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Pulse Volume Recording in the Diagnosis of Peripheral Vascular Disease

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Introduction

The pulse volume recorder (PVR) was introduced by Raines almost 35 years ago in a thesis based on graduate work conducted at the Massachusetts Institute of Technology (MIT), Harvard Medical School and Massachusetts General Hospital. The work was sponsored by the National Institutes of Health. The work built on earlier pioneering efforts by investigators such as T. Winsor and E. Strandness. The research took advantage of major recent advances in electronics, specifically in the area of pressure transducer design. However, the driving force was the increasing ability of the vascular surgeon to reconstruct peripheral arteries and the associated need to perform accurate diagnostic studies preoperatively and in follow-up.

In 1972 Raines, along with R. Darling, B. Brener, and W. Austen, presented the first clinical paper on the PVR at the Annual Meeting of the Society of Vascular Surgery; this was later published in Surgery. Earlier that year (in April 1972) this same group of investigators established the first clinically oriented vascular laboratory at the Massachusetts General Hospital. A similar laboratory was established at about the same time at Northwestern’s Medical School by Yao and Bergan. Founding these laboratories included obtaining codes for reimbursement from Medicare and other third party insurance carriers. Three years later the early experience of this laboratory was presented at the 1975 Annual Meeting of the Society for Vascular Surgery and again published in Surgery. At that time studies within the vascular laboratory were expanding to include functional evaluation of venous disorders and extracranial arterial occlusive disease. At this point many other centers had developed vascular laboratories and began publishing their results.

The early PVR was available in either a box or cart model. The first units also included a built-in continuous-wave Doppler in two frequencies (9 MHz and 5 MHz). Within 5 years of its introduction the PVR became an extremely popular device and was widely used throughout the world. In vascular laboratories its frequency of use was second only to the continuous-wave Doppler systems.

Guidelines for establishing vascular laboratories were published along with accuracy studies comparing noninvasive functional studies with angiography and clinical outcome in the areas of peripheral arterial occlusion, deep venous thrombosis, and extracranial arterial occlusive disease.

In 1978, W. Glenn introduced B-mode ultrasound. The first clinical studies using this technique were performed in the Vascular Laboratory of the Miami Heart Institute, which was directed at that time by Raines, who a number of years earlier introduced the PVR. Within several years B-mode ultrasound was producing images of peripheral arterial and venous vessels that were very useful clinically and augmented information obtained from functional studies. With B-mode ultrasound as a basis, ultrasound engineers developed duplex scanning, color duplex scanning, power duplex imaging, and more recently improved imaging with internal computer enhancement, storage, and image transfer.

Clearly technology in the field of noninvasive medical imaging as applied to peripheral vascular disease has been explosive and has made significant clinical contributions. Despite this, functional studies remain an integral component in the investigation of most forms of peripheral vascular disorders, and functional technology has also kept pace. In the remainder of this chapter a description of how the PVR has been improved over nearly 35 years will be given. This will be followed by descriptions of how the PVR may be used most effectively in today’s modern vascular laboratory.

Before closing the introduction it is instructive to note two important items. First, peripheral vascular disease of the elderly and in the United States the elderly is now the fastest growing segment of the population. The Census Bureau estimates this trend is
expected to continue to the year 2030. This is com-
pounded by the fact that in the United States over the
past 20 years mortality from coronary artery disease
has been decreasing. This means that more survivors
who would have died of coronary artery disease live
to present to the vascular laboratory with peripheral
vascular disease.

Second, while there will be increasing pressure to
provide services for peripheral vascular disease, medical
providers will be asked to do so at less cost. This means
more accurate less costly outpatient diagnostic studies
coupled with effective, less costly therapy. This is both
a challenge and an opportunity for manufacturers of
equipment and providers of care in peripheral vascular
disease.

Pulse Volume Recorder—2005

As described in the original PVR development work at
MIT, to maintain proper system calibration when a PVR
cuff is placed on an extremity, the system and operator
must inflate the cuff to a known cuff pressure (i.e.,
65 mmHg thigh/calf/ankle) and also know the amount of
injected atmospheric air necessary to produce the cuff
pressure. If the volume of injected air does not meet an
established criterion (i.e., 75 ± 10 cm$^3$, calf/ankle; 400 ±
75 cm$^3$, thigh) the operator must reapply the cuff.
Whereas a number of manufacturers market PVR-like
devices, some do not include this important calibration.
These manufacturers have suggested to operators that
after cuff application it is necessary to inflate the cuff only
to the recommended pressure. This assumes each cuff is
applied to the same tension despite variation in limb size;
we have found results can vary significantly based on
operator application and technique. There are manufac-
turers who provide a good external calibration as
described above. These systems provide reproducible
PVR data that almost eliminate operator application and
technique errors. In our laboratory, working with indus-
try, we have developed a computer-controlled internal
calibration system that is very accurate and completely
eliminates cuff reapplication at any level (Figure 4–1).

The ability to record and store data is most import-
ant to document testing for both reimbursement and
certification purposes. The new PVR systems include
patient interface ports (i.e., for PVR cuffs and Doppler
probes), color monitor, keyboard, and color printer.
Studies may be performed in a dedicated laboratory or
at the patient’s bedside. It should be acknowledged that
when earlier systems were making the transition from
non-PC-based to PC-based units, the PC units were slow,

FiguRe 4–1. (A) Picture of a prototype internally calibrated pulse volume recorder (PVR). This system is controlled by a
computer. The operator interfaces with the unit via Keyboard,
Joystick, and Monitor. The system also has a dedicated Printer
and Modem for report generation. (B) This schematic illustrates
how internal calibration is accomplished. During the early
phase of diastole, the piston in the calibration chamber rapidly
increases the system volume by a known amount. The resultant
instantaneous pressure reduction is measured along with
the pressure differential from tracing foot to peak. This
allows the total volume change to be calculated in near real-
time.