Survey of Automated Noninvasive Blood Pressure Monitors

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Automated noninvasive blood pressure (NIBP) monitors, or automated sphygmomanometers, have been increasingly used both inside and outside clinical environments. An extensive survey of such monitors was carried out over the past five years. This survey covers a broad spectrum of monitors including ambulatory monitors, bedside and transport monitors, stress-test monitors, and monitors that are intended for self-measurement. It includes more than 400 models from suppliers in the United States and many other countries. A review of NIBP measurement methods that have been used in automated NIBP monitors is presented in this paper, along with statistical distributions of their use in the surveyed monitors and a list of the suppliers and monitors.

Index Under: Noninvasive Blood Pressure Measurement; Blood Pressure Measurement, Noninvasive; Noninvasive Blood Pressure Monitors, Commercial, Survey of; Blood Pressure Monitors, Noninvasive; Pressure, Blood, Noninvasive Monitoring; Monitors, Noninvasive Blood Pressure.

INTRODUCTION

Since the introduction of the first known commercial automated oscillometric *noninvasive blood pressure* (NIBP) monitor — the **DINAMAP™ 825** — by Critikon (Tampa, FL) in 1976, the use of automated NIBP monitors inside and outside clinical environments has increased immensely. Beginning in the fourth quarter of 1989, a survey of commercial automated NIBP monitors was initiated by the authors in an attempt to collect information on the essential characteristics of such monitors, especially their measurement methods. To date, this survey has included a broad spectrum of monitors, with more than 400 models from many suppliers worldwide. Most of these suppliers come from the United States; others come from Canada, Denmark, Finland, France, Germany, Israel, Italy, Japan, Korea, the Netherlands, Spain, Switzerland, Taiwan, and the United Kingdom.

This paper first introduces a classification of the surveyed monitors, and then presents a review of NIBP measurement methods that have been used in automated NIBP monitors. Statistical distributions on the use of the measurement methods in the surveyed monitors are then summarized, followed by a discussion of issues related to automated NIBP monitors. A listing of the surveyed monitors, along with their suppliers and measurement methods, is given at the end of the paper.

CLASSIFICATION OF SURVEYED NONINVASIVE BLOOD PRESSURE MONITORS

The survey includes all monitors or devices that provide automated NIBP measurement for humans, regardless of whether the devices are also used for purposes. The surveyed monitors have been classified into three groups: (1) ambulatory monitors; (2) bedside and transport monitors; and (3) others.

Ambulatory monitors are typically strapped over the shoulder or attached to a belt around the waist for 24-hour monitoring of blood pressure at rest, during normal activities, and during physical exercise. They are usually used under the advice or supervision of a physician as part of a hypertension management program.

Bedside and *transport monitors* are typically used in hospitals and clinics. They include stand-alone monitors that provide NIBP and pulse-rate measurements, configured or configurable multiparameter monitors with NIBP measurement capabilities, and external NIBP modules or cartridges that are used with modular physiologic monitoring systems. Nonambulatory monitors designed for stress or exercise testing are included in this group of monitors.

The third group of monitors consists mainly of monitors that are used for *self-measurement* of blood pressure

at home, in the workplace and in public places, or for routine measurement by a physician. Most of these monitors are portable. The nonportable monitors are sometimes coin-operated, and they are usually installed in fixed locations such as offices, hotels, health and fitness clubs, schools, shopping malls and grocery stalls.

REVIEW OF NONINVASIVE BLOOD PRESSURE MEASUREMENT METHODS

Measurement of noninvasive blood pressure is accomplished by correlating intra-arterial blood pressure to certain physical phenomenal characteristics that are observed noninvasively. The correlations are usually established empirically or clinically. In automated NIBP measurements, the characteristics are detected by transducers, and the corresponding blood pressure is determined by electronic processing and analysis of the transducer signals without human judgment.

The survey reveals eight NIBP measurement methods that are currently used in commercial automated NIBP monitors: (1) the auscultatory method; (2) oscillometric method; (3) palpatory method; (4) volume-oscillometric method; (5) vascular unloading method; (6) arterial tonometry method; (7) pulse-wave velocity method; and (8) COR method. Two other methods, the *infrasound* and *ultrasound* methods, have been used in commercial automated NIBP monitors, but the authors have been unable to locate suppliers who currently supply automated monitors based on these two methods.

The ten measurement methods may be classified into two categories (see Table I): (1) *intermittent measurement methods*, and (2) *continuous measurement methods*. In intermittent measurement methods, point pressures, such as systolic pressure, diastolic pressure and *mean arterial pressure* (MAP), are obtained over a period of time encompassing more than one heart beat. In continuous measurement methods, blood pressure measurements are obtained on a beat-to-beat basis. Continuous methods provide: (1) absolute, continuous arterial pressure waveform only; (2) beat-to-beat point pressures only; or (3) both the waveform and point pressures. Of the ten measurement methods, all except the pulse-wave velocity method use a compressive cuff or bag that partially or fully occludes an artery during the measurement process.

The following review of NIBP measurement methods is based on information obtained from the survey and the literature. Emphasis is placed on fundamental operating principles. Historical developments of the methods are, however, not explicitly recounted, but many key references are cited and some recent developments are mentioned. It is not the intent of this paper to provide an appraisal of the measurement methods or the technologies associated with the implementation of the methods, as each method has its own strengths and weaknesses and its reliability can be expected to improve, within certain limits, with further research and development.

TABLE I
Noninvasive blood pressure measurement methods

Measurement Method	Intermittent	Continuous	Cuff*	Cuffless*
1. Auscultatory	■		Full	
2. Oscillometric	■		Full	
3. Palpatory	■		Full	
4. Infrasound	■		Full	
5. Ultrasound	■		Full	
6. Volume-Oscillometric	■		Full	
7. Vascular Unloading		■	Partial	
8. Arterial Tonometry		■		Partial
9. Pulse-Wave Velocity		■		None
10. COR		■	Partial	

* "Full" means that the artery is fully occluded at some point during the NIBP determination period (calibration period not included). "Partial" means that the artery is partially occluded throughout the NIBP determination period. "None" means that the artery is not occluded at all times during the NIBP determination period.

Auscultatory Method

The automated *auscultatory method* is based on the most widely accepted clinical standard for measuring blood pressure — the manual auscultatory method. The auscultatory method is often called the *Riva-Rocci/Korotkoff* method (Riva-Rocci, 1896; Korotkoff, 1905). Physicians have historically based their decisions regarding blood pressure management on manual auscultatory measurements. The cuff pressure at the onset of Phase I Korotkoff sounds (this onset is also called Swan's first point [Swan, 1914]), or tapping sounds, is generally taken as the systolic pressure. The cuff pressure at the onset of Phase V Korotkoff sounds (Swan's fifth point), or silence, is recommended as the diastolic pressure. For subjects whose Korotkoff sounds persist until zero cuff pressure, as is the case in some children and pregnant women, however, the onset of Phase IV Korotkoff sounds (Swan's fourth point), or muffling sounds, is recommended as the diastolic criterion (Petrie, 1986; Perloff, 1993).

Korotkoff sounds represent only the audible portion of a broader range of arterial vibrations called *Korotkoff vibrations*, which include both the audible and inaudible vibrations. In the automated auscultatory method, one or more microphones are used to detect the vibrations. At least one of the microphones is placed over the brachial artery under the distal end of the cuff, usually at a location where the brachial pulse can be most strongly felt. Because of the presence of the brachial pulse, the Korotkoff vibration signals obtained using the microphone will inevitably contain a component signal that is produced by this pulse. This component signal may be isolated and used to determine the pulse or heart rate.

Electrocardiogram-gating (ECG-gating) and oscillometric-pulse-gating (OP-gating) techniques have been used to augment microphone measurements in reducing the effects of artifacts and extraneous noise.

In *ECG-Gating Techniques*, one or more microphones are used with the ECG as a timing reference (Canzoneri, 1968; Lagerwerff, 1970; Wolthuis, 1974; Squires, 1980; Bertram, 1981; Weaver, 1983; Obara, 1987; White, 1987; Radaelli, 1990). A time window, or time gate, is typically opened after a certain time delay following the occurrence

of the R-wave of the ECG, which is usually obtained from the chest, and only measurements that are made by the microphones during this time window are used for blood pressure determination. These techniques are based on the fact that at cuff pressures between systolic and diastolic pressures, the time interval between the occurrence of the ECG or the initial rise of the arterial pulse wave, and the succeeding onset of Korotkoff vibrations during the same cardiac cycle, decreases with decreasing cuff pressure (Erlanger, 1916a; Geddes, 1968; da Costa, 1973).

OP-Gating Techniques are similar to ECG-gating techniques, except that the oscillometric pulse is used as the timing reference (Hatschek, 1984; Georgi, 1986; Mieke, 1990). They are based on the fact that at cuff pressures between systolic and diastolic pressures, the time interval between the onset of an oscillometric pulse and the succeeding onset of Korotkoff vibrations during the same cardiac cycle decreases with decreasing cuff pressure, diminishing to almost zero when the cuff pressure is equal to diastolic pressure (Erlanger, 1916a; Korns, 1926; Mieke, 1990; see discussion under Oscillometric Method).

A variety of *microphone placement configurations* has been used in commercial NIBP monitors to detect Korotkoff vibrations and, sometimes, to isolate the vibration signals from artifacts and extraneous noise. Some of the microphones are single-sided, capable of detecting signals only from one side of the microphone, while others are double-sided, capable of detecting signals from both sides of the microphone. At least one, called the *primary microphone*, is usually placed under the distal end of the cuff, embedded in a pouch, placed in such a way that there is a layer of material between the skin and microphone, or placed in direct contact with the skin. The microphone side that faces the artery detects Korotkoff vibrations, artifacts and extraneous noise. The various microphone placement configurations are illustrated in Figure 1 and described as follows:

- In configuration <a>, one single-sided microphone is placed under the cuff distal end. This is the most common configuration found in the surveyed monitors. It is used without any gating technique, with ECG-gating, or with OP-gating.
- Configuration <b> is called the "differential auscultatory technique." A double-sided microphone is placed under the cuff distal end (Kaspari, 1981, 1994). One side of the microphone faces the artery while the other side faces the cuff. The cuff side detects oscillometric pulses, artifacts and extraneous noise. The artery-side signal has its brachial pulse component, artifacts and extraneous noise removed by subtracting the cuff-side signal from the artery-side signal to yield a differential signal. The survey indicates use of this configuration without ECG-gating or OP-gating.
- In configuration <c>, two microphones are used. The primary microphone is placed under the cuff distal end. The *secondary microphone* is located at the cuff proximal end, embedded in a pouch on top of the cuff and laterally offset from the primary microphone (Tochikubo, 1988). The sensor side of the secondary microphone faces the cuff and detects oscillometric pulses, artifacts and extraneous noise. The primary microphone signal has its brachial pulse component, artifacts and extraneous noise removed through analysis of the time lag between the two microphone signals, and analysis of the difference between the waveforms of the two signals. This technique is a variation of the differential auscultatory technique. The survey shows use of this configuration without ECG-gating or OP-gating.
- In configuration <d>, two microphones are used. The primary microphone is placed under the cuff distal end, while the secondary microphone is placed under the cuff proximal end (Peel, 1986). The sensor side of both microphones faces the artery. The time delay between the arrival of the proximal microphone signal and the subsequent arrival of a distal microphone signal is used to accept or reject the distal microphone signal; at cuff pressures between systolic and diastolic pressures, this time delay decreases with decreasing

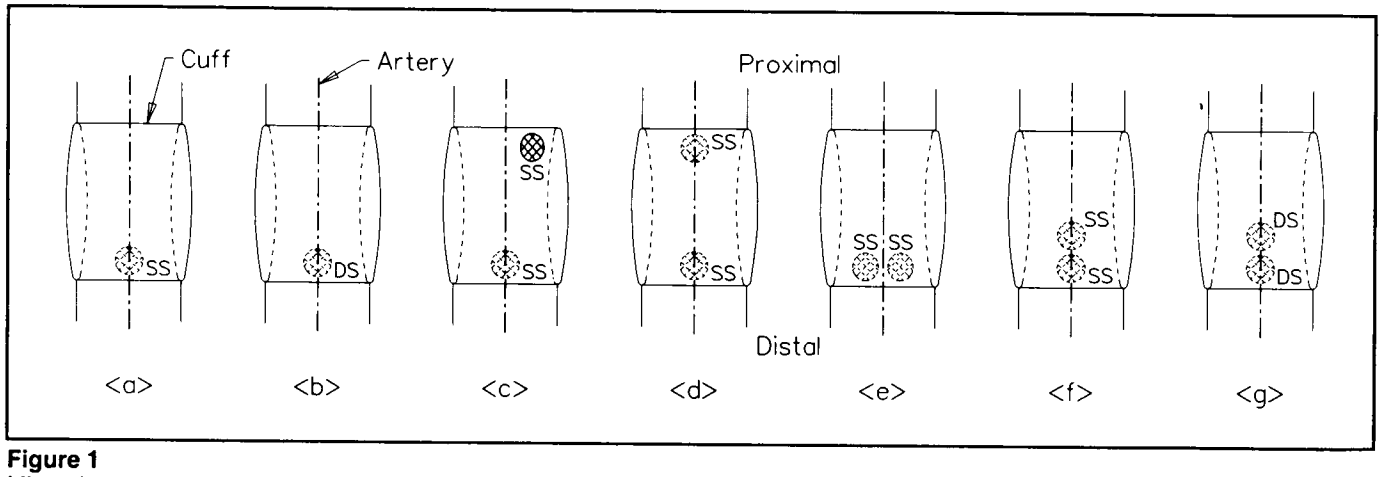

Figure 1
Microphone placement configurations for automated auscultatory blood pressure measurement. SS stands for single-sided microphone, while DS stands for double-sided microphone.

cuff pressure. The survey shows use of this configuration with ECG-gating, where the time window for the proximal microphone is first opened after a certain time delay following the occurrence of the R-wave of the ECG. If during this time window an acceptable signal is registered by the proximal microphone, another time window is then opened for the distal microphone.

- In configuration <e>, two primary microphones are placed a short distance apart under the cuff distal end, on opposite sides of the artery, and each is embedded in a pouch or in direct contact with the skin. One way of using this configuration to advantage is to select the stronger of the two microphone signals. The survey indicates use of this configuration with or without ECG-gating.
- In configuration <f>, two single-sided primary microphones are placed a short distance apart under the cuff distal end, along the artery, with each in direct contact with the skin. One way of using this configuration to advantage is to obtain the differential signal between the two microphone signals to reduce the effects of artifacts and extraneous noise. Because of the time delay between the detection of the Korotkoff vibration signal by the two microphones, however, the resulting Korotkoff vibration component in the differential signal is not negated but instead reinforced, resulting in an improved signal-to-noise ratio. Other ways of using this configuration to advantage are, however, possible (Georgi, 1986). The survey shows use of this configuration with ECG-gating.
- In configuration <g>, two double-sided microphones are placed a short distance apart under the cuff distal end, along the artery, with each in direct contact with the skin (Radaelli, 1990). The differential signal is obtained for each microphone. If a Korotkoff vibration is detected by the upper microphone, it is accepted only if it is also detected by the lower microphone after a certain time delay. The survey shows use of this configuration with ECG-gating.

All of the above configurations are being used in some of the surveyed monitors. Additionally, configuration <f> was used, without ECG-gating or OP-gating, in the **Puritan-Bennett Infrasonde® D4000** (Zezulka, 1985) and **Physiometrics SR-2** (Edwards, 1976) automated infrasound monitors, both of which were unavailable at the beginning of the survey.

