

1 Title: Accuracy of automated blood pressure measurements in the
2 presence of atrial fibrillation: systematic review and meta-analysis
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18 Abstract: 246

19 Words excluding abstract: 3184

20 Tables: 2

21 Figures: 3
22
23

24 Key words: ATRIAL FIBRILLATION, BLOOD PRESSURE DETERMINATION, SYSTEMATIC REVIEW
25
26

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30 **Abstract**

31 Atrial fibrillation (AF) affects ~3% of the general population and is twice as common with
32 hypertension. Validation protocols for automated sphygmomanometers exclude people with AF,
33 raising concerns over accuracy of hypertension diagnosis or management, using out-of-office blood
34 pressure (BP) monitoring, in the presence of AF. Some devices include algorithms to detect AF; a
35 feature open to misinterpretation as offering accurate BP measurement with AF. We undertook this
36 review to explore accuracy of automated devices, with or without AF detection, for measuring BP.

37 We searched Medline and Embase to October 2018 for studies comparing automated BP
38 measurement devices to a standard mercury sphygmomanometer contemporaneously. Data were
39 extracted by two reviewers. Mean BP differences between devices and mercury were calculated,
40 where not reported and compared; meta-analyses were undertaken where possible.

41 We included 13 studies reporting 14 devices. Mean systolic and diastolic BP differences from
42 mercury ranged from -3.1 to +6.1/-4.6 to +9.0 mmHg. Considerable heterogeneity existed between
43 devices (I^2 80% to 94%). Devices with AF detection algorithms appeared no more accurate for BP
44 measurement with AF than other devices.

45 A previous review concluded that oscillometric devices are accurate for systolic but not diastolic BP
46 measurement in AF. The present findings do not support that conclusion. Due to heterogeneity
47 between devices, they should be evaluated on individual performance. We found no evidence that
48 devices with AF detection measure BP more accurately in AF than other devices. More home or
49 ambulatory automated BP monitors require validation in populations with AF.

50

51 246 words

52

53

54 Summary Table

55

56 What is known about the topic

- 57 • Hypertension and atrial fibrillation commonly co-exist, so accurate blood pressure
58 measurement is important to facilitate diagnosis and treatment.
- 59 • Guidelines recommend manual measurement of blood pressure with atrial fibrillation, but
60 also place emphasis on out of office measurement for diagnosis and management of
61 hypertension.
- 62 • Previous evidence suggests that automated blood pressure monitors are accurate for
63 systolic but not diastolic blood pressure measurement in the presence of atrial fibrillation.

64 What this study adds

- 65 • Whilst individual monitors have been shown to be accurate with atrial fibrillation, there is
66 considerable heterogeneity between devices, particularly for diastolic blood pressure
67 measurement, when compared to a mercury standard. Therefore accuracy for other devices
68 in atrial fibrillation cannot be assumed.
- 69 • There are relatively few studies of accuracy in atrial fibrillation, in comparison to the number
70 of different devices in current clinical use.
- 71 • Most published studies are of limited size, and all were conducted on populations who may
72 not represent the wider population with atrial fibrillation.

73

74

75 **Introduction**

76 Raised blood pressure (BP, hypertension) is the main risk factor globally for premature morbidity and
77 mortality.¹ Control of hypertension is fundamental for the prevention of cardiovascular disease, yet
78 international data show that the prevalence of hypertensive heart disease is not declining.^{1,2} Atrial
79 fibrillation (AF) affects 2-3% of adults in Europe and the USA, and over 10% of those aged 80 years or
80 older;^{3,4} prevalence is expected to double in the next 50 years as the population ages.⁵ Hypertension
81 is a risk factor for, and approximately doubles the risk of, AF due to development of left ventricular
82 hypertrophy and electrical remodelling where BP control is suboptimal.^{6,7} Hypertension is found in
83 half of those with AF, thus obtaining accurate BP readings is an important component of their
84 diagnosis and management.⁸ Current guidelines advise that BP should be measured manually when
85 the pulse is irregular.^{9,10} International protocols for the validation of BP monitors all exclude subjects
86 with an irregular pulse, identifying those with AF as a special population.^{11,12} In the absence of agreed
87 guidelines for BP measurement in AF it is not, therefore, possible to claim validation for accuracy of
88 BP readings for any monitor in the presence of AF.^{12,13} However, studies have undertaken
89 comparisons of various automated BP measurement devices with mercury sphygmomanometers,
90 which themselves are disappearing from clinical use on environmental grounds. In fact, a previous
91 review suggested that automated monitors might be accurate in measuring systolic but not diastolic
92 BP where AF is present.¹⁴ Automated devices are easy to operate and eliminate observer bias, and
93 are now preferred in some hypertension guidelines.¹⁵ There are suggestions that office BP may be
94 reasonably measured oscillometrically in some AF patients. This is a matter of debate,^{16,17} but out of
95 office BP measurement, by definition, relies on the use of automated devices.¹³ More recently,
96 automated BP devices are incorporating algorithms for the detection of AF; ¹⁸⁻²³ one (Microlife
97 WatchBP Home A device) being the subject of a positive National Institute for Health and Care
98 Excellence (NICE) Technology Appraisal.^{19,24} We therefore carried out a systematic review of the
99 literature to a) update the evidence base and to inform a position statement on recommendations
100 on BP measurement in the presence of AF (INSERT REFERENCE TO POSITION STATEMENT), and b) to

101 understand the accuracy of newer devices with AF detection in measuring BP, in comparison to
102 other devices.

