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Review: A century of confusion; which bladder for accurate blood pressure measurement?

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This paper reviews the literature on a century-old controversy relating to the error that may be introduced to blood pressure (BP) measurement by using a cuff with a bladder of inappropriate dimensions for the arm for which it is intended. The use of cuffs containing inappropriate bladders is a serious source of error which must inevitably lead to incorrect diagnosis in practice, and erroneous conclusions in hypertension research. There is unequivocal evidence that either too narrow or too short a bladder (undercuffing) will cause overestimation of BP and there is growing evidence that too wide or too long a bladder (overcuffing) may cause underestimation of BP. Undercuffing has the effect in clinical practice of overdiagnosing hypertension and overcuffing leads to hypertensive subjects being diagnosed as normotensive. Either eventuality has serious implications for the epidemiology of hypertension and clinical practice.

A detailed review of the literature permits a definitive statement on bladder dimensions for a given arm circumference and clearly indicates that substantial error is caused by the use of inappropriate cuffs. On the basis of this review and aware of the advances in cuff design, the features for an 'Adult Cuff', which would be applicable to all adult arms, are proposed in this paper, and it is hoped that manufacturers may take up the challenge of producing such a cuff.

Keywords: bladder dimensions; arm circumference; miscuffing; adult cuff

Since 1896 when Scipione Riva-Rocci[1] introduced the technique of blood pressure (BP) measurement to clinical practice just a century ago, there has been discussion and disagreement as to the optimum dimensions of the bladder used to occlude the brachial artery. As we celebrate the centenary of Riva-Rocci's valuable contribution to science, perhaps it is timely for us to put an end to a controversy that has consumed much energy and research resource, and which moreover has caused an inestimable number of persons who have had their BPs measured to be incorrectly diagnosed and, as a consequence, badly managed or inappropriately treated.

In fact Riva-Rocci himself was responsible for starting the whole affair. When he introduced the technique of cuff occlusion for the measurement of systolic BP (SBP), he used a narrow rubber tube, not unlike the rubber tube of a bicycle tyre, which was some 5 cm wide when uninflated but narrowed considerably when inflated.[1] However, within 5 years Von Recklinghausen[2] demonstrated that the narrow Riva-Rocci cuff gave measurements that were higher than those obtained with a 12 cm wide inflatable bladder in the human arm, but not necessarily in animals with narrow limb circumferences, and he may be credited as the first to show that bladder dimensions could influence the accuracy of measurement. Thus can the source of controversy be identified.[3]

The debate has simmered ever since, boiling over on occasion, and generally showing little sign of abating. It is fair to say that a review of the sizeable literature often serves to confuse rather than clarify because of varying methodologies, such as comparison between opposite arms without reference to inter-arm differences, comparison of indirect with direct intra-arterial measurement and the use of devices subsequently shown themselves to be inaccurate, such as the London School of Hygiene sphygmomanometer. It is, indeed, a remarkable indictment of clinical science that nearly 1 century after the introduction of sphygmomanometry to clinical practice, an internationally acceptable standard for the sphygmomanometer cuff is not available. This is all the more remarkable when consideration is given to the clinical criteria which are so readily accepted whereby, for example, an individual may be diagnosed as having an illness with serious prognostic implications on the basis of 5 mm Hg demarcating normotension from hypertension. A decision to treat, or otherwise, with antihypertensive medication perhaps for life, is based on a measurement for which there is overwhelming evidence from the literature that the choice of cuff may introduce an error well in excess of 5 mm Hg.

It is apparent from the official recommendations from a number of countries, that those vested with the responsibility for drawing up such recommendations, are faced with the dilemma of serving clini-

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cal science by making BP measurement as accurate as possible on the one hand, while establishing guide-lines that are feasible in clinical practice on the other. A compromise is invariably reached which tends to favour clinical expediency rather than accurate measurement for the individual. BP measurement is the rock on which virtually all clinical decisions relating to the diagnosis and management of hypertension are based, and yet even in research, where the standard of BP measurement might be expected to be impeccable, the technique is disregarded.[5] This review of the literature, which concentrates on the last 50 years, will permit a proposal which could end the controversy.

