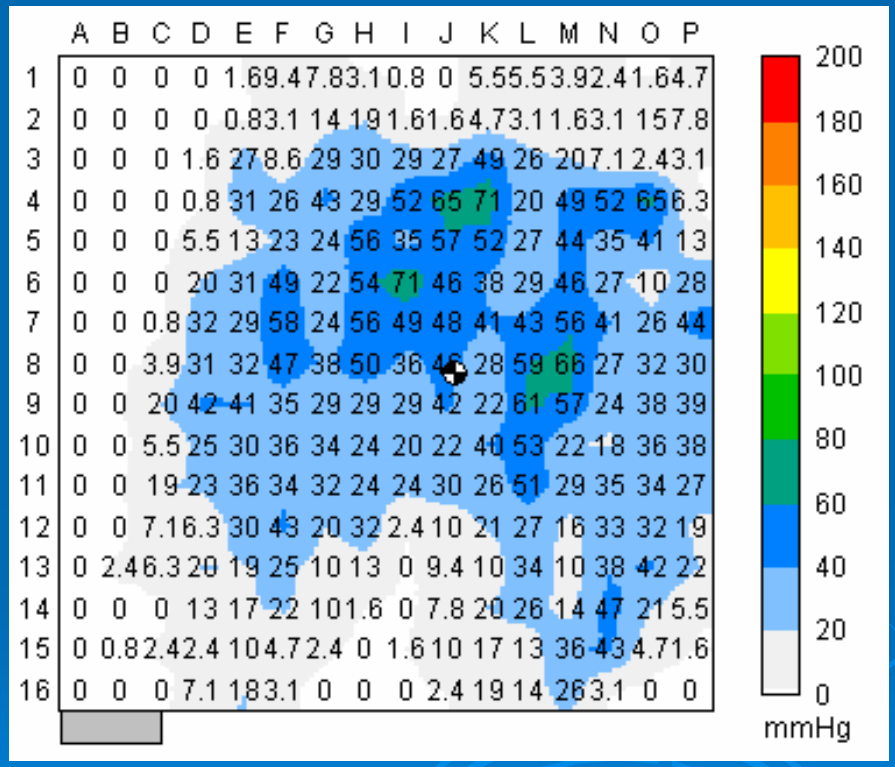




Using current cushion for ‘pressure-to-beat’