103

104 **Methods**

105 We searched Medline and Embase from inception to 26th October 2018 using a broad search
106 strategy (Box 1). Searches were augmented by checking reference lists in review and commentary
107 articles retrieved. We also reviewed relevant journal collections, conference abstracts, relevant
108 guidelines and personal archives for additional citations. We included studies that compared
109 brachial BP measurements using oscillometric or other automated devices with auscultatory
110 mercury sphygmomanometer measurement (as our non-invasive gold standard). Comparison could
111 be by either a simultaneous or contemporaneous sequential method. We sought studies of home,
112 office or ambulatory BP monitoring devices with, or without, automated AF detection functions. It is
113 important to note that we did not undertake assessment of the accuracy of AF detection of such
114 devices.

115 We excluded studies that split comparisons over different assessment sessions, retrospective
116 analyses, case reports, device studies not comparing BP measurements as primary outcome and
117 those using intra-arterial BP measurement as gold standard. We assessed conference abstracts as
118 eligible where sufficient data and detail could be extracted. Searches were confined to English
119 language papers. Selections were made by one reviewer and checked by a second, with discussion
120 and resolution of disagreements.

121 Data on study details and populations were extracted by two reviewers. We included mean and
122 variance of BP readings for automated devices and mercury comparisons and, where reported, the
123 proportions of systolic and diastolic BP readings reaching agreement within 5, 10 or 15 mmHg, for
124 comparison with the relevant standards of the European Society for Hypertension (ESH) 2010
125 International Protocol for validation of BP measuring devices.¹¹ Mean differences were expressed as

126 device minus mercury values. Where not reported, differences between devices and mercury were
127 calculated from the reported BP values using a matched pairs approach, with adjustment for intra-
128 class correlation coefficients for systolic and diastolic BP reported in a previous review.^{14, 25} Meta-
129 analyses of pooled data were undertaken using random effects models in Stata v14.0. Two reviewers
130 undertook independent quality assessment of included studies with the QUADAS-2 tool.²⁶

131

132

Medline

1. Exp blood pressure determination
2. Exp atrial fibrillation
3. 1 AND 2

Embase:

1. Blood pressure measurement
2. Atrial fibrillation
3. 1 AND 2

133 [Box 1. Search strategy](#)

134

135

136 Results

137 Searches up to 26th October 2018 retrieved a total of 746 unique citations. Fifty nine full texts were
138 assessed for eligibility and 13 studies covering 14 devices met inclusion criteria (Figure 1). There
139 were no disagreements on data extraction between reviewers. There were eight studies of
140 automated BP monitors designed for home and/or office use,²⁷⁻³⁴ and six studies of four ambulatory
141 BP devices,^{27, 35-39} one of these only reported mean 24 hour ambulatory BP, as opposed to
142 contemporaneous measurement with mercury comparison, so was not included in meta-analyses.³⁵
143 Three studies used a simultaneous method to compare BP measurements,^{30, 34, 39} the remainder used
144 varied sequential protocols. Studies were all undertaken in hospital settings, recruiting either

145 inpatients, outpatients or both, and the mean ages of participants ranged from 68 to 83 years (Table
146 1). Six studies reported achievement of some, or all, of the standards for the 2010 International
147 Protocol, although none adopted the precise protocol itself.^{27, 29, 30, 32, 34, 39} Four of the devices studied
148 included AF or arrhythmia detection features.^{31, 32, 34-36}

149 Mean BP differences between mercury and automated devices were reported, or calculated from
150 data, for nine studies: For six home or office devices, the pooled systolic difference from mercury
151 standard was 1.0 mmHg (-1.1 to 3.1; $I^2 = 81\%$; Figure 2); heterogeneity was accounted for by
152 exclusion of one outlying study on the Microlife BP A6 (Microlife, Heerbrugg, Switzerland),³¹ pooled
153 difference from mercury on exclusion was -0.2 mmHg (-1.1 to 0.8; $I^2 = 24\%$). Pooled diastolic
154 difference was 1.5 mmHg (-1.4 to 4.5; $I^2 = 94\%$; Figure 3), heterogeneity could not be accounted for
155 by any one study.

156 For two ambulatory devices (three studies), pooled systolic difference from mercury was 0.5 mmHg
157 (-0.9 to 1.9; $I^2 = 0\%$; Figure 2) and pooled diastolic difference was 2.0 mmHg (2.8 to 6.8; $I^2 = 92\%$;
158 Figure 3). Diastolic heterogeneity was accounted for by between device differences: A&D-TM-2430
159 (A&D Company, Tokyo, Japan) difference from mercury -2.4 mmHg (-4.1 to -0.7; $I^2 = 0\%$) and
160 Spacelabs 90207 (Spacelabs Healthcare, WA, USA) 6.4 mmHg (2.1 to 10.6; $I^2 = 68\%$).

161 QUADAS-2 quality assessments identified some concern over risk of bias, usually due to unclear
162 reporting of recruitment strategies, for all but two studies.^{35, 39} Inspection of funnel plots quantified
163 with Egger's tests did not suggest evidence of small study publication bias (systolic and diastolic BP;
164 $P = 0.15$).⁴⁰ Levels of agreement varied between and within device manufacturers.