The survey shows the use of contact microphones utilizing the following types of sensors: (1) *piezoelectric ceramic* (PZT), also called piezoceramic; (2) *piezoelectric polymer or film* (PVDF), also called piezofilm; and (3) *electret*. These microphones are generally capable of detecting Korotkoff vibrations with frequencies in the inaudible range, which lie below about 20 Hz. PZT microphones are the most commonly used microphones in the surveyed monitors. The quality of the microphone signal and the sensitivity of the microphone to artifacts from arm motion and muscle flexing depend on the shape of the sensor, as well as the orientation of the sensor with respect to the underlying artery (Georgi, 1986).

Automated auscultatory blood pressures are typically determined from the characteristics of the frequency spectra of Korotkoff vibrations, using one or more electronic filters. Despite their use of different and sometimes noncomparable methodologies, many studies collectively indicate that, in general, the proportion of spectral energy in the frequency range below 60 Hz in Phases I, IV and V Korotkoff vibrations is greater than the proportion in the same frequency range in Phase II and Phase III vibrations (Ware, 1966; McCutcheon 1969; Golden, 1974; Wolthuis, 1974; Maurer, 1976; Lange, 1985; Cozby, 1993).

Auscultatory blood pressures may also be determined from changes in the shape of the time-domain Korotkoff vibration signal or its second derivative. During cuff deflation, the cuff pressure at the appearance of a steep positive rise or spike-like wave in the Korotkoff vibration signal or its second derivative corresponds to systolic pressure, while the cuff pressure at the disappearance of a negative spike or notch corresponds to diastolic pressure (Irnich, 1970; Nakayama, 1979; Kaspari, 1981; Bertram, 1982; Lange, 1985; Fukuoka, 1987; Dietz, 1991). This method has been called the "objective recording method" (Fukuoka, 1987).

Korotkoff vibration signals may be characterized as a combination of three distinct time-domain component signals called K1, K2 and K3 (Blank, 1988). During cuff deflation, the cuff pressure at the onset of the K2 signal corresponds to systolic pressure, while that at the disappearance of the signal corresponds to diastolic pressure; this method has been called the "K2 algorithm." The waveform of the K3 signal is similar to that of the intra-arterial pressure waveform so that the MAP may be determined by calibrating the K3 signal against systolic and diastolic pressures that have been obtained using the K2 algorithm.

Auscultatory blood pressures may also be determined from the amplitude of the microphone signal, the signal without its brachial pulse component, or the signal after it has been processed to reflect only the audible components (Kaspari, 1977, 1981; Klaye, 1983; Sainomoto, 1986). Because the microphone signal amplitude is a measure of the Korotkoff vibration intensity, this method is basically an emulation of the manual auscultatory method.

The auscultatory method typically measures systolic and diastolic pressures but not MAP. The MAP is usually computed from the systolic and diastolic pressures using some predetermined mathematical formula. The patent literature reveals a technique in which the microphone signal waveform, after its brachial pulse component has been removed, is integrated to give a resulting waveform that resembles the intra-arterial waveform (Kaspari, 1981). This resulting waveform is then calibrated against systolic and diastolic pressures, which have been previously determined, to yield MAP. Recent studies have

demonstrated that the cuff pressure for the loudest Korotkoff sound is an estimate of MAP (Davis, 1988, 1990).

Oscillometric Method

The *oscillometric method* is based on pressure oscillations, called oscillometric pulses, that are generated in the blood pressure cuff by the beat-to-beat pulsatile displacement of the artery during cuff inflation or deflation. With increasing or decreasing cuff pressure, the peak-to-peak amplitude of the oscillometric pulses increases at first and then begins to decrease at some point (Marey, 1876).

Oscillometric blood pressures are typically determined from the locus, or envelope, of the successive baseline-to-peak or peak-to-peak oscillometric pulse amplitudes plotted against their corresponding baseline cuff pressures (baseline cuff pressure refers to cuff pressure with the pressure oscillations removed). The baseline cuff pressure at which the pulse amplitude is maximum, which corresponds to the highest point on the envelope, is generally regarded as the MAP (Hill, 1897; Gley, 1931; Posey, 1969; Ramsey, 1979; Yelderman, 1979; Mauck, 1980; Drzewiecki, 1994). Two general types of criteria have been used to determine systolic and diastolic pressures: *height-based criteria* (Geddes, 1982 Sapiński; Sapiński1986; Brooks, 1988; Ramsey, 1988; Bahr, 1989; Miyawaki, 1988; Inage, 1994), and *slope-based criteria* (Erlanger, 1916b; von Recklinghausen, 1940; Geddes, 1982; Nunn, 1984; Uemura, 1984; Link, 1987a; Miyawaki, 1988; Shirasaki, 1988; Susi, 1988; Chio, 1989; Lazarashvili, 1993). These criteria are illustrated in Figure 2, where the term *oscillometric pulse index* refers to the quantity used to construct the envelope.

In the height-based approach, the systolic pressure is typically determined as the baseline cuff pressure that is greater than the MAP and at which the ratio of the oscillometric pulse amplitude over the maximum pulse amplitude is equal to a certain predetermined value; the ratio at this determination point may be called the *systolic ratio*. The diastolic pressure is determined as the baseline cuff pressure that is lower than the MAP and at which the same ratio is equal to another predetermined value; the ratio at this determination point may be called the *diastolic ratio*. Some combinations of such ratios are given in Table II. Other variations to this height-based approach can be found in the literature (Kalaitzakis, 1989; Frankenreiter, 1991).

In the slope-based approach, and for determination during cuff deflation, the baseline cuff pressure at which the oscillometric pulse amplitude increases rapidly is taken as the systolic pressure, while that at which the amplitude decreases rapidly is taken as the diastolic pressure. A similar approach is used for determination during cuff inflation. The systolic or diastolic pressure determination point in the sloped-based approach has sometimes been defined as the point at which the oscillometric pulse amplitude starts to increase from a fairly uniform

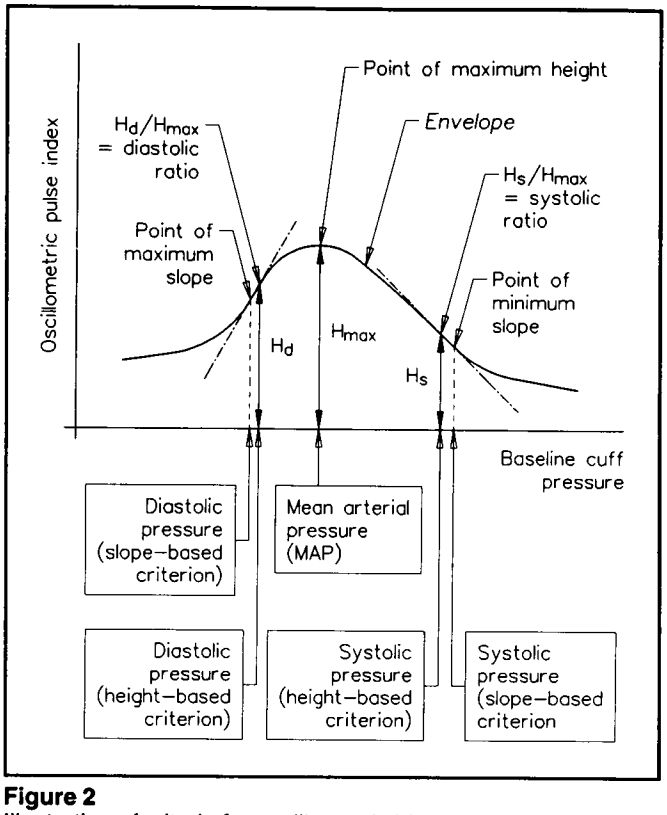

Figure 2
Illustration of criteria for oscillometric blood pressure measurement. Refer to text for possible quantities that may be used for the oscillometric pulse index in the vertical axis. This illustration does not suggest any relative magnitude of height-based and slope-based blood pressures.

level, or the point at which the falling amplitude starts to become fairly uniform. Mathematically, this determination point may be defined as the point at which the slope of the amplitude envelope is maximum or minimum.

The patent literature reveals variations in which a partial or full integral of each oscillometric pulse, a complementary integral between two successive oscillometric pulses, or the ratio of the integral over the integration time period, is used as the oscillometric pulse index (Terada, 1988; Nelson, 1989; Ruiter, 1990). In these variations, the MAP may be determined as the baseline cuff pressure at which the resulting envelope peaks, and the systolic and diastolic pressures, by applying height-based or slope-based criteria to the envelope (see Figure 2 and Table II).

TABLE II
Height-based ratios for determination of oscillometric blood pressures

Source	Oscillometric pulse index for envelope	Height / Maximum height		Remarks
		Systolic pressure	Diastolic pressure	
Geddes (1982)	Pulse amplitude	0.45 ~ 0.57	0.75 ~ 0.86	
Sapiński (1986)	Pulse amplitude	0.4	0.6	
Brooks (1988)	Pulse amplitude	0.5	-	
Miyawaki (1988)	Pulse amplitude	0.5	0.75	
Ramsey (1988)	Pulse amplitude	0.5	0.69	for normal deflation rates.
	Pulse amplitude	0.45	0.72	for rapid deflation rates.
Bahr (1989)	Pulse amplitude	0.75	0.8	
Nelson (1990)	Partial pulse integral	0.6	0.8	
Inage (1994)	Pulse amplitude	0.5	0.7	
One supplier	Pulse amplitude	0.67	0.75	used in one monitor; model cannot be disclosed.

Such integral-based determination has been claimed by the inventors to be more resilient to artifacts and hence more reliable than amplitude-based determination.

Oscillometric blood pressures determined from the envelope of oscillometric pulse amplitudes using the maximum pulse amplitude criterion for MAP, a set of fixed height-based criteria or a set of fixed slope-based criteria for systolic and diastolic pressures, are expected to vary with both cuff bladder size and cuff-arm compliance (Ng, 1993). Similar variations are also expected if an integral-based quantity is used as the oscillometric pulse index, because such a quantity is a function of the pulse amplitude.

The literature shows the use of many techniques to reduce the effects of artifacts and extraneous noise. Most of these techniques are based exclusively on analysis of the shape of the oscillometric pulse waveform and on the timing characteristics of the oscillometric pulses (Medero, 1985a, 1985b; Ramsey, 1988, 1991; Wallach, 1988; Dorsett, 1990; Lazarashvili, 1993). The survey indicates the use of an ECG-gating technique, where only those pressure pulses that are detected within a certain period of time with respect to the ECG are considered valid oscillometric pulses. This technique is based on the fact that there is a time interval between the occurrence of the ECG and the succeeding onset of the oscillometric pulse during the same cardiac cycle. At cuff pressures between systolic and diastolic pressures, this time interval changes only slightly (Mieke, 1990; see discussion of noise and artifact rejection techniques in above section on Auscultatory Method).

Although the criterion for MAP is the most established oscillometric criterion, the survey reveals that many oscillometric monitors do not provide MAP measurement. Most of these monitors are intended for self-measurement. The survey also reveals that, besides the upper arm and thigh, the finger and wrist are also used as measurement sites for oscillometric blood pressures.

An oscillotonometer, which typically employs two cuffs or a double-bag cuff, essentially uses slope-based criteria to determine systolic and diastolic pressures and, sometimes, the maximum pulse amplitude criterion to determine MAP (Gallavardin, 1922; Hutton, 1982). Oscillotonometry is, therefore, an implementation of the oscillometric method.

Palpatory Method

Also called the "return-to-flow" method, the *palpatory method* is usually used to estimate systolic pressure. During cuff deflation, the cuff pressure at which a cuff distal pulse, such as the radial pulse or a finger pulse, returns is taken as the systolic pressure (Block, 1991; Talke, 1991).

Infrasound Method

The *infrasound method* is a variation of the auscultatory method (Friedlander, 1975; Edwards, 1976; Zezulka, 1985). In this method, systolic and diastolic pressures are determined from low-frequency Korotkoff vibrations below about 50 Hz, which include the subaudible or infrasonic vibrations.

Ultrasound Method

The *ultrasound method* is based on the ultrasonic detection of arterial wall motion during cuff inflation or deflation (Stegall, 1968; Massie, 1975). A transducer assembly consisting of two piezoelectric transducers is located under the cuff about one-third of the cuff width from the distal end. One transducer generates ultrasound waves and transmits them to the artery, while the other transducer receives the reflected waves. Ultrasound blood pressures are determined from the frequency shift between the transmitted and reflected waves.

When the artery is fully occluded by the cuff, the transmitted ultrasound waves are reflected with no change in frequency. When it is partially occluded, the arterial wall pulsates with each heart beat, causing the transmitted ultrasound waves to be reflected with a shift in frequency due to the Doppler effect. Systolic pressure is determined as the cuff pressure at which a frequency shift is first detected. Diastolic pressure is determined as the cuff pressure at which the frequency shift is diminished.

Volume-Oscillometric Method

The *volume-oscillometric* (VO) *method* is similar to the oscillometric method except that it is based on arterial volume oscillations instead of cuff pressure oscillations (Yamakoshi, 1982a, 1982b, 1988; Herscovici, 1986; Kobayashi, 1990). With increasing or decreasing cuff pressure, the peak-to-peak amplitude of the arterial volume oscillations increases at first and then begins to decrease at some point.

VO blood pressures are typically determined from the locus, or envelope, of the successive peak-to-peak volume oscillation amplitudes plotted against their corresponding baseline cuff pressures. The baseline cuff pressure at which the volume oscillation amplitude is maximum is taken as the MAP. The baseline cuff pressure that is greater than the MAP and that corresponds to the onset of volume oscillations is taken as the systolic pressure. The criterion for determining diastolic pressure from the volume oscillations is apparently not well established, although several techniques have been attempted (Herscovici, 1986; Shimazu, 1986, 1989).

The literature indicates the use of pneumatic and water-filled cuffs, photoelectric and impedance plethysmography to detect arterial volume oscillations, and the following measurement sites: brachial, radial, finger, malleolar and superficial temporal arteries. The survey shows the use of pneumatic cuffs, photoelectric plethysmography, and the basal phalanx of a finger as the measurement site.

Vascular Unloading Method

The *vascular unloading* (VU) *method*, also called the volume-compensation method, volume-clamp method or

servo-plethysmomanometry, is based on the theory that if the external pressure applied to an artery is equal to the arterial pressure at all times, the artery will be unloaded and will not change in size (Peñáz, 1969; Wesseling, 1984; Boehmer, 1987; Yamakoshi, 1988; Kobler, 1991). An artery is unloaded when the transmural pressure across the arterial wall is zero. If an artery is kept unloaded at all times, the external pressure will always be equal to the arterial pressure.

To obtain absolute blood pressure measurement, a reference point needs to be established that relates an unloaded arterial volume to a particular value of blood pressure. The reference blood pressure that is typically used for this purpose is the MAP, which is the baseline cuff pressure at which the artery is maximally relieved of tension, or maximally unloaded, on average throughout the cardiac cycle (Marey, 1876). The MAP may be obtained by one of three methods: (1) the oscillometric method; (2) the volume-oscillometric method; or (3) the "physiocal" (physiological calibration) method. In the physiocal method, the unloaded state is identified from a certain time, amplitude or area characteristic of the plethysmogram of the underlying artery (Wesseling, 1985; Boehmer, 1987).