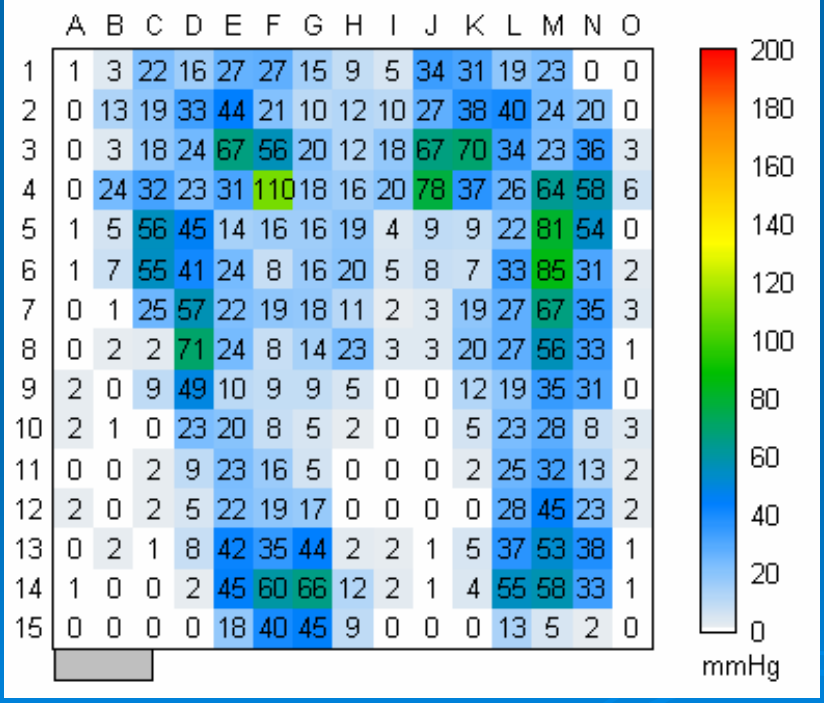
Current cushion

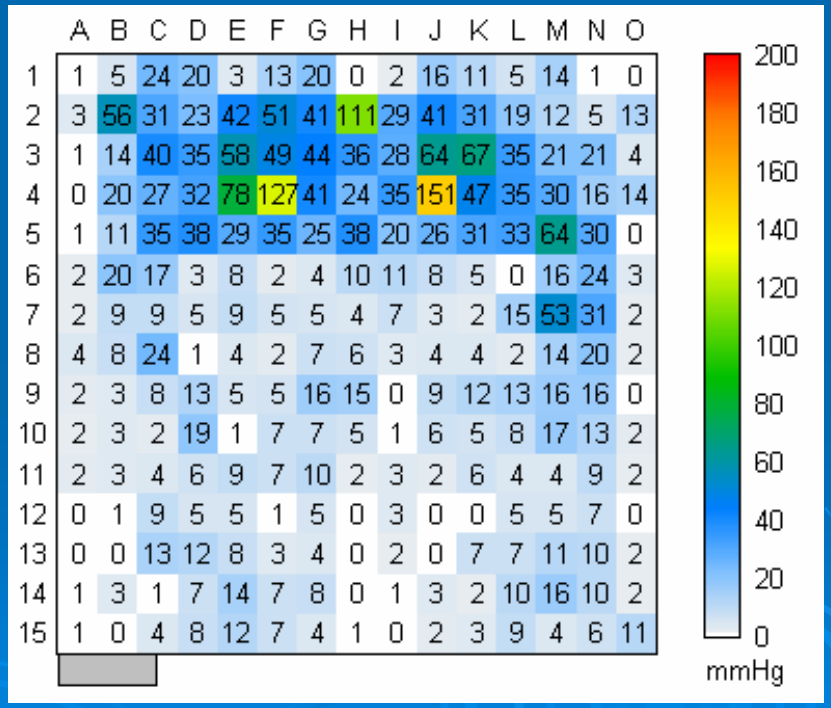


Evaluation cushion

Current cushions sets individualistic thresholds

Now how would you judge these?