165 Six studies of nine devices reported proportions of readings differing from mercury standard for one
166 or more of the thresholds set by the 2010 International Protocol (Table 2).¹¹ Reporting of all
167 thresholds was only complete in four studies.^{30, 39, 41, 42} In single studies, only one home device, the
168 Tensoval duo control (Hartmann-Rico AG, Heidenheim, Germany), and one ambulatory device, the
169 Spacelabs 90207, met all standards for BP accuracy; one other study of Spacelabs 90207 only

170 reported against the 5 mmHg thresholds, which were not met.²⁷ The Microlife Watch BPA100Plus
171 (Microlife, Heerbrugg, Switzerland) met the systolic but not the diastolic BP standards.

172 Four devices studied feature AF or arrhythmia detection indicators: the Tensoval duo control,
173 Microlife BP A6, Microlife Watch BPA100Plus and the A&D-TM-2430.^{31, 32, 34-36} Of these, all except the
174 Microlife BP A6 agreed well for systolic BPs. Only the Tensoval device was also accurate for diastolic
175 BP, although the Microlife BPA6 also showed reasonable diastolic agreement.

176

177 Discussion

178 This systematic review and meta-analysis examined the available evidence for accuracy of
179 automated BP measurements compared to a mercury standard. We only found data assessing 14
180 devices, a number of which are no longer in production. This represents only a small proportion of
181 the monitors currently available on the market. We found considerable heterogeneity of BP
182 differences according to individual device and type of device, which limited our ability to draw
183 general conclusions.

184 For systolic BP measurement, ambulatory measurements with either the A&D-TM-2430 device or
185 the Spacelabs 90207 appeared comparable to mercury readings, whilst, for clinical or home settings,
186 reports showed good agreement for the Philips Sure Signs VSi (Philips Medical Systems, Andover,
187 Massachusetts, USA), Welch Allyn Vital Sign 300 (Welch Allyn, Beaverton, Oregon, USA), Microlife
188 Watch BPA100Plus and the Tensoval duo control. The latter was the only monitor that met the
189 International Protocol limits of agreement for both systolic and diastolic BP.

190 The Microlife Watch BPA100Plus met the systolic International Protocol standards but also
191 underestimated systolic BP by 3mmHg. Two other devices, the Omron HEM-750CP (Omron
192 Healthcare Co. Ltd, Kyoto, Japan) and the Microlife BPA6, overestimated systolic BP by 5 to 6mmHg.

193 For diastolic BP measurements, the A&D-TM-2430 ambulatory BP monitor underestimated BP by 2
194 mmHg whilst the Spacelabs 90207 overestimated it by 6 mmHg. Among home and office devices
195 accurate for systolic readings, only the Tensoval device performed accurately for diastolic BP as well.

196 Our review included four monitors with AF detection technology. Accuracy was not consistently
197 better for these devices with considerable inter-device variation between the two Microlife devices,
198 and no evidence of better overall performance compared to devices without AF detection features
199 was noted.

200

201 [Strengths and weaknesses](#)

202 Pooled analysis of findings was limited by a lack of data, and relatively small sample sizes in most
203 studies. The mean age of participants was high (~70 years), with little evidence to support any
204 judgement on accuracy of monitors in participants of a younger age. Since AF is an age related
205 condition this may not be important.⁴ We undertook comprehensive searches and sought
206 unpublished data from colleagues actively researching in the field, however, there may be
207 manufacturer's data that we were not able to access. The key limitation in this review is the
208 restricted number of devices that appear to have any published assessment of their BP measuring
209 performance in AF. Although we present pooled mean differences from our analyses, the large
210 variation between device types and within the home and office monitor group, precludes any
211 assumption that the apparently small pooled mean differences can be generalised to other
212 monitors. We retrieved, but did not include, a small number of studies reporting device comparison
213 with intra-arterial BPs, since our interest was in the clinical interpretation of reported BP readings.⁴³⁻
214 ⁴⁶ Quality assessment using the QADAS-2 tool did not effectively discriminate between studies,
215 mainly due to unclear reporting of recruitment methods, so no subgroup analyses by study quality
216 were feasible.

217

218 [Relevance to existing literature](#)

