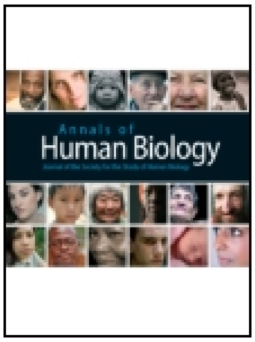

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REVIEW

British growth charts for height and weight with recommendations concerning their use in auxological assessment

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Summary. *Primary objective*: To review the appropriateness of current British growth charts for height and weight.
Methods and procedures: A review of their structure and function in the context of the problems posed by (1) secular trends for increasing size, (2) the external validity of source samples, (3) differences in the design and application of cross-sectional and longitudinal charts, and (4) the clinical significance of differences between current charts.
Main outcomes and results: Charts pre-dating the Freeman *et al.* 1995 and the Buckler–Tanner 1995 charts should be considered obsolete for the purposes of growth assessment on a sample or individual basis. Either the Freeman or the Buckler–Tanner chart is suitable for screening, surveillance or monitoring prior to adolescence but the Freeman chart is recommended for screening and surveillance of *samples* of children *throughout* childhood and adolescence. When comprehensive growth and development data are available it is advantageous to use the Buckler–Tanner chart *during* adolescence for the diagnosis and monitoring of *individual* children.

1. Introduction and historical background

The UK has had a long and distinguished part to play in the history of the development of charts to assess human growth and development. The publication of the Tanner–Whitehouse charts of the 1960s (Tanner, Whitehouse and Takaishi 1966) achieved the status of a 'citation classic' because they were the first to elucidate in detail the techniques required to construct growth charts from raw data. Constant updates, modifications, and new charts using variables other than height and weight appeared frequently and most were influenced by the pioneering work of Tanner and his associates. More recently the LMS methodology developed by Professor Tim Cole is being used both nationally and internationally as the preferred technique to develop accurate centiles from growth survey data. Thus the tradition of innovation and excellence in growth chart research continues. With it comes a need to critically examine what charts are being produced and their suitability for a changing British population. In addition, it is apparent that confusion may well exist outside the UK given that in addition to the 'international' NCHS reference charts, four specifically 'British' growth charts also exist in the UK.

J. M. Tanner and R. H. Whitehouse were the first to develop growth charts for British children, which they published in the *Lancet* in 1959 (Tanner and Whitehouse 1959). Further modifications took place to produce their 1965 charts (Tanner, Whitehouse and Takaishi 1966). The sampling source for the 1965 charts was a combination of three datasets; the Child Study Centre, London longitudinal study (1948–1954), the cross-sectional London County Council survey (1959), and finally children from the Harpenden Longitudinal Growth Study (1948 onwards). Because

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of its wide dissemination and clarity of explanation the Tanner *et al.* (1966) paper formed the technical basis for research teams throughout Europe to develop their own charts. Thus in other European countries auxologists and community health teams set up large-scale cross-sectional studies involving the most appropriate stratified random sampling techniques to arrive at externally valid *national* growth charts. In the UK the 'Tanner–Whitehouse' chart, whilst not initially promoted as a universal 'standard of reference', became widely used as the national reference to assess the growth and development of both samples and individuals throughout the country. Thus whilst other countries were developing externally valid growth charts the UK was relying on a growth chart that had never claimed external validity.

In the course of time the original Tanner–Whitehouse chart was updated to become a 'clinical longitudinal chart' (Tanner and Whitehouse 1976) but it was not until 1996, 30 years after the first appearance of the Tanner–Whitehouse chart that a team, primarily from the Institute of Child Health London under the statistical guidance of Professor Tim J. Cole from Cambridge, produced an alternative, and purportedly externally valid, national chart (Freeman, Cole, Chinn *et al.* 1995). That chart went through a further modification in 1997 following a critical comparative analysis by Wright and colleagues at the University of Newcastle upon Tyne (Wright, Corbett and Drewett 1997) to achieve its present form (Cole, Freeman and Preece 1998). Almost at the same time Tanner was working with John Buckler from Leeds to update the 1976 reference and produce the latest 'Buckler–Tanner' chart (Tanner and Buckler 1997).