The VU method typically uses a pneumatic or hydraulic finger cuff and a plethysmographic transducer to detect changes in arterial volume. The survey indicates the use of air-filled cuffs, water-filled cuffs and photoelectric plethysmographic transducers. The cuff is typically applied to the middle or basal phalanx of one finger and connected to a fast-response servo control system. In a recent development, two adjacent fingers alternated at regular intervals are used to minimize patient discomfort (Schmidt, 1992).

During measurement, the MAP is first determined along with the baseline unloaded arterial volume corresponding to the baseline cuff pressure that is equal to the MAP. When the baseline cuff pressure is kept equal to the MAP, the baseline volume in the artery will change with respect to the baseline unloaded arterial volume corresponding to the MAP because of the beat-to-beat pulsations of the artery under the cuff (see above discussion under Volume-Oscillometric Method). During cuff inflation or deflation, the point at which the baseline cuff pressure is equal to the MAP, and the arterial volume is precisely at its baseline unloaded size for that baseline cuff pressure (MAP), is first established. The servo control system then continuously monitors the changes in the baseline arterial volume and regulates the baseline cuff pressure to restore and maintain the original baseline unloaded arterial volume. In this way, the artery is kept unloaded at all times, and the baseline cuff pressure follows the instantaneous intra-arterial pressure, yielding continuous absolute, beat-to-beat blood pressure measurement.

To correct for changes in the arterial pressure during the measurement period, the baseline unloaded arterial volume, or equivalently, the MAP, is re-established from time to time during the period. This can be accomplished by simply redetermining the unloaded-artery state using any of the three methods described above, or by superimposing pressure oscillations on the cuff pressure and determining the unloaded-artery state from the amplitude envelope of the resulting component plethysmogram from the pressure oscillations (Penaz, 1992).

The literature reveals a variation of the VU method in which a pneumatic cuff is used on the upper arm, and the artery is kept close to the unloaded state by regulating the mean velocity of the flow of blood through the artery under the cuff instead of regulating the arterial volume (Aaslid, 1981).

Arterial Tonometry Method

Similar in principle to ocular tonometry, *arterial tonometry* (AT) is based on the fact that if a superficial artery close to an underlying bone is partially flattened or applanated with a flat rigid surface and kept in that state, the force exerted on the surface is nearly proportional to the pressure in the artery (Pressman, 1963; Drzewiecki, 1983). This relationship can be used to derive the relative arterial pressure waveform, which when calibrated against measurements made by a reference method, yields absolute, continuous blood pressure measurement. Superficial arteries where AT blood pressures may be measured include the brachial, radial, carotid, dorsalis pedis and temporal arteries.

The surveyed AT NIBP monitors use a tonometer consisting of the following components (Terry, 1990; Eckerle, 1991, 1993; Kemmotsu, 1991): (1) a pressure transducer made of an array of piezoresistive sensors; (2) an electropneumatic system to press the transducer against the artery; and (3) an electromechanical positioning system to move the transducer in the direction transverse to the axis of the artery. The tonometer is applied over the radial artery and strapped around the wrist so that it is fixed in position relative to the wrist. The use of an array of sensors circumvents the practical difficulty of precisely positioning the tonometer over the artery by increasing the chances that at least one sensor will be positioned over the artery.

When measurement is initiated with the tonometer in place on the wrist, the monitor first locates the artery. The positioning system of the monitor then positions the transducer so that the artery is below the transducer. The optimum pressure required to press and flatten the artery is then determined and applied to the artery. The sensor closest to the center of the flattened region, called the *active sensor*, is then identified. Algorithms based on pulse amplitudes as measured by the sensors have been developed to determine the optimum pressure and identify the active sensor (Eckerle, 1989; Wenzel, 1990; Narimatsu, 1992).

In the surveyed AT NIBP monitors, the oscillometric method is used as the reference method to calibrate the monitors; it is also used as a secondary measurement method. The calibration is performed continually throughout the measurement period.

Pulse-Wave Velocity Method

The *pulse-wave velocity* (PWV) *method* is based on the fact that pulse-wave velocity, the rate of propagation of pressure pulse waves along arteries, increases with increasing arterial pressure (Bramwell, 1922; Pruett, 1988; Lu, 1992). This relationship can be used to derive the relative arterial pressure waveform, which when calibrated against measurements made by a reference method, yields absolute, continuous blood pressure measurement.

The PWV is usually computed from the *pulse-transit time* (PTT), the time it takes for a pulse wave to travel from one arterial site to another. The pulse-transit time may also be determined as the difference in the time between the arrival of a pulse at two different arterial sites that are not located along the same artery. The survey reveals the use of photometric sensors to detect the pulse wave, and the use of the following pulse-wave detection sites: forehead, ear, finger, and wrist.

A simplified approach to implementing the PWV method is to use the *transit time* (TT) between the occurrence of some characteristic of the ECG and the occurrence, at a peripheral site, of some characteristic of the pulse wave during the same cardiac cycle (Pollak, 1983). This simplified approach is used in some of the surveyed PWV NIBP monitors (Carruthers, 1988; Orr, 1989), where the TT between the following two events is used: (1) the occurrence of the R-wave of the ECG at the chest or locations on the arms; and (2) the arrival of the pulse wave at the tip of a finger.

To obtain continuous beat-to-beat blood pressure measurement from the PWV alone, multiple PTT measurements or continuous PTT measurement would have to be made within each and every heart beat. Although the PWV method is theoretically capable of providing continuous beat-to-beat arterial pressure waveform, all of the surveyed PWV NIBP monitors provide only beat-to-beat point pressures.

The surveyed PWV NIBP monitors provide only one PTT or TT measurement per heart beat. This single measurement, when calibrated, provides only one point pressure — the diastolic pressure. Two techniques have been used, together with calibration measurements, to obtain more than one point pressure. The first technique uses, in addition to a single PTT measurement, the pressure-volume relationship of the artery at a pulse-wave detection site to determine both systolic and diastolic pressures (Hardy, 1982; Greubel, 1993). In the second technique, the following reference measurements are first obtained (Carruthers, 1988; Matsumoto, 1994): (1) systolic pressure, diastolic pressure, and heart rate, all of which are first taken at rest, and then after a prescribed exercise program; and (2) the corresponding TTs. Empirical equations are then used to relate systolic and diastolic pressures to these reference measurements and the current TT measurement.

The survey reveals two methods of calibrating a PWV NIBP monitor. In the first method, calibration is accomplished automatically by the monitor using the oscillometric method. For such a monitor, the oscillometric method is also used as a secondary measurement method. In the second method, systolic and diastolic pressures are obtained using another measurement method at rest and after exercise, while their corresponding heart rates and TTs are simultaneously measured using the monitor. The blood pressure measurements are then manually entered into the monitor.

The literature indicates a modified version of the PWV method in which the TTs for pressure pulse waves passing through an artery under a cuff are obtained for different cuff pressures and used to derive absolute blood pressure measurements (Geddes, 1981; Sharir, 1993). This method, however, is not capable of providing measurement on a beat-to-beat basis.

COR Method

The COR method is based on oscillometric pulses generated at a low, constant cuff pressure (Russell, 1987, 1988a-c; de Jong, 1993). While the oscillometric method uses only a certain characteristic of the oscillometric pulses at different cuff pressures to determine point blood pressures, the COR method uses the complete waveform of the oscillometric pulses generated at the constant cuff pressure to derive the arterial pressure waveform.

The surveyed COR monitors use a constant cuff pressure of 15 or 20 mmHg. The oscillometric method is used as the reference method for calibrating the surveyed COR monitors; it is also used as a secondary measurement method. The systolic pressure, MAP and diastolic pressure, all determined using the oscillometric method during each calibration, are used together with the constant-cuff-pressure oscillometric pulse waveform to establish an empirical relationship between the oscillometric pulse waveform and arterial pressure. After each calibration, this relationship is used to derive the absolute, continuous beat-to-beat arterial pressure waveform from the oscillometric pulse waveform in the cuff.

DISTRIBUTION OF MEASUREMENT METHODS

Statistical distributions on the use of the foregoing measurement methods in the surveyed monitors are presented numerically in Table III and illustrated in Figures 3 through 6.

For all the monitors combined, the distributions show that, among monitors that use only one measurement method, the oscillometric method is the most widely used, followed by the auscultatory method. The number of monitors using only the auscultatory method, however, is significantly smaller than those using only the oscillometric method. This is also true for each of the two groups of nonambulatory monitors. For ambulatory monitors, however, the auscultatory method is more prevalent than the oscillometric method. It may be noted from the characteristics tables (see Tables IV to VI at end of paper) that

TABLE III
Distribution of measurements methods used in automated NIBP monitors

Measurement Methods	Ambulatory Monitors	Bedside and Transport Monitors	Other Monitors	All Monitors
Single Method				
1. Auscultatory	14	16	14	44
2. Oscillometric	11	191	140	342
3. Volume-Oscillometric	0	2	0	2
4. Vascular Unloading	1	3	0	4
5. Pulse-Wave Velocity	2	0	2	4
Subtotal (1 to 5)	28	212	156	396
Multiple Methods				
6. ■ Auscultatory ■ Oscillometric	9	6	5	20
7. ■ Oscillometric ■ Palpatory	0	1	0	1
8. ■ Arterial Tonometry ■ Oscillometric	0	3	0	3
9. ■ Pulse-Wave Velocity ■ Oscillometric	0	1	0	1
10. ■ COR ■ Oscillometric	0	2	0	2
Subtotal (6 to 10)	9	13	5	27
TOTAL (1 to 10)	37	225	161	423

monitors for stress testing almost always use at least the auscultatory method.

The distributions also show that within each of the three groups of monitors, and for monitors that use multiple methods, the combination of the oscillometric and auscultatory methods is the most widely used combination. For all the monitors combined, the number of monitors using this combination represents the third largest number of monitors that use one or more methods.

DISCUSSION

In intermittent measurement methods that involve the inflation of a cuff to a pressure greater than the systolic pressure, the determination of systolic pressure is almost equivalent to the determination of the cuff pressure at which the flow of blood distal to the cuff is just blocked or restored. This blocking or restoration of blood flow is manifested in a different way in each of these cuff-based methods. In the auscultatory and infrasound methods, it is manifested through Korotkoff sounds or vibrations; in the oscillometric method, through oscillometric pulses; in the palpatory method, through a distal pulse; in the ultrasound method, through arterial wall motion; and in the volume-oscillometric method, through arterial volume oscillations.

Cuff-based methods that utilize cuff pressure oscillations or arterial volume oscillations derive their fundamental principles from the nonlinear relationship between the transmural pressure of the artery and the arterial volume (Hardy, 1982; Yamakoshi, 1982a; Langewouters, 1986). Cuff pressure oscillations, however, which are a direct result of arterial volume oscillations under the cuff, have a phase lag with respect to the volume oscillations due to the compliance of the fluid in the cuff. It can be inferred from the foregoing review of the oscillometric, volume-oscillometric and COR methods that there exist other possibilities for determining blood pressure from the cuff pressure oscillations or arterial volume oscillations. For example, the COR method could have been implemented using arterial volume oscillations instead of cuff pressure oscillations. As another example, it has been reported in the patent literature that it is possible to determine diastolic pressure to be the cuff pressure at which the slope at the end of the corresponding oscillometric pulse waveform is steepest, and that the systolic pressure may be determined from a knowledge of the diastolic pressure and a knowledge of the pressure-volume relationship of the artery (Link, 1987b). This method, like the COR method, obviates the need to subject the patient to cuff pressures above the systolic pressure, except during calibration, when the pressure-volume relationship or a similar relationship is determined.

From the earlier discussion of ECG-gating and OP-gating techniques for cuff-based methods, it may be

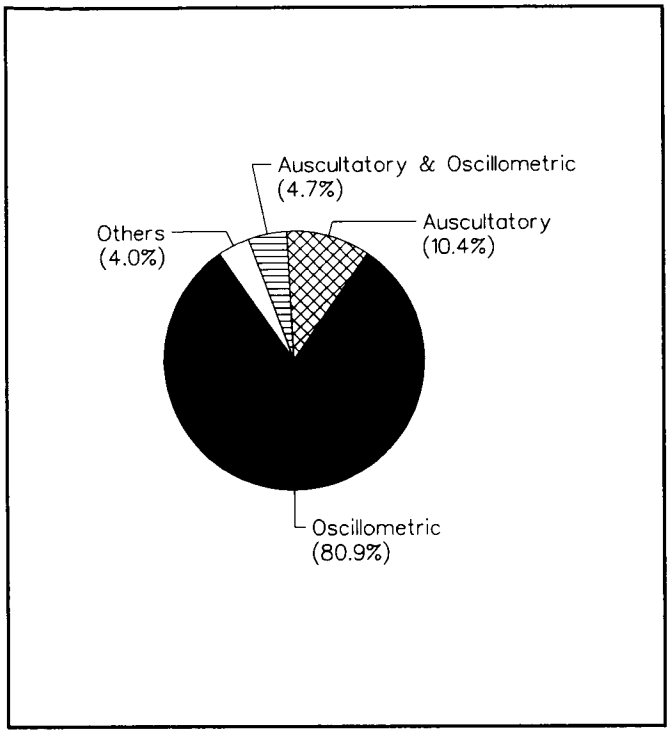

Figure 3
Distribution of measurement methods for all NIBP monitors.

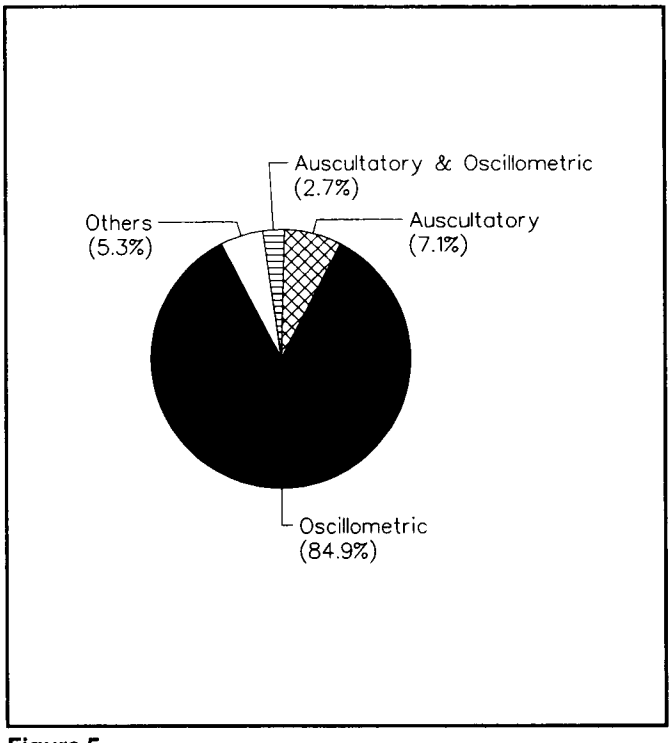

Figure 5
Distribution of measurement methods for bedside and transport monitors.