219 This review updates the 2012 review of Stergiou et al.¹⁴ They reviewed eight studies of 11 devices,
220 and observed that overall study methodology was variable and sample sizes were usually lower than
221 those dictated for validation studies.^{11, 47} Their pooled data from six studies showed systolic BP to be
222 overestimated, on average, by 0.5mmHg (-1.0 to 1.9; $I^2=39\%$) and diastolic BP by 2.5mmHg (-0.6 to
223 5.7; $I^2=93\%$). Preliminary findings from their current update confirm a similar systolic difference and
224 unchanged correlation coefficient (0.5mmHg (-1.0 to 1.9); correlation coefficient 0.87), but a smaller
225 pooled diastolic over-estimation of 1.5mmHg (-0.6 to 3.6); these overall updated pooled figures
226 remain subject to significant heterogeneity between studies ($I^2=77\%$ for systolic and 94% for
227 diastolic) emphasising the difficulty in generalising across different devices.⁴⁸ One other recent large
228 observational study pooling findings across N specialist centres reported correlation coefficients
229 consistent with previous reviews, and an overall over-estimation of BP of 1.1/0.6mmHg. There was,
230 however, no standardisation of choice of machine and no analysis by type of device, although this
231 does represent real clinic observational data.⁴⁹ For this review, we identified five additional studies
232 published since the 2012 review,¹⁴ covering three new devices.^{31, 35-37, 39} The Tensoval device study
233 was the highest weighted single study in the previous review (44%), but inclusion of only full study,
234 rather than subgroup data, masks a rate dependency for accuracy.⁴¹ Nevertheless, it still performed
235 well against other newer home BP monitors. Overall, we found substantial heterogeneity of accuracy
236 between devices according to setting and device. Whilst we identified evidence for accuracy of two
237 ambulatory devices for systolic BP readings, there was greater variation between home or office
238 monitors. Diastolic BP accuracy varied to a much greater degree in all settings.

239 Although no study followed the International Protocol for validation of BP devices, a number
240 reported against its standards.¹¹ Nine studies noted some absolute differences between automated
241 and auscultatory BP measurements, permitting a partial assessment against this criterion of the
242 International Protocol.¹¹ Several devices met one standard for systolic BP differences but only the

243 Spacelabs 90207 and the Tensoval Duo Control met these International Protocol criteria in full. The
244 Microlife Watch BPA100Plus met the standards for systolic BP but not diastolic readings.

245 In AF, beat to beat variations in stroke volume and ventricular filling lead to marked intra-person and
246 inter-observer variation in measured, particularly diastolic, BP.⁵⁰ Consequently, automated
247 oscillometric BP measurement is regarded as inaccurate in the presence of AF. Neither the 2014
248 NICE guidelines, nor the 2012 European Society for Cardiology guidelines, on management of AF
249 discuss BP measurement.^{51, 52} Therefore, current NICE guidance remains that of the 2011
250 hypertension guideline that BP should be measured manually in the presence of pulse irregularity,
251 following pulse palpation,⁹ and this is consistent with European guidelines (ESH 2013).¹⁰ It should,
252 however, be noted that intra and inter observer variability using mercury measurement of BP are
253 also greater in AF compared with sinus rhythm.^{53, 54} The systolic and diastolic BP differences may be
254 a consistent feature of the oscillometric method, which detects systolic and mean BP directly but
255 derives diastolic BP from an algorithm, leaving it more susceptible to error with pulse irregularity.¹⁶
256 Revised algorithms may be able to improve precision in AF,⁵⁵ and accuracy can be improved by
257 repetition of BP measurements.⁵⁶ We endorse advice to measure BP manually, exercising caution
258 with oscillometric devices, and recommend at least three BP measurements be undertaken with the
259 mean systolic BP value adopted, for maximal accuracy.

260

261 [Clinical implications](#)

262 Stergiou et al. concluded that monitors already validated in sinus rhythm against international
263 protocols are accurate in measuring systolic but not diastolic BP in the presence of sustained AF.¹⁴
264 The heterogeneity between devices in this review, in some cases including different models from the
265 same manufacturer derived from the same base model, suggests that no assumptions can be made
266 about the accuracy of other monitors in the presence of AF. We also found that inclusion of AF
267 detection functions does not indicate a greater likelihood of accuracy in BP measurement and care
268 should be taken not to assume this in practice. On the available evidence, the Tensoval device

269 appears to be a good choice for home BP monitoring in the presence of arrhythmia. This device is,
270 however, unusual in possessing both oscillometric and auscultatory modes of action. It is able to
271 detect arrhythmia and selects auscultatory mode in this setting, only using oscillometric mode if
272 unable to detect Korotkoff sounds. This technology may account for its superior performance
273 compared to other devices in this review. Importantly, we found no studies of accuracy based
274 outside of hospital settings where most BP measurement arises, and the available evidence is based
275 on a range of older populations.

276 There does, however, seem to be evidence to support accuracy in interpreting systolic ambulatory
277 BP measurements. Guideline recommendations of adoption of ambulatory BP monitoring for
278 diagnosis in sinus rhythm are based on robust evidence, associating measurements with outcomes.⁵⁷
279 The same cannot yet be said of ambulatory BP measurement in AF however,⁵⁸ yet given this caveat,
280 guidelines do not exclude AF patients from ambulatory monitoring.⁵⁹ The ambulatory devices
281 covered by this review appear accurate for systolic BP and should be preferred, compared to
282 unevaluated ambulatory devices.

283 Given the lack of available evidence for accuracy of most commonly used BP monitors in the
284 presence of AF, the British and Irish Hypertension Society (BIHS) stresses the importance of a patient
285 bringing their home BP monitor to appointments, and recommends occasional validation of home
286 monitors against clinical devices at individual clinic appointments ([https://bihsoc.org/wp-](https://bihsoc.org/wp-content/uploads/2017/11/BP-Measurement-Poster-Automated-2017.pdf)
287 [content/uploads/2017/11/BP-Measurement-Poster-Automated-2017.pdf](https://bihsoc.org/wp-content/uploads/2017/11/BP-Measurement-Poster-Automated-2017.pdf)). The BIHS also maintains
288 the only publicly available independent peer reviewed list of BP monitors ([https://bihsoc.org/bp-](https://bihsoc.org/bp-monitors/)
289 [monitors/](https://bihsoc.org/bp-monitors/)).