Thus, four sets of growth charts are currently to be found being used in paediatric health care facilities in the UK: (1) the 'Tanner–Whitehouse 1965 charts', (2) the 1976 modification of these charts to create 'clinical longitudinal standards' known as the 'Tanner–Whitehouse 1976 Clinical Standards', (3) the charts published by Freeman, Cole, Chinn, Jones, White and Preece in 1995 from data collated during the 1980s and their more recent modification to create the charts designated as 'Freeman *et al.* 1995/1 charts', and (4) the modification to the Tanner–Whitehouse 1976 Clinical Standards carried out by Tanner and Buckler in 1996 and published as a letter to the Editor of the *European Journal of Paediatrics* in 1997, described in this review as the 'Buckler–Tanner 1995 charts'.

The various revisions and updates have resulted in two charts (Buckler–Tanner 1997 and Freeman *et al.* 1995/1) that are considered by their authors to have superseded previous charts. Other 'British' charts in current use, i.e. Tanner–Whitehouse 1965 and 1976, should therefore be considered obsolete. However, no matter how forceful that recommendation, the fact remains that the previous growth charts are still widely used in hospitals, departments of paediatrics, community health departments and academic institutions and all of these venues need a rationale for the decision to replace them. The following review is offered in the hope that it will provide a rational and understandable basis for that decision.

There are four questions that are invariably posed by scientists and clinicians when faced with more than one growth chart to use in growth assessment: (1) Does the *secular trend* for increasing size and decreasing age at which puberty occurs affect the accuracy of the charts? (2) Are the charts properly *representative* of British children regardless of ethnic origin? In other words, do they possess external validity? (3) Should a *cross-sectional or longitudinal* chart be used? (4) What effect will chart type have on *diagnostic* accuracy?

2. Secular trends

Secular trends were documented for primary school children in the UK between 1972 and 1980 as 0.5–1.5 cm per decade (Chin and Rona 1984, Chinn, Rona and Price 1989). The National Study of Health and Growth, following analysis of data from 1972 through 1986, reported that this trend appeared to have ceased by 1980. It would seem likely, therefore, that positive secular trends leading to greater height-for-age and weight-for-age are likely to have been evident in some parts of the country up to 1979 but there has been little or no change since that time. Both the Freeman 1995/1 and the Buckler–Tanner 1997 charts should be free of problems due to the secular trend because in both cases the source samples were assessed after 1980. Charts based on earlier samples will be contaminated by secular trend problems.

3. External validity

External validity involves two issues: (1) the *morphological similarity* of the source samples to the sample under investigation, and (2) the *numerical validity* of the sample size in appropriately reflecting accurate *population* parameters. This issue is fundamentally important, probably more important than that of secular trends, in that the effect of variations in height between different areas of the country are likely to be greater than variations due to secular trends because different areas of the country represent proxy measures of socio-economic status.

The Buckler–Tanner chart is based on an update of the previous 1965 and 1976 charts using the amalgamated dataset from Freeman *et al.* (1995), and data from Buckler's 1980s longitudinal study of 198 Sheffield adolescents (Buckler 1990). The original Tanner–Whitehouse datasets were composed of small longitudinal samples of about 80 children from the Child Study Centre Study (1948–1954) and the Harpenden Growth Study (1948–1972), and a large cross-sectional sample of about 1000 children per age and sex group from the 1959 London County Council survey. Buckler and Tanner did not establish external validity for the current charts although claims of some degree of representativeness have been made (Tanner and Buckler 1997). Cole *et al.* (1998) maintain that the collation of 12 data sets used for the Freeman *et al.* 1995/1 charts is nationally representative. The datasets were required to be 'recent, cross-sectional, representative of Britain and of high quality'. Cole *et al.* (1998) admit that 'in practice most but not all of these aims were met'. Sample sizes by sex and age reported by Freeman *et al.* (1995) are between a minimum of 139 for pre-term girls to a maximum of 1264 for 5-year-old girls and 9-year-old boys.

