EVALUATION OF TWO PROTOTYPE DEVICES PRODUCING NONINVASIVE, PULSATILE, CALIBRATED BLOOD PRESSURE MEASUREMENT FROM A FINGER

N. Ty Smith, MD,† Karel H. Wesseling, PhD,*‡ and Benjamin de Wit, BS*†

ABSTRACT. We evaluated two prototype instruments that measure pulsatile blood pressure continuously and noninvasively and compared the mean arterial pressure obtained from these devices with that obtained invasively in 17 male surgical patients. Each prototype consisted of an infrared photoplethysmograph mounted inside a finger cuff. The cuff was connected to a pressure control valve, which rapidly changed the cuff pressure so as to maintain a null pressure difference across the finger arterial wall. The resultant cuff pressure rapidly tracked the pulsatile intraarterial pressure. The prototypes reproduced absolute pressure, as well as pressure changes, accurately and linearly over a wide range of mean arterial pressures (from 2 to 164 mm Hg), with an average offset error of 0.8 mm Hg (SD ± 3.8; range, −4.6 to 7.9), a mean scatter error of 5.3 mm Hg (range, 3.6 to 8.6), a mean regression slope of 0.97 (range, 0.79 to 1.22) and a mean correlation coefficient of the regression of 0.96 (range, 0.89 to 0.98).

Both prototypes worked satisfactorily on all 17 patients, but not all the time on all patients. In 7 patients, probable arterial spasm prevented measurement of finger blood pressure 12.1% of the time, or 5.4% of the time for all patients. Ninety-six percent of the lost samples occurred with prototype 2, suggesting an instrument-related cause, rather than one related to the principle itself.

The prototypes were simple to use and were almost free from artifact. Continuous monitoring for up to 7 hours on a single finger caused no harm to the finger.

KEY WORDS. Monitoring; Blood pressure; Invasive monitoring; Noninvasive monitoring; Computers

A noninvasive method yielding a pulsatile blood pressure recording similar in form and content to that obtained from an intraarterial cannula would be useful for intraoperative monitoring. This study evaluated the accuracy and precision of two prototype devices for noninvasive measurement of pulsatile, beat-to-beat finger blood pressure during anesthesia and surgery, comparing the information obtained from these devices with that obtained via an intraarterial cannula. To evaluate the accuracy of the devices, we concentrated on mean pressure. The prototypes functioned well most of the time; when they did, their accuracy was very good.

MATERIALS AND METHODS

The Principle

The prototypes were based on a principle originally described by Marey [1,2] and more recently by Shirer [3] and Peñaz [4,5]. The basic method is described in some detail by Peñaz et al [4,5] and by Yamakoshi et al [6–8].
These descriptions include diagrams. Each instrument uses an infrared photoplethysmograph mounted inside an inflatable, flexible finger cuff. The operation of the system is divided into two modes: an open-loop mode to detect mean pressure and a closed-loop mode to track the arterial pressure waveform. The open-loop mode uses the following principle, as first enunciated by Marey [1,2]: Recorded pulsations, whether pressure or plethysmographic, are maximum when a surrounding inflated cuff is at mean arterial pressure. This same principle is used by many of the commercially available oscillometric noninvasive blood pressure devices [9,10]. Once mean pressure is detected by this method, the system operates around this pressure in the closed-loop mode. In this mode, a fast servo system uses the signal from the plethysmograph to maintain air pressure in the cuff at the intraarterial pressure level. The cuff pressure is modulated by the servo system so that the finger volume (collectively referred to as arterial diameter) as seen by the photoplethysmograph is constant. The arterial diameter tends to change with a varying intraarterial pressure. To dynamically oppose this changing pressure, the cuff pressure must change by the same amount, in the same direction, and at the same rate so that the pressure difference across the arterial wall—the transmural pressure—stays constant at nearly zero, that is, it remains nulled. When transmural pressure is zero, cuff pressure equals intraarterial pressure, and the latter can be continuously measured. The system can thus be characterized as a “noninvasive catheter–manometer system.” It delivers a continuous arterial pressure waveform, with the mean pressure calibrated by the device, in a finger noninvasively, analogous to the way a catheter–manometer system delivers this waveform invasively at the catheter tip. The arterial system from the aortic valve to the finger acts as a catheter, transmitting the aortic pressure wave to the finger. When the device is operating, the finger arterial wall functions as the membrane of the manometer.

An electropneumatic transducer, a manometer, and the plethysmographic preamplifier are mounted in a small box, which is strapped to the back of the patient’s hand to keep connections to the finger cuff as short as possible (see Figure 1A, B).

The two prototypes used the same principles for the measurement of blood pressure. For example, either could use any cuff–box combination. The major difference between the two prototypes entailed automation. Many of the procedures were performed manually with prototype 1 and automatically with prototype 2. These procedures included detection of mean pressure, as described earlier, and generation of the signal for calibrating any device for recording or display. Thus, prototype 2 depended much more on the satisfactory operation of components, as well as the robustness of the algorithms.

Since the system measures blood pressure from a finger, we call it FIN. Prototype 1, as well as the blood pressure value derived from it, is referred to as FIN1; prototype 2 and its blood pressure value as FIN2.

Patients

Seventeen male patients, ranging in age from 50 to 78 years, underwent a variety of surgical procedures as listed in Table 1. The protocol was approved by the university and hospital Institutional Review Boards, and each patient gave informed consent. Eight patients underwent coronary artery bypass graft (CABG) procedures. Various anesthetic agents were given (see Table 1),