Can We Trust Ambulatory Blood Pressure Monitors? Approved Monitor Underestimates Diastolic Pressure & Misclassifies Patients

VP Lombardi, DR Taaffe, M Kaltenhauser, DL Pate
BACKGROUND

1. Health-care providers & clinicians urged to consider advantages of using 24-hr ABPM.

2. ABPMs theoretically appealing – up to 200 values ≤ 24 hr
   a. refine classification of suspected hypertensives,
   b. establish diurnal impact of treatments &
   c. tailor specific plans for optimizing BP.

3. Each step is entirely contingent upon obtaining data that is both accurate & reliable.

4. International (ESH, BHS) & US national (AAMI) approval protocols require testing only for subjects who are seated, yet ABPMs that achieve a passing grade are deemed accurate & reliable over 24-hr when patients assume multiple postures.
• 4579 articles with key words *ambulatory blood pressure*
• 91 (~ 2%) contained key word *validation*
• 17 (~ 0.4%) classified as true validation studies
• 3 studies measured all postures for all subjects
• 12 of 19 ABPMs currently available are recommended for use, yet only 2 have been tested for a variety of postures
• 1 ABPM is approved for multiple body positions

www.dableducational.org
KEY QUESTIONS

1. If ABPM accuracy & reliability differ based on posture, could this lead to errors in classifying patients & in comparing data?

2. How do two approved, identical ABPMs differ in assessing same arm BPs simultaneously in the lab & in the field?

3. How do ABPMs differ from clinicians using a Hg column when assessing subjects who assume multiple postures?
Dual Monitor Protocol (DMP): Lab + Field
Dual Monitor Protocol (DMP): Lab + Field

Valve: A1-A2 Sequential vs Simultaneous Testing
# Results Presented Today

<table>
<thead>
<tr>
<th>Subjects</th>
<th>Gender</th>
<th>Age</th>
</tr>
</thead>
<tbody>
<tr>
<td>1. 1 Labile HTN</td>
<td>♂</td>
<td>35 yr</td>
</tr>
<tr>
<td>2. 15 Normotensives</td>
<td>8 ♀</td>
<td>7 ♂</td>
</tr>
<tr>
<td>3. 14 Hypertensives</td>
<td>8 ♀</td>
<td>6 ♂</td>
</tr>
<tr>
<td>4. 11 1° ETOH</td>
<td>2 ♀</td>
<td>9 ♂</td>
</tr>
</tbody>
</table>
**Original Dual Monitor Field Protocol**, 10 hr Case Study, Labile Hypertensive, 35 yr O

151 Simultaneous, Same Arm BPs

<table>
<thead>
<tr>
<th></th>
<th>SBP (mm Hg)</th>
<th>DBP (mm Hg)</th>
<th>HR (bpm)</th>
</tr>
</thead>
<tbody>
<tr>
<td>A1</td>
<td>134.3 ± 10.8</td>
<td>86.9 ± 8.8</td>
<td>69.2 ± 7.2</td>
</tr>
<tr>
<td></td>
<td>2.7 ± 4.3</td>
<td>1.7 ± 6.6</td>
<td></td>
</tr>
<tr>
<td>A2</td>
<td>131.6 ± 11.1</td>
<td>85.2 ± 8.8</td>
<td>69.8 ± 7.3</td>
</tr>
</tbody>
</table>

**NB: A1 & A2 accounted for 85% of SBP variance** (R = 0.92) but only **52%** of DBP variance (R = 0.72)

**P < 0.01, ***P < 0.001**
OBSERVER 1 vs OBSERVER 2
DIASTOLIC BLOOD PRESSURE (DBP)

95% of t
+ 4-5 mm Hg

Lab

15 NTN
8 ♀, 7 ♂
243 BPs

Auscultatory Gaps
ACCUTRACKER 1 vs ACCUTRACKER 2
DIASTOLIC BLOOD PRESSURE (DBP)

$R^2 = 0.69$

15 NTN
8 $\varnothing$, 7 $\odot$
243 BPs

95% of t

$\pm 10-12$ mm Hg
Within 16 mm Hg below & 7 mm Hg above

95% of t

up to 23 mm Hg below!

Average 5 mm Hg below

up to 15 mm Hg above!

15 NTN 8 Q, 7 O'
243 BPs
OBSERVERS vs ABPMs in NORMOTENSIVES

POSTURAL DIFFERENCES

BP DIFFERENCE (MM HG)

SUPINE
N=58

SEATED
N=92

STANDING
N=93

*** P < 0.001, DBP Supine vs Standing

*** P = 0.006, DBP Seated vs Standing

*** P < 0.001, DBP Standing vs Supine & Seated
OBSERVERS vs ABPMs in 10 ETOH-DEPENDENTS
POSTURAL DIFFERENCES

**P = 0.01, DBP Supine vs Standing
**P = 0.02, DBP Standing vs Supine & Seated
OBSERVERS vs ABPMs IN NORMOTENSIVES

ARM POSITION DIFFERENCES

***P = 0.002

BP DIFFERENCE (MM HG)

PHLEBOSTATIC N=151

RELAXED N=92

***P = 0.002, DBP Relaxed vs Phlebostatic
OBSERVERS vs ABPMs IN HYPERTENSIVES
ARM POSITION DIFFERENCES

**P = 0.04, DBP Relaxed vs Phlebostatic**
OBSERVER CORRECTED VS 24-HR ABPM DIASTOLIC BLOOD PRESSURE (DBP) IN A MEDICATED HYPERTENSIVE (HF-8)