In the absence of nationally representative samples, both of the current growth charts are adversely affected by questionable external validity but both sets of authors claim that a lack of differences with other convenient datasets demonstrates that the effect is minimal. Tanner *et al.* (1996a, b) choose to use a lack of differences with data collected in Oxford at young ages and 'Services' data at older ages to suggest external validity. Freeman *et al.* (1995) do the same by including the Whittington data set which they then 'verify against a representative sample of children from Newcastle' to demonstrate that they are 'clinically not different'. Combining existing datasets, rather than obtaining an externally valid national sample, is viewed by all of those involved in growth chart design as being less than ideal. However, Freeman *et al.* (1995) also comment that this strategy 'was the only realistic alternative given the cost of obtaining a new national sample'.

Are the charts also valid for other ethnic groups? Current international opinion based on empirical evidence from South America and Africa holds that ethnic differences in growth are minimal when compared to the effect of socio-economic differences (Martorell and Habicht 1986, WHO 1995), i.e. the vast majority of differences in growth between ethnic groups are for socio-economic rather than genetic reasons. Calls by some UK researchers for separate growth charts for different ethnic groups (Chinn, Price and Rona 1989) increase the likelihood that socio-economic differences will be ignored in favour of an ethnic, i.e. genetic explanation for growth differences. Such an explanation should be accepted with a great deal of caution in view of the fact that children of different ethnic groups, when reared in similar socio-economic, nutritional and health-care circumstances, appear to demonstrate similar growth curves. Chinn, Cole, Preece and Rona (1996), for instance, published estimates of differences between the Freeman 1995/1 charts and different ethnic groups within the UK for whom there was limited data for birthweight and growth between 5 and 11 years of age. These included samples of African, Afro-Caribbean and Gujurati, and children from the 'Indian sub-continent' excluding those from Urdu- and Punjabi-speaking homes. The advice was to shift the published centile lines upwards by one division (0.67 Z-scores or Standard Deviation Scores (SDS)) for Afro-Caribbeans and downards by a similar amount for most Indian subcontinent groups'. Approximately a two division downward adjustment would be necessary for Gujurati groups. However, the authors emphasized the problems of suitable adjustment and interpretation created by variable secular trends in succeeding generations of immigrants of all ethnic groups, and the confounding effect of intermarriage.

4. Chart design: longitudinal vs cross-sectional

In order to make an informed choice of chart type it is fundamentally important to be clear about the differences in design and application of cross-sectional and longitudinal charts. Cross-sectional studies are, by definition, designed as an assessment of a group of children on one measurement occasion. Longitudinal studies are designed to reassess the same group of children on more than one occasion. When the resulting data are appropriately analysed and presented in the form of cross-sectional or longitudinal growth charts it is clear that prior to the adolescent growth spurt there are no major differences as a result of study design, i.e. the centiles are virtually superimposed. Thereafter the differences are significant for the end user because of differences in the representation of the timing and duration of the adolescent growth spurt. The cross-sectional Freeman 1995/1 chart represents growth *as is*, i.e. the actual distribution of the chosen sample or population at different chronological ages. The longitudinal tempo-conditional Buckler–Tanner chart incorporates an adjustment to the curves at adolescence to reflect the duration of the growth spurt when peak height (or weight) velocity occurs at the average age. The aim of growth charts at adolescence is to illustrate *normal* variation in the timing and duration of the growth spurt as reflected in height or weight-for-age distance centiles. Cross-sectional data cannot be used to do this because different children are assessed at each age and no *individual* increments exist. Individual increments from longitudinal studies can be grouped by, for example, the timing of peak height velocity (PHV), to properly represent the timing, magnitude, duration and variation of the adolescent growth spurt. Cross-sectional distance charts display an adolescent growth spurt at the appropriate time but of reduced magnitude, greater duration and greater variation than longitudinal charts. Thus the growth curve of an individual child during adolescence plotted on a cross-sectional distance chart will, on average, cross centiles. Tanner and Whitehouse were the first to try to properly illustrate the adolescent growth spurt by presenting a 'tempo-conditional' velocity chart in 1976 (Tanner and Whitehouse 1976). Tempo-conditional charts are charts in which the different centiles exhibited by early and late developers in the timing and magnitude of the adolescent growth spurt have been included. By definition, early developers will on average exhibit PHV some 2 years before average developers, and late developers some 2 years after average developers. In addition, the negative correlation between age and magnitude of PHV means that early developers will have greater magnitude of PHV than average developers and late developers a lower magnitude. Thus the growth of an individual during adolescence is *conditional* on the individual's *tempo*. Theoretically, tempo-conditional charts will result in centile lines during adolescence that will be followed by individual children without 'crossing', i.e. without changing from one centile canal to another if they experience PHV at the average age of the source sample.