Literature review

The 1950s

Before the 1950s little attention was given to the influence of bladder length on the accuracy of BP measurement. Apparently, the view prevailed that, as long as an extremity was completely encircled by some inextensible cuff material, the length of the inner bladder was of much less importance than its width.[6] The standard bladder in clinical use was 12 × 23 cm in spite of World Health Organisation (WHO) recommendations that the bladder should completely encircle the arm.[7,8] Early workers in sphygmomanometry[2,9–11] were agreed that a minimum bladder width of 12 cm was desirable for adults arms and a number of workers showed that bladder width was a significant influence on BP measurement.[12–14]

Simpson, who reviewed the growing literature of this period was of the opinion that using a cuff with an inflatable bladder 12 × 35 cm yielded the best results, defining as 'best' the bladders which showed the least intersubject variation and gave reasonable correlation with direct pressure.[6] Official recommendations in the 1950s were conflicting but a critical analysis of the literature at this stage would tend to support the WHO recommendation for a bladder 14 cm wide and long enough to completely encircle the arm.[8]

The 1960s

The classic experimental work of King[15] in 1967 dominates the literature of the 1960s. He enunciated the principle, based on his experimental work, that provided the cuff was 12–13 cm wide, increasing the width had little effect provided bladder length was sufficient to completely encircle the arm. In an extensive review of the literature, he concluded that many earlier studies were difficult to evaluate as the length of the bladder and arm circumference had not been standardised. As a result of his experiments, he concluded that greater accuracy with a reduction of random errors was achieved with longer bladders, and he recommended a cuff containing a bladder 42 cm long, a recommendation that did not go unchallenged.[16]

Sir George Pickering,[17] in his classic book published in 1968, returned to Von Recklinghausen's recommendation for a standard bladder of 13 × 30 cm² and deplored the fact that manufacturers no longer produced cuffs with bladders of these dimensions. He added that an inappropriate bladder was the commonest source of error in BP measurement.

King's recommendation for a bladder measuring 12–13 cm wide by 42 cm also acknowledged the fact that many adult arms simply would not accommodate bladders of greater width without encroaching on the antecubital fossa and thereby interfering with auscultation.[15] This difficulty has also been encountered by other workers.[18,19]

The 1970s

The 1970s belongs to Geddes. In his classic monograph, published in 1970, the literature is reviewed comprehensively, and from this review he concluded that the American Heart Association (AHA) recommendations for a bladder 20% wider than the diameter of the arm is correct, but as it is easier to measure arm circumference, this recommendation should be restated as a requirement for bladder width to be about 40% of arm circumference.[20] With regard to bladder length, Geddes found the literature inconclusive and stated: 'As it stands now, there appears to be no general agreement on the optimum length of the pneumatic cuff. The important fact, however, is that cuff pressure must be evenly communicated to the underlying artery. To attain this goal, the cuff (if short) should be carefully placed over the artery to be compressed; if long, the risk of misalignment is reduced'.[20] In a later review, Geddes and Tivey,[21] concluded that there was well-documented evidence that an excessively narrow cuff overestimated BP and that underestimation occurred with an excessively wide one. However, they could not determine the optimum cuff width in relation to arm circumference from the literature other than to show that the cuff width/arm circumference ratio ranged from 0.4 to 0.6 and their recommendation was that this should be 0.4. The work of Geddes influenced the 1981 American Heart Association recommendations which suggested bladder widths of 11, 13, 17 cm for measurement of BP in adult arms so as to provide a range of cuffs containing bladders wide enough to cause no more than a mean error of 5%.[22] Maxwell[23] criticised these recommendations. He pointed out that quite apart from the fact that such cuffs were not available commercially, the AHA had misinterpreted Geddes data so that the recommended arm circumference range for each cuff width was skewed to the left towards narrower arms, thus resulting in underestimation of BP with an error exceeding 5%.[23]

