Cuff blood pressure is progressively more biased with increasing age: individual participant level analysis from the INSPECT consortium

Disclosures
Blood pressure is a potent risk factor

High blood pressure #1 risk factor for death and disability worldwide

High blood pressure leading cause of CVD

Lowering blood pressure reduces risk

All evidence based on blood pressure measurement from upper arm cuff

Blood pressure measurement is one of the most important tests in clinical medicine
Accuracy of Cuff-Measured Blood Pressure
Systematic Reviews and Meta-Analyses

Dean S. Picone, BMEdRes(Hons), a Martin G. Schultz, PhD, a Petr Otahal, GDipSci, a Svend Aakhus, MD, PhD, b
Ahmed M. Al-Jumailly, PhD, c J. Andrew Black, MBBS(Hons), a,d Willem J. Bos, MD, PhD, e John B. Chambers, MD, f
Chen-Huan Chen, MD, g Hao-Min Cheng, MD, PhD, g Antoine Cremer, MD, h Justin E. Davies, PhD, i
Nathan Dwyer, MBBS, PhD, a,d Brian A. Gould, MD, PhD, j Alun D. Hughes, MBBS, PhD, k Peter S. Lacy, PhD, l
Esben Laugesen, MD, PhD, m Fuyou Liang, PhD, n Roman Melamed, MD, o Sandy Muecke, PhD, p
Nobuyuki Ohte, MD, PhD, q Sho Okada, MD, PhD, r Stefano Omboni, MD, s Christian Ott, MD, t Xiaoping Peng, MPHARM, a
Telmo Pereira, PhD, u Giacomo Pucci, MD, v Ronak Rajani, MD, f Philip Roberts-Thomson, MBBS, a,d
Niklas B. Rossen, MD, PhD, m Daisuke Sueta, MD, PhD, w Manish D. Sinha, PhD, x Roland E. Schmieder, MD, t
Harold Smulyan, MD, y Velandai K. Srikanth, PhD, a,z,aa Ralph Stewart, MD, bb George A. Stouffer, MD, cc
Kenji Takazawa, MD, PhD, dd Jiguang Wang, MD, PhD, ee Berend E. Westerhof, PhD, ff Franz Weber, MD, gg
Thomas Weber, MD, hh Bryan Williams, MD, l Hirotugu Yamada, MD, PhD, ii Eiichiro Yamamoto, MD, PhD, w
James E. Sharman, PhD a
**Cuff and invasive aortic systolic BP (studies from 1966-2016)**