- **HF-8** Observer Corrected
- **DBP = 93 mm Hg** Stage I Hypertension
- **DBP = 83 mm Hg** Normotension

TIME (hr)

- **S** = Onset of Sleep
- **A** = Awake
- **M** = Medication
- **C** = Cigarette

LAB TEST

ABPM
OBSERVER CORRECTED VS 24-HR ABPM DIASTOLIC BLOOD PRESSURE (DBP) IN A PRIMARY ALCOHOL DEPENDENT (ABPSL-4)

DBP = 94 mm Hg
Stage I Hypertension

Observer Corrected

DBP = 87 mm Hg
Pre-Hypertension

LAB TEST

ABPM

ABPSL-4

ABPM

S = ONSET OF SLEEP
A = AWAKE
C = CIGARETTE

TIME (hr)
**CLINICALLY SIGNIFICANT DIFFERENCES IN ABPM & OBSERVER-CORRECTED NHLBI (1997, 2003) CLASSIFICATIONS OF 1275 ABPM FIELD SYSTOLIC (SBP) & DIASTOLIC (DBP) PRESSURES IN 11 PRIMARY ALCOHOL-DEPENDENTS**

<table>
<thead>
<tr>
<th>ABPM vs Observer NHLBI Classification</th>
<th>%SBP Values</th>
<th>%DBP Values</th>
</tr>
</thead>
<tbody>
<tr>
<td>+1 <em>ABPM 1 Category Above Observers</em></td>
<td>3%</td>
<td>1%</td>
</tr>
<tr>
<td>(eg ABPM indicates Prehypertension, Observers Normotension)</td>
<td></td>
<td></td>
</tr>
<tr>
<td>+0 <em>ABPM Identical Category as Observers</em></td>
<td>85%</td>
<td>44%</td>
</tr>
<tr>
<td>(eg Both ABPM &amp; Observers indicate Normotension)</td>
<td></td>
<td></td>
</tr>
<tr>
<td>-1 <em>ABPM 1 Category Below Observers</em></td>
<td>12%</td>
<td>~40%</td>
</tr>
<tr>
<td>(eg ABPM indicates Normotension, Observers Prehypertension)</td>
<td></td>
<td></td>
</tr>
<tr>
<td>-2 <em>ABPM 2 Categories Below Observers</em></td>
<td>0%</td>
<td>15%</td>
</tr>
<tr>
<td>(eg ABPM indicates Normotension, Observers STAGE I Hypertension)</td>
<td></td>
<td></td>
</tr>
<tr>
<td>-3 <em>ABPM 3 Categories Below Observers</em></td>
<td>0%</td>
<td>~1%</td>
</tr>
<tr>
<td>(eg ABPM indicates Normotension, Observers STAGE II Hypertension)</td>
<td></td>
<td></td>
</tr>
<tr>
<td>Patient</td>
<td>BP Source</td>
<td>SBP</td>
</tr>
<tr>
<td>---------</td>
<td>-----------</td>
<td>--------</td>
</tr>
<tr>
<td>1</td>
<td>ABPM</td>
<td>129.7</td>
</tr>
<tr>
<td></td>
<td>Δ</td>
<td>127.7</td>
</tr>
<tr>
<td></td>
<td></td>
<td>2.0</td>
</tr>
<tr>
<td>2</td>
<td>ABPM</td>
<td>128.4</td>
</tr>
<tr>
<td></td>
<td>Δ</td>
<td>124.5</td>
</tr>
<tr>
<td></td>
<td></td>
<td>3.9</td>
</tr>
<tr>
<td>3</td>
<td>ABPM</td>
<td>155.7</td>
</tr>
<tr>
<td></td>
<td>Δ</td>
<td>151.2</td>
</tr>
<tr>
<td></td>
<td></td>
<td>4.5</td>
</tr>
<tr>
<td>4</td>
<td>ABPM</td>
<td>121.8</td>
</tr>
<tr>
<td></td>
<td>Δ</td>
<td>120.2</td>
</tr>
<tr>
<td></td>
<td></td>
<td>1.6</td>
</tr>
<tr>
<td>5</td>
<td>ABPM</td>
<td>104.5</td>
</tr>
<tr>
<td></td>
<td>Δ</td>
<td>103.8</td>
</tr>
<tr>
<td></td>
<td></td>
<td>0.7</td>
</tr>
<tr>
<td>Age</td>
<td>Sex</td>
<td>Observed</td>
</tr>
<tr>
<td>-----</td>
<td>-----</td>
<td>----------</td>
</tr>
<tr>
<td>6</td>
<td>31 yr</td>
<td>Observers</td>
</tr>
<tr>
<td>ABPM</td>
<td>117.9</td>
<td>Optimal BP</td>
</tr>
<tr>
<td>Δ</td>
<td>1.4</td>
<td></td>
</tr>
<tr>
<td>7</td>
<td>39 yr</td>
<td>Observers</td>
</tr>
<tr>
<td>ABPM</td>
<td>138.2</td>
<td>Pre HTN</td>
</tr>
<tr>
<td>Δ</td>
<td>0.5</td>
<td></td>
</tr>
<tr>
<td>8</td>
<td>35 yr</td>
<td>Observers</td>
</tr>
<tr>
<td>ABPM</td>
<td>110.0</td>
<td>Optimal BP</td>
</tr>
<tr>
<td>Δ</td>
<td>4.3</td>
<td></td>
</tr>
<tr>
<td>9</td>
<td>30 yr</td>
<td>Observers</td>
</tr>
<tr>
<td>ABPM</td>
<td>109.8</td>
<td>Optimal BP</td>
</tr>
<tr>
<td>Δ</td>
<td>2.7</td>
<td></td>
</tr>
<tr>
<td>10</td>
<td>43 yr</td>
<td>Observers</td>
</tr>
<tr>
<td>ABPM</td>
<td>120.4</td>
<td>Normal</td>
</tr>
<tr>
<td>Δ</td>
<td>0.4</td>
<td></td>
</tr>
<tr>
<td>11</td>
<td>59 yr</td>
<td>Observers</td>
</tr>
<tr>
<td>ABPM</td>
<td>165.1</td>
<td>Stage II HTN</td>
</tr>
</tbody>
</table>
SUMMARY & CONCLUSIONS

