Validation of the TM-2441 ambulatory blood pressure measurement device according to the ISO 81060-2:2013 standard

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Objective The aim of this study was to validate the TM-2441 ambulatory blood pressure monitoring (ABPM) device using the ISO 81060-2:2013 standard.

Participants and methods Participants were healthy individuals aged more than 12 years who were recruited from among the outpatients and volunteers of Jichi Medical University (Tochigi, Japan). The same-arm sequence protocol (clinical validation) and the opposite-limb simultaneous method (ambulatory validation) from the ISO 81060-2:2013 standard were used.

Results One hundred and seven participants were enrolled; 85 participated in the clinical validation and 35 participated in the ambulatory validation (13 participants were included in both validation protocols). The TM-2441 device performed well against the standard in both the clinical and ambulatory validations; the mean and SD values for the differences between device and observed systolic and diastolic blood pressure values in both tests fulfilled criterion 1 and criterion 2 of the standard. The Bland–Altman plots did not show any systematic variation in the error.

Conclusion The TM-2441 ABPM device was accurate and fulfilled all ISO 81060-2:2013 standard requirements for ABPM determination in adults. It is therefore suitable for use for ABPM in adults with hypertension. *Blood Press Monit* 00:000–000

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Introduction

Ambulatory blood pressure monitoring (ABPM) has been possible for more than 50 years. Developments in the devices used to measure ambulatory blood pressure (BP) mean that ABPM can now be measured easily and non-invasively during routine clinical practice [1].

Use of ABPM to diagnose hypertension is recommended by major international guidelines [2–4]. This facilitates identification of white-coat hypertension (patients who have elevated clinic BP but normal readings during daily activities) and masked hypertension (normal clinic BP, but elevated BP outside the clinic) [5].

ABPM also plays an important role in monitoring BP variability, including morning BP surge and nocturnal hypertension. Both morning BP surge and nocturnal hypertension have been shown to increase the risk of cardiovascular adverse events [6,7]. Determination of BP over a 24 h period using ABPM can provide a better estimation of hemodynamic load than clinic-based BP, and is therefore a useful tool for cardiovascular risk management in patients with hypertension [8,9].

In all clinical applications, a validated ABPM device must be used for self-measurement of BP [10]. This study was designed to validate the TM-2441 ABPM device against the ISO 81060-2:2013 standard [11] under clinical and ambulatory conditions.

Participants and methods

Device

The TM-2441 (A&D Co. Ltd, Tokyo, Japan) is a lightweight (135 g), compact (66 × 24.5 × 95 mm) BP monitoring device that can be used for ABPM, home BP monitoring, and automated office BP measurement using the left or right upper arm, with four cuff sizes available (small, adult, large, and extra-large). It uses the oscillometric technique and can measure systolic blood pressure (SBP) in the range 60–280 mmHg and diastolic blood pressure (DBP) from 30 to 160 mmHg. The TM-2441 has USB and Bluetooth connectivity capabilities, and an irregular heartbeat detection function. It runs on two alkaline or nickel-cadmium/nickel-metal hydride AA batteries. ABPM monitoring settings allow ambulatory BP to be measured every 5, 10, 15, 20, 30, 60, or 120 min, and up to 600 sets of data can be stored in the device.

Participants

The goal was to enroll at least 85 participants as per the ISO 81060-2:2013 standard [11]. Individuals aged more than 12 years were recruited from among the outpatients

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and volunteers of Jichi Medical University (Tochigi, Japan). A total of 107 adults were screened, provided informed written consent, and were enrolled in the study (85 participated in the clinical validation and 35 participated in the ambulatory validation). The majority of the 85 participants included in the clinical investigations (ISO 81060-2:2013, section 5.2.4.2) were male ($n = 59$; 69%). Participant age was 20 – 84 years (mean ± SD, 41.1 ± 15.1 years) and arm circumference was 19 – 43 (29.9 ± 6.7) cm (Table 1). SBP measurements were ≤ 100, ≥ 140, and ≥ 160 mmHg in 13.7, 26.3, and 6.7% of measurements, respectively; 11.8% of DBP measurements were up to 60 mmHg, 32.2% were at least 85 mmHg, and 10.6% were at least 100 mmHg (Table 1). Thirty-five individuals (13 from the 85 who underwent clinical validation and an additional 22 participants) participated in ambulatory device validation (ISO 81060-2:2013, section 5.2.4.3) [age 21–74 (mean 42.8 ± 16.3) years, 54.3% male, arm circumference 21–35 (mean 26.2 ± 3.6) cm] (Table 2).