The Cushion is not always the bad guy

Some *pressure* problems are really *posture* problems not *cushion* problems

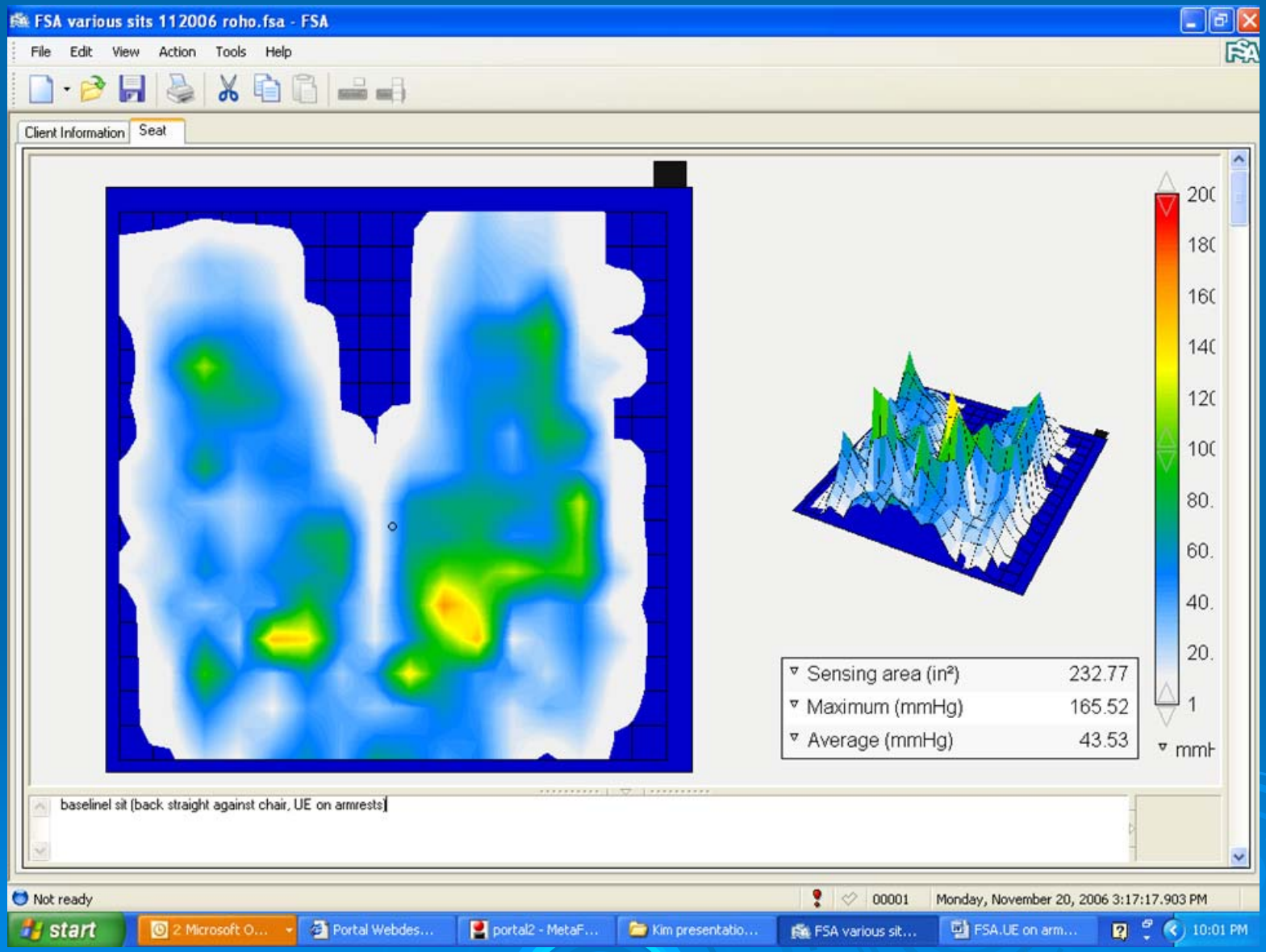
And sometimes it's the cushion…

Education
IPM evaluation

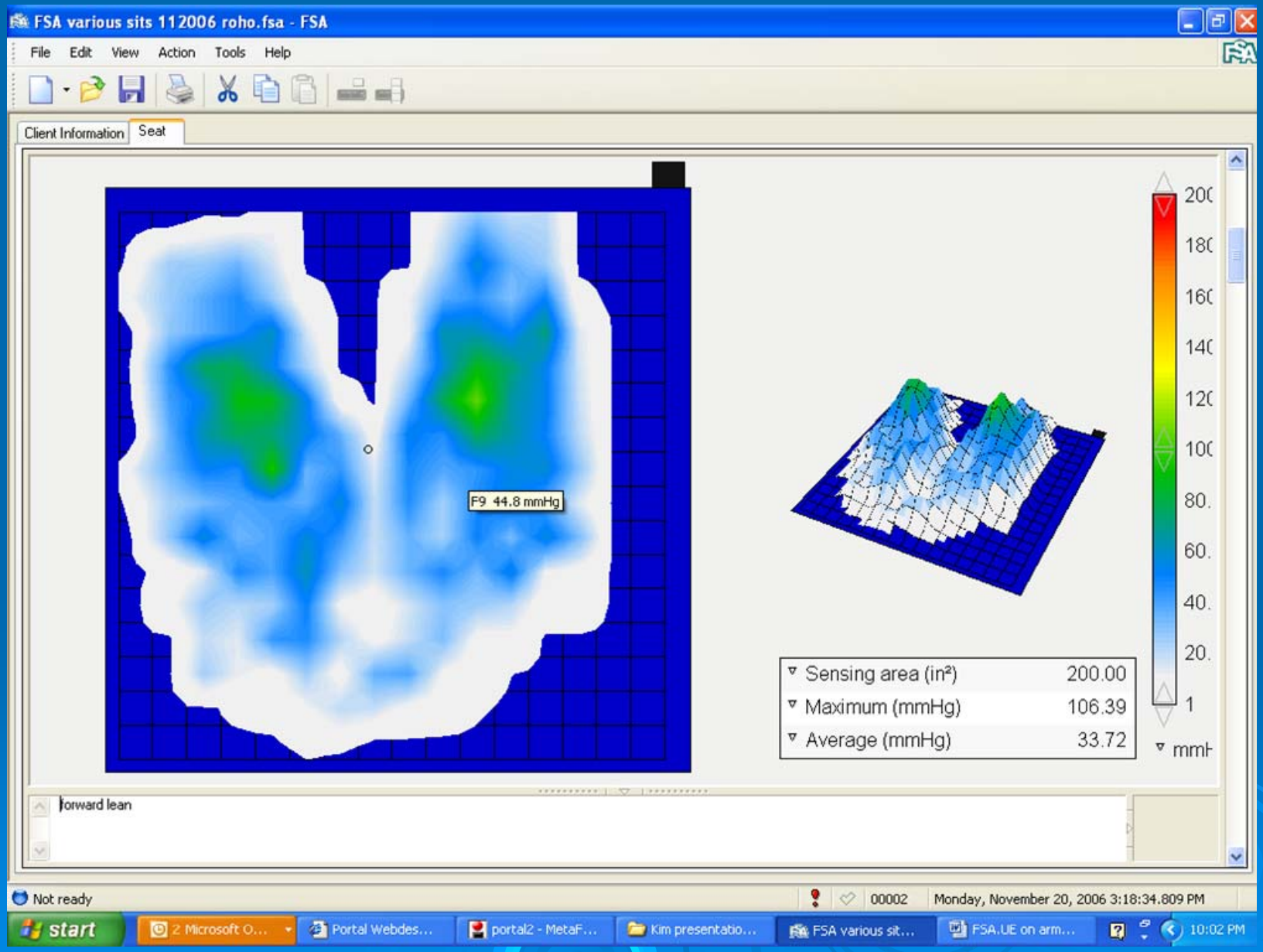
IPM as an Educational Tool

- Client and caregiver
- Effectiveness of pressure relief technique
- Effects of propulsion techniques
- Effects of postural changes