1. An approved ABPM significantly underestimates DBP. Two identical model ABPMs have a lower level of agreement than two clinicians using a Hg column.

2. The magnitude of ABPM underestimation is statistically & clinically significant & varies according to posture.

3. Diastolic pressure underestimations are greatest when subjects are awake & standing with the arm relaxed.

4. Variable underestimations may lead to misdiagnosis & mismanagement of patients & to errors in interpreting research results.

5. International (ESH, BHS) & US National (AAMI) approval protocols should be revised to require testing for a variety of postures. Without more comprehensive, postural & activity testing, ABPMs cannot be claimed as approved for truly ambulatory conditions.
DISCUSSION
Are ABPMs truly superior to Clinic BPs in predicting cardiovascular mortality?

Difficulty in Determining Diastolic Endpoint

Grass Model 7P8

Tachograph

HR RANGE = 68-80 B/MIN, X = 73.3 B/MIN

Sphygmomanometer

BP = 130/75? MM HG

Where is DBP?
K-Sound Intensity Changes w/Body & Arm Position

Standing posture, Elbow relaxed @ side

Systolic = Sensitivity = 20 mV/cm
Deflation Rate = 2.8 mm Hg/s
Diastolic??

Blood Pressure = 135/85

Standing posture, Elbow @ Phlebostatic Axis or ❤️ level

Systolic = Sensitivity = 20 mV/cm
Deflation Rate = 2.9 mm Hg/s
Diastolic??

Blood Pressure = 125/50

20 mV
K-Sound Intensity Changes with Activity

Pre-exercise, Standing, Relaxed Arm

> 2.5 to 3-fold increase in K-sound intensity

Post-exercise, Standing, Relaxed Arm

15 squat repetitions
Oscillometry Flashlight-Nomogram Effect

Assume $PP = C$

Difficult to determine cut points, especially Diastolic BP

Auscultatory BP (K-sounds)

Oscillometric BP (Pulses in cuff)
Oscillometry Flashlight Effect

MAP
PP = C

Underestimate DBP
Oscillometry Flashlight Effect

Overestimate SBP
1. Use Dual Monitor Protocol with postural challenges to verify accuracy & reliability

2. Use Correction Factors for 24-hr ABPM values

3. Develop postural & activity adjusting ABPMs

4. Modify AAMI, BHS, & ESH/IP criteria to require postural & activity challenges

5. Reflect back & return to basic physiology
AVERAGE 24-HR DIASTOLIC BLOOD PRESSURE (DBP) vs. LABORATORY STANDING RELAXED ARM DBP IN SUSPECTED HYPERTENSIVES

$R = .914, P = .001, R^2 = .835$

$24$-hr DBP $= .61 \times \text{Lab DBP} + 33.0$
AVERAGE 24-HR SYSTOLIC BLOOD PRESSURE (SBP) vs. LABORATORY SUPINE PHLEBOSTATIC ARM SBP IN PRIMARY ALCOHOL DEPENDENTS (1^0 ETOH)

\[
R = 0.941, \ P < 0.001, \ R^2 = 0.886
\]

\[
24\text{-hr SBP} = 0.65 \times \text{Lab SBP} + 49.6
\]
Comparing Posture & Arm Position for Lab Measurements with 24-hr, Awake & Sleep Systolic (SBP) and Diastolic (DBP) Blood Pressures Obtained by Ambulatory Blood Pressure Monitoring (ABPM) In Medicated & Non-Medicated Hypertensives

<table>
<thead>
<tr>
<th>Lab Position</th>
<th>SBP from ABPM</th>
<th>DBP from ABPM</th>
</tr>
</thead>
<tbody>
<tr>
<td></td>
<td>24-hr R R²</td>
<td>Awake R R²</td>
</tr>
<tr>
<td>Supine</td>
<td>.671* .450</td>
<td>.516 .266</td>
</tr>
<tr>
<td>Phlebostatic</td>
<td>P=.048</td>
<td>P=.155 NS</td>
</tr>
<tr>
<td>Seated</td>
<td>.680* .462</td>
<td>.426 .181</td>
</tr>
<tr>
<td>Phlebostatic</td>
<td>P=.044</td>
<td>P=.253 NS</td>
</tr>
<tr>
<td>Seated</td>
<td><em><em>.752</em> .566</em>*</td>
<td><strong>.578 .334</strong></td>
</tr>
<tr>
<td>Relaxed</td>
<td><strong>P=.019</strong></td>
<td><strong>P=.103 NS</strong></td>
</tr>
<tr>
<td>Standing</td>
<td>.327 .107</td>
<td>.174 .030</td>
</tr>
<tr>
<td>Phlebostatic</td>
<td>P=.390 NS</td>
<td>P=.655 NS</td>
</tr>
<tr>
<td>Standing</td>
<td><strong>.489 .239</strong></td>
<td><strong>.257 .066</strong></td>
</tr>
<tr>
<td>Relaxed</td>
<td><strong>P=.181 NS</strong></td>
<td><strong>P=.505 NS</strong></td>
</tr>
<tr>
<td>Overall</td>
<td>.581 .338</td>
<td>.584 .341</td>
</tr>
<tr>
<td></td>
<td>P=.101 NS</td>
<td>P=.099 NS</td>
</tr>
</tbody>
</table>
## Best Lab/Clinic Postures, Arm Positions & Equations for Predicting ABPM 24-hr, Awake & Sleep Blood Pressures in Primary Alcohol-Dependents (1⁰ ETOH) & Hypertensives (HTN)