290

291 Further research

292 The guideline development group for the 2011 NICE guidelines on hypertension remarked on
293 concerns about the accuracy of automated devices for measuring BP in people with AF and

294 considered this an important area for technology development to see if such problems can be
295 resolved.⁹ The findings of this review emphasise that caution. There is currently a lack of evidence
296 regarding the accuracy of most commonly used BP monitors in the presence of AF, and validity of a
297 device in sinus rhythm cannot be assumed to imply similar accuracy with arrhythmia. Proposals for a
298 new universal standard for validation of BP monitors recognise this problem, and suggest that
299 subgroup validation studies in AF should follow successful validation of devices.⁶⁰

300 Further work is required to determine which automated BP monitors are suitable for people with
301 hypertension and AF, to explore whether existing algorithms should be modified or replaced to
302 improve accuracy of BP measurement in AF compared to mercury standard, and to confirm the
303 validity of ambulatory BP measurements in predicting cardiovascular outcomes in the presence of
304 AF.

305

306 [Conclusions](#)

307 The limited data available support the accuracy of some monitors for ambulatory, home or clinical
308 use to measure and monitor BP in the presence of AF. For most widely used devices, no evidence
309 has been found. Devices intended for use with AF should be chosen according to existing evidence of
310 accuracy and have this confirmed by comparison against validated clinical devices for individuals
311 being assessed. Further validation studies are needed, particularly for devices equipped to detect AF,
312 before any general conclusions can be drawn regarding accuracy of BP measurement in the presence
313 of AF.

314

315 **Acknowledgements**

316 **Funding statement**

317 CEC is supported by a NIHR Clinical Lectureship and RMcM by a NIHR Professorship. The views
318 expressed are those of the authors and not necessarily those of the NIHR, the NHS or the
319 Department of Health.

320 **Authors' contributions**

321 This study was conceived by CEC and RMcM. CEC undertook the searches, selected studies,
322 extracted and analysed the data. SMcD reviewed the search results, checked and agreed study
323 selections and extracted data. CEC drafted the manuscript which was revised by SMcD and RMcM.
324 All authors have read and reviewed the final manuscript.

325 **Conflict of interest statement**

326 CEC sits on, and RMcM chairs the British and Irish Hypertension Society Blood Pressure
327 Measurement Working Party. We both regularly review validation studies of blood pressure
328 monitors against objective criteria set out in international protocols as part of our work with this
329 registered charity. No manufacturer funding is received. CEC, has, in the past been loaned bilateral
330 blood pressure monitors by Microlife and Jawon Medical for unrestricted evaluation. No company
331 had any involvement in the design or conduct of this study.

332

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576 [Table and Figure legends](#)

