

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

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Abstract—In the past 30 years, several organizations, such as the US Association for the Advancement of Medical Instrumentation (AAMI), the British Hypertension Society, the European Society of Hypertension (ESH) Working Group on Blood Pressure (BP) Monitoring, and the International Organization for Standardization (ISO), have developed protocols for clinical validation of BP measuring devices. However, it is recognized that science, as well as patients, consumers, and manufacturers, would be best served if all BP measuring devices were assessed for accuracy according to an agreed single validation protocol that had global acceptance. Therefore, an international initiative was taken by the AAMI, ESH, and ISO experts who agreed to develop a universal standard for device validation. This statement presents the key aspects of a validation procedure, which were agreed by the AAMI, ESH, and ISO representatives as the basis for a single universal validation protocol. As soon as the AAMI/ESH/ISO standard is fully developed, this will be regarded as the single universal standard and will replace all other previous standards/protocols. (*Hypertension*. 2018;71:368-374. DOI: 10.1161/HYPERTENSIONAHA.117.10237.)

Key Words: accuracy ■ blood pressure measurement ■ device ■ monitor ■ protocol ■ standard ■ validation

History of Validation Protocols

The accurate measurement of blood pressure (BP) is an important prerequisite for the reliable diagnosis and efficient management of hypertension and other medical conditions. Therefore, the evaluation of the accuracy of automated devices available on the market for BP measurement in the

medical environment and the community is of paramount importance.

Validation of BP measuring devices began in the 1980s with a series of ad hoc validation protocols.¹ In 1987, the US Association for the Advancement of Medical Instrumentation (AAMI) standard for automated BP monitors included

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G.S.S. is a member of the European Society of Hypertension (ESH) and the International Organization for Standardization (ISO). B.A., T.L., and J.S. are members of the US Association for the Advancement of Medical Instrumentation (AAMI) and the ISO. S.M., S.E., T.G., A.M., and T.U. are members of the ISO. R.A., N.A., J.P.I., M.M., P.P., G.P., A.S., and J.W. are members of the ESH. G.F., B.F., D.Q. and C.O.W. are members of the AAMI. P.L. and R.M. are members of the British Hypertension Society (BHS). E.O.B. is a member of the ESH and the BHS.

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a clinical validation procedure.² In 1990, the British Hypertension Society (BHS) published a protocol dedicated to the validation of BP monitors in the clinical setting, which incorporated many of the features of the AAMI validation standard, but also had many important differences.³ The AAMI standard was revised in 1992 and 2002 and the BHS protocol in 1993.^{4,5} In 1999, the German Hypertension League introduced its own validation protocol.⁶ In 2002, the European Society of Hypertension (ESH) Working Group on Blood Pressure Monitoring developed the ESH-International Protocol (ESH-IP), with the major difference that a smaller sample size was required ($n=33$ compared with $n=85$ in the AAMI and BHS protocols).⁷ A revised version of the ESH-IP with more stringent validation criteria was published in 2010.⁸ In 2009, the International Organization for Standardization (ISO)⁹ developed another standard, which incorporated aspects of EN 1060–4 and the AAMI SP-10 (eg, sample size and validation criteria) and has been adopted by the AAMI Sphygmomanometer Committee.¹⁰ A revised version of the American National Standards Institute (ANSI)/AAMI/ISO standard was released in 2013.¹¹ Despite whatever differences, all these protocols have major similarities and a common objective, namely, the standardization of the validation procedures to establish minimum standards of accuracy and performance. The history and evolving progress of protocols to ensure accuracy of BP monitors has recently been reviewed.¹²

Objective

The authors of the different validation procedures appreciate that science, as well as patients, manufacturers, and consumers, would be best served if all BP measuring devices were assessed for accuracy according to an agreed single validation protocol that had global acceptance. The aim of this statement is to establish international willingness for a universally acceptable protocol and, having done so, to build on past experience to produce a single protocol for the validation of BP measuring devices that will replace all previous ones. It is not within the scope of the present work to provide a detailed comparison of the different validation protocols, which have indeed been the subject of extensive scientific discussion and debate in the past 2 decades.^{13–22}

AAMI/ESH/ISO Collaboration

In acknowledgment of this objective, members of the AAMI, ESH, and ISO committees agreed to meet and discuss all the aspects of validation that deserve to be reexamined, so as to be able to achieve a consensus on an optimal validation standard.