These differences mean that for the screening and surveillance of large samples of children, cross-sectional charts are appropriate tools but in a monitoring situation a longitudinal, tempo-conditional chart should be the preferred tool. Another way to say this is that cross-sectional charts are for screening or surveying *groups* and longitudinal charts are for monitoring *individuals*. The former are more likely to be appropriate in research situations and the latter in clinical situations. The Buckler–Tanner chart is designed as a longitudinal tempo-conditional chart and the authors maintain that it should be used only to plot the growth of individuals assessed repeatedly. The cross-sectional references of Freeman and her colleagues are by definition not based on longitudinal data and whilst they can be used to monitor the growth of children during adolescence they are more likely to exhibit centile crossing. Of course, centile crossing will occur whatever chart is being used but in tempo-conditional charts it should be less.

Preece (1998) argues that the longitudinal source sample in the Tanner charts is too small and selected to be considered as externally valid, and that, because of differences in the age at PHV, *individual* growth curves cross the centile lines whether one uses a longitudinal tempo-conditional chart or cross-sectional chart. Thus it is better to have a chart based on a large representative sample and interpret the centile crossing liberally than to have a small non-representative sample and a conservative interpretation of centile crossing. The fact that individuals will cross centiles during adolescence is generally accepted but Preece is absolutely correct in suggesting a large externally valid sample is preferred. The fact is that such a sample does not exist. It is not really surprising that Cole (1998) argues that the discussion about cross-sectional versus longitudinal charts is an 'arid controversy'. He suggests a pubertal stage-specific conditional chart that can be superimposed on the 1990 cross-sectional chart of Freeman *et al.* (1995) to account for individual growth.

5. Diagnostic accuracy

The fact that two growth charts are currently being used means that the majority of clinicians will need to know whether the continued use of one or the other chart increases the possibility of erroneous diagnosis. In other words, are there clinically significant differences between the charts? It is fundamentally important to understand that the tempo-conditional centiles at puberty in the Buckler–Tanner chart are not distance centiles in the conventional sense. The 2nd centile in the Freeman 1995/1 charts identifies the heights, weight, etc. below which 2% of the population are to be found. The Buckler–Tanner 3rd centile, conversely, is the height below which 3% of children *of average age at peak height velocity* are to be found. By applying a tempo-conditional format variability is reduced resulting in less extreme outer centiles. Thus it would be erroneous to imply abnormal growth for a child outside the Buckler–Tanner extremes but within the Freeman 1995/1 extremes.

Figures 1–4 illustrate a comparison of the 3rd, 50th and 97th centiles from the Buckler–Tanner 1995 charts with the 2nd, 50th and 98th centiles from the Freeman 1996/1 charts for height and weight in boys and girls. Note that differences in heights prior to the adolescent growth spurt are minimal and vary between ±0.5 cm. However, at adolescence the Buckler–Tanner curves accelerate more dramatically resulting in the Freeman 2nd centile and to a lesser extent the 98th centile assuming more extreme positions. This means that a child classified as tall according to Buckler–Tanner (i.e. > 97th centile) will in most cases also be tall according to Freeman (i.e. > 98th centile). However, a few more children will be referred for further investigation for short stature as a result of using the Buckler–Tanner charts than as a result of using the Freeman chart.