In 1975, the *British Medical Journal* took what has, unfortunately, become an all too familiar compromising attitude when it declared that though the usual standard cuff of 12 × 23 cm was too short and that a 12 × 35 cm cuff would be a better standard 'it seems unlikely to be followed widely in Britain, and we must accept that there is generally a small error'.[24] This in spite of growing scientific evidence that the most accurate measurements were obtained with a bladder that completely encircled the arm[25] and that the AHA bladder recommendations produced a narrow cuff effect resulting in overestimation of BP.[26]

The third revision of the AHA recommendations, published in 1980,[22] recommended a bladder 12 to 14 cm wide with a length approximately twice bladder width. It was concluded that such a bladder would nearly encircle most adult arms and minimise the risk of misapplication. The final recommendation was for three cuffs for measurement of arm BP in adults.[22]

The 1980s and 1990s

In 1982 Maxwell and colleagues performed a major study in 1240 obese patients attending a weight reduction clinic, in whom they performed replicate BP measurements at clinic visits using cuffs containing the standard, large and thigh bladders.[23] The methodology of this work may be faulted, therefore, in that calculated mean BP might have been influenced by the phenomenon of regression to the mean[27] (though the large numbers of measurements would tend to correct for this error) and the effect of weight reduction (and therefore decrease in arm circumference) over time does not appear to have been considered. Mean readings of systolic and diastolic pressure were consistently higher with the standard bladder than with the large bladder, and the differences rose linearly with each increment increase in arm circumference. Maxwell produced a correction formula for different cuff sizes applied to varying arm circumferences and then calculated precise numerical corrections for each cuff at various arm circumferences.[23] Whether or not these adjustments are optimum may be a matter for discussion, but the concept of considering individual BP measurements in relation to bladder size and arm circumference is scientifically attractive. Indeed, the 1988 AHA recommendations recommend using Maxwell's correction table when 'highly accurate BP measurements are necessary for research studies'.[28]

A number of studies in the past 20 years have indicated that using large bladders might lead to BP being underestimated in subjects with lean arms,[23,29–31] though this has been challenged by some workers.[32–35]

On the basis of literature reviews and recent research, the British Hypertension Society (BHS) in 1986[36] and again in 1990,[37] recommended that a cuff containing a bladder 35 × 12.5 cm should be used for measurement of BP in adults and grown children, with the proviso that a cuff containing a bladder 42 cm might be needed for very obese arms; if such was not available the centre of a 35 cm long bladder should be placed over the brachial artery to ensure as accurate a measurement as possible. The British Standards Institution (BSI) in drawing up a *Specification for aneroid and mercury non-automated sphygmomanometers* in 1990 was influenced by the BHS recommendations and was particularly drawn to the practical need for simplifying the number of cuffs required. It recommended, therefore, only one cuff for measurement of BP in adults, namely, one containing a bladder with dimensions 12.5 ± 0.5 × 35 ± 1 cm.[38] Support for the BHS and BSI recommendations was provided by a number of studies.[31–35] Beevers,[39] reviewing the topic of cuff sizes in 1990, concluded, on the basis of population data drawn from clinic attendees and the INTERSALT project, that the standard bladder (12.5 × 23 cm) would be too small for 7% of the general population and 15% of hypertensive subjects, and that the recommendation of the BHS for a single adult cuff containing a bladder 12.5 × 35 cm would almost eliminate the problem of miscuffing. He also pointed out that increasing bladder width to 15 cm was unsatisfactory because such cuffs were difficult to apply in subjects with short upper arms and those with prominent biceps muscles.

Official US and UK recommendations in the 1980s and 1990s

US: In its 1988 revision of recommendations, the AHA moved away from recommending a series of cuffs with different sized bladders to basing selection of the appropriate cuff on the individual characteristics of the arm in which pressure is to be measured.[28] These recommendations, which are not as clearly defined as previously may be interpreted as follows: firstly, the correct bladder width should be established by multiplying the width of the bladder by 2.5 and if this figure is not greater than the measured arm circumference, width may be taken as adequate. However, length cannot be ignored and this should be at least twice the width. The recommendations state: 'when highly accurate BP measurements are necessary for research studies, arm circumferences should be measured and corrections made' from Maxwell's Correction table.[23]