Table 1 Baseline characteristics for participants in the clinical investigation

	Participants ($n = 85$)	ISO standard
Age [range (mean ± SD)] (years)	20–84 (41.1 ± 15.1)	
Age > 12 years, patients	85 (100)	100
Male, patients [*n* (%)]	59 (69.4)	≥ 30
Female, patients [*n* (%)]	26 (30.6)	≥ 30
Arm circumference [range (mean ± SD)] (cm)	19 – 43 (29.9 ± 6.7)	
Cuff size, patients [*n* (%)] (cm)		
Small, 15–22	13 (15.3)	≥ 12.5
Adult, 20–31	36 (42.4)	≥ 12.5
Large, 28–36	17 (20.0)	≥ 12.5
Extra-large, 34–50	19 (22.4)	≥ 12.5
SBP, proportion of measurements (mmHg) (%)		
≤ 100	13.7	≥ 5
≥ 140	26.3	≥ 20
≥ 160	6.7	≥ 5
DBP, proportion of measurements (mmHg) (%)		
≤ 60	11.8	≥ 5
≥ 85	32.2	≥ 20
≥ 100	10.6	≥ 5

DBP, diastolic blood pressure; SBP, systolic blood pressure.

Table 2 Baseline characteristics for participants in the ambulatory investigation

	Participants ($n = 35$)	ISO standard
Age [range (mean ± SD)] (years)	21–74 (42.8 ± 16.3)	NA
Male, patients [*n* (%)]	19 (54.3)	NA
Female, patients [*n* (%)]	16 (45.7)	NA
Arm circumference [range (mean ± SD)] (cm)	21–35 (26.2 ± 3.6)	NA
Cuff size, patients [*n* (%)] (cm)		
Small, 15–22	5 (14.3)	NA
Adult, 20–31	27 (77.1)	NA
Large, 28–36	3 (8.6)	NA
SBP, proportion of measurements ≥ 160 (mmHg) (%)	14.3	≥ 10
DBP, proportion of measurements ≥ 100 (mmHg) (%)	11.4	≥ 10

DBP, diastolic blood pressure; NA, not applicable; SBP, systolic blood pressure.

In this group, 14.3% of SBP measurements were at least 160 mmHg and 11.4% of DBP measurements were at least 100 mmHg (Table 2).

Procedures

Clinical validation was performed using the same-arm sequence protocol as per the ISO 81060-2:2013 standard (section 5.2.4.2) [11]. Clinic BP for each participant was first determined by one of two trained observers using a standardized reference mercurial sphygmomanometer (no. 605 P; Kenzmedico Co. Ltd, Saitama, Japan). After waiting for at least 1 min, BP measurement was repeated using the TM-2441 device. Device memory was then cleared. Neither of these measurements was used to determine accuracy. After again waiting for at least 1 min, sequential BP measurements were performed using the reference sphygmomanometer and the test device (three per device, with > 1 min between measurements). The allowed observer difference was ± 5 mmHg.

Additional clinical investigation for use in ambulatory monitoring (ambulatory validation) was performed using the opposite-limb simultaneous method as per the ISO 81060-2:2013 standard (section 5.2.4.3) [11]. BP was determined in one arm using the reference sphygmomanometer and simultaneously in the other arm using the TM-2441 device. Device memory was then cleared and there was a waiting period of at least 1 min. The reference sphygmomanometer and the TM-2441 device were swapped to the opposite arm, and BP measurements were repeated after waiting for at least another minute. The procedure of swapping devices to the opposite arm and BP measurements were repeated until six paired determinations had been performed (>1 min between device swapping and BP measurement). The allowed observer difference was ± 5 mmHg.

The study protocol was approved by the institutional review board of the Jichi Medical University School of Medicine (Shimotsuke, Japan), and all of the patients provided written informed consent to participate.