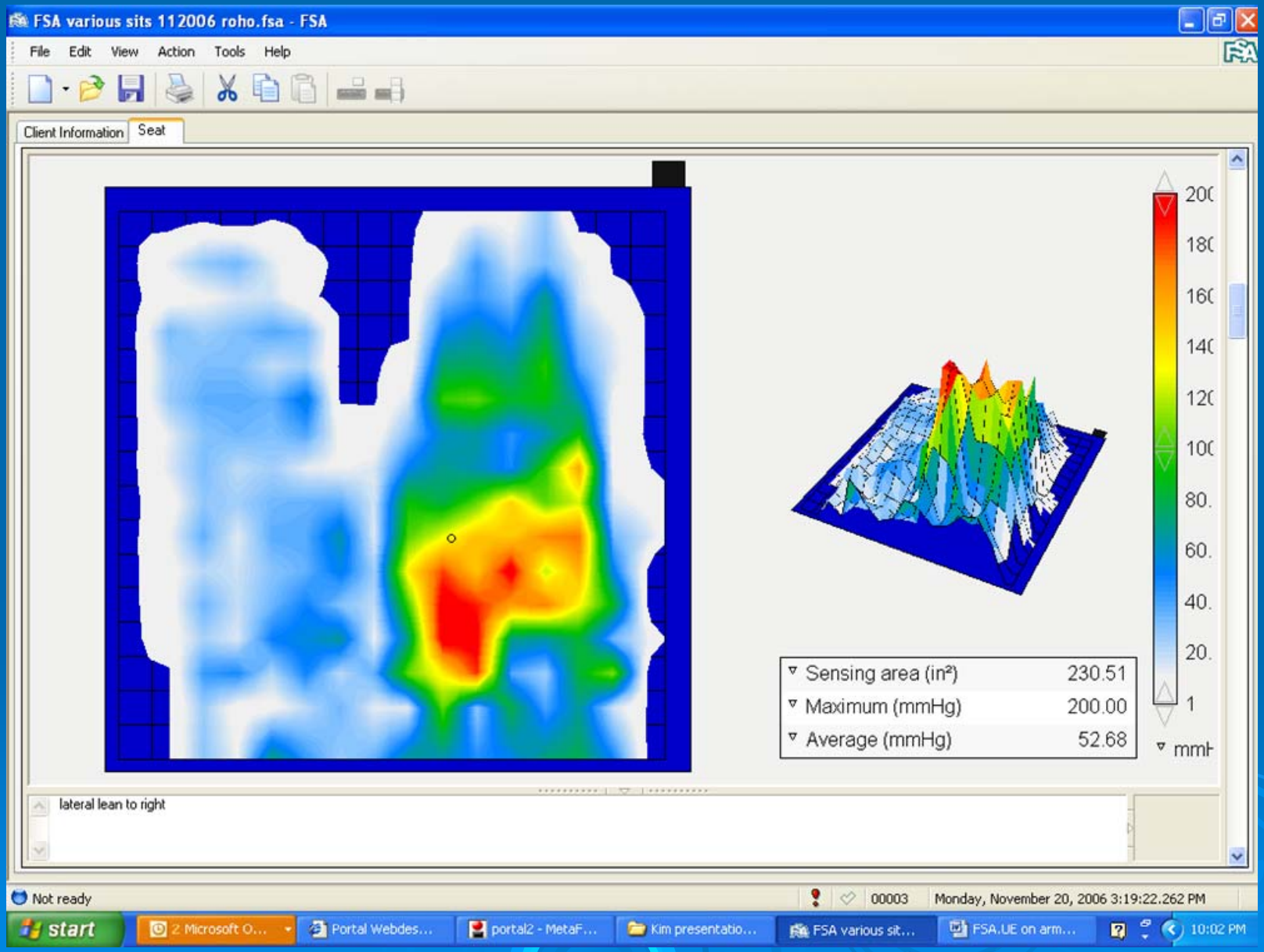
Pressure Relief - Baseline posture



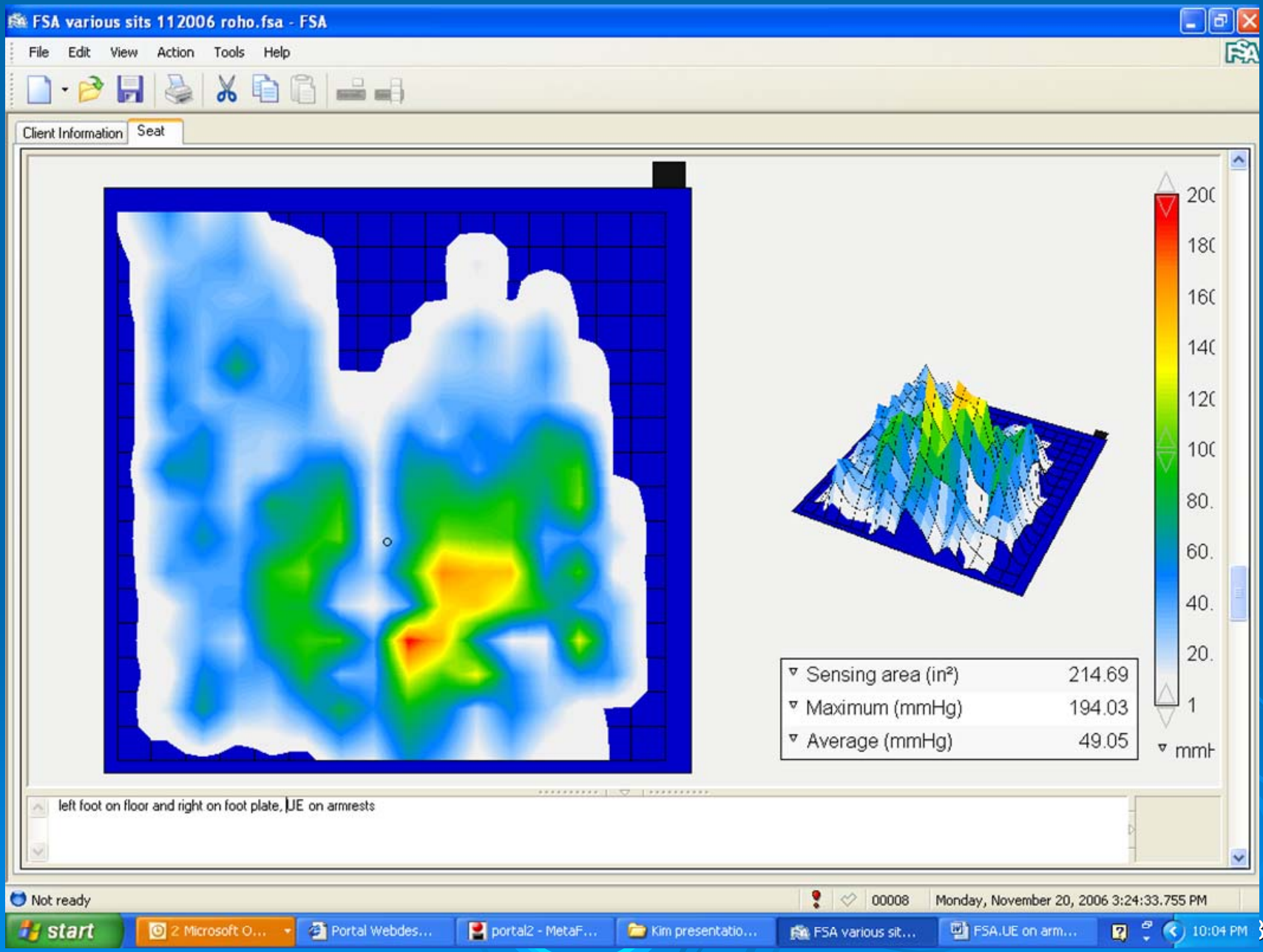
Forward lean



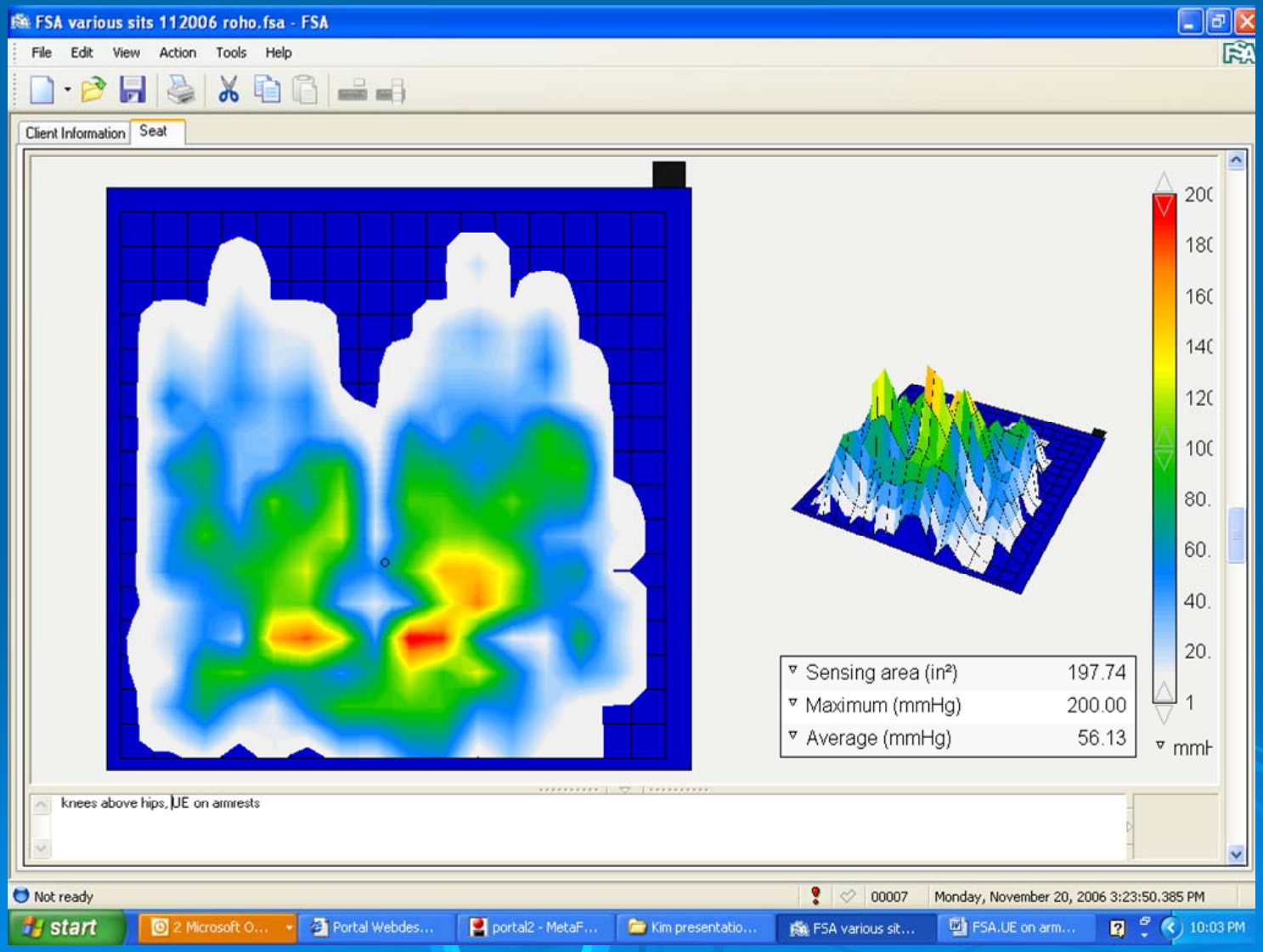
Right lateral lean



Foot propulsion



Knees above hips



IPM seating eval guidelines

- Use note or eval section in IPM software.
- Label every frame / group of readings that you want to use for documentation. Describe thoroughly.
- Use consistent file naming protocol for each client – allows efficient retrieval for comparison at f/u assessments.
- Use correlative photo documentation to reflect posture and seating set-up.
- Hand washing, gloves and isolation bags for mat.

General set-up guidelines

- Consistently place the mat on the cushion, per client session.
- If w/c small, caution re: folds at edges.
- Make sure Mat is relaxing into cushion contours (avoid hammocking). Use hands to smooth / match contour as needed.
- Avoid transfer boards if mat fragile.
- Make sure mat stays in place after transfer, squared, no wrinkles.