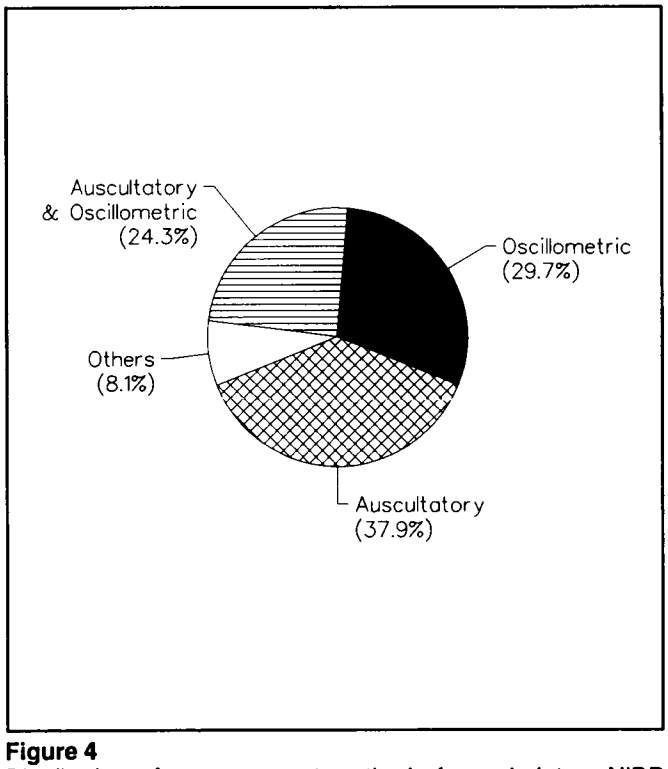

Figure 4
Distribution of measurement methods for ambulatory NIBP monitors.

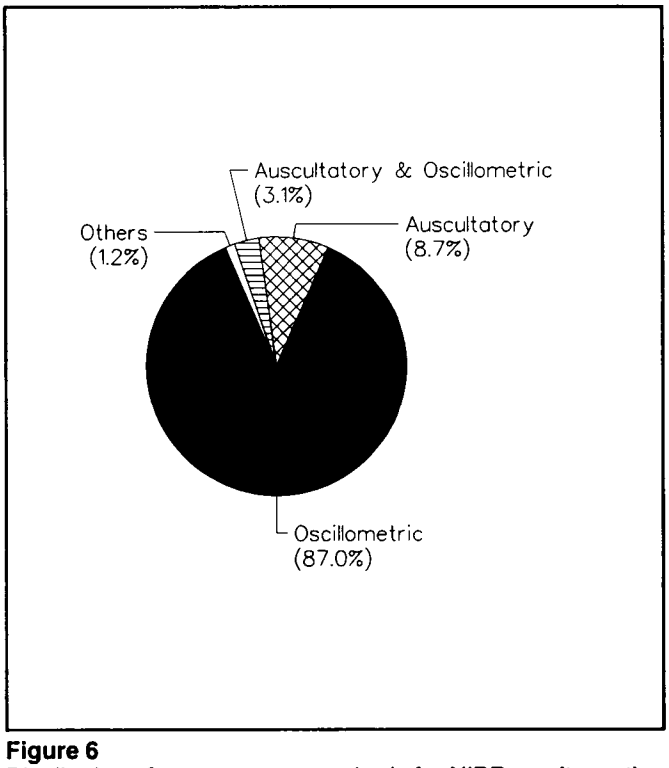

Figure 6
Distribution of measurement methods for NIBP monitors other than ambulatory, bedside and transport monitors.

inferred that, in general, the following signals may be used to validate each other: Korotkoff vibration signal, oscillometric pulse signal, distal arterial pulse signal, and ECG signal. This cross-validation is possible because of the time relationships that exist among these signals during each cardiac cycle. It may also be inferred from the various microphone placement configurations discussed earlier that other microphone placement configurations are possible, and that any microphone placement configuration could be used with at least one of the aforementioned signals as a timing reference.

The complete and exact criteria and algorithms used by commercial automated NIBP monitors to reduce artifacts and extraneous noise and determine blood pressure

are usually proprietary and not disclosed to the user. In addition to other objectives, algorithms for cuff-based methods also seek to minimize patient discomfort and injury by minimizing the total occlusion time in each measurement cycle. The survey and patent literature indicate the use of linear continuous cuff deflation or linear stepwise deflation during blood pressure determination, or the use of nonlinear deflation rates that are dependent on measurements such as cuff pressure and heart rate. Deflation steps as high as 8 mmHg and deflation rates as high as 9 mmHg per second, during NIBP determination, are used in the surveyed monitors. The cuff is typically deflated at the fastest possible rate once the diastolic pressure has been determined.

The survey and patent literature also indicate the use of adaptive algorithms, where previous NIBP and heart-rate measurements are used to improve the algorithm for the current measurements. One common adaptive feature is to use phenomenal characteristics measurements, such as cuff oscillation pressure and Korotkoff vibration intensity, obtained during the first cuff inflation to provide an initial estimate of systolic pressure, and hence an initial maximum cuff inflation pressure. Another common adaptive feature is to inflate the cuff to a predetermined pressure, typically 20 to 50 mmHg, higher than the systolic pressure measured during the previous measurement cycle. Yet another common adaptive feature, specifically for auscultatory measurement using a gating technique, is to establish more precisely the point in time for a time window to be opened, and how long the window should be opened.

For monitors that use both the auscultatory and oscillometric methods, the survey reveals at least three different ways in which the two methods are used. First, both methods are used concurrently to determine blood pressure. Second, one method is used as the primary method, while the second method is used as a secondary or back-up method should the primary fail. Third, only one method is operative at any one time, and that method is selectable by the user.

The survey shows that in monitors using a combination of a continuous measurement method and the oscillometric method, the oscillometric method is typically used not only to calibrate the continuous measurement method, but also as a secondary or back-up measurement method. The oscillometric blood pressure measurements are typically performed on the same limb as the continuous measurements, however. Because of this, and the fact that executing an oscillometric blood pressure measurement cycle requires complete occlusion of the artery for a period of time usually lasting more than one heart beat, only one of the two measurement methods can be operative at any one time.

Intermittent blood pressures are obtained over a period of time encompassing more than one heart beat, and blood pressure generally varies from beat to beat. Intermittent methods are, therefore, not capable of registering beat-to-beat changes in blood pressure, while continuous measurement methods are, at least in principle. Because continuous methods are typically calibrated using an intermittent method, however, the measurement accuracy of a continuous method depends, to a large extent, on the measurement accuracy of the intermittent method used for the calibration.

Of the four continuous measurement methods used in the surveyed monitors, the vascular unloading and COR methods do not need an additional cuff for calibration purposes; both methods use the same cuff for NIBP measurement and calibration. The other two continuous methods, the arterial tonometry and pulse-wave velocity methods, require an additional cuff to perform the calibration.

The surveyed monitors feature a variety of measurement modes including manual inflation, manual cycling, automatic cycling, STAT, and SYS STAT modes. In monitors with the manual inflation mode, cuff inflation is performed manually, usually with an inflating-deflating bulb, but cuff deflation is typically performed automatically by the monitors. *Manual cycling* refers to manual on-demand initiation of a single measurement cycle for intermittent measurement methods, or continuous measurement for continuous measurement methods. In the *automatic cycling* mode, a blood pressure measurement cycle is initiated at pre-selected intervals. Most of the ambulatory monitors allow each 24-hour period to be divided into two or more measurement periods, each of which can be independently programmed with a different measurement interval. The STAT mode refers to continual, sometimes rapid, cycling of measurement, usually for a period of five minutes, with each cycle beginning a few seconds after the completion of the last cycle. This mode is also called the Turbo Cuff mode (used by Siemens Medical Systems), **TURBOCUF™** (trademark of Protocol® Systems) mode, CONT mode, or simply continuous mode. The automatic cycling and STAT modes are applicable only for intermittent measurement methods. The SYS STAT mode (used by Ohmeda), or SYST mode (used by Industrial & Biomedical Sensors), refers to continual automatic cycling of measurement where only systolic pressure is measured, and cuff pressure fluctuates about systolic pressure. In some monitors, an NIBP measurement cycle can be initiated, through preprogramming, by the ECG measurement based on some predefined criteria, such as when the ST segment experiences a certain level of change, when an arrhythmia is encountered, or when the heart rate drops below or exceeds a certain value. For cuff-based measurement methods, the survey indicates NIBP measurement cycle times as low as 12 seconds and as high as 120 seconds.

Although it is clear from the survey that intermittent NIBP measurement methods dominate commercial NIBP monitors at this time, the literature indicates that there is a growing interest in continuous NIBP measurement methods. Some recent developments on continuous methods include: (1) those that are based on distension of an artery that is subjected to zero or minimal external loading, such as the deformation of a surface close to an

artery (Karr, 1985; Nitsche, 1987), and the volumetric changes of an artery (Jones, 1994); (2) those that are based on the oscillometric pulse waveform or the plethysmogram of the underlying artery, at a constant cuff pressure that is lower than the diastolic pressure (Takeda, 1993; Sciarra, 1994; see discussion on COR method above); (3) those that are based on arterial tonometry (Drzewiecki, 1992; Butterfield, 1994); and (4) one that is based on pulse-wave velocity (Greubel, 1994). In these continuous methods, calibration is necessary to obtain absolute blood pressure measurement. Several recent studies, however, have demonstrated the use of uncalibrated arterial pressure waveforms obtained by the arterial tonometry method (Kelly, 1989; LaCourse, 1991; Ifuku, 1993) or arterial distension method (Karr, 1985; Nitsche, 1987) to examine relative changes in the arterial pulse pressure or to provide diagnostic information about different pathological conditions.

CONCLUSIONS

To the best of the authors' knowledge, this survey of automated NIBP monitors is the most current and extensive of its kind. The results are intended to serve as a useful source of information to manufacturers and suppliers of automated NIBP monitors, as well as hospitals, individuals and other institutions using such devices. They can be used to provide directions to those involved in the research and development of NIBP measurement methods, those involved in the research and development of NIBP simulators for evaluating the measurement accuracy of NIBP monitors (Ng, 1992, 1994), and those involved in establishing performance guidelines or standards for automated NIBP monitors (Standards Australia, 1989; AAMI, 1993; CEN, 1994).

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REFERENCES

AAMI (1993), American national standard *ANSI/AAMI SP10 — 1992: Electronic or automated sphygmomanometers,* Association for the Advancement of Medical Instrumentation, Arlington, VA.

Aaslid, R. and Brubakk, A.O. (1981), Accuracy of an ultrasound Doppler servo method for noninvasive determination of instantaneous and mean arterial blood pressure, *Circulation,* 64:753-759.

Bahr, D.E., Clark, K.R. and Post, K.E. (1989), Automatic blood pressure measuring device and method, U.S. patent 4,796,184, assigned to CAS Medical Systems.

Bertram, B., von Wallenberg, E.L. and Meyer-Erkelenz, J.D. (1981), Automatische indirekte Blutdruckmessung in Ruhe und bei Belastung: Formanalyse der Korotkov-Geräusche; Variables Zeitfenster zur Artefaktunterdrückung [Automatic indirect measurement of blood pressure in resting and exercising subjects: Analysis of the Korotkov sound pattern; variable »time gate« for artifact suppression], *Biomedizinische Technik,* 26:81-84.

Bertram, B., von Wallenberg, E.L. and Meyer-Erkelenz, J.D. (1982), Indirekte Blutdruckmessung in Ruhe und bei Belastung durch Formanalyse der Korotkov-Geräusche [Indirect measurement of blood pressure in resting and exercising subjects by analysis of Korotkov sound pattern], *Zeitschrift für Kardiologie,* 71:665-668.

Blank, S.G. et al. (1988), Wideband external pulse recording during cuff deflation: A new technique for evaluation of the arterial pressure pulse and measurement of blood pressure, *Circulation,* 77:1297-1305.

Block, F.E. Jr. et al. (1991), A clinical evaluation of rapid automatic noninvasive blood pressure determination with the Ohmeda 2120 "return-to-flow" method, *Journal of Clinical Monitoring,* 7:241-244.

Boehmer, R.D. (1987), Continuous, real-time, noninvasive monitor of blood pressure: Peñaz methodology applied to the finger, *Journal of Clinical Monitoring,* 3:282-287.

Bramwell, J.C. and Hill, A.V. (1922), The velocity of the pulse wave in man, *Proceedings of the Royal Society of London,* Series B, 93:298-306.

Brooks, J.R. (1988), Method and apparatus for systolic blood pressure measurement, U.S. patent 4,785,820, assigned to SpaceLabs.

Butterfield, R.D. et al. (1994), Tonometry system for determining blood pressure, U.S. patent 5,284,150, assigned to IVAC.

Canzoneri, J. III et al. (1968), An electronic system for the detection of indirect systolic and diastolic blood pressure. In: *Biomedical Sciences Instrumentation,* Vol. 4, Instrument Society of America, Research Triangle Park, NC, pp. 65-70.

Carruthers, M. and Taggard, P. (1988), Validation of a new, inexpensive, non-invasive miniaturized blood-pressure monitor, *Journal of Ambulatory Monitoring*, 1:163-170.

CEN (1994), European standard (draft): *Nichtinvasive Blutdruckmessgeräte — Teil 3: Ergänzende Anforderungen für elektromechanische Blutdruckmesssysteme*, Comité Européen de Normalisation, Brussels, Belgium. [In English, French or German.]

Chio, S.-S. (1989), Method and apparatus for determining blood pressure and cardiovascular condition, U.S. patent 4,880,013. [Associated with Pulse Metric, CA.]

Cozby, R.C. and Adhami, R.R. (1993), Low-frequency Korotkoff signal analysis and application, *IEEE Transactions on Biomedical Engineering*, 40:1067-1070.

da Costa, J.N. et al. (1973), Correlation of Korotkoff sounds with the onset of QRS (QK time), *Angiology*, 24:570-575.

Davis, G. and Geddes, L.A. (1988), Comparison of the auscultatory and oscillometric mean blood pressures in man, *Journal of Clinical Engineering*, 13:443-446.

Davis, G.J. and Geddes, L.A. (1990), Auscultatory mean blood pressure, *Journal of Clinical Monitoring*, 6:261-265.

de Jong, J.R. et al. (1993), Noninvasive continuous blood pressure measurement: A clinical evaluation of the Cortronic APM 770, *Journal of Clinical Monitoring*, 9:18-24.

Dietz, U. and Belz, G.G. (1991), Low frequency arterial wall movements for indirect blood pressure measurement in man, *Arzneimittel-Forschung*, 41:557-562.

Dorsett, T.J. and Davis, C.L. (1990), Method of artifact rejection for noninvasive blood-pressure measurement by prediction and adjustment of blood-pressure data, U.S. patent 4,949,710, assigned to Protocol Systems.

Drzewiecki, G.M., Melbin, J. and Noordergraaf, A. (1983), Arterial tonometry: Review and analysis, *Journal of Biomechanics*, 16:141-152.

Drzewiecki, G.M., Butterfield, R.D. and Ciaccio, E.J. (1992), Pressure waveform monitor, U.S. patent 5,154,680, assigned to Rutgers University.

Drzewiecki, G., Hood, R. and Apple, H. (1994), Theory of the oscillometric maximum and the systolic and diastolic detection ratios, *Annals of Biomedical Engineering*, 22:88-96.

Eckerle, J.S. (1989), Blood pressure monitoring method and apparatus, U.S. patent 4,799,491, assigned to SRI International. [Associated with Colin Medical Instruments, TX.]

Eckerle, J.S. and Newgard, P.M. (1991), Arterial tonometry: The development of a new medical sensor, *Sensors*, 8(5):11-16.

Eckerle, J.S. et al. (1993), Tonometer transducer positioning system, U.S. patent 5,176,143, assigned to Colin Electronics Company.