The ESH Working Group on Blood Pressure Monitoring and Cardiovascular Variability, which consists of an international group of clinicians with expertise in BP monitoring with members from Europe, United States, Canada, Japan, China, and Australia appointed a committee (G.S. Stergiou [chairman]; R. Asmar, N. Atkins, and J.P. Ioannidis [medical statistician]; R. McManus and P. Lacy [also members of BHS Working Group on Blood Pressure Monitoring]; M. Myers, P. Palatini, G. Parati, A. Shennan, J. Wang, and E. O'Brien), which met with representatives from AAMI and ISO (ISO/

TC 121/SC 3/JWG 7, noninvasive sphygmomanometers; B. Alpert, S. Mieke, D. Quinn, S. Eckert, G. Frick, T. Graßl, T. Ichikawa, A. Murray, J. Sarkis, T. Usuda, and C. Wu) on March 7–8, 2016, in Berlin, Germany.

A list of methodological–statistical and practical–clinical issues for the AAMI/ISO standard and the ESH-IP protocol was prepared by the ESH representatives and a medical statistician and presented for discussion with the AAMI/ISO representatives during the joint meeting in Berlin, Germany. A point-by-point discussion followed, aiming to identify areas of agreement and also disagreement requiring further consideration and research. Another AAMI/ESH/ISO meeting took place in April 2017 in Athens, Greece.

This summary report presents 9 key aspects of the validation procedure, which were agreed by all the AAMI, ESH, and ISO representatives as the basis for developing a single universal protocol for the validation of BP monitors. Consensus was based on the evidence from previous validation studies using the AAMI, BHS, ESH-IP, and ISO protocols, new statistical analyses on power of study sample and subgroups, and expert opinion. It is not the purpose of this preliminary document to present a detailed description of all the aspects of the validation procedure, which will, however, become available as the organizations involved develop the procedural detail of the universal protocol.

Methodological and Clinical Issues Affecting the Validation Procedure

Validation Study Efficacy Measure

A tolerable error of ≤ 10 mm Hg (using an individual's average of 3 BP readings versus a reference BP measurement method) and an estimated probability of that error of at least 85% is acceptable as a compromise, taking into account the performance of currently available BP monitors. This is compatible with the current ANSI/AAMI/ISO requirements¹¹ and those of the revised ESH-IP allowing for a 10 mmHg error with frequency of 12% to 18%.⁸

This error does not reflect an acceptable level of inaccuracy for BP measurement but takes into account the variability of the validation methodology and also leaves room for devices' accuracy improvement. Setting this level of accuracy is expected to separate devices with high or moderate accuracy from those with low accuracy (unacceptable). It is stressed that high accuracy does not mean necessarily excellent. Thus, passing these requirements does not equate to ideal accuracy, and some patients may still have inaccurate measurements. Clinicians need a higher level of accuracy in BP measurement and encourage the industry to continue efforts in technological improvement to develop more accurate devices.

Consensus

- A device is considered acceptable if its estimated probability of a tolerable error (≤ 10 mmHg) is at least 85%.

Validation Study Sample Size

As stated above, a standard is needed that acknowledges potential advances in technology, while still allowing for many contemporary devices to fulfill the protocol requirements. The standard should ensure that high and moderate

accuracy devices will pass and low accuracy devices will fail. In addition, it should be feasible for the standard to be implemented by many research centers.