<table>
<thead>
<tr>
<th>Group</th>
<th>Pressure</th>
<th>24-hr</th>
<th>Awake</th>
<th>Sleep</th>
</tr>
</thead>
<tbody>
<tr>
<td>1⁰ ETOH</td>
<td>SBP</td>
<td>Supine Phlebostatic</td>
<td>Seated Relaxed*</td>
<td>Supine Phlebostatic</td>
</tr>
<tr>
<td></td>
<td></td>
<td>R=.941, P&lt;.001, R²=.886</td>
<td>R=.921, P&lt;.001, R²=.848</td>
<td>R=.864, P=.001, R²=.746</td>
</tr>
<tr>
<td></td>
<td></td>
<td>24-hrBP=.65LabBP+49.6</td>
<td>AwakeBP=.85LabBP+30.1</td>
<td>SleepBP=.79LabBP+12.7</td>
</tr>
<tr>
<td></td>
<td>DBP</td>
<td>Supine Phlebostatic</td>
<td>Supine Phlebostatic</td>
<td>Supine Phlebostatic</td>
</tr>
<tr>
<td></td>
<td></td>
<td>R=.732, P=.010, R²=.536</td>
<td>R=.670, P=.024, R²=.449</td>
<td>R=.672, P=.023, R²=.452</td>
</tr>
<tr>
<td></td>
<td></td>
<td>24-hrBP=.49LabBP+45.5</td>
<td>AwakeBP=.39LabBP+57.1</td>
<td>SleepBP=.94LabBP-7.5</td>
</tr>
<tr>
<td>HTN</td>
<td>SBP</td>
<td>Seated Relaxed</td>
<td>NS</td>
<td>NS</td>
</tr>
<tr>
<td></td>
<td></td>
<td>R=.752, P=.019, R²=.566</td>
<td></td>
<td></td>
</tr>
<tr>
<td></td>
<td></td>
<td>24-hrBP=.47LabBP+73.9</td>
<td></td>
<td></td>
</tr>
<tr>
<td></td>
<td>DBP</td>
<td>Standing Relaxed</td>
<td>Standing Relaxed</td>
<td>Standing Relaxed</td>
</tr>
<tr>
<td></td>
<td></td>
<td>R=.914, P=.001, R²=.835</td>
<td>R=.828, P=.006, R²=.686</td>
<td>R=.761, P=.017, R²=.579</td>
</tr>
<tr>
<td></td>
<td></td>
<td>24-hrBP=.61LabBP+33.0</td>
<td>AwakeBP=.50LabBP+48.7</td>
<td>SleepBP=.51LabBP+25.3</td>
</tr>
</tbody>
</table>

*NB: For 1⁰ETOH, in predicting Awake ABPM, Supine Phlebostatic (R=.920, P<.001, R²=.846; AwakeBP=.61LabBP+58.3) was a close second behind the Seated Relaxed position.*
SpaceLabs 90207 Problems with Variability
Underestimation & Special Populations

In pregnancy
In pregnancy
In pre-eclampsia**
In pre-eclampsia
In children
In elderly, supine over all pressures
During hemodialysis

NB: **SBP Underestimation 10 ± 10 mm Hg
**DBP Underestimation 8 ± 7 mm Hg

See www.dableducational.org for detailed references.
<table>
<thead>
<tr>
<th>Overall, Limited Motion</th>
<th>Stair Ascent/Descent Only</th>
</tr>
</thead>
<tbody>
<tr>
<td><strong>SL1</strong></td>
<td><strong>SL1</strong></td>
</tr>
<tr>
<td><strong>S</strong> 81%</td>
<td><strong>S</strong> 12%</td>
</tr>
<tr>
<td><strong>E</strong> 19%</td>
<td><strong>E</strong> 88%</td>
</tr>
<tr>
<td><strong>M</strong> (14%)</td>
<td><strong>M</strong> (13%)</td>
</tr>
</tbody>
</table>

<table>
<thead>
<tr>
<th><strong>SL2</strong></th>
<th><strong>SL2</strong></th>
</tr>
</thead>
<tbody>
<tr>
<td><strong>S</strong> 81%</td>
<td><strong>S</strong> 29%</td>
</tr>
<tr>
<td><strong>E</strong> 19%</td>
<td><strong>E</strong> 71%</td>
</tr>
<tr>
<td><strong>M</strong> (11%)</td>
<td><strong>M</strong> (20%)</td>
</tr>
</tbody>
</table>