Edwards, R.C. et al. (1976), The infrasound blood-pressure recorder. A clinical evaluation, *Lancet*, ii:398-400.

Erlanger, J. (1916a), Studies in blood pressure estimation by indirect methods. II. The mechanism of the compression sounds of Korotkoff, *American Journal of Physiology*, 40:82-125.

Erlanger, J. (1916b), Studies in blood pressure estimations by indirect methods. I. The mechanism of the oscillatory criteria, *American Journal of Physiology*, 39:401-446.

Frankenreiter, M. (1991), Oscillometric non-invasive method for measuring blood pressure and apparatus for automated oscillometric blood pressure measuring, U.S. patent 4,984,577, assigned to Hewlett-Packard Company.

Friedlander, S.L. (1975), Blood pressure measuring device utilizing sub-audible frequency for detection, U.S. patent 3,867,926, assigned to Sphygmetrics. [Associated with Puritan-Bennett, MA.]

Fukuoka, M. et al. (1987), Evaluation of a new non-invasive semiautomatic blood pressure monitoring device, *Clinical and Experimental Hypertension*, A9:141-152.

Gallavardin, L. (1922), Sur un nouveau brassard sphygmomanométrique, *Presse Médicale*, 30(72):776-777.

Geddes, L.A. et al. (1968), Indirect determination of the rate of rise of arterial pressure, *Cardiovascular Research Center Bulletin*, 7:71-78.

Geddes, L.A. et al. (1981), Pulse arrival time as a method of obtaining systolic and diastolic blood pressure indirectly, *Medical & Biological Engineering & Computing*, 19:671-672.

Geddes, L.A. et al. (1982), Characterization of the oscillometric method for measuring indirect blood pressure, *Annals of Biomedical Engineering*, 10:271-280.

Georgi, H.W. (1986), Electronic sphygmomanometer, U.S. patent 4,592,365, assigned to IVAC.

Gley, P. and Gomez, D.M. (1931), La détermination des pressions moyenne et minima par la méthode oscillométrique, *Presse Médicale*, 39(16):284-286.

Golden, D.P. Jr. et al. (1974), Development of a Korotkov sound processor for automatic identification of auscultatory events — Part I: Specification of preprocessing bandpass filters, *IEEE Transactions on Biomedical Engineering*, BME-21:114-118.

Greubel, W. et al. (1993), Method of continuous measurement of blood pressure in humans, U.S. patent 5,237,997, assigned to Vectron Gesellschaft für Technologieentwicklung und Systemforschung.

Hardy, H.H. and Collins, R.E. (1982), On the pressure-volume relationship in circulatory elements, *Medical & Biological Engineering & Computing*, 20:565-570.

Hatschek, R.A. (1984), Blood pressure measuring equipment, U.S. patent 4,459,991, assigned to Asulab.

Herscovici, H. and Roller, D.H. (1986), Noninvasive determination of central blood pressure by impedance plethysmography, *IEEE Transactions on Biomedical Engineering*, BME-33:617-625.

Hill, L. and Barnard, H. (1897), A simple and accurate form of sphygmometer or arterial pressure gauge contrived for clinical use, *British Medical Journal*, 2:904.

Hutton, P. and Prys-Roberts, C. (1982), The oscillotonometer in theory and practice, *British Journal of Anaesthesia*, 54:581-591.

Ifuku, H., Taniguchi, K. and Matsumoto, H. (1993), Continuous record of carotid artery pulse during exercise, *Japanese Journal of Physiology*, 43:111-116.

Inage, K. et al. (1994), Electronic Blood Pressure Meter, U.S. patent 5,316,006, assigned to Omron.

Irnich, W. (1970), Zur Problematik der unblutigen Blutdruckmessung, *Archiv für Kreislaufforschung*, 61(1): 1-27.

Jones, P.H. and Wang, W.-M. (1994), Method of measuring blood pressure with a plethysmograph, U.S. patent 5,269,310, assigned to SpaceLabs Medical.

Kalaitzakis, K.C., Papamarkos, N.E. and Vachtsevanos, G.J. (1989), Development of a microprocessor-based adaptive technique for blood pressure measurements, *Medical Progress through Technology*, 14:63-72.

Karr, S.G. et al. (1985), Transducer system for the noninvasive recording of arterial pressure contours, *Annals of Biomedical Engineering*, 13:425-442.

Kaspari, W.J., Wong, H. and Kirch, J.L. (1977), Blood pressure measuring apparatus, U.S. patent 4,058,117, assigned to Palo Alto Research Associates.

Kaspari, W.J. (1981), Non-invasive vascular waveform transducer and apparatus, U.S. patent 4,295,471. [Associated with DeBusk Technology, TN.]

Kaspari, W.J. (1994), Differential auscultatory technique, *Medical Electronics*, 25(2):131-132.

Kelly, R. et al. (1989), Noninvasive carotid pressure wave registration as an indicator of ascending aortic pressure, *Journal of Vascular Medicine and Biology*, 1:241-247.

Kemmotsu, O. et al. (1991), Arterial tonometry for noninvasive, continuous blood pressure monitoring during anesthesia, *Anesthesiology*, 75:333-340.

Klaye, F. (1983), Procédé de mesure de la pression sanguine d'un sujet, European patent EP 0 079 306 A2, assigned to Asulab.

Kobayashi, H. et al. (1990), Indirect measurement of eye-level arterial pressure by the volume oscillometric method, *Journal of Clinical Engineering*, 15:195-204.

Kobler, H., Cejnar, M. and Hunyor, S.N. (1991), A continuous non-invasive blood pressure monitor, *Journal of Electrical and Electronics Engineering, Australia*, 11:102-109.

Korns, H.M. (1926), The nature and time relations of the compression sounds of Korotkov in man, *American Journal of Physiology*, 76:247-264.

Korotkoff, N.S. (1905), K voprosu o metodakh izsledovaniya krovyanogo davleniya (iz Kliniki Prof. S.P. Federov) [On the subject of methods of determining blood pressure (from the clinic of Prof. S.P. Fedorov)], *Izvestiya Imperatorskoi Voenno-Meditsinskoy Akademii [Bulletin of the Imperial Military-Medical Academy]*, 11(4):365-367, St. Petersburg, Russia.

LaCourse, J.R., Sivaprasad, K. and Rogers, D.B. (1991), A system to measure a pilot's temporal pulse pressure during acceleration, *Aviation, Space, and Environmental Medicine*, 62:356-362.

Lagerwerff, J.M. and Luce, R.S. (1970), Artifact suppression in indirect blood pressure measurements, *Aerospace Medicine*, 41:1157-1161.

Lange, T. and Schoknecht, G. (1985), Graphische und audiometrische Blutdruckmessung — Fourier-Analysen von Korotkov-Geräuschen. In: Poretti, G., ed., *Medizinische Physik 1985*, Deutsche Gesellschaft für Medizinische Physik, Göttingen, Germany, pp. 338-343.

Langewouters, G.J. et al. (1986), Pressure-diameter relationships of segments of human finger arteries, *Clinical Physics and Physiological Measurement*, 7:43-56.

Lazarashvili, L.T. (1993), Pomekhoustoychivost ostsillometricheskikh avtomatizirovannykh sfigmomanometrov [Interference resistance in automated oscillometric sphygmomanometers], *Meditsinskaya Tekhnika*, (3):19-28. [English translation in (1993), *Biomedical Engineering*, New York, 27(3):139-151.]

Link, W.T. (1987a), Method of and apparatus for determining the diastolic and systolic blood pressure of a patient, U.S. patent 4,712,563, assigned to Baxter Travenol Laboratories.

Link, W.T. (1987b), Techniques for obtaining information associated with an individual's blood pressure including specifically a STAT mode technique, U.S. patent 4,664,126, assigned to Baxter Travenol Laboratories.

Lu, W. et al. (1992), Research on the main elements influencing blood pressure measurement by pulse wave velocity, *Frontiers of Medical and Biological Engineering*, 4:189-199.

Marey, E.-J. (1876), Pression et vitesse du sang. In: École Practique des Hautes Études, *Physiologie expérimentale*, Travaux du laboratoire de M. Marey, Vol. II, Chapter VII, G. Masson, Paris, pp. 307-343.

Massie, H.L. (1975), Artifact rejection for blood pressure monitoring, U.S. patent 3,885,551, assigned to Hoffmann-La Roche. [Associated with Kontron Instruments, MA.]

Matsumoto, K. et al. (1994), Evaluation of a wrist watch sphygmomanometer BP-100 which works on the basis of pulse wave velocity, *Kokyu to Junkan [Respiration and Circulation]*, 42(2):167-172. [In Japanese.]

Mauck, G.W. et al. (1980), The meaning of the point of maximum oscillations in cuff pressure in the indirect measurement of blood pressure — Part II, *Journal of Biomechanical Engineering*, 102:28-33.

Maurer, A.H. and Noordergraaf, A. (1976), Korotkoff sound filtering for automated three-phase measurement of blood pressure, *American Heart Journal*, 91:584-591.

McCutcheon, E.P., Baker, D.W. and Wiederhielm, C.A. (1969), Frequency spectrum changes of Korotkoff sounds with muffling, *Medical Research Engineering*, 8(1):30-33.

Medero, R. et al. (1985a), Method of automated blood pressure detection, U.S. patent 4,543,962, assigned to Critikon.

Medero, R. (1985b), Detection of blood pressure complexes in automated vital signs monitors, U.S. patent 4,546,775, assigned to Critikon.

Mieke, S., Neubert, D. and Gülch, R.W. (1990), Automatic detection of Korotkoff sounds, markers for systolic and diastolic blood pressure in automated instruments, In: Meyer-Sabellek, W. et al., eds., *Blood Pressure Measurements*, Springer-Verlag, New York, NY, pp. 1-5.

Miyawaki, Y. et al. (1988), Electronic blood pressure measuring device, U.S. patent 4,793,360.

Nakayama, K. and Yagi, S. (1979), Blood pressure measuring instrument, U.S. patent 4,144,879, assigned to Zaidanhojin Nipponrodobunkakyokai.

Narimatsu, K. and Ohmori, K. (1992), An algorithm for tonometric absolute blood pressure measurement. In: *Computers in Cardiology 1992*, IEEE Computer Society Press, Los Alamitos, CA, pp. 559-562.

Nelson, C.H., Dorsett, T.J. and Davis, C.L. (1989), Method for noninvasive blood-pressure measurement by evaluation

of waveform-specific area data, U.S. patent 4,889,133, assigned to Protocol Systems.

Ng, K. and Small, C.F. (1992), Review of methods & simulators for evaluation of noninvasive blood pressure monitors, *Journal of Clinical Engineering*, 17:469-479. [Errata in 18:37 (letter) and 19:125-134.]

Ng, K. and Small, C.F. (1993), Changes in oscillometric pulse amplitude envelope with cuff size: Implications for blood pressure measurement criteria and cuff size selection, *Journal of Biomedical Engineering*, 15:279-282.

Ng, K. and Small, C.F. (1994), Update on methods & simulators for evaluation of noninvasive blood pressure monitors, *Journal of Clinical Engineering*, 19:125-134. [Erratum in 19:348 (letter).]

Nitsche, W. and Thünker, R. (1987), Application of the piezo-electric effect in measuring the arterial pressure pulse, *Ferroelectrics*, 75:381-384.

Nunn, D.E. and Beveridge, R.W. (1984), Apparatus and method for measuring blood pressure, U.S. patent 4,427,013, assigned to CR Bard.

Obara, S. et al. (1987), An auscultatory recording method for blood pressure measurement during exercise, *Japanese Journal of Physiology*, 37:757-760.

Orr, T. and Carruthers, M.E. (1989), Device for displaying blood pressure, U.S. patent 4,869,262, assigned to Pulse Time Products. [Associated with Healthcare Technology, U.K.]

Peel, H.H. et al. (1986), Blood pressure monitoring system, U.S. patent 4,617,937, assigned to Nippon Colin Company.

Peñáz, J. (1969), Instrument for indirect continuous recording of blood pressure, Czech patent 133,205. [In Czech.]

Peñáz, J. (1992), Criteria for set point estimation in the volume clamp method of blood pressure measurement, *Physiological Research*, 41:5-10.

Perloff, D. et al. (1993), Human blood pressure determination by sphygmomanometry, *Circulation*, 88(5):2460-2470.

Petrie, J.C. et al. (1986), Recommendations on blood pressure measurement, *British Medical Journal*, 293:611-615.

Pollak, M.H. and Obrist, P.A. (1983), Aortic-radial pulse transit time and ECG Q-wave to radial pulse wave interval as indices of beat-by-beat blood pressure change, *Psychophysiology*, 20:21-28.

Posey, J.A. et al. (1969), The meaning of the point of maximum oscillations in cuff pressure in the indirect measurement of blood pressure. Part I, *Cardiovascular Research Center Bulletin*, 8:15-25.

Pressman, G.L. and Newgard, P.M. (1963), A transducer for the continuous external measurement of arterial blood pressure, *IEEE Transactions on Bio-Medical Electronics*, BME-10:73-81.

Pruett, J.D., Bourland, J.D. and Geddes, L.A. (1988), Measurement of pulse-wave velocity using a beat-sampling technique, *Annals of Biomedical Engineering*, 16:341-347.

Radaelli, A. et al. (1990), The effects of posture and activity on the accuracy of ambulatory blood pressure recording: A validation of the Oxford Medilog system, *Journal of Ambulatory Monitoring*, 3:155-161.

Ramsey, M. III (1979), Noninvasive automatic determination of mean arterial pressure, *Medical & Biological Engineering & Computing*, 17:11-18.

Ramsey, M. III, Medero, R. and Hood, R.W. Jr. (1988), Automated mean arterial blood pressure monitor with data enhancement, U.S. patent 4,754,761, assigned to Critikon.

Ramsey, M. III (1991), Blood pressure monitoring: Automated oscillometric devices, *Journal of Clinical Monitoring*, 7:56-67.

Riva-Rocci, S. (1896), Un nuovo sfigmomanometro [A new sphygmomanometer], *Gazzetta Medica di Torino*, 47:981-996 & 1000-1017.

Ruiter, K.A. (1990), Automatic non-invasive blood pressure reading device, U.S. patent 4,922,918, assigned to Medical Data Electronics.

Russell, T.W. (1987), Apparatus and method for continuous non-invasive cardiovascular monitoring, U.S. patent 4,669,485. [Associated with Cor Medical.]

Russell, T.W. (1988a), Method for determining diastolic arterial blood pressure in a subject, U.S. patent 4,718,426. [Associated with Cor Medical.]

Russell, T.W. (1988b), Method for determining systolic arterial blood pressure in a subject, U.S. patent 4,718,427. [Associated with Cor Medical.]

Russell, T.W. (1988c), Method for determining diastolic arterial blood pressure in a subject, U.S. patent 4,718,428. [Associated with Cor Medical.]

Sainomoto, Y. and Kitagawa, F. (1986), Automated blood pressure monitoring instrument, U.S. patent 4,592,366, assigned to Matsushita Electric Works.

Sapiński, A., Świdzińska, S. and Sapiński, F. (1986), Theoretical principles of arterial blood pressure measurement by sphygmooscillographic method, *Kardiologia Polska*, 29:576-582. [In Polish.]

Schmidt, T.F.H. et al. (1992), Twenty-four-hour ambulatory noninvasive continuous finger blood pressure measurement with PORTAPRES: A new tool in cardiovascular research, *Journal of Cardiovascular Pharmacology*, 19(suppl 6):S117-S145.