The optimal sample size for a validation study has been a matter of debate and an important point of disagreement between the AAMI/ISO and the ESH-IP, requiring 85 and 33 subjects, respectively. A smaller sample size can reduce the cost of validation studies.¹⁴ However, a smaller sample size also decreases the study power and accuracy and does not allow subgroup evaluation, for example, for different cuff sizes, age groups, or other special populations.¹⁴

A calculation of the power of studies with different sample sizes, which was performed specifically for this article by C.O.W., an US National Institutes of Health biostatistician with extensive experience, showed that a study with sample size of $n=35$ is

1. adequate for a high accuracy device (defined as mean BP difference between reference and test device measurement and its associated SD $0\pm 3-6$ [mean \pm SD] mmHg), as it would have <14% chance to fail;
2. adequate for a low accuracy device (difference $6-8\pm 5$ mmHg or $0\pm 10-12$ mmHg or $4-6\pm 8$ mmHg), as it would have 94% chance to fail;
3. inadequate for a moderate accuracy device (difference 4 ± 5 mmHg), as it would have 28% chance to fail, which is unacceptably high.

On the contrary, with an $n=80$ study, a moderate accuracy device (difference 4 ± 5 mmHg) has 18% chance to fail, and this is only marginally improved with $n=90$ (17%).

Given that many of the BP monitors currently available are at the moderate accuracy level, the $n=85$ sample size that has been used in previous versions of AAMI, ISO, and BHS standards seems to be reasonable and also necessary to allow any consideration of cuff size–stratified or other subgroups and special population evaluations.

Consensus

- At least 85 subjects are required for an AAMI/ESH/ISO validation study.

Cuff Size–Stratified Subgroups

This is a necessity because devices often come with ≥ 2 cuffs. Although according to the formal sample size calculation described above an $n=85$ study is optimal for each cuff, in practice, this requirement is unrealistic. It was agreed that a compromise would be to accept cuff size–stratified subgroups. These subgroups are not intended for separate analyses (per cuff size) but only to ensure an even representation of all cuffs with a minimum number of participants. Indeed, these stratified subgroups may hide or smooth the differences observed with 1 cuff. Thus, the mean test-reference BP difference and SD per cuff shall be reported.

For test devices that have multiple (n) cuffs, each cuff shall be tested on at least $1/(2\times n)$ of the subjects, $\geq 40\%$ of the subjects shall have arm circumference within the upper half of the specified range of use of the cuff, and $\geq 40\%$ within the lower half.

A proposal was considered for more controlled investigation of cuffs in validation studies, which might include the following: (1) a minimum of 22 subjects per cuff, which means

that 4 cuffs could be evaluated in an 88-subject study, and (ii) for test devices that have a single cuff, $\geq 40\%$ of the subjects shall have arm circumference within the upper half of the specified range of use of the cuff, $\geq 40\%$ within the lower half, $\geq 20\%$ within the upper quarter, $\geq 20\%$ within the lower quarter, $\geq 10\%$ within the upper octile, and $\geq 10\%$ within the lower octile.

Consensus

- There is a minimum number of subjects to be tested per cuff depending on the number of the test device cuffs. Cuff subgroups are not intended for separate analyses.
- Requirements are set for the distribution of the participants' arm circumference according to the specified range of use of the test device.

General Population and Special Populations Studies

The AAMI/ESH/ISO protocol should be applicable not only in general population samples with normal or high BP but also in special populations, in which there is theoretical and clinical evidence of different accuracy of BP monitors.

Special population studies with smaller sample sizes should be performed only after a full general population study has been successfully completed. If the device is intended only for a special population, then a full 85-subject study is required. Special population study data should be analyzed and reported independently of the general population study data. There are no specific criteria (pass/fail requirements) defined for special populations, apart from pregnancy.