In 1986 the Association for the Advancement of Medical Instrumentation recommended that: 'the bladder shall be long enough to extend at least halfway around the largest-circumference limb for which it is intended. The width of the bladder shall be at least 0.38 times the circumference of the largest limb for which the bladder is intended'.[40] In its revised version in 1994, which is now the American National Standard, the recommendation is for a bladder the length and width of which 'shall be 0.8 times and minimally 0.37 times (optimally 0.40 times) the circumference of the limb at the midpoint of cuff application'. This recommendation was based on 'a compromise of the long-standing controversy of optimal bladder dimensions'.[41]

The American Society of Hypertension recommended that bladder length should nearly or completely encircle the arm and that bladder width, which was less important than length, should be at least 40% of the arm circumference.[42]

The AHA revised its recommendations in 1993.[43] Influenced by the work of Ratsam *et al*[44] it was recommended that the width of the bladder should be 40% the length, at least 80% of arm circumference in adults and 100% in children. On this basis, four cuffs were recommended for adults: (1) small adult – 10 × 24 cm (for arm circumference 22–26 cm); (2) adult – 13 × 30 cm (for arm circumference 27–

34 cm); (3) large adult – 16 × 38 cm (for arm circumference 35–44 cm); and (4) adult thigh – 20 × 42 cm (for arm circumference 45–52 cm). The recommendations admitted that it would not be feasible for every examiner to have all the requisite cuff sizes but it 'strongly recommended that the practitioner have several sizes available to meet the needs of the population served'. The BHS recommendation for a single adult cuff was criticised on the basis that such a cuff could led to systematic underestimation or overestimation of BP when the ratio of bladder to arm circumference was different from 0.40.[43]

UK: The BHS[36,37] and BSI[38] each decided to recommend only two cuffs for routine clinical use in adults and grown children with the proviso that for very large arms care should be taken to ensure that the centre of the bladder is placed over the brachial artery. All cuffs should be imprinted with a clear white line indicating the centre of the inflatable bladder. Furthermore, consideration has been given by the BHS, to the availability of non-standard cuffs in clinical practice. For example, in an American study an inadequate cuff was used in 32% of hospital BP measurements, the use of too small a bladder being accountable in 84% of cases.[31] In an Irish study of hospital and family practice over half the cuffs examined had bladder widths less than the recommended size and 94% had bladders shorter than 24 cm.[45] In a postal survey of 94 general practitioners in England only 32 reported having access to cuffs larger than the standard size.[46] A number of manufacturers now provide a cuff containing a bladder measuring 12–13 cm × 35 cm but its use is the exception rather than the rule.

What lessons can be gleaned from the literature?

The literature on the issue of bladder dimension, however large and however conflicting does yield data that permits some principles to be stated. First, longer and wider bladders give more accurate BP measurements than bladders that are too short or too narrow for the circumference of the arm to which they are being applied. Second, a cuff containing a bladder that is too narrow or too short (or both) will result in normotensive subjects being diagnosed as hypertensive, and bladders that are too wide or too long (or both) will result in hypertensive subjects being diagnosed as normotensive. Third, the prevalence of arm circumferences in different populations can vary considerably and the use of cuffs containing bladders suitable for one population may result in errors in another, leading to inaccurate diagnosis for individuals and inaccurate prevalance estimates in population studies. Finally, the only way to resolve the cuff controversy is to devise a cuff that contains a bladder which can be adjusted simply and efficiently for all adult arms.

Longer and wider bladders are best?

From the literature it is evident that wider and longer bladders give pressures that are lower than with smaller bladders, and that these pressures are probably closer to true arterial pressures. There has been much confusion concerning the influence of a width greater than 12 cm when the bladder completely encircles the arm. Also it was not evident until recently that disproportionately large bladders underestimate BP. Recently, two studies applying modern statistical methods to examine the difference between cuffs containing large and small bladders, confirmed that larger bladders give lower pressures than the standard bladder[47,48] with the magnitude of difference being as great as 14/12 mm Hg.[48] As larger bladders did not underestimate BP in subjects with lean arms in one of these studies, the authors call for the large cuff to be used routinely in the US.[48] Indeed, such had been the reasoning of the BHS[37] when it recommended that a cuff containing a bladder 35 × 12.5 cm should be used for measurement of BP in adults and grown children, with the proviso that a cuff containing a bladder 42 cm might be needed for very obese arms, and that if such was not available the centre of a 35 cm long bladder should be placed over the brachial artery to ensure as accurate a measurement as possible.