- Butt fully on mat.

Taking data - the steps

- Baseline data (how they rolled in)
- Notes: name, date, cushion, w/c, system tilt, SBA, extremity position, postural issues / asymmetries.
- Palpate – verify peaks - match to bony prominence?
- Select desired software / statistic features and be consistent for comparison.

Steps – recording the map

- Time to sit prior to recording map
  - Time to settle into cushion.
  - Settling varies based on cushion materials.
  - Minimum of 1 minute – longer for viscous materials.
  - Be consistent per client session across cushions.
  - Set time based on the outer estimate.

Steps – physical/postural eval

- Transfer to mat.
- Supine and sitting eval to determine asymmetries.
- Use IPM in sitting on mat table to precisely define wt bearing areas, check if asymmetries fixed or flexible, and determine location of postural supports (hands), amount of force needed.

Steps - Skin inspection

- Assessment vs. verbal report
- Client can be unreliable historian.
- Note at-risk / involved sites – match to IPM.

Steps

- Inspect cushion for defects, correct set-up.
- Make changes in cushion as needed, then re-do IPM.
- Assess for other postural changes or seating adjustments needed before abandoning original cushion (need to rule it out).
- Consider additional surfaces as contributing / causative factor.

Steps

- Pre-select small # of cushions (2-3) based on client needs (pressure, posture, balance, function, temperature, continence, large-fanged pets…) and risk level.
- Adjust postural supports as needed to accommodate differences in trial cushion(s).
- Be consistent with postural support – i.e. UE always on lap or armrests, etc.
- Completely off-weight mat between readings.

Steps

- Beat the current cushion.
- Relative comparisons.
- Record IPM “movie” of propulsion, transfer.
- Use IPM to rule out versus definitive selection.
- IPM result should not be sole deciding factor.