Definition of General Population

Consensus was reached that a general population study should include only subjects aged >12 years, untreated or treated. The source of recruiting both hypertensive and normotensive subjects should be reported. An $n=85$ adults study shall include $\geq 30\%$ males and $\geq 30\%$ females and shall have $\geq 5\%$ of the reference systolic BP readings ≤ 100 mmHg, $\geq 5\%$ with ≥ 160 mmHg, and $\geq 20\%$ with ≥ 140 mmHg and $\geq 5\%$ of reference diastolic BP readings ≤ 60 mmHg, $\geq 5\%$ with ≥ 100 mmHg, and $\geq 20\%$ with ≥ 85 mmHg.¹¹

Definition of Special Populations

The following are regarded as special populations: (1) age <3 years, (2) pregnancy including preeclampsia, (3) arm circumference >42 cm, and (4) atrial fibrillation. There is no agreed procedure for BP monitor validation in atrial fibrillation. Subjects aged 12 to 21 or >80 years and those with end-stage renal disease were considered as possible special groups, but there was uncertainty on the adequacy of existing data suggesting altered accuracy of the BP monitors in these groups.

Sample Size for Special Population Studies

According to the formal sample size calculation described above, a sample of 85 subjects is desirable for each special population. In case that an independent general population 85-subject study has been completed successfully, a compromise was agreed to accept a minimum of 35 special population subjects (45 for pregnancy).

BP Distribution Criteria for Special Population Studies

Those of general population studies cannot be applied but need to be defined for each special population because of their

different usual BP levels (eg, children, pregnancy, and atrial fibrillation).

Pediatric Studies

For devices intended for general population and children, 35 subjects aged 3 to 12 years can be included together with 50 subjects aged >12 years, and the BP distribution criteria apply to the total 85-subject study. In such studies, further to the formal analysis of the total 85-subject sample, the mean systolic and diastolic BP difference (test versus reference device) and their SD (criterion 1) shall also be reported separately for subgroups aged 3 to 12 and >12 years. For devices with a special BP measurement mode for children, 35 subjects aged 3 to 12 years shall be included, and these are exempt of BP distribution requirements. Korotkoff K5 shall be used for reference diastolic BP. If K1 or K5 are not audible, the child shall be excluded.

Pregnancy and Preeclampsia

Include 45 women in second and third trimesters of pregnancy, of whom 15 with preeclampsia, defined as elevated systolic BP ≥140 mmHg and/or diastolic BP ≥90 mmHg with proteinuria; 15 with gestational hypertension (new onset in pregnancy with systolic BP ≥140 mmHg and/or diastolic ≥90 mmHg without proteinuria); and 15 normotensives. Chronic hypertension is not included as an additional group because (1) the hemodynamics are similar to gestational hypertension and (2) its diagnosis is often retrospective because it presents as gestational hypertension. Korotkoff K5 shall be used for reference diastolic BP. Age criteria and BP distribution criteria will not be applied. The pass/fail criterion 1 of the ANSI/AAMI/ISO 81060–2:2013 (mean difference of test versus reference BP measurements ≤5 mmHg with SD ≤8 mmHg for systolic and diastolic BP)¹¹ will be applied in the 45-women sample. Data from preeclampsics (mean difference and SD) shall be reported separately to allow comparison across studies.

Consensus

- A general population study should include only subjects aged >12 years.
- Special populations include at least the following: (1) age <3 years, (2) pregnancy including preeclampsia, (3) arm circumference >42 cm, and (4) atrial fibrillation. Other special populations may be added as special groups.
- Special population studies to include ≥35 subjects, provided that a general population study has been completed successfully. For special populations, BP distribution criteria to differ from those of general population studies. Data to be analyzed independently of general population study data.
- Studies in pregnancy to include 45 women, of whom 15 with preeclampsia, 15 with gestational hypertension, and 15 normotensive. Korotkoff K5 shall be used for reference diastolic BP.
- For devices intended for adults and children, 35 subjects aged 3 to 12 years can be included and analyzed together with 50 subjects aged >12 years. Mean BP difference and SD shall also be reported separately for age 3 to 12 and >12 years groups. Korotkoff K5 shall be used for reference diastolic BP.