Overcuffing and undercuffing – underestimation and overestimation of BP

The literature also gives an insight into the magnitude of error associated with miscuffing both in terms of pressure differences and attempts have been made to extrapolate the magnitude of error to the population as a whole. One issue that needs to be addressed is that if cuffs with large bladders give more accurate readings than cuffs with small bladders, is there any reason why we should not propose a cuff containing as large a bladder as possible for all adult arms? Could such a cuff underestimate BP in lean arms? A most important finding in Maxwell's work was, not so much the fact that in moderately obese subjects (arm circumference 33–41 cm) using a regular (ie inappropriately small size) rather than a large cuff (ie correct size) incorrectly classified 37% of the normotensive subjects as hypertensive, but that the use of a large cuff rather than a regular cuff in patients with arm circumferences less than 33 cm misdiagnosed 30% of truly hypertensive subjects as normotensive.[23] In other words, this study confirmed that the larger the bladder the lower the pressure, and therefore the importance of using an appropriately sized bladder in obese subjects, but it also supported evidence from earlier studies that in subjects with leaner arms the use of an inappropriately large bladder may give excessively low pressures thereby leading to misdiagnosis of normotension in patients who are truly hypertensive. The practical relevance of the issue of underestimation of BP whereby patients with hypertension can be misdiagnosed as normotensive by using cuffs containing bladders suitable for normal or obese arms in subjects with lean arms, has also been raised by Arcuri and colleagues especially in populations with particularly lean arms, such as Brazilian females.[29,30] Applying the AHA recommendations in a population of 900 Brazilians, the standard cuff resulted in an underestimation of 12.7 mm Hg for systolic pressure and 7.7 mm Hg for diastolic pressures.[30] On the basis of these findings, it was suggested that use of a bladder suitable for western arms in a Brazilian population may have led to underestimation of the prevalence of hypertension.[29] The concept that using a cuff containing too large a bladder might lead to underestimation of BP has been challenged by a number of workers who have failed to show that a large cuff underestimates BP in subjects with lean arms.[32–35]

Estimates of the magnitude of error, both from undercuffing and overcuffing have also been made. It has been estimated, for example, that using too small a bladder may result in an error as great as 30 mm Hg in obese subjects[12] with average differences ranging from 3.2/2.4 to 9.4/7.7 mm Hg in one study,[23] to average 12/8 mm Hg and 8.5/4.6 mm Hg respectively in others.[16,31] The error introduced by using a cuff containing too large a bladder has been estimated to average 12.7/7.7 mm Hg in a Brazilian population[30] and Manning has concluded that underestimation of BP may range from 10 to 30 mm Hg.[31] In hypertensive subjects in the Seychelles the magnitude of difference between a standard and a large cuff varied from about 5/3 mm Hg for lean arms to 10/8 mm Hg for large arms.[48] Estimates have also been made of the numbers of people who would be misdiagnosed because of using inappropriate cuffs. The error of underestimation of BP resulting from the use of too large a bladder is less than that of overestimation with too small a bladder. On the side of overestimation of BP with too small a bladder these estimates range from 14%[33] to 37%.[23] It has been estimated that 300 000 adults in England and Wales might have been treated unnecessarily as a result of overestimation of BP resulting from the use of too small a bladder.[35] If the conservative Swedish estimation of £40 as being the annual cost of treating a patient with hypertension[49] is applied to these figures an unnecessary expenditure of £12 million per annum is incurred. It has been estimated that some 12% of men and 24% of women in the Seychelles would be diagnosed erroneously as hypertensive using a standard rather than a large cuff.[48]