**NB:** Both SL1 & SL2 exhibited “run-away” inflations on stair ascent, likely incorrectly perceiving motion artifact as inability to exceed SBP. Both devices largely motion & vibration intolerant.
TWO 24-HR ABPM SPACELABS 90207 UNITS
DUAL-MONITOR FIELD PROTOCOL, LABILE HYPERTENSIVE

Valid Cases SL1 = 137
Valid Cases SL2 = 142
SPACELABS 1 vs SPACELABS 2
DIASTOLIC BLOOD PRESSURE (DBP)
LABILE HYPERTENSIVE (52 yr σ') FIELD TEST
SIMULTANEOUS, SAME ARM, N = 57 TRIALS
AO-pABPM Prototype Model

O = Oscillometric Transducer *
  detects pulse ∆s in BP cuff

C = Cone-shaped, velcro cuff **
  5 sizes: large adult, adult, small adult, pediatric, neonatal

A = Ausculatory Transducer **
  piezo-electric curved crystal microphone detects K-sounds

connecting pressure tube

p = pump

MedSmartt ***
AO-pABPM

a₁, a₂ = accelerometers 1 & 2
detect static acceleration,
tilt = body position

\[
\begin{align*}
\text{d} &= \text{distance between components} \\
\text{i} &= \text{interference potential}
\end{align*}
\]

*1979, **1992, ***2005-2006
Potential pump types: (1) Piezo-electric pump enables silent pumping & consumes little power, but currently has too low of a flow rate, (2) CO2 gas canister which has near-silent pumping but with potential safety issues, & (3) Conventional diaphragm pump which is noisier and has higher power consumption.
Dedication to Dr. Milton Eugene Davis
NFL All-Pro Baltimore, 30 yr NFL Scout
Professor of Zoology, Field Ornithology & Natural History, May 31, 1929 – September 29, 2008
**GOALS**

1. Provide a small sample of some of Dr. Davis’ work on sports medicine injuries in NFL Combine players. We will focus on ~5-yr injury history of 314 players from 2004.

2. Describe prevalence, anatomical sites & diagnoses with an emphasis on player position in attempt to develop an injury-diagnoses-player position continuum.

3. Provide suggestions to minimize injuries & maximize NFL longevity & ultimately quality of life after retirement.

4. Help younger athletes who play football & their coaches & allied health & medical practitioners.

5. Provide impetus to move from descriptive to more causal mechanistic & integrative research with input from biomechanists, physiologists, physicians, NATA & PT.
Medical Evaluation
2 Orthopedists MD
1 Internist MD, 1 ATC, 1 Asst
Routine & Individualized Exams

Medical History & Surveys
Family History, Psychological Questionnaires, IQ Test, Team-Specific Surveys

Anthropometrics, Strength, Agility & Speed Tests
Ht, Wt, Strength Testing, 40-yd Dash, General Agility Drills

Specific Agility Drills Based On Position
Specific Agility Drills Conducted By Preselected Position Coaches

Follow-up X-Rays MRIs

Follow-up Medical Tests
Medical History, DL Major University

• 3/04 L Ankle Arthroscopy, Removal Symptomatic Os Trigonum, 10/03 L High Ankle Sprain, MRI Peroneal Tendonosis, Split in Peroneus Brevis, 10/02 R Foot 5th Metatarsal Jones Fracture, ORIF, 02/03 R Wrist Chronic Pain, Surgical Cyst Removal, 02/00 R Lunotriquetral Ligament Tear, Surgical Debridement, 8/99 L Knee Patellar Tendonitis, Probable Grade 2

• 4/2 ORTHO, MED 0
CODED: 17,9, 17,3, 17,7, 17,4, 11,9, 18,5, 11,4, 15,7
726 Documented Injuries in 314 Players
2.3 Injuries/Player
Range: 0 – 10 Injuries
63% of Players ≥ 1 Injury
  7%    1 Injury
  9%    2 Injuries
29%    3 or 4 Injuries
18%    ≥ 5 Injuries

NB: 3 yr prior, 1.4 Injuries/Player
58% of Players ≥ 1 Injury
INJURIES/PLAYER BY PLATOON
NFL COMBINE 2004, N = 314
INJURY FREQUENCY/PLAYER BY POSITION
NFL COMBINE 2004, N = 726/314, 2.3/PLAYER

INJURY FREQUENCY/PLAYER

RB: 3.4
DL: 3.1
OL: 2.9
WO: 2.5
TE: 2.3
LB: 1.7
QB: 1.4
DB: 1.3
PK: 1.1

2.3 = \bar{X}
INJURY DIAGNOSES
NIC 2004, 314 PLAYERS
726 INJURIES OVER 5 YR

NB: 1\textsuperscript{st} time in top 3!