Method for BP Data Collection

The same arm sequential method (Table 1) is, to date, the most well studied and supported by all protocols.^{1–11} Thus, this is the preferred method for BP data collection. Because the test device cuff may not fulfill the requirements for reference auscultatory BP measurement and some devices have fast deflation rate or measure BP during inflation, it was agreed that the same arm simultaneous method is no longer included as a possibility. The opposite arm simultaneous method will be retained as presented in the ANSI/AAMI/ISO protocol.¹¹

Consensus

- The same arm sequential BP measurement is the preferred method for validation.
- The same arm simultaneous method has been eliminated.

Reference BP Measurement and Validation Procedure

The auscultatory standard is retained for reference BP measurement with measurements taken simultaneously by 2 trained observers blinded to each other’s readings and to the measurements taken with the test device (Y-tube–connected double stethoscope, observers qualified for their agreement according to the BHS protocol criteria within 12 months before the validation³, and baseline and repeat audiogram every 3 years). Korotkoff K1 shall be used for reference systolic BP and K5 for diastolic BP in all subjects, including adults, adolescents, children aged ≥3 years, and pregnant women. If K1 or K5 is not audible, the subject shall be excluded. A third observer (supervisor) is necessary to supervise the validation procedure, the adequacy of reference and test device BP measurements, the agreement between the 2 observers who should be unaware of the magnitude or direction of their disagreement, and any other issue during the validation procedure.

The validation procedure starts with the subject seated comfortably and relaxed for at least 5 minutes, her/his back and arm supported with the middle of the upper arm at heart level, legs uncrossed, and feet flat on the floor. Talking and any other interference needs to be avoided throughout the

Table 1. Procedure for Reference and Test Device BP Measurements in Same Arm Sequential Validation Method

Initial BP Measurements*		
1.	Take reference BP measurement by the 2 observers	R ₀
2.	Take test device BP measurement	T ₀
Validation BP measurements for accuracy evaluation		
3.	Take first reference BP measurement by the 2 observers	R ₁
4.	Take first test device BP measurement	T ₁
5.	Take second reference BP measurement by the 2 observers	R ₂
6.	Take second test device BP measurement	T ₂
7.	Take third reference BP measurement by the 2 observers	R ₃
8.	Take third test device BP measurement	T ₃
9.	Take fourth reference BP measurement by the 2 observers	R ₄

*Measurement R₀ shall not be used in the evaluation of reference BP distribution and variability criteria. Measurements R₀ and T₀ shall not be used in the evaluation of the test device accuracy. BP indicates blood pressure.

entire validation procedure. The sequential method (Table 1) requires a reference BP measurement (R_0) taken by the 2 observers, followed by a test device measurement (T_0) to confirm the device function. Then, 4 reference BP measurements follow, alternated by 3 test device measurements ($R_1-T_1-R_2-T_2-R_3-T_3-R_4$). Measurements will be performed with at least 60-second intervals.

The supervisor will review each pair of test/reference BP measurements. If one of them (test or reference BP) has to be excluded (because of test device failure or observers' disagreement >4 mmHg in systolic or diastolic BP), then, another pair of BP readings (test and reference) is taken. A maximum of 8 pairs is allowed (4 additional pairs). Observers' BP comparison during the validation study shall be reported (mean difference, SD, and range) together with the number of repeated measurements. Subjects with systolic BP difference >12 mmHg and/or diastolic >8 mmHg in any 2 of the 4 reference (average of two observers) BP measurements (R_1 to R_4) shall be excluded.

Because of concern with mercury toxicity, in many countries, mercury devices are not available or the maintenance of mercury sphygmomanometers is difficult. Therefore, reference BP measurements can be obtained using mercury sphygmomanometers or nonmercury manometers (aneroid or other) that fulfill the ISO 81060–1 requirements for accuracy (maximum permissible error shall be ± 1 mmHg).⁹ The accuracy of nonmercury devices shall be evaluated against a mercury sphygmomanometer or a calibrated and certified pressure device at the beginning of each validation study. National metrology institutes and other institutions might provide such calibration services.