<table>
<thead>
<tr>
<th>Author and Year</th>
<th>Study n</th>
<th>Mean difference[95%CI]</th>
</tr>
</thead>
<tbody>
<tr>
<td>Aakhus et al., 1993</td>
<td>28</td>
<td>-2.5 [-4.9, 0.0]</td>
</tr>
<tr>
<td>Bhatt et al., 2011</td>
<td>98</td>
<td>-7.4 [-9.9, -4.9]</td>
</tr>
<tr>
<td>Borow et al., 1982</td>
<td>30</td>
<td>0.7 [-1.1, 2.5]</td>
</tr>
<tr>
<td>Bos et al., 1992</td>
<td>19</td>
<td>0.6 [-2.4, 3.7]</td>
</tr>
<tr>
<td>Broyd et al, unpublished</td>
<td>25</td>
<td>-12.0 [-15.0, -6.1]</td>
</tr>
<tr>
<td>Cheng et al, 2010</td>
<td>100</td>
<td>2.5 [-1.0, 4.8]</td>
</tr>
<tr>
<td>Cheng et al, unpublished</td>
<td>17</td>
<td>-3.9 [-9.5, 1.7]</td>
</tr>
<tr>
<td>Costello et al, 2015</td>
<td>40</td>
<td>-0.8 [-4.1, 2.5]</td>
</tr>
<tr>
<td>Cremer et al, 2012</td>
<td>144</td>
<td>-5.5 [-9.9, -1.1]</td>
</tr>
<tr>
<td>Davies et al, 2003</td>
<td>26</td>
<td>3.4 [-0.5, 7.3]</td>
</tr>
<tr>
<td>Ding et al, 2013</td>
<td>33</td>
<td>-4.0 [-2.4, 0.4]</td>
</tr>
<tr>
<td>Kobayashi et al, 2013</td>
<td>20</td>
<td>-4.8 [-3.0, -8.0]</td>
</tr>
<tr>
<td>Korolkova et al, unpublished</td>
<td>14</td>
<td>9.5 [-0.6, 19.5]</td>
</tr>
<tr>
<td>Laugesen et al, 2013</td>
<td>34</td>
<td>4.1 [1.4, 6.7]</td>
</tr>
<tr>
<td>Lin et al, 2012 (A)</td>
<td>78</td>
<td>1.3 [-1.4, 4.0]</td>
</tr>
<tr>
<td>Lin et al, 2012 (B)</td>
<td>35</td>
<td>1.8 [-2.6, 6.1]</td>
</tr>
<tr>
<td>Lowe et al, 2009</td>
<td>37</td>
<td>-0.7 [-5.1, 3.7]</td>
</tr>
<tr>
<td>Mîlne et al, 2015</td>
<td>9</td>
<td>6.8 [-0.5, 14.1]</td>
</tr>
<tr>
<td>Nagle et al, 1966</td>
<td>2</td>
<td>-3.4 [-8.7, 1.9]</td>
</tr>
<tr>
<td>Nakagomi et al, 2016</td>
<td>139</td>
<td>-4.8 [-7.3, -2.4]</td>
</tr>
<tr>
<td>Ott et al, 2007</td>
<td>82</td>
<td>-1.8 [-4.3, 0.8]</td>
</tr>
<tr>
<td>Ott et al, 2011</td>
<td>52</td>
<td>10.9 [6.5, 15.3]</td>
</tr>
<tr>
<td>Park et al, 2014</td>
<td>6</td>
<td>0.0 [-7.5, 7.5]</td>
</tr>
<tr>
<td>Pereira et al, 2014</td>
<td>15</td>
<td>8.6 [2.4, 10.8]</td>
</tr>
<tr>
<td>Pencina et al, unpublished</td>
<td>148</td>
<td>3.1 [0.6, 4.6]</td>
</tr>
<tr>
<td>Pucci et al, 2013</td>
<td>33</td>
<td>1.7 [-1.0, 4.4]</td>
</tr>
<tr>
<td>Pucci et al, unpublished</td>
<td>29</td>
<td>-2.7 [-6.2, 0.9]</td>
</tr>
<tr>
<td>Rajani et al, 2008</td>
<td>14</td>
<td>2.3 [-2.4, 6.9]</td>
</tr>
<tr>
<td>Rossen et al, 2013</td>
<td>3</td>
<td>0.7 [-15.4, 19.7]</td>
</tr>
<tr>
<td>Saul et al, 1995</td>
<td>97</td>
<td>1.0 [-1.3, 3.2]</td>
</tr>
<tr>
<td>Smulyan et al, 2003</td>
<td>25</td>
<td>18.4 [13.0, 23.8]</td>
</tr>
<tr>
<td>Smulyan et al, 2008</td>
<td>100</td>
<td>-0.8 [-3.0, 1.4]</td>
</tr>
<tr>
<td>Smulyan et al, 2010</td>
<td>25</td>
<td>0.2 [-4.5, 4.9]</td>
</tr>
<tr>
<td>Suets et al, 2015</td>
<td>18</td>
<td>-13.4 [-15.5, -11.4]</td>
</tr>
<tr>
<td>Takazawa et al, 2007</td>
<td>18</td>
<td>4.1 [-0.8, 9.0]</td>
</tr>
<tr>
<td>Takazawa et al, 2012</td>
<td>52</td>
<td>1.4 [-1.7, 4.5]</td>
</tr>
<tr>
<td>Weber et al, 1999</td>
<td>36</td>
<td>1.6 [-1.4, 4.6]</td>
</tr>
<tr>
<td>Weber et al, 2011</td>
<td>30</td>
<td>-8.8 [-12.5, -5.1]</td>
</tr>
<tr>
<td>Williams et al, 2011</td>
<td>20</td>
<td>7.5 [5.2, 9.8]</td>
</tr>
</tbody>
</table>

39 studies, N=1823 patients

Mean difference: 0.3 [-1.5 to 2.1] mmHg

Cuff underestimates aortic SBP

Cuff overestimates aortic SBP
Cause of cuff inaccuracy?

Greater vascular stiffness / calcification → difficulty compressing the artery?

Disease related changes to blood flow and vascular function – affect ability of measurement algorithms to correctly detect BP?

Occur with advancing age

Influence of age on cuff accuracy?
Blood pressure in middle to older age

Blood pressure (mm Hg)

Age (years)

DBP
PP
SBP

Picone et al. unpublished
Aim and hypothesis

To determine the influence of age on the accuracy of cuff measured BP by comparison with invasive (intra-arterial) aortic BP

*Age will significantly influence the accuracy of cuff BP*
Study design

INSPECT consortium

n=1689 subjects in the current analysis

Cuff BP compared with invasive aortic BP

- oscillometric devices (except n=21 with mercury sphygmomanometer)
Quality control of consortium database

Studies that recorded data under basal conditions

Invasive (intra-arterial) BP measured from micromanometer tip or fluid-filled catheters