1. TEAR
2. SPRAIN
3. DJD

24% TEAR
18% SPRAIN
12% ARTHRITIS/DJD
12% DISLOCATION/SUBLUX
11% REPETITIVE TRAUMA
10% FRACTURE
9% INFLAMMATION NOT DJD
2% STRAIN
139 of 314 or ~44% had 228 surgeries ≡ 0.73 surgeries/player for all 314 players:

1 Surgery: 25%
2 Surgeries: 13%
3 Surgeries: 5%
4 Surgeries: 2%
SURGERY FREQUENCY/PLAYER BY POSITION
NFL COMBINE 2004, N = 228/314, 0.73/PLAYER
12% of All Players & 22% of Injured Players Have Significant DJD or Arthritis
% PLAYERS WITH ARTHRITIS BY PLATOON
NFL COMBINE 2004, N = 68/314, 22%

\[
\begin{align*}
\text{OFFENSE} & \quad 27\% \\
N=44/162 \\
\text{DEFENSE} & \quad 16\% \\
N=23/141 \\
\text{KICKER} & \quad 9\% \\
N=1/11
\end{align*}
\]

22% Average
% PLAYERS WITH ARTHRITIS BY POSITION
NFL COMBINE 2004, N = 68/314, 22%

<table>
<thead>
<tr>
<th>Position</th>
<th>% Arthritis</th>
</tr>
</thead>
<tbody>
<tr>
<td>RB</td>
<td>38%</td>
</tr>
<tr>
<td>TE</td>
<td>33%</td>
</tr>
<tr>
<td>OL</td>
<td>32%</td>
</tr>
<tr>
<td>DL</td>
<td>30%</td>
</tr>
<tr>
<td>WO</td>
<td>23%</td>
</tr>
<tr>
<td>LB</td>
<td>11%</td>
</tr>
<tr>
<td>PK</td>
<td>9%</td>
</tr>
<tr>
<td>DB</td>
<td>6%</td>
</tr>
<tr>
<td>QB</td>
<td>5%</td>
</tr>
</tbody>
</table>

22% = X
No NFL player ever has collected interceptions at a faster rate than Baltimore's Milt Davis.
TAKE-AWAY POINTS FROM DR. DAVIS:

1. Over 3 yr, the surgery rate remained relatively constant (0.7 surgeries/player) while the injury rate increased from 1.4 to 2.3 injuries/player (↑ 64%).

2. An injury rate continuum spans from highest near the point of attack -- RB (3.4/player), OL (3.1/player) & DL (2.9/player) – to lowest further from the point of attack: PK (1.1), DB (1.3) & QB (1.4).
3. The knee, shoulder & ankle are primary sites of injury, while primary diagnoses include tears, sprains & degenerative joint disease.

4. Over 3 yr, the % of injured players with documented degenerative arthritis increased from 8% to 12% (↑ 50%) which seems to mirror the increased injury rate.

5. While anatomical sites of injury appear identical to earlier results, diagnoses appear to be shifting toward more arthritis. We suspect that this trend is likely to impact NFL participation and longevity. We hope to continue Dr. Davis’ work with this as a focus for future investigations.
DISCUSSION
Medical History, DB, 8th Round!

- No significant injuries on arrival to NFL
- 1956 L Hand 1st, 2nd, 3rd Metacarpal Fracture
- 1957 R Hand 2nd, 3rd, 4th Metacarpal Fracture
- 1957 Nose Fracture
- 1957 R Hand 1st Metacarpal Fracture
- 1957 R Knee ACL Sprain
- 1958 L Knee ACL Sprain
- 1958 L Foot 3rd Metatarsal Fracture
- 1959 L Hip Fracture

Participation 95-100% for all yr
MEDICAL STATUS OF PLAYERS PRIOR TO NFL?

2. Multiple Variables:
   - Medical
   - Physical
   - Performance

   - Participation
   - Longevity
   - Productivity
LONGEVITY?

1. 15% of players in the NFL (275/1889) are rookies in the NFL, that is with no prior experience. Only 2.9% (55/1889) have 1 year experience, while 15% (284/1889) have 2 years experience, indicating a significant cut-point/longevity threshold > rookie yr.

2. ≤ 7% of players make it longer than 10 yr in the NFL, and < 2% 13 yr or longer. Player position rather than any significant medical variable with the exception of RB, WO, and LB, appears to be more of a determinant in longevity. Of course, there are many other intrinsic variables which may prove difficult to measure.
From Our Past Research Which Seems To Be Verified by Present Ongoing Analyses

1. For offensive players, only for RB and WO do any of the medical variables make a difference in predicting future participation. Orthopedic Grade and Total # of Injuries provide a small degree of predictability (8-11%).

2. For defensive players, only for LB do total number of injuries & total number of surgeries offer a marginal degree of predictability (11%).
Running Backs
Orthopedic Grade
8% of Participation Variance*
P<0.05
Wide Receivers
Orthopedic Grade*
10% of Participation Variance*
P<0.05*
Linebackers
Total Injuries* & Total Surgeries*
Each 11% of Participation Variance*
P<0.05*
%O/D PLAY TIME VS DRAFT #, YR 2001

R = 0.0340, NS

8% (30/384) > 75%
National Football League salaries

Chart NFL salaries by position
Average annual salary in the 2003 season by position (includes bonuses):

- Wide receiver $1.27 million
- Offensive lineman $1.32 million
- Defensive tackle $1.30 million
- Defensive end $1.41 million
- Linebacker $1.34 million
- Safety $1.09 million
- Cornerback $1.18 million
- Running back $992,000
- Quarterback $2.14 million
- Tight end $884,000
- Kicker $888,000
- Punter $785,000

Source: USA TODAY research

By Sam Ward, USA TODAY
BMI Silhouettes

Men

QB  RB
28  31

WR  K  TE
26  29  31

OL
38

DB  LB  DE  DT
27  31  34  38

< 25
MOST RECENT INJURY DIAGNOSIS

- 42% None
- 18% Tear
- 9% Dis/Sublux
- 7% Fracture
- 7% Rep Trauma
- 7% DJD
- 6% Sprain
- 6% Infl not DJD
- 6% Other
- 2% None
- 3%
QUALITY? OF PARTICIPATION OVER BOTH YEARS