577

578 Table 1. Included studies

579 Table 2. Agreement with International Protocol Standards

580 Figure 1. PRISMA flow chart of review

581 Figure 2. Mean systolic differences by device

582 Figure 3. Mean diastolic differences by device

Study ID	Subjects	Mean age (years)	Setting	Device description	Device type	AF or arrhythmia detection	BP measurement method	QUADAS-2 summary judgement - At risk of bias?
Anastas 2008	Male and female patients with AF aged 18 years or more, arm circumference 27 to 34 cm, and able to co-operate with protocol	79	Medical telemetry unit of a community hospital, Pacific Northwest	Welch Allyn Vital Sign 300 (Welch-Allyn, Beaverton, Oregon) with standard BP cuff (5082-206-2, Welch-Allyn, Tyco Instruments Inc, Skanetateles Falls, New York)	Office	No	Single sequential same arm BP measurements were undertaken in randomised order using a calibrated mercury sphygmomanometer and a Welch Allyn Vital Sign 300 monitor	Yes
Farsky 2011	Male and female patients aged 18 years or more with permanent AF and peripheral frequency of up to 100 bmin ⁻¹ , independent of the disease aetiology	68	Two clinics (Faculty Hospital of Purkyne University in Brno and Regional Hospital in Novy Jicín) in Czech Republic and three clinics (Faculty Hospital of Nursing in Presov and Nitra and Dom srdca, Martin) in Slovakia	Tensovo duo control (TDC; Hartmann-Rico AG, Heidenheim, Germany)	Home	Yes	Simultaneous arm BP measurements were undertaken using both a calibrated mercury sphygmomanometer and a TDC digital device (which offers auscultatory and oscillometric BP monitoring methods)	Yes
Giantin 2013	Male and female inpatients, aged 65 years or more, with permanent, stable AF (heart rate; 60–100 bmin ⁻¹)	83	Geriatric hospital unit, Padua University Hospital	A&D-TM-2430 (Kitamoto Shi, Saitama, Japan)	ABPM	Yes	Using the dominant arm, three BP measurements using the ABPM device were calibrated against a standard Hawksley random zero mercury sphygmomanometer to confirm that the values did not differ by > 5 mmHg. The ABPM device recorded BP at 15 min intervals during the day (0701–2200 hours) and at 20 min intervals during the evening and night (2201–0700 hours)	No
Jani 2006	Medically stable male and female patients with rate controlled AF (heart rate; 75 bmin ⁻¹)	70	Cardiology clinic	Omron HEM-750CP (Omron Healthcare Co. Ltd, Kyoto, Japan)	Home	No	Four supine BP readings were undertaken in the right arm at 2 min intervals, after a rest period of 15 min	Yes
Lamb 2010 (Omron)	Male and female hospital outpatients or inpatients aged 18 years or more with AF and stable heart rate and BP for 24 hours	74	Royal University Hospital, Canada	Omron HEM 711 AC (Omron Healthcare Co. Ltd, Kyoto, Japan)	Home	No	Supine BP readings were recorded in each arm simultaneously using one test monitor and the mercury sphygmomanometer. The second test monitor then replaced the first and readings were repeated. The mean of two mercury readings for each arm was compared with each single device reading for each arm	Yes
Lamb 2010 (Welch-Allyn)	Male and female hospital outpatients or inpatients aged 18 years or more with AF and stable heart rate and BP for 24 hours	74	Royal University Hospital, Canada	Welch-Allyn 52000 series NIBP/oximeter (Welch-Allyn, Beaverton, Oregon, USA)	Office	No	Same as Lamb 2010 (Omron)	Yes
Lip 1996	Male and female normotensive and hypertensive outpatients with chronic AF	72	Medical outpatient clinic, City Hospital, Birmingham, England	Spacelabs 90207 (Spacelabs Healthcare, WA, USA)	ABPM	No	The ABPM device was calibrated using the mean of two readings from a Hawksley random zero mercury sphygmomanometer, taken before and after the first ABPM measurement. The ABPM recorded BP every 30 min over a 24 hour period (day: 0700-2300, night: 2300-0700 hours) and data were condensed into 1 hour averages	Yes
Maselli 2015	Male and female patients with persistent AF attending a cardiology department for cardioversion who remained stable with or without drugs to control heart rate (60-100 bmin ⁻¹)	68	Department of Cardiology (Centro Gallucci – Padua), Padua University Hospital	A&D TM-2430 (A&D Company, Tokyo, Japan)	ABPM	Yes	Using the higher reading arm, and after 5 min of supine rest, three sphygmomanometric (using a mercury Erkameter 300 device) and three oscillometric (using the ABPM device) BP measurements were obtained	Yes
Miskowska-Nagórna 2017	Male and female patients with stable AF attending a clinic for cardioversion	63	Department of Hypertension and Diabetology, and the Department of Cardiology and Cardiac Electrotherapy of the Teaching Hospital of Medical University of Gdańsk, Poland	Spacelabs 90207 (Spacelabs Healthcare, WA, USA)	ABPM	No	After several min of rest, BP was obtained simultaneously using a mercury sphygmomanometer and an ABPM oscillometric device (triggered every two min). Measurements were repeated 10 times and the average of successfully obtained pairs was used for analysis	No

Olson 2002	Male and female AF patients attending a clinic for cardioversion	71	Department of Heart Disease, Haukeland Hospital, Bergen, Norway	Accutracker II (Suntech Medical Instruments, Raleigh, North Carolina, USA, or Diasys Integra, Novacor, Ruell, France)	ABPM	No	BP was measured by the standard auscultatory technique by using an aneroid sphygmomanometer. Three measurements were performed during seated rest, with 1 min intervals. The mean of the last two measurements was noted as the patient's office BP. Thereafter a 24 hour ABPM monitor was fitted	Yes
Selmyte-Besuspare 2017	Male and female patients with AF and arterial hypertension, aged 18 years or more	68	Department of Cardiology, Vilnius University Hospital, Santariskiu Klinikos, Lithuania	Microlife BP A6 PC with AF detection system (Microlife, Heerbrugg, Switzerland)	Home	Yes	After 5 min of rest, four auscultatory BP measurements were performed on the non-dominant arm and used as the reference technique. Four oscillometric BP measurements were then obtained, using the Microlife device, according to the manufacturer's instructions, using the same arm	Yes
Stergiou 2011	Subjects with AF	74	Hypertension Centre, Third University Department of Medicine, Sotiria Hospital, Athens-Greece	Microlife Watch BPA100Plus (Microlife, Heerbrugg, Switzerland)	Home	Yes	Two sets of three BP measurements were obtained using the test device or a mercury sphygmomanometer and each set of measurements were averaged to give a single systolic and diastolic value	Yes
Stewart 1995 (Takeda UA-751)	Male and female inpatients and outpatients, with normotension and hypertension and confirmed AF	72	Medical wards and outpatient department, Western General Hospital, Edinburgh, Scotland	Takeda UA-751 (A&D Company, Tokyo, Japan)	Office	No	BP was measured twice with each device and a Hawksley random-zero sphygmomanometer during seated rest. Hawksley BP readings were taken immediately before and after each device test using a sequential arm technique. Each patient also had three sequential measurements with the Hawksley sphygmomanometer	Yes
Stewart 1995 (Copal UA-251)	Male and female inpatients and outpatients, with normotension and hypertension and confirmed AF	72	Medical wards and outpatient department, Western General Hospital, Edinburgh, Scotland	Copal UA-251 (A&D Company, Tokyo, Japan)	Office	No	Same as Stewart 1995 (Takeda UA-751)	Yes
Stewart 1995 (Accutracker 1)	Male and female inpatients and outpatients, with normotension and hypertension and confirmed AF	72	Medical wards and outpatient department, Western General Hospital, Edinburgh, Scotland	Accutracker 1 (Suntech Medical Instruments, Raleigh, North Carolina, USA)	ABPM	No	Same as Stewart 1995 (Takeda UA-751)	Yes
Stewart 1995 (Spacelabs 90207)	Male and female inpatients and outpatients, with normotension and hypertension and confirmed AF	72	Medical wards and outpatient department, Western General Hospital, Edinburgh, Scotland	Spacelabs 90207 (Spacelabs Healthcare, WA, USA)	ABPM	No	Same as Stewart 1995 (Takeda UA-751)	Yes
Vazquez-Rodriguez 2010	Inpatients with AF, aged 24-96 years	74	Short-Stay Medical Unit of the Complejo Hospitalario Universitario A Coruña, Spain	Philips Sure Signs VSi (Philips Medical Systems, Andover, MA)	Office	No	Using the higher reading arm, four automatic and four manual measurements were made alternately, with 5 min intervals of rest in between each measurement	Yes