Prevalence of arm circumference

One of the surprising weaknesses to emerge from this survey of the literature is, that whereas much energy and thought has been applied as to whether a long or a short bladder is best, virtually no attention has been directed towards the characteristics of the arms in which BP is being measured. Recent papers have begun belatedly to ask the empirical question that should have motivated much of our reasoning in this controversial area, namely what is the prevalence of the arm circumference in the population in which BP is being measured? In fairness to early workers, there were occasions when the beam of enquiry was focused on the issue. King[15] found that a 26 cm long bladder encircled the arm in only 30% of a general adult clinic population of both sexes and all ages in which the largest arm measured was 42 cm. Conceico and colleagues[50] estimated the distribution of arm circumference in 500 hospital patients and showed that 75% of arm circumferences were between 24 and 31.5 cm and that a bladder 36 cm long would encircle 99% of arms. In a smaller sample of 167 patients attending an outpatient clinic 94% of arm circumferences were between 24 and 42 cm.[31] In an ethnically mixed sample of 209 men and women 11% had arm circumferences greater than 34 cm and 64% had arm circumferences less than 28 cm.[46]

In an analysis of over 1300 male and female Irish subjects ranging in age from 17–80 years, the minimum arm circumference for the group as a whole was 17.5 cm, the maximum being 46 cm with a mean arm circumference of 30.2 (±4) cm. In females aged 17–29 years the mean circumference was 27 cm *vs* a male circumference of 30 cm in the same age group. Females overall were within 1 cm of male arm circumference.[51] If the AHA criterion that a bladder should be long enough to encircle at least 80% of the arm is applied to the Irish population, a bladder measuring 26 × 12 cm would correctly cuff 79% of arms in this population, and incorrectly cuff 21% of arms, 10% from undercuffing and 11% from overcuffing. Using a bladder with dimensions recommended by the BHS[37] and BSI[38] (12 × 35 cm), only 6% of arms would be correctly cuffed with 94% being overcuffed and none being undercuffed.[51] All in all, these demographic features suggest that the optimum bladder dimensions should be recommended according to the arm circumference of the population for which the recommendation applies, and that current recommendations for bladder length may be excessive, resulting in overcuffing in the majority of the population.[52] From the data available it can be estimated that the average European arm circumference is 30 cm, and that 30–40% of the adult population will have arm circumferences >28 cm which is the upper limit for which the standard 12 × 23 cm bladder is adequate according to AHA recommendations:[28] (80% of circumference). Put another way, the so-called 'standard' cuff (12 × 23 cm) is only adequate for about 60% of the adult population. The consensus from the literature seems to suggest, therefore, that a cuff containing a bladder 12 × 35 cm would give accurate BP measurements only in adults with arm circumferences measuring 35–42 cm. However, if this bladder is used in subjects with arm circumferences below 35 cm there will be an error due to underestimation of BP. It might be argued, of course, that as so many factors – for example the alarm reaction, white-coat hypertension and regression to the mean – mitigate to give erroneously high BP measurements that a tendency to underestimation may be no bad thing. In subjects with arm circumferences above 42 cm, an error due to overestimation of BP will occur with a cuff containing a bladder measuring 12 × 35 cm, and this may have more serious consequences in terms of misdiagnosis. It would seem appropriate, therefore, to have available a bladder of a larger size for very obese arms, such as the thigh cuff, and a smaller bladder, for medium sized children (8 × 18 cm) and subjects with very lean arms. As a consequence of these findings, it has been suggested that rather than recommending one large adult cuff containing a bladder measuring 12 × 35 cm, that three cuffs containing bladders with the dimensions 12 × 26 cm for the majority of adult arms, 12 × 40 cm for obese arms, and 12 × 18 cm for lean adult arms and children, should be available,[52] and so we retrace our steps back to the unrealistic solution of providing a range of cuffs for clinical practice.

A solution for the 21st century?