The cuffs used for reference auscultatory BP measurement shall have an inflatable bladder length that covers 75% to 100% of the arm circumference of each subject and width that covers 37% to 50% of the arm circumference. The test device cuffs shall not be used for reference BP determination. Detailed description of cuffs used for reference BP measurement shall be reported in each study (manufacturer, construction, and bladder dimensions). An example of cuff use (inflatable bladder dimensions) for reference auscultatory BP measurement in a general population validation study including children is shown in Table 2.

Consensus

- Reference BP measurement to be performed with mercury sphygmomanometers or accurate nonmercury devices. The accuracy of nonmercury devices shall be evaluated at the beginning of each study.
- Detailed description of cuffs used for reference BP measurement shall be provided.

Table 2. Example of Cuff Use (Inflatable Bladder Dimensions) for Reference Auscultatory BP Measurement in a General Population Validation Study Including Children

Bladder Dimensions	Participant's Midarm Circumference, cm					
	12–15	15–18	18–23	23–28	28–35	33–42
Length, cm	12	15	18	23	28	33
Width, cm	6	7	9	12	14	16

- The test device cuffs shall not be used for reference BP determination.

Validation Criteria and Reporting

Each of the reference BP measurements (R_0 – R_4) is the average of the simultaneous readings of the 2 observers. Each of the test device measurements is compared against the average of the previous and next reference BP reading (eg, T_1 versus the average of R_1 – R_2 , T_2 versus average of R_2 – R_3 , T_3 versus average of R_3 – R_4). Differences are calculated by subtracting the reference BP measurement from the test device measurement. The mean BP difference (test versus reference device) and its SD, that is, criteria 1 and 2 of the ANSI/AAMI/ISO 81060–2:2013¹¹ will be applied for the AAMI/ESH/ISO validation data evaluation. The same criteria will be used for systolic and diastolic BP measurements. In studies including children, further to the total 85-subject analysis, the mean systolic and diastolic BP difference and their SD (criterion 1) shall also be reported separately for subgroups aged 3 to 12 years and >12 years.

The number of absolute BP differences (test BP minus average of previous and next reference BP readings) within 5, 10, and 15 mmHg used by the ESH-IP⁸ shall also be reported. This categorization is important so that the validation data can be understood by a variety of potential users, that is, clinicians, public, industry, etc. Standardized Bland–Altman scatterplots as shown in Figure⁸ will be presented in the AAMI/ESH/ISO validation study report.

Consensus

- The mean BP difference (test versus reference) and its SD, criteria 1 and 2 of the ANSI/AAMI/ISO 81060–2,¹¹ to be applied for systolic and diastolic BP.
- The number of absolute BP differences within 5, 10, and 15 mmHg and standardized Bland–Altman scatterplots will be presented.

Validation of Other BP Monitors

Separate validation protocols need to be developed for specific functions of certain BP monitors, including continuous, cuffless, and central BP monitors. Task groups have been established to explore the methodology of such protocols.

Devices that have >1 BP measurement mode (eg, auscultatory and oscillometric) require separate validation of each mode in an 85-subject study. Devices that have peripheral (brachial) and other BP measurement modes (eg, central BP) should first be assessed for peripheral BP measurement accuracy using the main 85-subject study.

Consensus

- Separate validation protocols will be developed for continuous, cuffless, and central BP monitors.

Quality and Reliability of Validation Study Reports

Violations of the validation protocols and incomplete reporting (missing and unclear data) are particularly common and are likely to be missed by the peer-review process of scientific journals.^{16,23–25} Tools and forms (printed and electronic) for reporting complete data from validation studies similar to