Sciarra, M.J. (1994), Non-invasive continuous blood pressure monitoring system, U.S. patent 5,303,711.

Sharir, T. et al. (1993), Validation of a method for noninvasive measurement of central arterial pressure, *Hypertension*, 21:74-82.

Shimazu, H. et al. (1986), Idea to measure diastolic arterial pressure by volume oscillometric method in human fingers, *Medical & Biological Engineering & Computing*, 24:549-554.

Shimazu, H. et al. (1989), Vibration technique for indirect measurement of diastolic arterial pressure in human fingers, *Medical & Biological Engineering & Computing*, 27:130-136.

Shirasaki, O. et al. (1988), Electronic blood pressure measuring device, U.S. patent 4,776,344, assigned to Omron Tateisi Electronics Company.

Squires, W.D., Anderson, D.L. and Cherry, I.R. (1980), Blood pressure monitoring system, U.S. patent 4,216,779, assigned to Del Mar Avionics.

Standards Australia (1989), Australian Standard® *AS 3655 — 1989: Sphygmomanometers*, South Melbourne, Victoria, Australia.

Stegall, H.F., Kardon, M.B. and Kemmerer, W.T. (1968), Indirect measurement of arterial blood pressure by Doppler ultrasonic sphygmomanometry, *Journal of Applied Physiology*, 25:793-798.

Susi, R.E. (1988), Method and apparatus for automatically determining blood pressure measurements, U.S. patent 4,729,383.

Swan, J.M. (1914), The auscultatory method of blood-pressure determination: A clinical study, *International Clinics*, 4:130-190.

Takeda, S. et al. (1993), Continuous noninvasive blood pressure measuring apparatus and method, U.S. patent 5,255,686, assigned to Nihon Kohden.

Talke, P.O. (1991), Measurement of systolic blood pressure using pulse oximetry during helicopter flight, *Critical Care Medicine*, 19:934-937.

Terada, H., Ishino, K. and Iwai, N. (1988), Blood pressure measuring system, U.S. patent 4,751,930, assigned to Matsushita Electric Works.

Terry, S. et al. (1990), Silicon pressure transducer arrays for blood-pressure measurement, *Sensors and Actuators*, A21-A23:1070-1079.

Tochikubo, O. et al. (1988), A new compact 24-hour indirect blood-pressure recorder and its clinical application, *Japanese Heart Journal*, 29:257-269.

Uemura, M. (1984), Method and apparatus for blood pressure measurement, U.S. patent 4,484,584, assigned to Nippon Colin Company.

von Recklinghausen, H. (1940), *Bluckdruckmessung und Kreislauf in den Arterien des Menschen*, Verlag von Theodor Steinkopff, Dresden & Leipzig, Germany.

Wallach, R.A. and Nelson, C.H. (1988), Artifact detection based on heart rate in a method and apparatus for indirect blood pressure measurement, U.S. patent 4,777,959, assigned to SpaceLabs.

Ware, R.W. and Anderson, W.L. (1966), Spectral analysis of Korotkoff sounds, *IEEE Transactions on Bio-Medical Engineering*, BME-13:170-174.

Weaver, C.S. and Chittenden, C.T. (1983), Blood pressure measurement with Korotkov sound artifact information detection and rejection, U.S. patent 4,408,614, assigned to SRI International.

Wenzel, D.J., Winter, D.C. and Honeyager, K.S. (1990), Active element selection for continuous blood pressure monitor transducer, U.S. patent 4,893,631, assigned to Colin Electronics Company. [Associated with Colin Medical Instruments, TX.]

Wesseling, K.H. (1984), Non-invasive continuous blood pressure wave form measurement by the method of Peñáz, *Scripta Medica*, 57:321-334.

Wesseling, K.H. (1985), Plethysmograph pressure correcting arrangement, U.S. patent 4,510,940, assigned to Toegepast-Natuurwetenschappelijk Onderzoek (TNO).

White, W.B. et al. (1987), Clinical validation of the Accutracker, a novel ambulatory blood pressure monitor using R-wave gating for Korotkoff sounds, *Journal of Clinical Hypertension*, 3:500-509.

Wolthuis, R.A., Golden, D.P. and Hoffler, G.W. (1974), Development of a Korotkoff sound processor for automatic identification of auscultatory events — Part II: Decision logic specifications and operational verification, *IEEE Transactions on Biomedical Engineering*, BME-21:119-124.

Yamakoshi, K., et al. (1982a), New oscillometric method for indirect measurement of systolic and mean arterial pressure in the human finger. Part 1: Model experiment, *Medical & Biological Engineering & Computing*, 20:307-313.

Yamakoshi, K. et al. (1982b), New oscillometric method for indirect measurement of systolic and mean arterial pressure in the human finger. Part 2: Correlation study, *Medical & Biological Engineering & Computing*, 20:314-318.

Yamakoshi, K., Rolfe, P. and Murphy, C. (1988), Current developments in non-invasive measurement of arterial blood pressure, *Journal of Biomedical Engineering*, 10:130-137.

Yelderman, M. and Ream, A.K. (1979), Indirect measurement of mean blood pressure in the anesthetized patient, *Anesthesiology*, 50:253-256.

Zezulka, A.V., Sloan, P.J.M. and Beevers, D.G. (1985), Clinical evaluation of the Infrasonde D4000 blood pressure monitor, *Postgraduate Medical Journal*, 61:321-323.

BIOGRAPHIES

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Kim-Gau Ng received his B.Eng. from the National University of Singapore in 1982 and his M.S. from The University of Alabama in 1989, both in mechanical engineering. Before pursuing his M.S., he worked for 4-1/2 years as a mechanical design engineer at PCI Displays Pte. Ltd., an electronics manufacturing firm in Singapore. At PCI Displays, he was involved in the design and development of equipment and tools for the production of liquid crystal displays (LCDs), printed circuit boards (PCBs), LCD modules and PCB assemblies. He is registered as a chartered engineer with The Engineering Council in the U.K. and is a corporate member of the Institution of Engineering Designers in the U.K. and a student member of both the American Society of Mechanical Engineers and the Canadian Medical and Biological Engineering Society. He has published eight conference papers and three journal papers, and is currently completing his Ph.D. in biomedical engineering at Queen's University.

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Carolyn F. Small received her B.Sc. in mechanical engineering from Queen's University at Kingston, Ontario in 1973, and her Ph.D. in bioengineering from the University of Strathclyde in Glasgow, Scotland in 1977. After a year as a Research Fellow at Strathclyde, she joined the Biomedical Engineering Department of Vancouver General Hospital in Vancouver, British Columbia. In 1987, she returned to Queen's University and is currently an associate professor of mechanical engineering. She is a registered professional engineer, a certified clinical engineer, and current President of the Canadian Medical and Biological Engineering Society.

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TABLE IV*
Measurement methods in ambulatory NIBP monitors

Manufacturer/Supplier†	Models‡ [Total Number of Models§]	Measurement Methods
A&D Engineering, Milpitas, CA [A&D Co., Tokyo, Japan]	TM-2420 recorder w/ TM-2020 processor/printer [AD] [1]	Auscultatory w/ PZT mikes, Config <c>
	TM-2421 recorder w/ TM-2021 processor/printer [AD] [1]	■ Oscillometric [primary] ■ Auscultatory w/ PZT mikes, Config <c>, "K2 algorithm"
Advanced Medical Products, Columbia, SC	■ AM5200 Micro Recorder for MICRO FD 7000 & MICRO SI 7000 ABP systems [AD/PE] ■ AM5600 Micro Recorder for MICRO FD 7400 & MICRO SI 7400 ABP/Holter systems [M] [AD/PE] [2]	■ Auscultatory w/ ECG-gating, PZT mike, Config <a> ■ Oscillometric Note: Either method may be selected as the primary method.
BioAnalogics Systems, Beaverton, OR	ABP monitor, used w/ an IBM® PC system [AD] [1]	Auscultatory w/ PZT mike, Config <a>
Biotrac, Largo, FL	Auto-Cuff® monitor w/ Auto-Print® printer [AD] [1]	Oscillometric
Circadian, San Jose, CA	BPMate™ monitor w/ control module [AD/PE] [1]	Oscillometric
Colin Medical Instruments, San Antonio, TX [Colin, Aichi, Japan]	ABPM-630 monitor w/ AA-200 analyzer/printer [AD/PE] [1]	■ Auscultatory w/ ELT mikes, Config <e> ■ Oscillometric Note: Either method may be selected, or both methods may be used concurrently.
Custo Med, Munich, Germany	Custo Screen [AD] [1]	Oscillometric
Del Mar Avionics, Irvine, CA	1990 Pressurometer® IV monitor w/ 1991 Pressurometer® Programmer [AD/PE] [1]	Auscultatory w/ ECG-gating, PZT mike, Config <a>
Disetronic Medical Systems, Burgdorf, Switzerland	■ Profilmat® system [AD] ■ CH-DRUCK® system (marketed as PressureScan by ERKA., Germany) [AD] [2]	Auscultatory w/ PZT mike, Config <a>
ERKA., Bad Tölz, Germany	PressureScan system (see Disetronic Medical Systems, Switzerland)	
GH Medical, Minneapolis, MN	ABP monitor w/ controller (Model 901); ABP monitor w/ controller/printer (Model 911); or ABP monitor w/ controller board & software for IBM® PC (Model 941) [AD/PE] [1]	Oscillometric
Healthcare Technology, West Sussex, U.K.	Pulse Time BP10 monitor/stop watch/chronometer [AD] [1]	Pulse-Wave Velocity [ECG measured from hands, pulse arrival detected at finger]
	BP-50 monitor w/ interface unit, used w/ an IBM® PC [AD] [1]	Pulse-Wave Velocity [ECG measured from chest, pulse arrival detected at finger]
Hellige, Freiburg im Breisgau, Germany	TONOPORT II (see PAR Medizintechnik, Germany)	
	TONOPORT III (see PAR Medizintechnik, Germany)	
Hillusa, Miami, FL	"Revelation" system, used with an IBM® PC [AD] [1]	Oscillometric
I.E.M. Electromedicina, Barcelona, Spain	ACP 2200 recorder, used w/ an IBM® PC [AD/PE] [1]	Oscillometric
Imex Medical Systems, Golden, CO	ABP 9000 monitor for IMEXLAB 9000™ Modular Diagnostic System™ [AD] [1]	Auscultatory w/ PZT mike, Config <a>
Instromedix®, Hillsboro, OR	BARO-GRAF™ 24 [AD] [1]	Auscultatory w/ PZT mike, Config <a>
Koven Technology, St. Louis, MO [Nihon Seimitsu Sokki Co., Gunma-ken, Japan]	Nissei DS-240 recorder w/ DS-241 analyzer/printer, or w/ DS-242 software for IBM® PC [AD] [1]	■ Auscultatory w/ ECG-gating (selectable), PZT mikes, Config <e> [primary] ■ Oscillometric
Novacor, Rueil-Malmaison CEDEX, France	DIASYS® 200 series [AD] [1]	Auscultatory w/ ECG-gating (selectable), PZT mike, Config <a>
Oxford Medical, Clearwater, FL [Oxford Medical, Oxon, U.K.]	Medilog® ABP [AD/PE] [1]	Auscultatory w/ ECG-gating (selectable), PVDF-bimorph mikes, Config <g>
PAR Medizintechnik, Berlin, Germany	PAR-PHYSIO-PORT III, used w/ an IBM® PC or a printer (marketed as TONOPORT II by Hellige, Germany) [AD] [1]	■ Auscultatory w/ ECG-gating, PZT mike, Config <a> ■ Oscillometric Note: Only one method may be selected and used at any one time.
	PAR-PHYSIO-PORT IIIA, used w/ an IBM® PC or a printer (marketed as TONOPORT III by Hellige, Germany) [AD] [1]	Oscillometric
PulseTrend™, Minneapolis, MN	PulseTrend™ ABP monitor w/ controller & printer, or w/ IBM® PC & accessories [AD] [1]	Oscillometric
Save 33 Electronique Medicale, Bruay sur Escaut, France	MAPA 33 recorder w/ control box [AD] [1]	Oscillometric

TABLE IV*—*Continued*
Measurement methods in ambulatory NIBP monitors

Manufacturer/Supplier†	Models‡ [Total Number of Models§]	Measurement Methods
Schiller, Baar, Switzerland	BR-102 [AD] [1]	Auscultatory w/ PZT mike, Config <a>
SpaceLabs Medical, Redmond, WA	■ 90207 monitor w/ 90229 or 90239A report generator [AD/PE] ■ First Medic® 310 monitor w/ data interface unit [AD/PE] [2]	Oscillometric
Speidel + Keller (A Welch Allyn Co.), Jungingen, Germany	TENSO24™ (see Tycos® Instruments, NC)	
Stuart Medical, Owings Mills, MD	SmartLINK™, comprising an ABP 310 monitor, an ECG 210 monitor, & an IBM® PC system [AD] [1]	■ Auscultatory w/ ECG-gating (when ECG monitor is used), PZT mike, Config <a> ■ Oscillometric
Suntech Medical Instruments, Raleigh, NC	Accutracker® II [AD/PE] [1]	Auscultatory w/ ECG-gating, PZT mike, Config <a>
	Accutracker® Dx [AD/PE] [1]	Auscultatory w/ PZT mike, Config <a>
Suzuken Co., Nagoya, Japan [Hillusa, Miami, FL]	Kenz-BPM AM-200 recorder w/ AM-200P processor/ printer [AD] [1]	■ Oscillometric [primary] ■ Auscultatory w/ PZT mikes, Config <c>
TNO Biomedical Instrumentation, Amsterdam, The Netherlands	Portapres™ Model-2 [1]	Vascular Unloading [2 fingers]
Tycos® Instruments (A Welch Allyn Co.), Arden, NC	QuietTrak™ (marketed as TENSO24™ by Spiedel + Keller, Germany) [AD] [1]	Auscultatory w/ OP-gating, PZT mike, Config <a>
Zewa, Miami, FL [Zewa, Hergiswil, Switzerland]	Delwa-Star 24 recorder w/ interface unit, used w/ an IBM® PC [AD] [1]	■ Auscultatory w/ ECG-gating (selectable), PZT mike, Config <a> [primary] ■ Oscillometric
Zymed, Camarillo, CA	MultiTrak-Plus ABP/ECG monitor [AD/PE] [1]	Auscultatory w/ ECG-gating, PZT mike, Config <a>

* The following notations are used in Tables IV, V & VI: AD = for adults; clinical = primarily for clinical use; Config < > = one of the microphone placement configurations as described in the text; ELT = electret; INFL = NIBP determination is performed during cuff inflation; M = multiparameter model(s); NE = for neonates; OP-gating = oscillometric-pulse-gating; PE = for children; primary = primary measurement method; PZT = lead zirconate titanate, used here to represent piezoelectric ceramic in general; PVDF = polyvinylidene fluoride, a piezoelectric polymer/film; station = nonportable type; & transport = designed for transport use.

† Not all the listed suppliers in Tables IV, V & VI are original equipment manufacturers (OEMs). The NIBP measurement unit or module in some of the monitors is provided by another supplier whose name may or may not be listed in the tables. In some cases, an entire system of one supplier is provided by another supplier.

‡ Because information on the monitors was collected over a period of about 5 years, some of the models have been discontinued.

