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Discussion

Application of arterial hemodynamics to clinical practice: A testament to medical science in London

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Abstract A strong heritage of science has been handed down in Britain from outstanding individuals, promoted and encouraged by strong scientific and medical societies. Application to clinical practice in recent years has been slow but can be expected to advance in the present and future age of new sensors, fast computing and clinical problems awaiting explanation. Agreement on terminology and physical mechanisms needs be fostered.

Britain has contributed more than any other nation to the theory and application of arterial hemodynamics. Within England, no city has spawned more ideas in this domain than London, home to University College and this meeting. Isaac Newton was the pioneer. His Principa Mathematica established the principles of physics through quantification of information, and observations, using appropriate mathematical analysis. While Newton's main establishment was at Cambridge, he spent much time in London at meetings of the Royal Society, and in his later life, as Warden of the Mint.[1,2]

William Harvey in 1628 wrote his famous tome "Exercitatio Anatomica de Motu Cordis et Sanguinis in Animalibus" while Anatomist to the Royal College of Physicians of London.[3] His establishment of the circulation was contentious and generated widespread controversy. One subject he championed was wave reflection, not in "de Motu Cordis ...", but more fully in later work, principally his Second

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Open Letter to Jean Riolan.[4] He was well aware of wave travel and reflection, but could not confirm whether the pressure wave travelled within the lumen of an artery or along its wall. He described experiments where an artery was occluded with an intraluminal reed. It was left to his followers to confirm that velocity of the arterial pressure wave depended both on the properties of the wall and viscosity of the blood within. But he was emphatic about the importance of wave reflection.

> *"For, so soon as you have tied the artery above the reed or tube with a string, the vessel in question promptly dilates heartwards from the end of the reed under the impact of the blood from above. In consequence, the (forward) flow of blood is impeded and its impact is reflected backwards."*

Harvey's views were put into practice in London by John Hunter,[5] considered to be the pioneer of scientific surgery. His famous operation for popliteal aneurysm was successful not only as he tied off the femoral artery proximal to the aneurysm, but because he applied further ligatures proximally to protect the repaired artery. He reasoned that waves travelling from the heart to the leg could be reflected backwards to the heart, so damping the wave which reached the aneurysm site, and allowing the aneurysm to heal.

Stephen Hales[6] first measured arterial pressure from the height of a blood column in a tube that was connected to the crural artery of a horse. By measuring pressure in very small arteries, he showed that high pressure was maintained, deducing that the principal reduction in pressure occurred in small peripheral arteries, opening the way for Poiseuille to confirm that resistance to blood flow is principally peripheral. Hales, an Anglican clergyman, had a parish in North London.

William Bright[7] established the relationship between renal disease, stroke and cardiac failure via elevation of arterial pressure and quantified this from palpation of the pulse. From this early work at Guy's Hospital followed the careful clinical/pathological work of Gull and Sutton[8] then of Frederick Mahomed[9] who developed his own quantitative sphygmogram as an improvement of Marey's in Paris.[10] It was Mahomed who confirmed Marey's observations that the characteristic feature of ageing disease (arteriosclerosis) and of hypertension was prominence of the tidal wave at the radial artery — of the late systolic peak of radial artery pressure — which is now described paradoxically by some of our colleagues as a "reservoir wave". Mahomed described characteristic features of the radial pulse wave in hypertension (Fig. 1) as:

> *"The dicrotic wave is very small and often scarcely perceptible; the vessels, however, are full during the diastolic period, and collapse slowly. ... The tidal wave is prolonged and too much sustained. . . . The most constant of these indications is the prolongation of the tidal wave; any one or all of the other characters may under certain conditions be absent."*

He also declared that elevated blood pressure, and its adverse clinical course could be diagnosed from contour of the radial artery pulse.

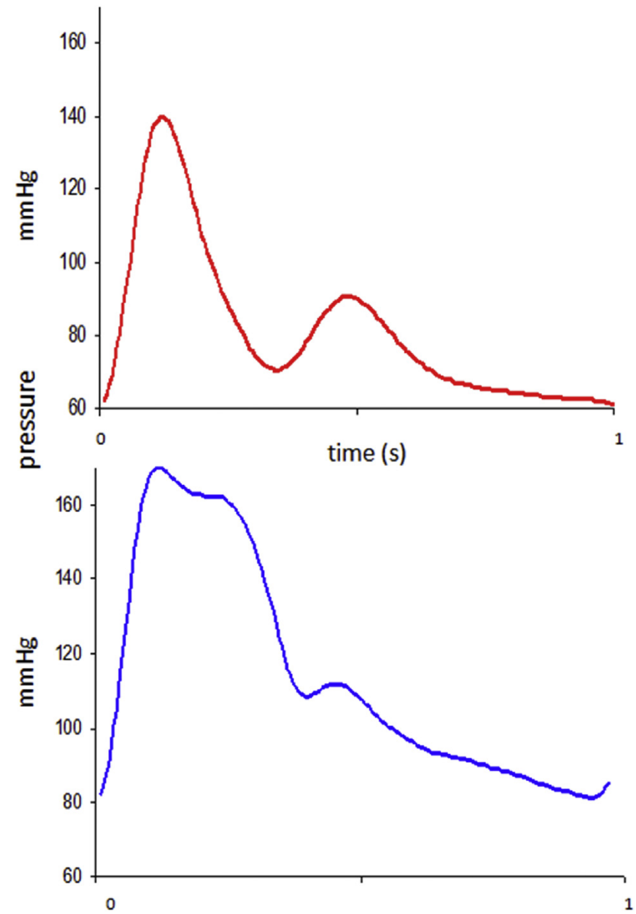

Figure 1 Characteristic features of radial pulse wave in a normal (top) and a hypertensive (bottom) person.

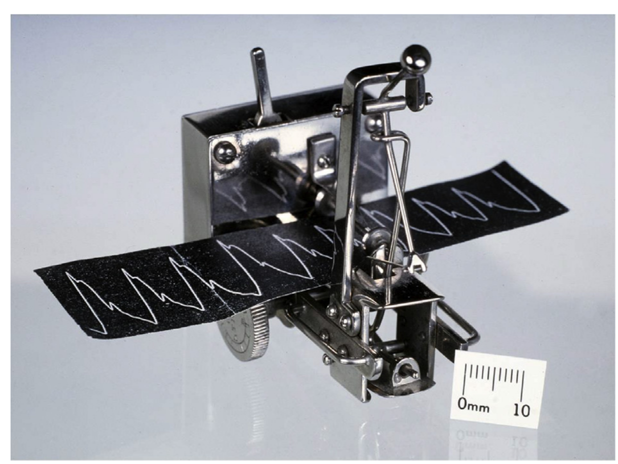

Figure 2 Dudgeon sphygmograph.

> *"These persons appear to pass on through life pretty much as others do and generally do not suffer from their high blood pressures, except in their petty ailments upon which it imprints itself . . . As age advances the enemy gains accession of strength . . . the individual has now passed forty years, perhaps fifty years of age,*