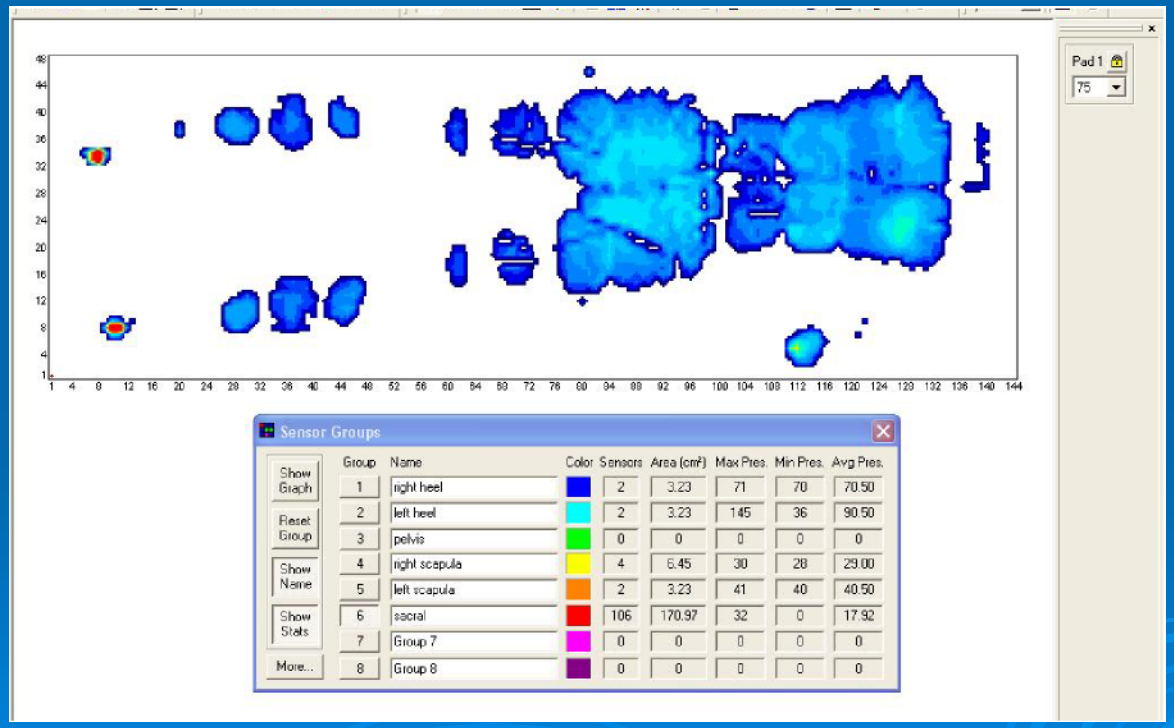
Steps

- Additional considerations for cushion selection:
  - Maintenance and set-up requirements
  - # of caregivers / staff turnover.
  - Provide client and staff education.
  - Do follow up.

Bed IP measurement

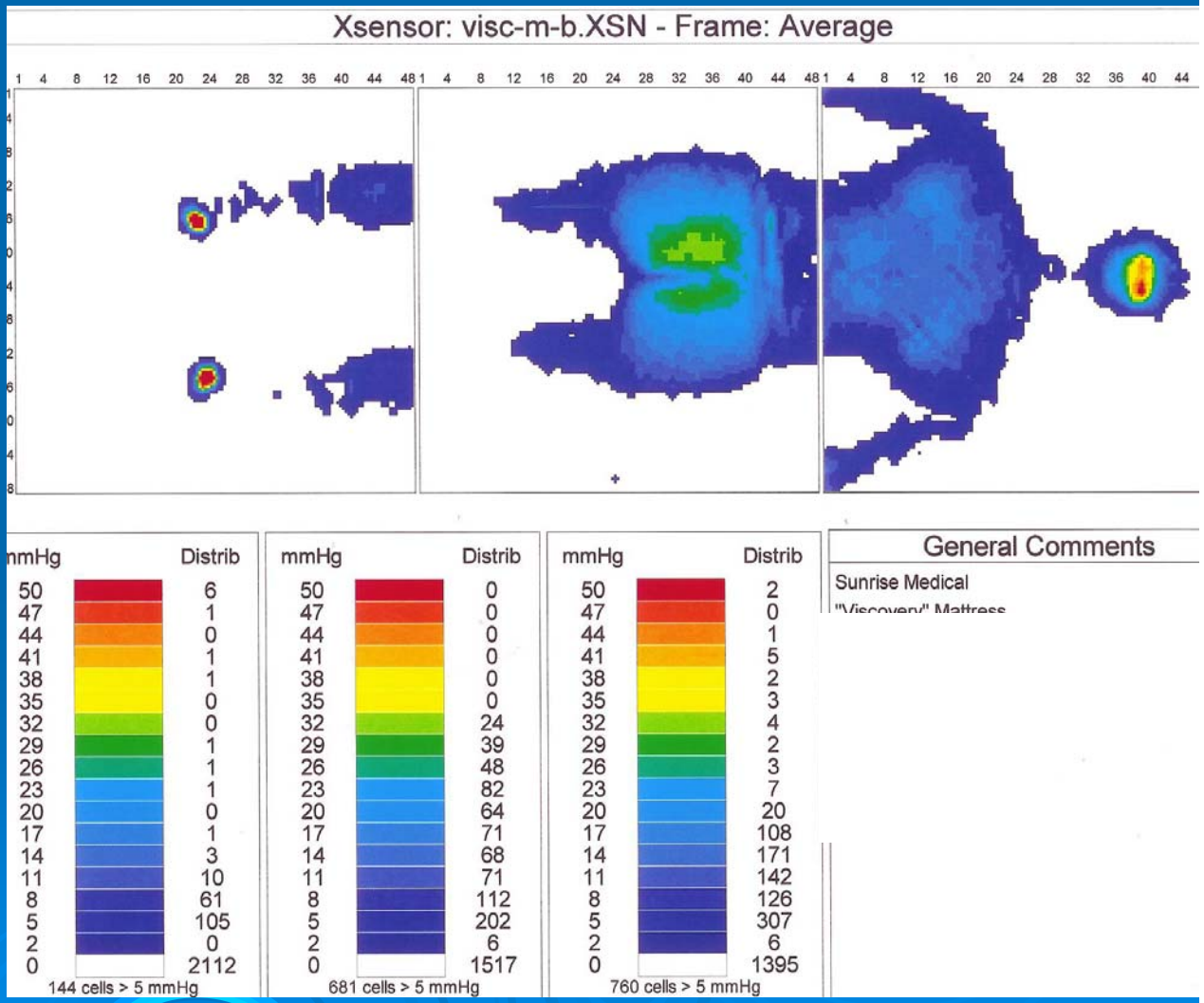
- A little different from seated measurements
  - A less dynamic environment
    - People move in sitting more than in bed
  - Fewer functional implications
  - Greater surface area
  - Different primary ‘at risk’ sites
    - Sacrum may never get a break
  - Lower pressures can cause major problems on tissues
  - Lower pressure thresholds complicate interpretation