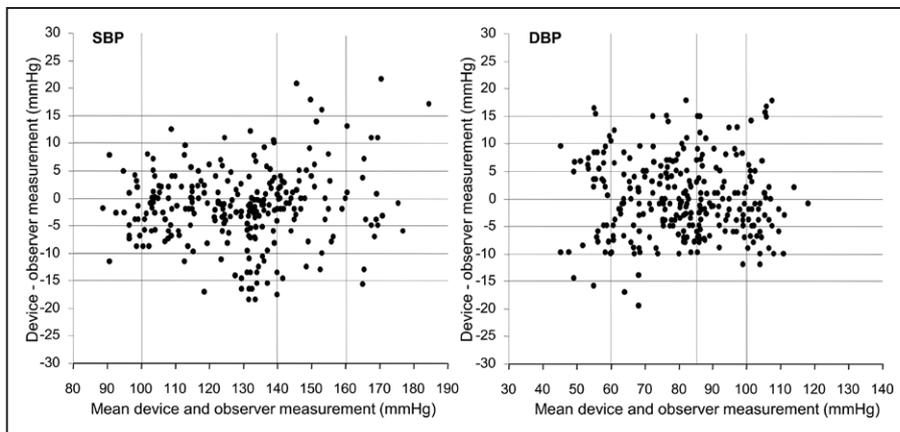


Figure. Standardized Bland–Altman scatterplots as shown below will be presented in the Association for the Advancement of Medical Instrumentation/European Society of Hypertension/International Organization for Standardization (AAMI/ESH/ISO) validation study report (adapted from O’Brien et al⁸ with permission. Copyright © 2010, Wolters Kluwer Health, Inc). The x axes represent BPs in the systolic range 80 to 190 mmHg and diastolic range 30 to 140 mmHg. The y axes represent errors from –30 to +30 mmHg. Horizontal reference lines are drawn at 5 mmHg intervals from +15 to –15 mmHg. The mean of each device BP and its corresponding observer BP is plotted against their difference with a point. Differences >30 mmHg are plotted at 30 mmHg. Differences <–30 mmHg are plotted at –30 mmHg. Vertical lines represent BP distribution boundaries. The same y axis scale should be used for systolic BP (SBP) and diastolic BP plots (DBP).⁸

those in the revised ESH-IP⁸ should be developed to prevent protocol violations and incomplete reporting.

Measures to ensure transparency in selecting data for inclusion into analysis should be applied, that is, providing reasons for excluding data and stipulating inclusion in chronological order to fill BP ranges (eg, electronic online patient report forms). This provides safeguards against potential exclusion of inaccurate data when actual sample size exceeds specified sample size and is necessary to fill BP ranges.

Consensus

- Tools need to be developed to prevent protocol violations and incomplete reporting and to secure appropriate and transparent patient and data selection.
- Detailed forms should be developed to fill in all the data from validation studies that need to be reported.

Further Procedures

The objective of this initiative is to satisfy the existing need for a single standard for BP monitor validation to be internationally accepted and used. The AAMI, ESH, and ISO experts agreed to develop a universal standard for device validation, as described in this statement. This preliminary document does not present a detailed description of all the aspects of the validation procedure, which will become available as the organizations involved develop the universal protocol in more detail. As soon as the AAMI/ESH/ISO standard is fully developed, this will be regarded as the single universal standard and will replace all other previous standards/protocols.

Disclosures

G.S. Stergiou, B. Alpert, R. Asmar, P. Palatini, G. Parati, and Eoin O’Brien conducted validation studies for various manufacturers and advised manufacturers on device and software development. N. Atkins conducted validation studies for various manufacturers, advised manufacturers on device and software development, and is a Medaval employee. G. Frick is a Microlife employee. B. Friedman is a GE Healthcare employee. T. Graßl is a Dräger employee. T.

Ichikawa is an Omron employee. R. McManus received blood pressure-monitoring equipment for research purposes from Omron and Lloyds Pharmacies and is Chair of British Hypertension Society Blood Pressure Monitoring Working Party, which oversees validation studies for various manufacturers. A. Murray is a patent holder for manual blood pressure device and is a research grant holder for blood pressure measurement techniques. D. Quinn is a Welch Allyn employee, USA. J. Sarkis is a PharmaSmart International employee, USA. A. Shennan conducted validation studies for various manufacturers and developed the CRADLE VSA. T. Usuda is a Nihon Kohden employee. J. Wang conducted validation studies for various manufacturers. The other authors report no conflicts.

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