§ The total number of models refers to the sum of the following: (1) the number of basic models, and (2) the number of extended models that are built upon the basic models, through configuration, by the addition of vital signs other than NIBP. An extended model that is distinguished from a basic model or another extended model by the addition of an integrated printer, battery support, a different type of screen display, an external interface, or other accessories, is not considered to be another model. An external module or cartridge that has NIBP measurement capability is considered one model. For a configurable series, the series is sometimes considered one model.

TABLE V*
Measurement methods in bedside and transport NIBP monitors

Manufacturer/Supplier†	Models‡ [Number of Models§]	Measurement Methods
A&D Engineering, Milpitas, CA [A&D Co., Tokyo, Japan]	■ TM-2510 or TM-2520 (w/ integral printer) [AD] ■ TM-2610 or TM-2620 (w/ integral printer) [AD/PE] ■ TM-2710 or TM-2720 (w/ integral printer) [AD/PE] [3]	Oscillometric
Advanced Medical Instruments, Broken Arrow, OK	■ System 7100 series [AD/PE/NE] ■ System 7500 NIBP/SpO_2 monitor [M] [AD/PE/NE] [2]	Oscillometric
Advanced Medical Systems, Hamden, CT	■ SMU411 w/ adult or neonatal NIBP option — [M]; [AD/PE] or [NE] ■ PM20A w/ adult or neonatal NIBP option — [M]; [AD/PE] or [NE] [2]	Oscillometric
Air-Shields, Hatboro, PA [S&W Medico Teknik, Albertslund, Denmark]	■ S&W Athena® 9225 NIBP module [AD/PE] ■ S&W Athena® NT 9226 Combi NIBP module [AD/PE/NE] [2]	Oscillometric
B. Braun Melsungen, Melsungen, Germany	HD-secura dialysis machine w/ NIBP option [AD/PE] [1]	Auscultatory w/ PZT mike, Config <a>

TABLE V*—*Continued*
Measurement methods in bedside and transport NIBP monitors

Manufacturer/Supplier†	Models‡ [Number of Models§]	Measurement Methods
BCI International, Waukesha, WI	■ Biochem® 6100 [M] [AD/PE/NE] ■ BCI 9100 series multigas monitor w/ NIBP option (9182 module) [M] [AD/PE/NE] [2]	Oscillometric
Bosch + Sohn, Jungingen, Germany [SOHA Scientific and Medical Co., San Diego, CA]	■ boso 'BC 42' monitor w/ BD 52 thermal printer, may be used for stress-testing [AD] ■ boso-tron2, may be used for stress-testing [AD/PE] [2]	Auscultatory w/ ELT mike, Config <a>
Brethren, Tokyo, Japan [Nihon Seimitsu Sokki Co., Gunma-ken, Japan]	Nissei DS-1010 [AD/PE] [1]	Oscillometric
CardioDyne, Brookline, MA	■ Kinetorr™ motion-tolerant stress-test NIBP monitor [AD] ■ Kinetorr™ PC [AD] [2]	Auscultatory w/ ECG-gating, PVDF mikes, Config <f>
Cardiopulmonary Instrumentations, Miami, FL	■ EK-SAT 1 NIBP/ECG/SpO_2 monitor [M] [AD/PE/NE] ■ CPI 3000 NIBP/temperature monitor [M] [AD/PE/NE] [2]	Oscillometric
CAS Medical Systems, Branford, CT	■ OscilloMate® 820 [AD/PE] ■ OscilloMate® 901 [NE] ■ OscilloMate® 915 [AD/PE] ■ OscilloMate® 920/EMS [AD/PE] [transport] ■ OscilloMate® 930 [AD/PE] ■ OscilloMate® 1630, for hyperbaric chambers [AD/PE] ■ OscilloMate® 9000 [AD/PE] [transport] ■ OscilloMate® 9300 [AD/PE/NE] [8]	Oscillometric
Colin Medical Instruments, San Antonio, TX [Colin, Aichi, Japan]	STBP-780 stress-test monitor [AD/PE] [1]	Auscultatory w/ ECG-gating, ELT mikes, Config <d>
	■ BP-308 or -308P [M] [AD/PE/NE] ■ BP-408 or -408P [M] [AD/PE/NE] ■ Pulsemate® BX-5 NIBP/SpO_2 monitor [M] [AD/PE/NE] ■ Press-Mate® BP-8800 series [M] [AD/PE/NE] ■ BP-306 [M] [AD/PE/NE] [5]	Oscillometric
	CBM-3000 [M] [AD/PE] [1]	■ Arterial Tonometry [wrist] ■ Oscillometric
	BP-508/Pilot™ w/ TBP (tonometry blood pressure) module [M] [AD/PE/NE] [1]	■ Oscillometric [AD/PE/NE] ■ Arterial Tonometry [wrist] [AD/PE only]
Cor Medical (formerly in Kings Park, NY)	■ 7000 [AD/PE] ■ 7001 NIBP/SpO_2 monitor [M] [AD/PE] [2]	■ COR [primary] ■ Oscillometric
Corometrics® Medical Systems, Wallingford, CT	■ 555 series [AD/PE/NE] ■ NIBP module for 556 monitor [AD/PE/NE] ■ 118 fetal/maternal monitor [M] [AD] [3]	Oscillometric
Criticare Systems, Waukesha, WI	■ 507 [M] [INFL] [AD/PE] ■ 1100-3 [M] [AD/PE] ■ 1100-4 anesthesia monitor [M] [AD/PE] ■ 508 & 508-I — all [M] [AD/PE] ■ 500 NIBP/SpO_2 monitor [M] [AD/PE/NE] [transport] [6]	Oscillometric
Critikon, Tampa, FL	■ DINAMAP™ 1846SX or 1846SX/P [AD/PE/NE] ■ DINAMAP™/OXYTRAK™ NIBP/SpO_2 monitor [M] [AD/PE/NE] ■ DINAMAP™ 8100; or 8100IR (w/ attached thermometer probe) — [AD/PE/NE] [transport] ■ DINAMAP™ 8100T NIBP/temperature monitor [M] [AD/PE/NE] [transport] ■ DINAMAP™ PLUS 8700, 8710 & 8720 — all [M] [AD/PE/NE] ■ DINAMAP™ PLUS 9700, 9710 & 9720 — all [M] [AD/PE/NE] [w/ Nellcor® SpO_2] [10]	Oscillometric
Datascope®, Paramus, NJ	■ 3000 or 3000A™ [M] [AD/PE/NE] ■ Accutorr® 3 (w/ integral printer) & 4 NIBP monitors — all [AD/PE/NE] ■ Accutorr® 3SAT & 4SAT NIBP/SpO_2 monitors [M] — all [AD/PE/NE] ■ Passport™/Passport™ EL [M] [AD/PE/NE] [transport] [4]	Oscillometric
Datex Medical Instrumentation, Tewsbury, MA [Instrumentarium, Datex Division, Helsinki, Finland]	■ Cardiocap™ CC-104, CCI-104, CM-104, CMO-104 & CTO-104 — all [M] [AD/PE] ■ Cardiocap™ II series [M] [AD/PE/NE] ■ M-NIBP NIBP module for Datex AS/3™ anesthesia monitor [AD/PE/NE] [7]	Oscillometric

TABLE V*—*Continued*
Measurement methods in bedside and transport NIBP monitors

Manufacturer/Supplier†	Models‡ [Number of Models§]	Measurement Methods
DeBusk Technology, Powell, TN	9200 [AD/PE] [1]	■ Auscultatory w/ PZT mike, Config <b> ■ Oscillometric
	■ 9350 stress-test monitor [AD/PE] ■ DTC 9600 stress-test monitor [AD/PE] [2]	Auscultatory [INFL] w/ PZT mike, Config <b>
DIMEQ Medizinelektronik, Berlin, Germany [Electra-Med, Flint, MI]	■ EBM 503 D stress-test monitor [AD/PE] ■ EBM 600 NIBP monitor, integrated w/ ERG 600 series ergometers [2]	■ Auscultatory with PZT mike, Config <a> [primary] ■ Oscillometric
Drägerwerk, Lübeck, Germany	■ NIBP module for PM 8014 monitor [AD/PE/NE] ■ Parameter Box (multiparameter module) w/ NIBP option, for Cicero EM anesthetic workstation [M] [AD/PE/NE] ■ Babyguard 8000 [M] [AD/PE/NE] [3]	Oscillometric
Elmed, Augsburg, Germany	ASM 1000 & 2000 — all [AD/PE] [2]	Oscillometric
ergo-line, Bitz, Germany	ergometrics 900/900L ergometer [AD/PE] [1]	Auscultatory w/ PVDF mike, Config <a>
Fresenius USA, Concord, CA	BPS-08 NIBP module for 2008 series dialysis machines [AD/PE] [1]	Oscillometric
Fukuda Denshi America, Redmond, WA [Fukuda Denshi Co., Tokyo, Japan]	HB-310 NIBP module for DynaScope DS-3300 patient monitoring system [AD/PE/NE] [1]	Oscillometric
GS-Elektromedizinische Geräte Günter Stemple, Kaufering, Germany	■ corpuls CD 90 defibrillator/multiparameter monitor w/ NIBP option [M] [AD/PE] ■ corpuls 08/16 defibrillator/multiparameter monitor w/ NIBP option [M] [AD/PE] [transport] [2]	Oscillometric
Hellige, Freiburg im Breisgau, Germany	■ VICOM-SM™ SMK 210 & 211 — all [M] [AD/PE/NE] ■ PRESSNI NIBP module for VICOM-SM™ patient monitor SMU611 [AD/PE/NE] [3]	Oscillometric
	BP 511 stress-test monitor [AD/PE] [1]	■ Auscultatory w/ PZT mike, Config <a> [primary] ■ Oscillometric
Hewlett-Packard Co., Andover, MA	■ HP 78352C & 78354C, each w/ NIBP option — all [M] [AD/PE/NE] ■ HP M1008A NIBP module [AD/PE] ■ HP M1008B NIBP module [AD/PE/NE] [4]	Oscillometric
Industrial & Biomedical Sensors, Waltham, MA	SD-700A series [AD/PE/NE] [1]	Auscultatory w/ ELT mike, Config <a>
Invivo Research, Winter Park, FL	■ Omega 1400™ series [AD/PE/NE] ■ Omega 1445 NIBP/SpO_2 monitor [M] [AD/PE/NE] ■ Omni-Trak™ NVS & TVS — all [M] [AD/PE/NE] [4]	Oscillometric
IVAC®, San Diego, CA	VITAL•CHECK® 4000A & 4200 — all [M] [AD/PE] [2]	■ Auscultatory w/ PZT mike, Config <a> [primary] ■ Oscillometric
Ivy Biomedical Systems, Branford, CT	■ 404 [M] [AD/PE] ■ 405A & 405D — all [M] [AD/PE/NE] [3]	Oscillometric
JPI, Santa Monica, CA [Nihon Seimitsu Sokki Co., Gunma-ken, Japan]	Nissei DS-1000 [AD/PE] [1]	Oscillometric
Kontron Instruments, Herts, U.K. [Medical Equipment Specialists, Shrewsbury, MA]	■ Minimon 7133B, 7137B & 7138B — all [M] [AD/PE] ■ Adult NIBP module for KOLORMON & SUPERMON® patient monitoring systems [AD/PE] ■ Neonatal NIBP module for KOLORMON & SUPERMON® patient monitoring systems [NE] [5]	Oscillometric
Lohmeier Medizin Elektronik, Munich, Germany	■ M 608, M 808 & M 910, each w/ NIBP option — all [M] [AD/PE/NE] ■ NIBP module for M 915 universal monitoring system [AD/PE/NE] [4]	Oscillometric w/ ECG-gating (selectable)
Marquette Electronics, Milwaukee, WI	1950 [1]	Auscultatory w/ PZT mike, Config <b>
	■ NIBP module for 7005, 7010, 7010RA & Tramscope® 12 monitors [AD/PE/NE] ■ TRAM® 100, 200, 200SL, 400SL, 800A & 800SL multiparameter modules — all [M] [AD/PE/NE] ■ Eagle® [M] [AD/PE/NE] [8]	Oscillometric

TABLE V*—*Continued*
Measurement methods in bedside and transport NIBP monitors

Manufacturer/Supplier†	Models‡ [Number of Models§]	Measurement Methods
Medical Data Electronics, Arleta, CA	■ ESCORT® 100 series, 100T series & 300/300A series [transport], each w/ NIBP option — all [M] [AD/PE/NE] ■ ESCORT® II 100 series & 300 series [transport], each w/ NIBP option — all [M] [AD/PE/NE] [5]	Oscillometric
Medical Research Laboratories, Buffalo Grove, IL	MRL NIBP monitor [AD/PE], may be used w/ Porta-Pak 90 integrated monitoring system [1]	Oscillometric
Mennen Medical, Clarence, NY	■ Horizon 1100 w/ built-in NIBP capability, or w/ NIBP module [M] [AD/PE/NE] ■ Horizon 1110 w/ built-in NIBP capability, or w/ NIBP module [M] [NE] ■ Horizon 2000 w/ built-in NIBP capability, or w/ NIBP module [M] [AD/PE/NE] ■ Horizon XL w/ built-in NIBP capability, or w/ NIBP QuickModule™ [M] [AD/PE/NE] ■ NIBP/SpO_2 QuickModule™ for Horizon XL [M] [AD/PE/NE] ■ MR-1270 [M] [AD/PE] ■ MR-1280 & MR-1282 — all [M] [AD/PE/NE] ■ Mercury w/ NIBP option [M] [AD/PE/NE] [transport] [9]	Oscillometric
NBS Medical, Costa Mesa, CA	SENTRY II series [AD/PE] [1]	Oscillometric
Nellcor®, Hayward, CA	Nellcor® N-CAT™ N-500 [AD/PE/NE] [1]	■ Arterial Tonometry [wrist] [AD/PE only] ■ Oscillometric [AD/PE/NE]
	Nellcor® Symphony™ N-3100 NIBP monitor [1]	Oscillometric
Nihon Kohden America, Irvine, CA [Nihon Kohden, Tokyo, Japan]	■ MPV-7201A [AD/PE] ■ Life Scope 7 OEC-7102A NIBP/ECG monitor [M] [AD/PE] ■ Life Scope 9 BSM-8301A [M] [AD/PE/NE] ■ Life Scope L BSM-2101A NIBP/ECG/SpO_2 monitor [M] [AD/PE/NE] [transport] [4]	Oscillometric
North American Dräger, Telford, PA	■ Vitalert® 1000 [M] [AD/PE/NE] ■ Vitalert® 3100 & 3200 — all [M] [AD/PE/NE] [3]	Oscillometric
ODAM, Wissembourg CEDEX, France	■ 2000 NI NIBP module for DEFIGARD 2005 defibrillator [AD/PE/NE] [transport] ■ MAGLIFE® monitor for MRI monitoring environment [M] [AD] ■ PHYSIOGARD LC 785 NI [AD/PE] ■ PHYSIOGARD SM 785 NI, NI-OX, P-NI & R-NI — all [M] [AD/PE] [7]	Oscillometric
Ohmeda, Madison, WI	2120 [AD/PE/NE] [1]	■ Oscillometric [AD/PE/NE] ■ Palpatory [return-to-flow detected at finger] [AD/PE only]
	■ Finapres® 2300 [AD] ■ Finapres® 2350 NIBP/SpO_2 monitor [AD] [2]	Vascular Unloading [finger]
Pace Tech, Clearwater, FL	■ VITALMAX 800 II, II-S, IV, IV-S, II-SN & IV-SN — all [M] [AD/PE/NE] ■ VITALMAX 800-C [M] [AD/PE/NE] ■ VITALMAX 800 PLUS-B & -C — all [M] [AD/PE/NE] ■ VITALMAX 810 PLUS-B & -C — all [M] [AD/PE/NE] ■ VITALMAX 2100 & 2200 — all [M] [AD/PE/NE] ■ VITALMAX 3000 [M] [AD/PE/NE] ■ VITALMAX 4000-B & 4000-C — all [M] [AD/PE/NE] ■ VITALMAX 4100 [M] [AD/PE/NE] ■ MINIPACK 300-B & 300-BS — all [M] [AD/PE/NE] ■ MINIPACK 911 [AD/PE/NE] [transport] ■ MINIPACK 911-S, 911-ST & 911-STC — all [M] [AD/PE/NE] [transport] ■ MINIPACK 3000-B & 3000-C — all [M] [AD/PE/NE] [transport] ■ MINIPACK 3100-B & 3100-C — all [M] [AD/PE/NE] [transport] [27]	Oscillometric
Pentam, Milano, Italy	■ M 500 series monitor w/ NIBP option [M] [AD/PE/NE] ■ PE 3000 series monitor w/ NIBP option [M] [AD/PE/NE] [2]	Oscillometric
Physio-Control, Redmond, WA	■ LIFESTAT® 100 & 200 — all [AD/PE] [transport] ■ VSM® 2 [M] [AD/PE] [3]	Oscillometric