Device (study)	Device type	Systolic agreement			Diastolic agree	
		≤5mmHg	≤10mmHg	≤15mmHg	≤5mmHg	≤10mmHg
International protocol standards	All of:	65	81	93	65	81
	Two of:	73	87	96	73	87
ABPM devices						
Accutacker 1 (Stewart 1995)		50			36	
Spacelabs 90207 (Miskowska-Nagórna 2017)**		60	91	96	72	96
Spacelabs 90207 (Stewart 1995)		50			29	
Home and office devices						
Copal UA-251 (Stewart 1995)		68			75	
Microlife Watch BPA100Plus (Stergiou 2011)*		69	85	93	47	76
Omron HEM 711 AC (Lamb 2010)		49	72	84	47	77
Takeda UA-751 (Stewart 1995)		65			54	

Tensoval duo control (Farsky 2011)**	80	93.6	97.7	81.6	93.7
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Welch Allyn Vital Sign 300 (Anastas 2008)		51	85		85
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Welch-Allyn 52000 (Lamb 2010)	46	72	81	57	86
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*meets International Protocol standards for systolic blood pressure accuracy

** meets International Protocol standards for systolic and diastolic blood pressure accuracy

ABPM: ambulatory blood pressure monitoring

ment

≤15mmHg

93

96

98