A number of issues emerge from this review of the literature which can guide us in enunciating policy for the next century, in the hope that we can avoid the confusion of the past. It is abundantly clear that the standard cuff measuring 12 × 23 cm is inadequate for many subjects and that as result high BP is being overdiagnosed in many people leading to misdiagnosis and inappropriate management which often results in unnecessary prescribing of antihypertensive medication. A number of solutions have been tried over the years to overcome this problem and none has been ideal; these have included various correction formulae, having a range of cuffs available, and, as recommended by the BHS,[37] the use of a single cuff that would encircle most adult arms. This approach, although flawed by virtue of the error introduced by overcuffing, is the one most likely to provide a solution to the problem. The clinical reality is that though the inaccuracy of measurement associated with using an inappropriate cuff has been known since the beginning of the century, and that this fact has been stressed by various national bodies in their recommendations, in clinical practice arm circumferences are not measured, the standard cuff containing a bladder with the dimensions 12 × 23 cm continues to be the most widely used and a range of cuffs is not a realistic proposal.[53] Indeed the recommendation from the AHA that physicians should have several cuffs available, though deriving from sound principles ignores this state of affairs both in general and hospital practice. Various methods of labelling or marking cuffs have not been successful, and will, at best, indicate that another cuff is required. A way must be devised, therefore, for designing a cuff that will suit the majority of arms regardless of the physical characteristics of the arm. Such a cuff must be reasonably priced, easily applied to the majority of adults arms, contain a bladder that completely encircles the arm without either overcuffing or undercuffing and its width should be least 13 + 1 cm so as to avoid undercuffing in relation to width but it must not be too wide to be applied easily to the arm.

A cuff containing three inflatable bladders of varying dimensions has been designed to permit the choice of the most suitable bladder for the arm in which pressure is being measured (Tricuff, Pressure Group AB, Sweden).[47,54,55] In one evaluation comparisons were made between pressures measured in the same arm with the Tricuff containing bladders with dimensions 9 × 26 cm, 12 × 37 cm, and 15 × 46 cm and a cuff containing a bladder 12 × 35 cm, and direct arterial measurements in th opposite arm in patients whose inter-arm differ ences did not exceed 10 mm Hg and whose arm cir cumferences ranged from 20–41 cm.[54] The Tricuf tended to underestimate systolic pressure and th standard cuff to overestimate diastolic pressur compared to intra-arterial pressure. In a recent stud Bovet *et al*[47] comparing a standard cuff with th Tricuff in hypertensive subjects in the Seychelle with varying arm circumference, showed that th Tricuff gave lower measurements than the standar cuff, and that this difference increased as did th arm circumference being of the magnitude of abo 5/3 mm Hg for arm circumference of 30–31 cm; an 10/8 mm Hg for arm circumferences greater tha 36 cm. If 95 mm Hg was taken as a decision cut-o figure, 40% of subjects who were at or above th level using the standard cuff, were below it using th Tricuff. If this figure was extrapolated to the enti population of the Seychelles the prevalence hypertension would be reduced 12% in men an 24% in women. The authors of this study conclude that the systematic difference between the standa cuff and the Tricuff was a function of cuff wid whereas the difference might have been a functi of length, or most likely both length and width co tributed to the large difference noted.[47]

The Tricuff, however, is not without problem Firstly, it is expensive and could not be afforded developing countries. Secondly, it is large a necessitates having to undress many patients so th it can be accommodated on the arm, and in practi this adds greatly to the procedure of BP measur ment and is unlikely to become part of clinical pra tice. Such is its width that auscultation can be int fered with because the stethoscope has to be plac under the cuff.[55] Moreover, in populations w short arms it will be difficult to apply to the arm One surprising feature in a study by Stolt and c leagues[54] was the fact that in subjects whose arm c cumferences were in the range 22–31 cm for wh the standard cuff would have been suitable, bet results were obtained with the Tricuff when a bla der of similar dimensions was in operation, raisi the possibility that the firmer texture of the Tric may have been a contributory factor. That the t ture of the material of the cuff enclosing the infl able bladder might also be a factor affecting accura of measurement was made as far back as 1942[56] a later by other workers who emphasised the imp tance of preventing the bladder bulging from bel the cuff on obese arms by the provision of a stiff c backing. Ragan and Bordley[12] recommended t 'the bag should be covered with a cuff of inext sible material of such a nature that an even press is exerted throughout the width of the cuff wh lies over the artery'.[12] King[15] reviewed the subj and showed that if the error caused by using inappropriate bladder on an obese arm is due to d tortion of the bladder on inflation so that it a effectively as a narrow bladder, using a blad enclosed in a leather armlet did not remove error. The Federal Supply Service in the US p duced a standard in 1978, stipulating the quali of material to be used in both bladder and cuffs sphygmomanometers.[57] A further limitation to the Tricuff is that it is not, as claimed, a 'universal cuff' in that it cannot be used on very large (arm circumference ≥44 cm) or very lean (arm circumference ≤15 cm) arms.[47]