Statistical analysis

Data were analyzed as required by the ISO 81060-2:2013 standard [11]. Bland–Altman plots were created to assess agreement between the two measurement systems. All statistical analyses were carried out using SAS version 9.4 software (SAS Institute Inc., Cary, North Carolina, USA).

Results

Clinical investigation

The observer and device SBP measurements were 60–186 and 61–181 mmHg, respectively. The corresponding values for DBP were 44–120 and 40–116 mmHg. The calculated mean ± SD values for the difference between device and observer BP measurements were − 0.80 ± 6.46 for SBP and − 0.95 ± 6.45 for DBP on the basis of criterion 1 and − 0.80 ± 5.13 for SBP and − 0.95 ± 5.87 for DBP on the basis

of criterion 2. The results showed that the overall performance of the device was very good, on the basis of both criterion 1 and criterion 2 of the standard, as shown by the calculated mean ± SD values for the differences between device and observer BP values (Table 3). In addition, variation between the observer and device measurements of SBP and DBP was generally small (± 10 mmHg for the majority of comparisons) and there was no systematic variation in the error based on the Bland–Altman plots (Fig. 1).

Ambulatory investigation

The observer and device SBP measurements were 84–234 and 77–226 mmHg, respectively. The corresponding values for DBP were 50–154 and 47–154 mmHg. The calculated mean and SD values for the difference between device and observer BP measurements were − 1.55 ± 7.02 for SBP and − 0.24 ± 6.11 for DBP on the basis of criterion 1 and − 1.55 ± 4.63 for SBP and − 0.24 ± 4.41 for DBP on the basis of criterion 2. The overall performance of the device, on the basis of both criterion 1 and criterion 2 of the standard, was very good, as shown by the calculated mean and SD values for the differences between device and observer BP values (Table 4). In addition, variation between the observer and device measurements was usually small (± 10 mmHg for the majority of comparisons) and there was no systematic variation in the error based on the Bland–Altman plots (Fig. 2).

Discussion

To the best of our knowledge, this is the first validation study of an ABPM device using the ISO 81060-2:2013 standard [11]. Previously, ABPM devices have often been validated against the European Society of Hypertension International protocol or the British Hypertension Society protocol [12–21].

The results of this study showed that the TM-2441 ABPM device fulfilled all the requirements of the ISO standard in both the clinic and ambulatory testing. Data for criterion 1 and criterion 2 in both evaluations showed that the device performed very well compared with observer BP measurements. Therefore, the TM-2441 is appropriate for use in the clinic and for ABPM in the general adult population. The device is small and light, making it suitable for use in the ambulatory setting.

It has been suggested that the majority of previous validation studies of ABPM devices did not reliably adhere to the underlying protocols (which was an ISO protocol in only one of 28 studies), calling into question the actual device validity [22]. In particular, differences of >5 mmHg between the test device and the reference sphygmomanometer occurred for at least 30% of readings in half of all studies assessed [22]. Although the Bland–Altman plots in this study did show that some readings varied from the

Table 3 Mean and SD for the difference of the device minus the observer blood pressure measurements for 85 participants in the clinical investigation

	SBP	DBP	ISO standard
Criterion 1			
Mean	−0.80	−0.95	≤ ± 5 mmHg
SD	6.46	6.45	≤ 8 mmHg
Criterion 2			
Mean	−0.80	−0.95	NA
SD	5.13	5.87	SBP: ≤ 6.89 mmHg DBP: ≤ 6.88 mmHg

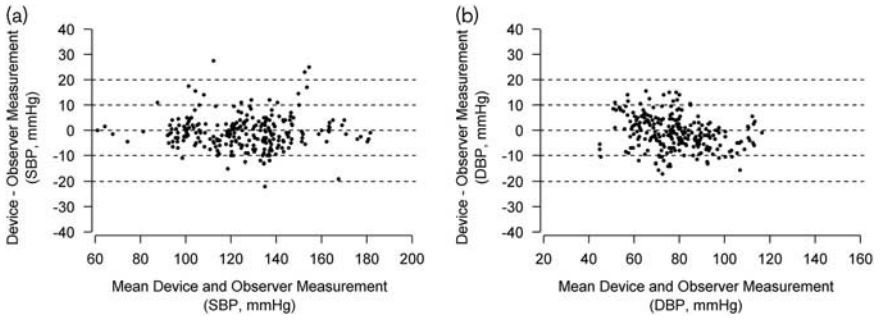
DBP, diastolic blood pressure; NA, not applicable; SBP, systolic blood pressure.