BP measurements recorded within the immediate period of each other

Study quality score based on important methodological attributes
## Participants

<table>
<thead>
<tr>
<th></th>
<th>40 to 49 years (n=169)</th>
<th>50 to 59 years (n=406)</th>
<th>60 to 69 years (n=555)</th>
<th>70 to 79 years (n=453)</th>
<th>80 to 89 years (n=106)</th>
</tr>
</thead>
<tbody>
<tr>
<td>Age, years</td>
<td>45 ± 3</td>
<td>55 ± 3</td>
<td>64 ± 3</td>
<td>74 ± 3</td>
<td>83 ± 2</td>
</tr>
<tr>
<td>Female sex, %</td>
<td>45 (27)</td>
<td>123 (31)</td>
<td>181 (33)</td>
<td>147 (33)</td>
<td>40 (38)</td>
</tr>
<tr>
<td>Height, cm</td>
<td>170.7 ± 9.5</td>
<td>167.0 ± 9.1</td>
<td>165.3 ± 10.3</td>
<td>162.9 ± 10.2</td>
<td>158.9 ± 10.1</td>
</tr>
<tr>
<td>Weight, kg</td>
<td>84.3 ± 20.8</td>
<td>78.2 ± 18.5</td>
<td>73.6 ± 17.6</td>
<td>68.0 ± 14.5</td>
<td>61.1 ± 13.0</td>
</tr>
<tr>
<td>Body mass index, kg/m²</td>
<td>28.9 ± 5.9</td>
<td>27.9 ± 5.8</td>
<td>26.7 ± 5.5</td>
<td>25.4 ± 4.4</td>
<td>24.1 ± 4.1</td>
</tr>
<tr>
<td>Heart rate, beats/min</td>
<td>70 ± 12</td>
<td>69 ± 12</td>
<td>68 ± 12</td>
<td>67 ± 12</td>
<td>66 ± 12</td>
</tr>
</tbody>
</table>
Age and cuff accuracy

Cuff overestimates invasive aortic

Cuff – invasive aortic BP (mm Hg)

Cuff underestimates invasive aortic

Age (years)

40 to 49 (n=169) 50 to 59 (n=406) 60 to 69 (n=555) 70 to 79 (n=453) 80 to 89 (n=106)

DBP
SBP
PP
Age and cuff accuracy

Cuff overestimates invasive aortic
Cuff underestimates invasive aortic
Cuff – invasive aortic BP (mm Hg)

Adjustment for:
Sex, invasive mean arterial pressure, body mass index, heart rate

Age (years)
40 to 49 (n=169)
50 to 59 (n=406)
60 to 69 (n=555)
70 to 79 (n=453)
80 to 89 (n=106)

DBP
SBP
PP
Is the influence of age on cuff accuracy different according to BP guideline categories?
Cuff **overestimates** invasive aortic

Cuff **underestimates** invasive aortic SBP (mm Hg)

Cuff optimal
Cuff normal
Cuff high-normal
Cuff grade 1 HTN
Cuff grade 2 HTN

Age (years)
Cuff *overestimates* invasive aortic DBP (mm Hg)
Cuff **overestimates** invasive aortic PP (mm Hg)

Cuff – invasive aortic PP (mm Hg)

Cuff **underestimates** invasive aortic

- Cuff optimal
- Cuff normal
- Cuff high-normal
- Cuff grade 1 HTN
- Cuff grade 2 HTN

Age (years):
- 40 to 49
- 50 to 59
- 60 to 69
- 70 to 79
- 80 to 89
Does the type of catheter used for invasive BP influence the cuff accuracy results?
Cuff – invasive aortic systolic BP

Cuff – invasive aortic diastolic BP

Cuff – invasive aortic pulse pressure

Fluid-filled (n=1273)

Micro-manometer tip (n=416)
Speculative implications of the influence of age on cuff BP accuracy?

Optimal BP management thresholds

Messerli and Bangalore, *JACC*, 2018; 72(11): 1313-16
Speculative implications of the influence of age on cuff BP accuracy?

Optimal BP management thresholds

Epidemiological data on prevalence of hypertension
Speculative implications of the influence of age on cuff BP accuracy?

Optimal BP management thresholds

Epidemiological data on prevalence of hypertension

BP device validation protocols

Consensus Document

A universal standard for the validation of blood pressure measuring devices: Association for the Advancement of Medical Instrumentation/European Society of Hypertension/International Organization for Standardization (AAMI/ESH/ISO) Collaboration Statement

Stergiou et al, J Hypertens, 2018, 36:472–478
Speculative implications of the influence of age on cuff BP accuracy?

Optimal BP management thresholds

Epidemiological data on prevalence of hypertension

BP device validation protocols

Natural history of BP with ageing
Blood pressure in middle to older age

Blood pressure (mm Hg)

Age (years)

DBP
PP
SBP

Picone et al., unpublished
Blood pressure in middle to older age

Blood pressure (mm Hg)

Age (years)

40 to 49, 50 to 59, 60 to 69, 70 to 79, 80 to 89

DBP, PP, SBP

Picone et al. unpublished
Conclusions

Cuff BP becomes progressively more inaccurate with increasing age (systolic, diastolic, pulse pressure)

Vascular age versus chronological age?

Expose older people to greater chance for misdiagnosis of risk related to BP
Thank you

All co-authors for contribution of data and valuable feedback

Royal Hobart Hospital cardiac lab nurses

ARTERY Society travel grant

Broadreach Postdoctoral scholarship funding
For more information or to contribute study data and join INSPECT please contact me (dean.picone@utas.edu.au) or Prof. James Sharman (james.sharman@utas.edu.au).

@deanp_BP