Full body IP mats



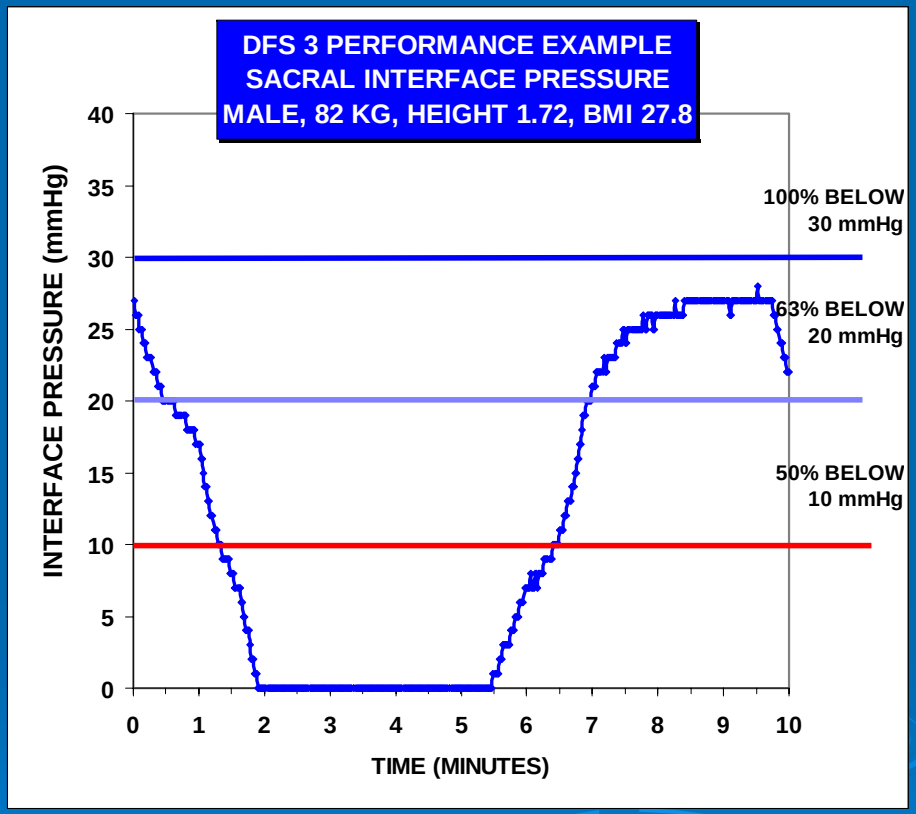
Segment the areas of interest

- Full mat vs. Seat size mats - can be moved across body
- Note: in this set-up, 50mmHg was deemed a threshold
  - Saturated beyond 50 mmHg
- Acceptable or can you do ‘better’?



Alternating pressure mattress

- Take readings throughout the entire cycle.
- Compare time at load, in addition to pressure distribution.



Kim Davis, MSPT, ATP
Shepherd Center
Crawford Research Institute
2020 Peachtree Rd NW
Atlanta, GA 30309
404-894-0561 (GA Tech)
kim_davis@shepherd.org

Stephen Sprigle, PhD, PT
CATEA
Georgia Institute of Technology
490 10th Street NW
Atlanta, GA 30332-0156
404-385-4302
stephen.sprigle@coa.gatech.edu