Table 4 Mean and SD for the difference of the device minus the observer blood pressure measurements for 35 participants on additional clinical investigation for use in ambulatory monitoring

	SBP	DBP	ISO standard
Criterion 1			
Mean	−1.55	−0.24	≤ ± 5 mmHg
SD	7.02	6.11	≤ 8 mmHg
Criterion 2			
Mean	−1.55	−0.24	NA
SD	4.63	4.41	SBP: ≤ 6.76 mmHg DBP: ≤ 6.95 mmHg

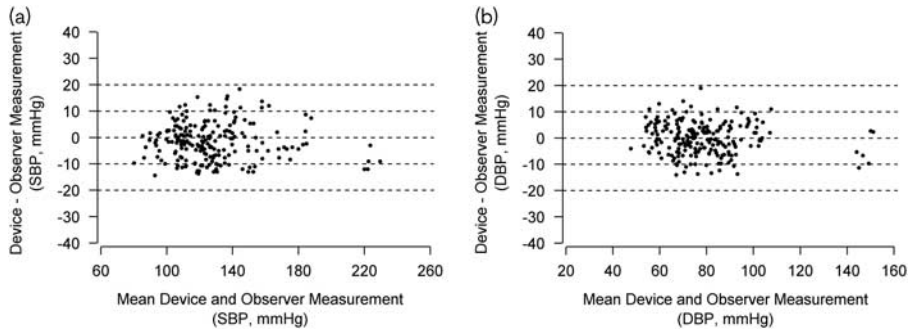
DBP, diastolic blood pressure; NA, not applicable; SBP, systolic blood pressure.

Fig. 1



Bland–Altman plots of mean device and observer measurement of systolic (a) and diastolic (b) blood pressure versus the device minus the observer measurements in the clinical investigation. DBP, diastolic blood pressure; SBP, systolic blood pressure.

Fig. 2



Bland–Altman plots of mean device and observer measurement of systolic (a) and diastolic (b) blood pressure versus the device minus the observer measurements in the ambulatory investigation. DBP, diastolic blood pressure; SBP, systolic blood pressure.

reference by more than 5 mmHg, the number of these was acceptable. In addition, the ISO 81060-2:2013 standard used [11] is up-to-date and more recent than the European, British, or Association for the Advancement of Medical Instrumentation protocols [20,21]. Furthermore, we used two validation protocols from the ISO standard, with similar results obtained with both.

Conclusion

This study showed that the TM-2441 device had a high level of accuracy for determining BP in the clinic and under ambulatory conditions. Therefore, this validated device can be recommended for ABPM in adults.

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Conflicts of interest

There are no conflicts of interest.