- Minimal/Dwindlers: 62%
- Trans Down: 4%
- Trans Up: 19%
- Late Bloomers+: 2%
- Major Impact 1st yr: 10%
- Major Impact Both yr: 3%
- Late Bloomers+: 2%
The Seated, Routine-Office Posture Is Not Optimal For Predicting 24-Hr Ambulatory Blood Pressure

V. Patteson Lombardi¹, Dennis R. Taaffe², Marc Kaltenhauser³, & Donald L. Pate⁴. University of Oregon, Departments of Biology¹ & Human Physiology³ & Institute of Neuroscience⁴, Eugene, OR USA 97403 & School of Human Movement Studies², The University of Queensland, St. Lucia, QLD, Australia 4072

BACKGROUND Zacharias, Sheeps and Moore (Int J Cardiol, 1990, 28, 353-60) examined relationships among 24 hr ambulatory blood pressure monitoring (ABPM) and clinic blood pressure measurements, but we have determined that an ABPM and FDA approved ABPM can underestimate pressures and that unless ABPM field values are corrected, up to 90% of patients can be misdiagnosed and potentially mismanaged. The question was to whether there exist a best posture for measuring office blood pressure and how posture measurements relate to corrected ABPM values.

METHODS We developed a protocol with postural challenges to establish corrections factors specific for each subject, posture and arm position prior to 24-h ABPM field testing. We assessed routine office systolic (SBP) and diastolic (DBP) pressures, then exposed hypertensive (HTN, n=6) and primary alcohol dependents (1st ETN, n=13) to a series of lab measurements involving postural challenges. Two observers using a mercury column and teaching stethoscope assessed same arm pressures simultaneously with ABPMs.

Best Lab/Clinic Postures, Arm Positions & Equations for Predicting ABPM 24-hr, Awake & Sleep Blood Pressures in Primary Alcohol-Dependent (1st ETN) & Hypertensives (HTN)

<table>
<thead>
<tr>
<th>Group</th>
<th>Pressure</th>
<th>24-hr</th>
<th>Awake</th>
<th>Sleep</th>
</tr>
</thead>
<tbody>
<tr>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>SBP</td>
<td>Supine Phlebotatic</td>
<td>r = 0.91</td>
<td>24-hr</td>
<td>r = 0.89</td>
</tr>
<tr>
<td></td>
<td>Seated Phlebotatic</td>
<td>r = 0.89</td>
<td>24-hr</td>
<td>r = 0.87</td>
</tr>
<tr>
<td></td>
<td>Standing Phlebotatic</td>
<td>r = 0.92</td>
<td>24-hr</td>
<td>r = 0.90</td>
</tr>
</tbody>
</table>

**NB:** For 1st ETN, in predicting Awake ABPM, Supine Phlebotatic (r=0.92; P< 0.01; r=0.44; Adjusted r=61.6ABP=28.3) was a close second behind the Seated Relaxed position.

Comparing Posture & Arm Position for 24-hr Blood Pressure with the ABPM, Awake & Sleep Systolic (SBP) and Diastolic (DBP) Blood Pressures Obtained by Ambulatory Blood Pressure Monitoring (ABPM) In Medicated & Non-Medicated Hypertensives

**RESULTS** For all subjects (n=20), compared to standard, routine office pressures, comprehensive posture measurements were more predictive of ABPM 24-hr and awake pressures, improving the prediction of ABPM SBP by approximately 23-29%, and ABPM DBP by 17-23%. For 1st ETN, supine phlebotatic arm SBP was the most predictive of 24-hr and sleep SBP, while together with seated relaxed arm SBP was a powerful awake SBP predictor. For HTN, standing relaxed arm SBP was the most powerful predictor of 24-hr, awake, and sleep DBP.

**CONCLUSIONS** Our results, in a small group of carefully studied subjects, indicate that standard routine office measurements in the seated phlebotatic position, are less than optimal for predicting field pressures obtained from an ABPM. Measurements at the extreme ends of the posture challenge continuum from supine phlebotatic to standing relaxed arm positions – appear to be the most predictive. This may explain at least partially why ABPM values are slightly more correlated with target-organ damage, CVD risk and CVD mortality compared to routine office seated pressures obtained at a single point in time. While certainly more research is warranted, we encourage all practitioners to employ postural challenges in their routine assessments of blood pressure in attempt to envision a more comprehensive pressure profile. We also suggest that all ABPM values be corrected based on differences observed in the clinic prior to field testing, particularly for DBP.
CLINICALLY SIGNIFICANT DIFFERENCES IN ABPM & OBSERVER-CORRECTED NHLBI (1997, 2003) CLASSIFICATIONS OF LABORATORY FIELD SYSTOLIC (SBP) & DIASTOLIC (DBP) PRESSURES IN 11 PRIMARY ALCOHOL-DEPENDENTS

**ABPM vs Observer NHLBI Classification**

<table>
<thead>
<tr>
<th>SBP Values</th>
<th>DBP Values</th>
</tr>
</thead>
<tbody>
<tr>
<td>1st Category Above Observers</td>
<td>3%</td>
</tr>
<tr>
<td>1st Category Below Observers</td>
<td>12%</td>
</tr>
<tr>
<td>2nd Category Above Observers</td>
<td>85%</td>
</tr>
<tr>
<td>2nd Category Below Observers</td>
<td>0%</td>
</tr>
<tr>
<td>3rd Category Above Observers</td>
<td>15%</td>
</tr>
<tr>
<td>3rd Category Below Observers</td>
<td>0%</td>
</tr>
</tbody>
</table>

**METHODS**

1. To determine if our results could be applied to special patients in a controlled clinical setting, we validated our routine office multi-postural lab (SBP & DBP) pressures in 11 primary alcohol-dependent undergoing detoxification & abstinence. We hypothesized that the approved ABPM would underestimate DBP leading to misclassification of patients according to NHLBI guidelines.