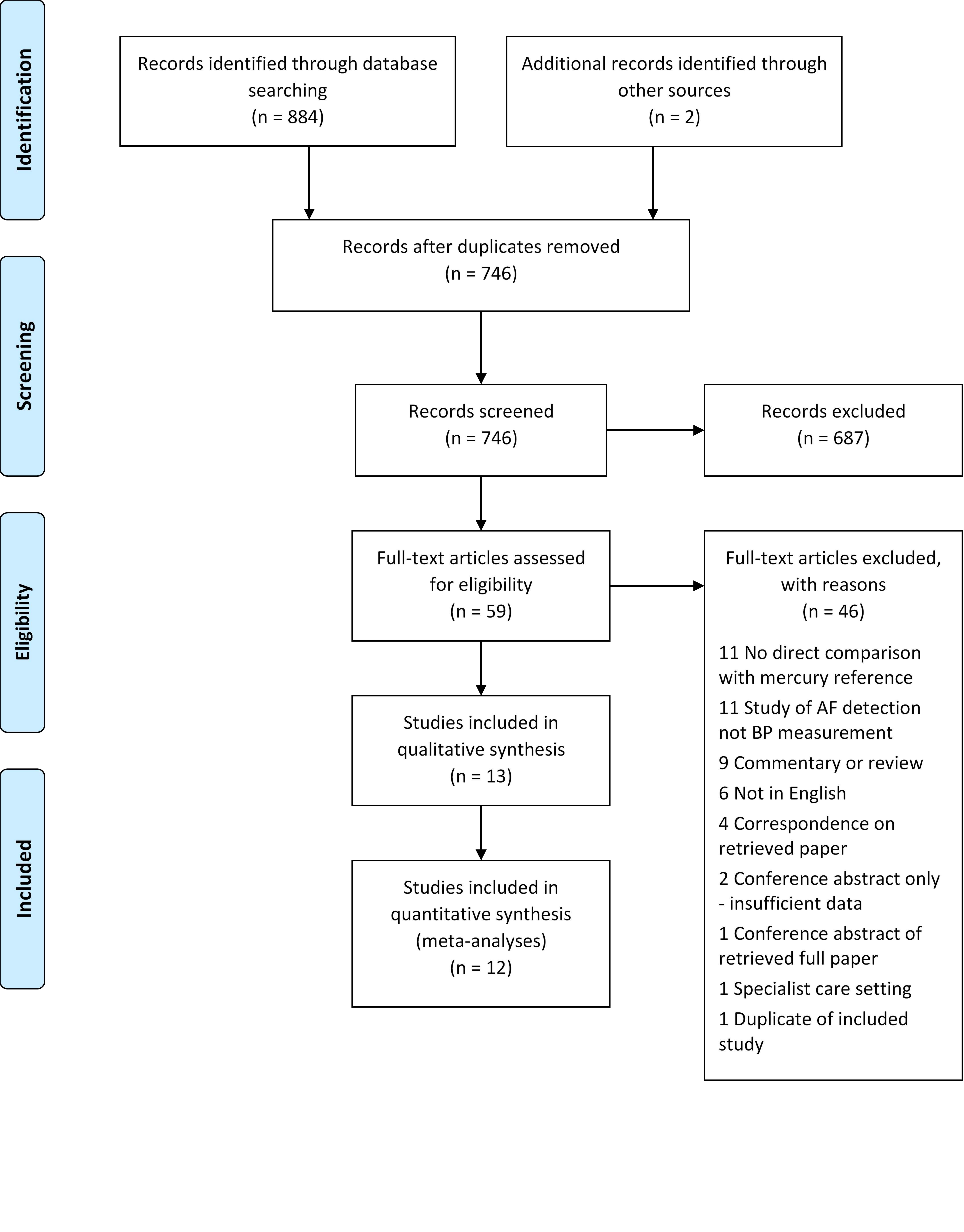
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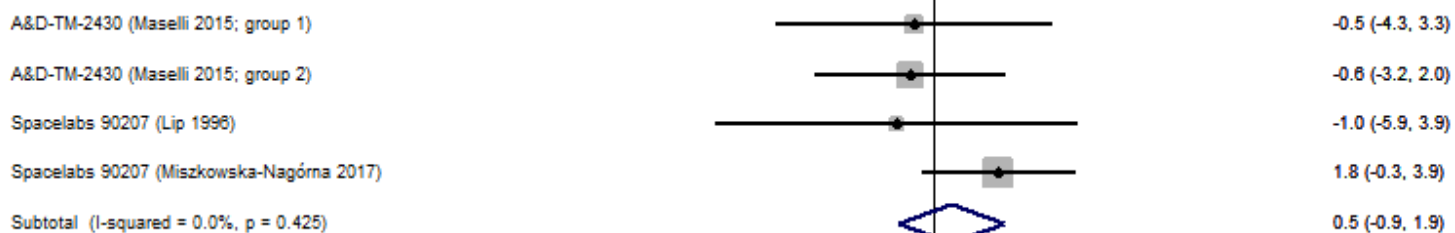
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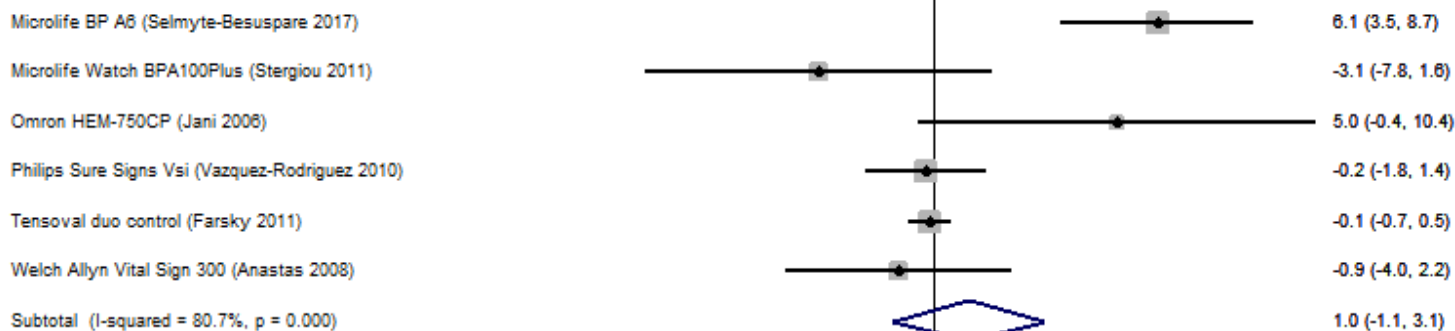
Device (study)

Mean difference (95% CI)

ABPM



Home or office



Mean systolic difference (device - mercury) mmHg

Device (study)

Mean difference (95% CI)
ES (95% CI)

ABPM

A&D-TM-2430 (Maselli 2015; group 1)

-2.4 (-5.4, 0.6)

A&D-TM-2430 (Maselli 2015; group 2)

-2.4 (-4.5, -0.3)

Spacelabs 90207 (Lip 1998)

9.0 (4.6, 13.4)

Spacelabs 90207 (Miskowska-Nagórna 2017)

4.6 (2.4, 6.8)

Subtotal (I-squared = 92.2%, p = 0.000)

2.0 (-2.8, 6.8)

Home or office

Microlife BP A6 (Selmyte-Besuspare 2017)

2.1 (-0.6, 4.8)

Microlife Watch BPA100Plus (Stergiou 2011)

7.0 (4.6, 9.4)

Omron HEM-750CP (Jani 2008)

1.0 (-5.5, 7.5)

Philips Sure Signs Vsi (Vazquez-Rodriguez 2010)

-4.6 (-8.0, -3.2)

Tensoval duo control (Farsky 2011)

0.7 (0.1, 1.3)

Welch Allyn Vital Sign 300 (Anastas 2008)

3.3 (1.4, 5.2)

Subtotal (I-squared = 94.3%, p = 0.000)

1.5 (-1.4, 4.5)

-10 -5 0 5 10

Mean difference (device - mercury) mmHg