References

1 O'Brien E, Parati G, Stergiou G, Asmar R, Beilin L, Bilo G, *et al*. European Society of Hypertension position paper on ambulatory blood pressure monitoring. *J Hypertens* 2013; **31**:1731–1768.
2 Mancia G, Fagard R, Narkiewicz K, Redon J, Zanchetti A, Bohm M, *et al*. 2013 ESH/ESC Practice Guidelines for the Management of Arterial Hypertension. *Blood Press* 2014; **23**:3–16.
3 National Institute for Health and Care Excellence. Hypertension: clinical management of primary hypertension in adults (update). Clinical guideline 127 (2011). Available at: *https://www.nice.org.uk/guidance/cg127/chapter/1-guidance*. [Accessed 1 November 2017].
4 Shimamoto K, Ando K, Fujita T, Hasebe N, Higaki J, Horiuchi M, *et al*. The Japanese Society of Hypertension Guidelines for the Management of Hypertension (JSH 2014). *Hypertens Res* 2014; **37**:253–390.
5 Parati G, Stergiou G, O'Brien E, Asmar R, Beilin L, Bilo G, *et al*. European Society of Hypertension practice guidelines for ambulatory blood pressure monitoring. *J Hypertens* 2014; **32**:1359–1366.
6 Gosse P, Lasserre R, Minifie C, Lemetayer P, Clementy J. Blood pressure surge on rising. *J Hypertens* 2004; **22**:1113–1118.
7 Hansen TW, Li Y, Boggia J, Thijs L, Richart T, Staessen JA. Predictive role of the nighttime blood pressure. *Hypertension* 2011; **57**:3–10.
8 Dolan E, Stanton A, Thijs L, Hinedi K, Atkins N, McClory S, *et al*. Superiority of ambulatory over clinic blood pressure measurement in predicting mortality: the Dublin outcome study. *Hypertension* 2005; **46**:156–161.
9 O'Brien E, Turner JR. Assessing blood pressure responses to noncardiovascular drugs: the beneficial role of ambulatory blood pressure monitoring. *J Clin Hypertens (Greenwich)* 2013; **15**:55–62.
10 Parati G, Stergiou GS, Asmar R, Bilo G, de Leeuw P, Imai Y, *et al*. European Society of Hypertension practice guidelines for home blood pressure monitoring. *J Hum Hypertens* 2010; **24**:779–785.
11 International Organization for Standardization. Non-invasive sphygmomanometers. Part 2: Clinical investigation of automated measurement type. Available at: *https://www.iso.org/standard/57977.html*. [Accessed 22 November 2017].
12 Barna I, Keszei A, Dunai A. Evaluation of Meditech ABPM-04 ambulatory blood pressure measuring device according to the British Hypertension Society protocol. *Blood Press Monit* 1998; **3**:363–368.
13 Bramlage P, Deutsch C, Kruger R, Wolf A, Muller P, Zwingers T, *et al*. Validation of the custo screen 400 ambulatory blood pressure-monitoring device according to the European Society of Hypertension International Protocol revision 2010. *Vasc Health Risk Manag* 2014; **10**:303–309.
14 Dorogova IV, Panina ES. Comparison of the BPLab(R) sphygmomanometer for ambulatory blood pressure monitoring with mercury sphygmomanometry in pregnant women: validation study according to the British Hypertension Society protocol. *Vasc Health Risk Manag* 2015; **11**:245–249.
15 Franssen PM, Imholz BP. Evaluation of the Mobil-O-Graph new generation ABPM device using the ESH criteria. *Blood Press Monit* 2010; **15**:229–231.
16 Jean-Michel Mallion J, Pierre H, Neuder Y, Ormezzano O, Baguet JP. Validation of the AGILIS ambulatory blood pressure monitor according to the European Society of Hypertension International Protocol for validation of blood pressure measuring devices in adults. *Blood Press Monit* 2005; **10**:97–101.
17 Ledyaev MY, Stepanova OV, Ledyaeva AM. Validation of the BPLab® 24-hour blood pressure monitoring system in a pediatric population according to the 1993 British Hypertension Society protocol. *Med Devices (Auckl)* 2015; **8**:115–118.
18 Nakamura K, Kikuya M, Hara A, Hirose T, Obara T, Metoki H, *et al*. Validation of the FM-800 ambulatory blood pressure monitor according to the Association for the Advancement of Medical Instrumentation criteria and the International Protocol. *Clin Exp Hypertens* 2010; **32**:523–527.
19 Zawadzki MJ, Vandekar L, Smyth JM, Haas D, Gerin W. An extended validation of the ScottCare 320 ambulatory blood pressure monitor: recommendations for clinical application. *Blood Press Monit* 2013; **18**:151–155.
20 O'Brien E, Atkins N, Stergiou G, Karpettas N, Parati G, Asmar R, *et al*. European Society of Hypertension International Protocol revision 2010 for the validation of blood pressure measuring devices in adults. *Blood Press Monit* 2010; **15**:23–38.
21 O'Brien E, Petrie J, Littler W, de Swiet M, Padfield PL, Altman DG, *et al*. An outline of the revised British Hypertension Society protocol for the evaluation of blood pressure measuring devices. *J Hypertens* 1993; **11**:677–679.
22 Hodgkinson JA, Sheppard JP, Heneghan C, Martin U, Mant J, Roberts N, *et al*. Accuracy of ambulatory blood pressure monitors: a systematic review of validation studies. *J Hypertens* 2013; **31**:239–250.