These problems would be obviated if cuff designers and clinical scientists came together to produce a cuff suitable for all adult arms. The scientific input would have to acknowledge firstly, that the confusion of the past cannot be perpetrated in the future and that there is sufficient evidence to suggest that a bladder which completely encircles the arm is ideal as far as length goes. When we come to the issue of width we are faced with a limiting feature of the human arm in most populations, and the reality that in practice most subjects having their BP measured are not completely undressed and the arm exposed for measurement is further limited by a rolled up shirt or blouse sleeve permitting application of a cuff containing a bladder with a width of only about 13 cm.

My proposal for what I will simply call the 'Adult Cuff' is for a single cuff suitable for all adult arms. It is based on the presupposition that provided the bladder completely encircles the arm and that cuff width is 13 ± 0.5 cm, there will be little or no error deriving from miscuffing. The recommendations are for a bladder measuring 13 ± 0.5 cm wide and 50 ± 1 cm long but capable of being reduced to suit the individual dimensions of the arm. The material of the bladder could be such as to allow it to serve as the cuff, ie a 'cuffless bladder' (see Figure 1). The unique feature of the proposed bladder is dependent on a clipping bracket which closes the inflatable bladder when the arm has been completely encircled. The bladder can therefore be adjusted for the individual arm regardless of arm circumference. The use of a bladder with these dimensions would avoid miscuffing in the majority of adult arms, whether the arm was lean or large. Even in those subjects with very large arms, the error introduced by the width of the bladder being inappropriate would be negligible when the bladder completely encircles the arm. In proposing the 'Adult Cuff', I do so in the hope that cuff manufacturers will see the virtue in developing it for clinical practice.

In conclusion, this review illustrates a century of confusion and a state of affairs that should not be permitted in a clinical discipline that has pretensions to being considered 'scientific'. If we are not to perpetuate the confusion and if we wish to re-establish the scientific credibility of BP measurement, an examination of the literature should enable us to devise a solution that will secure the integrity of the data on which we will base our diagnostic, epidemiological and prognostic decisions in the next century.

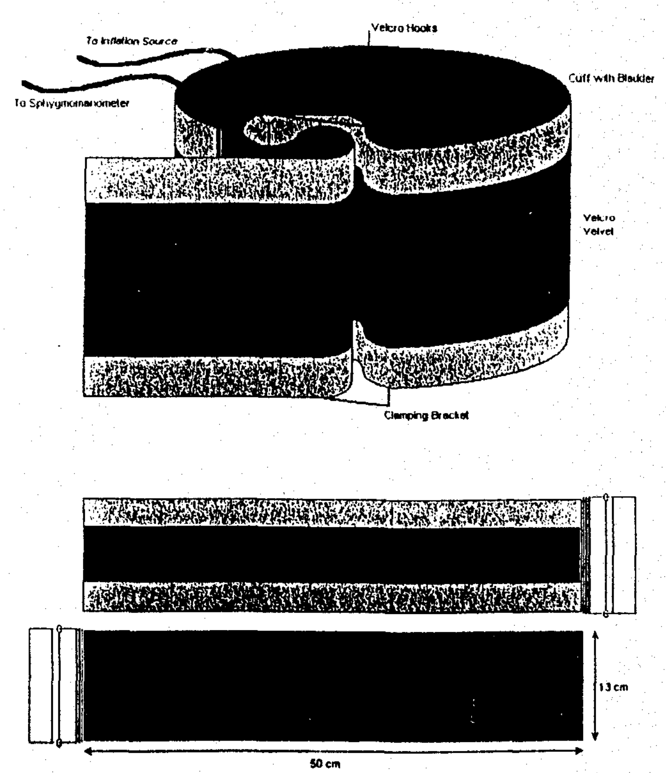

Figure 1 Diagram of the 'Adult Cuff'.

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