**RESULTS**

3. For 10 of 11 patients in the lab, the ABPM incorrectly assessed DBP based on NHLBI classifications. (Table 1) The stepwise underestimation of lab DBP from supine to seated, was identical to previous findings. (5) For 11 DBP values from 24-hr tests, ABPM underestimated the observer’s NHLBI DBP classification by at least 1 category 56% of the time, and misclassified patients as normalizing when prehypertensive, prehypertensive when hypertensive & optimally when optimally normal when normalized.

**CONCLUSIONS**

These results confirm conclusively that an approved auscultatory ABPM underestimates DBP & leads to patient misclassification. (7) Cofracimetric ABPMs are perceived as being more robust, yet they are susceptible to underestimation & misclassification due to the flash effect, 2nd generation indirect-echolocation methods, & basic hemodynamic laws. (8) Create a 10-hr measurement frequency advantage, ABPMs are only marginally (1-2%) better than clinic BP in predicting cardiovascular death & only for nighttime SBP (>180 mmHg), when subjects are supine.

Ambulatory DBP is < 1/3 as effective as SBP in predictability, supporting our finding of inaccurate diastolic assessment. The highest ABPM DBPs are 10-15 mmHg lower than the highest clinic DBPs. Implying ABPM DBP underestimation above & beyond the white coat effect. To ensure accuracy, reliability, realistic office, & practical patient management & results interpretation, ABPM data points must be corrected based on postural challenges prior to field tests. All US & International Protocols (AAMI, BHS, EHNP) for validating ABPM should require multi-postural tests. Intensive basic hemodynamic & auscultatory & oscillometric relationships will foster the design of more accurate & reliable monitors.

Are ABPMs truly superior to Clinic BPs in predicting cardiovascular mortality?

**OBSERVER 1 vs OBSERVER 2** DIASTOLIC BLOOD PRESSURE (DBP)

**OBSERVER CORRECTED VS 24 HR ABPM BLOOD PRESSURE (DBP) IN A MEDICATED HYPERTENSIVE (DBP 160)**

**OBSERVERS vs ACCUTRACKER II ALCOHOL-DEPENDENT STUDY**

**CLINICALLY SIGNIFICANT DIFFERENCES IN ABPM & OBSERVER-CORRECTED NHLBI (1997, 2003) CLASSIFICATIONS OF LABORATORY FIELD SYSTOLIC (SBP) & DIASTOLIC (DBP) PRESSURES IN 11 PRIMARY ALCOHOL-DEPENDENTS**
A Postural-Adjustment 24-hr Ambulatory Blood Pressure Monitor (pABPM) for Improving Accuracy & Reliability?

V. Patteson Lombardi & Donald Pate
University of Oregon, Department of Biology & Institute of Neuroscience, Eugene, OR USA 97403

A popular ABPM significantly and variably underestimates diastolic blood pressure (DBP) relative to two trained observers using a mercury column to assess same arm pressures simultaneously. We have demonstrated this in normotensives, medicated and nonmedicated hypertensives, and primary alcohol-dependent patients. Underestimations differ significantly according to posture and the highest variability is demonstrated in transitional measurements, those that occur after a change in body or arm position. Two identical make ABPMs measuring same arm pressures simultaneously have a poor ($R^2 < 52\%$) level of agreement. Our theory that ABPM accuracy and reliability problems were linked to Korotkoff sound intensity variations with posture and activity was supported by polygraph data.

The AO-pABPM is the most sophisticated model in the evolution of the pABPM prototypes. Like the accessory/wart Pre-pABPM, the AO-model can assess a subject’s posture. However, unique to this model are: (1) embedding of our Dual Monitor Protocol (DMP) into a single unit, (2) use of synchronized oscillograms and auscultatory sensors which compare and contrast measurements, and (3) use of curved sensors which traverse the brachial artery and are fitted to the natural contour of the arm.

Since current ABPMs do not determine subject posture and activity level, it is likely that all ABPMs (without regard for make or model) are at best 1-step behind in sensor sensitivity adjustments, and thus prone to error and high variability. We sought to develop a postural- and activity-adjusting ABPM (pABPM) and initially envisioned four prototype stages, the first of which we have established. This manual pABPM involves observers assessing same arm pressures simultaneously with any ABPM, as subjects assume multiple postures in the laboratory prior to field studies. During 24-hr testing, subjects record posture and activities immediately after each measurement, and later each data point is adjusted based on original laboratory differences.

The second generation prototype is the Pre-pABPM wart/auto-correction calculator, which theoretically can be attached to any currently available auscultatory or oscillometric ABPM. Unlike our Manual pABPM prototype, the Pre-pABPM uses accelerometers to assess body position & automatically adjusts each BP measurement according to previously established postural correction factors. The graph illustrates BP data point adjustments similar to those made by the Manual pABPM and the Pre-pABPM accessory, auto-correction prototype.