TABLE V*—*Continued*
Measurement methods in bedside and transport NIBP monitors

Manufacturer/Supplier†	Models‡ [Number of Models§]	Measurement Methods
Protocol® Systems, Beaverton, OR	■ PROPAQ 102 or 102EL™ [M] [AD/PE] [transport] ■ PROPAQ 104 or 104EL™ [M] [AD/PE] [transport] ■ PROPAQ 106 or 106EL™ [M] [AD/PE] [transport] [3]	Oscillometric
Quinton® Instrument Co., Seattle, WA	Quinton® 412 stress-test monitor [AD/PE] [1]	Auscultatory w/ ECG-gating, ELT mikes, Config <d>
Save 33 Electronique Medicale, Bruay sur Escaut, France	NIBP/SpO_2 unit for 2651 monitor [M] [AD/PE/NE] [1]	Oscillometric
Schiller America, Tustin, CA [Schiller, Baar, Switzerland]	CARDIOSWISS CM-8 series w/ NIBP option [M] [AD/PE/NE] [1]	Oscillometric
Sein Electronics, Kyungki-do, Korea	■ SE-100 [AD/PE/NE] ■ SE-351 [M] [AD/PE] [2]	Oscillometric
Siemens Medical Systems, Iselin, NJ [Siemens, Erlangen, Germany]	■ SIRECUST® System NIBP cartridge [INFL] [AD/PE] ■ SIRECUST® 610, 620 & 630 — all [M] [AD/PE] [transport] ■ SIRECUST® 342R [M] [AD/PE/NE] ■ SIRECUST® 732 [M] [AD/PE] ■ SIRECUST® System NP cartridge [AD/PE] [7]	Oscillometric
Smiths Industries Medical Systems, Indianapolis, IN	ARTRAC™ 7000 NIBP/SpO_2 monitor [M] [AD/PE] [1]	■ Pulse-Wave Velocity [ear, forehead, finger] [AD only] ■ Oscillometric [AD/PE]
SpaceLabs Medical, Redmond, WA	■ 90426 PC NIBP module [AD/PE/NE] ■ 90429 PC NIBP module [NE] ■ 90430 PCMS NIBP module [AD/PE] ■ 90465 NIBP/SpO_2 module [M] [AD/PE/NE] ■ 90466 NIBP/SpO_2 module [M] [NE] ■ 90467 NIBP/SpO_2 module [M] [AD/PE] ■ 90600A series monitor w/ adult, neonatal, or adult/neonatal NIBP option — [M]; [AD/PE], [NE], or [AD/PE/NE] ■ 90309 PC Scout™ monitor w/ NIBP option [M] [AD/PE/NE] [transport] [8]	Oscillometric
Spegas Industries, Jerusalem, Israel	GABRIEL monitor [M] [AD/PE/NE] [1]	Oscillometric
Speidel + Keller (A Welch Allyn Co.), Jungingen, Germany	■ Tonomed, may be used for stress-testing [AD/PE] ■ Tonoprint, may be used for stress-testing [AD/PE] [2]	Auscultatory w/ PZT mike, Config <a>
Suntech Medical Instruments, Raleigh, NC	4240 Dynamic stress-test BP monitor [AD/PE] [1]	Auscultatory w/ ECG-gating, PZT mike, Config <a>
Suzuken Co., Nagoya, Japan [Hillusa, Miami, FL]	Kenz-BPM OS-21 & OS-22 — all [AD] [2]	Oscillometric
S&W Medico Teknik, Albertslund, Denmark	Diascope™ NT w/ NIBP option [M] [AD/PE/NE] [transport] [1]	Oscillometric
UEDA® Electronic Works, Tokyo, Japan [Matsui, City of Industry, CA]	■ U-Vision UV-101 [AD/PE] ■ U-Vision UV-101DX or UV-101EX [AD/PE] [2]	Volume-Oscillometric [finger] [air-filled cuff]
	UM-3000 [AD/PE] [1]	Auscultatory w/ PZT mike, Config <a>
	USM-803 [AD] [1]	Vascular Unloading [finger] [water-filled cuff]
	■ Oscillovision USM-700G [AD/PE] ■ USM-700GV [AD/PE] ■ USM-700GSi [AD/PE] [3]	Oscillometric [INFL]
Vogel & Halke, Hamburg, Germany	SECA Cardiotest 7500 [AD/PE] [1]	Oscillometric

*†‡§ See corresponding footnotes for Table IV.

TABLE VI*
Measurement methods in NIBP monitors other than ambulatory, bedside and transport monitors

Manufacturer/Supplier†	Models‡ [Number of Models§]	Measurement Methods
A&D Engineering, Milpitas, CA [A&D Co., Tokyo, Japan]	■ Manual inflation [AD]: UA-701 & UA-711 ■ Automated inflation [AD]: UA-731, UA-732, UA-751, UA-743, UA-830 & UA-833, UB-211 [finger] & TM-2650 [station] [10]	Oscillometric
Aquamed Medizinische Gërate, Göttingen, Germany	■ Manual inflation [AD]: Vitagnost® 1001 & 2015 OC ■ Automated inflation [AD]: Vitagnost® 1007, 1008 & 1011 [5]	Oscillometric
Bosch + Sohn, Jungingen, Germany [SOHA Scientific and Medical Co., San Diego, CA]	■ Manual inflation [AD]: boso-Compact & boso-Prestige ■ Automated inflation [AD]: boso-Prestige <automatic>; boso-Prestige <automatic> w/ audio-response unit; boso-Oscillomat; & boso-medicus [6]	Oscillometric
Brethren, Tokyo, Japan [Nihon Seimitsu Sokki Co., Gunma-ken, Japan]	■ Manual inflation [AD]: Nissei DS-105E & DS-125D ■ Automated inflation [AD]: Nissei DS-143D, DS-156E & DS-172D [5]	Oscillometric
Casio, Dover, NJ [Casio Computer Co., Tokyo, Japan]	BP-100 series BP monitor/watch [AD] [1]	Pulse-Wave Velocity [ECG measured from wrist and finger, pulse arrival detected at finger]
	HBP-500 series hand-held BP monitor/clock [AD] [1]	Pulse-Wave Velocity [ECG measured from palm and finger, pulse arrival detected at finger]
Citizen Watch Co., Tokyo, Japan	Automated inflation [AD]: CH-401B [1]	Oscillometric
Computerized Screening, San Dimas, CA	■ CSI 1000, 2000 & 7000 — all [AD] [station] ■ CSI 501, 502 & 505 — all [AD] [station] [6]	Auscultatory w/ PZT mike, Config <a>
ERKA., Bad Tölz, Germany	■ Manual inflation [AD]: OS 90-1 & 90-10 ■ Automated inflation [AD]: OS 90-2, 90-3, 90-20 & 90-30 [6]	Oscillometric
Focal, Tokyo, Japan	Manual inflation [AD]: FC-130M & FC-150D [2]	Oscillometric
Graham-Field, Happauge, NY	■ Manual inflation [AD]: Labtron 02-707; & HEALTHTEAM™ 05-HT8115 & 05-HT8116 ■ Automated inflation [AD]: Bristoline™ BR1735; Labtron 02-847, 02-947 & 02-949 [finger]; & HEALTHTEAM™ 05-HT8100 [finger], 05-HT8145, 05-HT8146 & 05-HT8175 [11]	Oscillometric
Healthcheck (formerly in Woodbury, CT)	■ Manual inflation [AD]: Pulsonic™ BP-3/060014 ■ Automated inflation [AD] [finger]: Cuffless™ CX-5/060020 & CX-10/10025 [3]	Oscillometric
Hestia Pharma, Mannheim, Germany	■ Manual inflation [AD]: D2 International ■ Automated inflation [AD]: D20 Automatic [2]	Oscillometric
Ito Co., Tokyo, Japan	■ Manual inflation [AD]: BP-550S & DS-122D ■ Automated inflation [AD]: DS-142D & FS-60D [finger] [4]	Oscillometric
JPI, Santa Monica, CA [Nihon Seimitsu Sokki Co., Gunma-ken, Japan]	■ Manual inflation [AD]: Nissei DS-115 & DS-165 ■ Automated inflation [AD]: Nissei DS-145, DS-175, FS-40 [finger], DS-2001 [station] [6]	Oscillometric
Karelia Medical, Birmingham, U.K.	Manual inflation [AD/PE]: Sphygmomat 2 [clinical] [1]	Auscultatory w/ piezoelectric mike, Config <a>
Kas. Haiss (Kas. = Kasimir), Jungingen, Germany	■ Manual inflation [AD]: HAKO E-830 ■ Automated inflation [AD]: HAKO E-840 [2]	Oscillometric
The Lumiscope Co., Edison, NJ	■ Manual inflation [AD]: Nelkin/Piper HOMECARE CLINIC'S™ 282; & Digitronic 1060 ■ Automated inflation [AD]: 1081, 1085M, 1086M & 1091; & Digitronic 1096 ■ Automated inflation [AD] [finger]: Nelkin/Piper HOMECARE CLINIC'S™ 254; & 1083 & 1084 [10]	Oscillometric
Mars Metal Co., Taipei, Taiwan	■ Manual inflation [AD]: MS-701 & MS-702 ■ Automated inflation [AD]: MS-700 [3]	Oscillometric
Matsushita Electric Works, Osaka, Japan	■ Automated inflation [AD] [fuzzy logic]: National EW 243W & EW 245W ■ Automated inflation [AD] [fuzzy logic] [wrist]: National EW 273H, EW 277W & EW 278W [5]	Oscillometric
MBO Medizintechnik, Plauen, Germany	■ Manual inflation [AD]: OSC Compact 100 & 200 ■ Automated inflation [AD]: OSC Compact 300 automatic [3]	Oscillometric

TABLE VI*—*Continued*

Measurement methods in NIBP monitors other than ambulatory, bedside and transport monitors

Manufacturer/Supplier†	Models‡ [Number of Models§]	Measurement Methods
Omron® Healthcare, Vernon Hills, IL [Omron, Tokyo, Japan]	■ Manual inflation [AD]: Marshall® 80 & 85; Omron® HEM-400C, -401C, -405C & -413C; & Omron® HEM-425C or -425CLC ■ Automated inflation [AD]: Marshall® 91, 94, 96, 97 & 98; Omron® HEM-601 [wrist]; Omron® HEM-703CP, -703CPS, -704C & -705CP; Omron® HEM-706 [fuzzy logic] & -707 [fuzzy logic]; Omron® HEM-713C; & Omron® HEM-725C ■ Automated inflation [AD] [finger]: Marshall® F88, F89 & F99; & Omron® HEM-812F & -815F [26]	Oscillometric
Philips Domestic Applicances and Personal Care, Groningen, The Netherlands	■ Manual inflation [AD]: HP5330 ■ Automated inflation [AD]: HP5331 & HP5332 [3]	Oscillometric
Pulse Metric®, San Diego, CA	■ Manual inflation [AD/PE]: DynaPulse™ 200M monitor, used w/ an IBM® PC ■ Automated inflation [AD/PE]: CARDio™ NIBP interface card w/ software, for IBM® PC systems [2]	Oscillometric
Radio Shack®, Fort Worth, TX	Manual inflation [AD]: Micronta® 63-663 [1]	Oscillometric
Roland Arzneimittel, Hamburg, Germany	Manual inflation [AD]: RR-Test Digital primus [1]	Auscultatory w/ Config <a>
	■ Manual inflation [AD]: RR-Test Compact OS ■ Automated inflation [AD]: RR-Test Automat OS & RR-Test Compamat OS [3]	Oscillometric
Rudolf Riester, Jungingen, Germany	■ Manual inflation [AD]: ri-gital® N ■ Automated inflation [AD]: ri-matic® N [2]	Oscillometric
Spiedel + Keller (A Welch Allyn Co.), Jungingen, Germany	■ Manual inflation [AD]: Tensoplus® OSZ 1 ■ Automated inflation [AD]: Tensoplus® OSZ 2 [2]	Oscillometric
Sunbeam-Oster Household Products, Laurel, MS	■ Manual inflation [AD]: Sunbeam® 7594, 7621 & 7640-10 ■ Automated inflation [AD]: Sunbeam® 7592, 7650-10, 7655-10 [finger], 7656-10 [finger] & 7657-10 [8]	Oscillometric
Terumo®, Tokyo, Japan	Automated inflation [AD]: ES-P101, ES-P102, ES-P103 [3]	■ Auscultatory w/ PZT mike, Config <a> ■ Oscillometric
	Automated inflation [AD]: ES-P202 [1]	Auscultatory w/ PZT mike, Config <a>
	Manual inflation [AD]: ES-H51 [clinical] [1]	■ Auscultatory w/ OP-gating, PZT mike, Config <a> [primary] ■ Oscillometric
Thermor, Toronto, ON, Canada	■ Manual inflation [AD]: Taylor® 7052-09 ■ Automated inflation [AD]: Taylor® 7052-07, Thermor 7052-06 & Thermor 7052-10 [finger] [4]	Oscillometric
Tycos® Instruments (A Welch Allyn Co.), Arden, NC	Manual inflation [AD/PE] [clinical]: A-10 & A-1000 acoustic sphymomanometers [2]	Auscultatory w/ PZT mike, Config <a>
	■ Manual inflation [AD]: ARDEN 7052-27 ■ Automated inflation [AD]: Tycos® 7052-23 [2]	Oscillometric
UEDA® Electronic Works, Tokyo, Japan [Matsui, City of Industry, CA]	Automated inflation [AD] [station]: Cardex, Cardex-II & Udex-1 [3]	Auscultatory w/ PZT mike, Config <a>
	Automated inflation [AD]: Udex-II [station] [1]	■ Auscultatory w/ PZT mike, Config <a> [primary] ■ Oscillometric
VasoPlex™ (formerly in Wayne, NJ)	Automated inflation [AD]: VasoPlex™ System [clinical] [1]	Oscillometric
Vita-Stat Medical Services, Redmond, WA	Automated inflation [AD] [station]: 9000 & 90550 [2]	Oscillometric

*†‡§ See corresponding footnotes for Table IV.