The comparison of weight curves (figures 3 and 4) demonstrates greater differences between the charts. Whilst the 50th centiles are not too different, the outer centiles are considerably different. In boys the increased variance of the Freeman sample has raised the 98th centile cut-off point to a level significantly greater than that of the Buckler–Tanner 97th centile implying that far greater weights are considered normal (i.e. < 98th centile) according to Freeman *et al.* than according to Buckler–Tanner. This may be of only minor significance in a situation in which a child is being assessed from a variety of perspectives, e.g. physical, physiological,

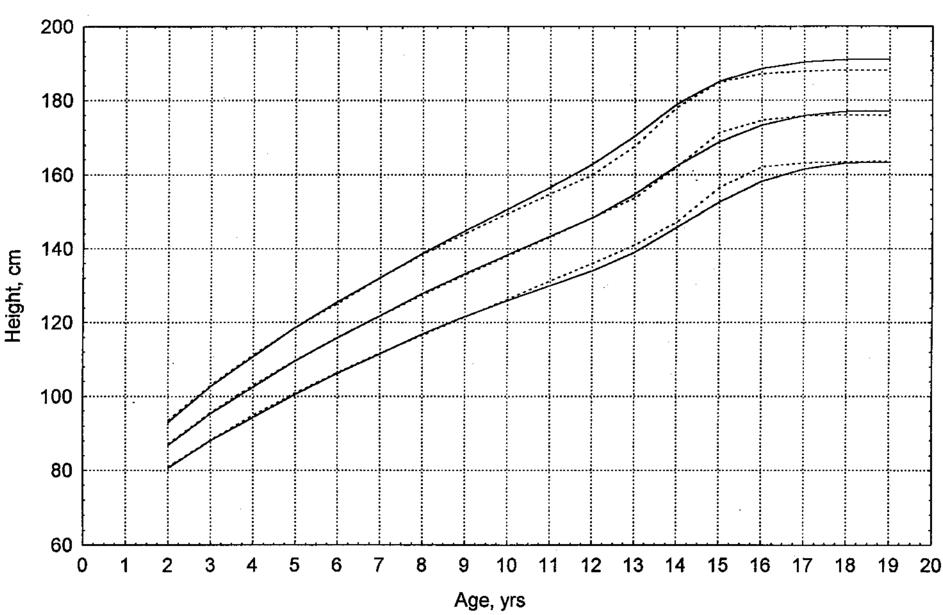

Figure 1. Comparison of the 3rd, 50th and 97th centiles from the Buckler–Tanner 1995 chart (– – –) with the 2nd, 50th and 98th centiles from the Freeman *et al.* 1995/1 chart (—); boys' height.

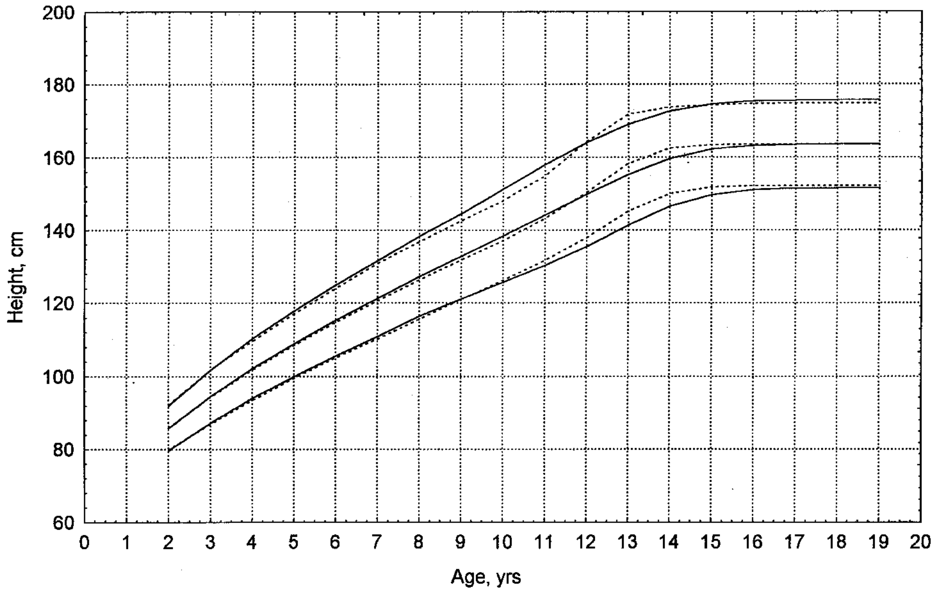

Figure 2. Comparison of the 3rd, 50th and 97th centiles from the Buckler–Tanner 1995 chart (– – –) with the 2nd, 50th and 98th centiles from the Freeman *et al.* 1995/1 chart (—); girls' height.

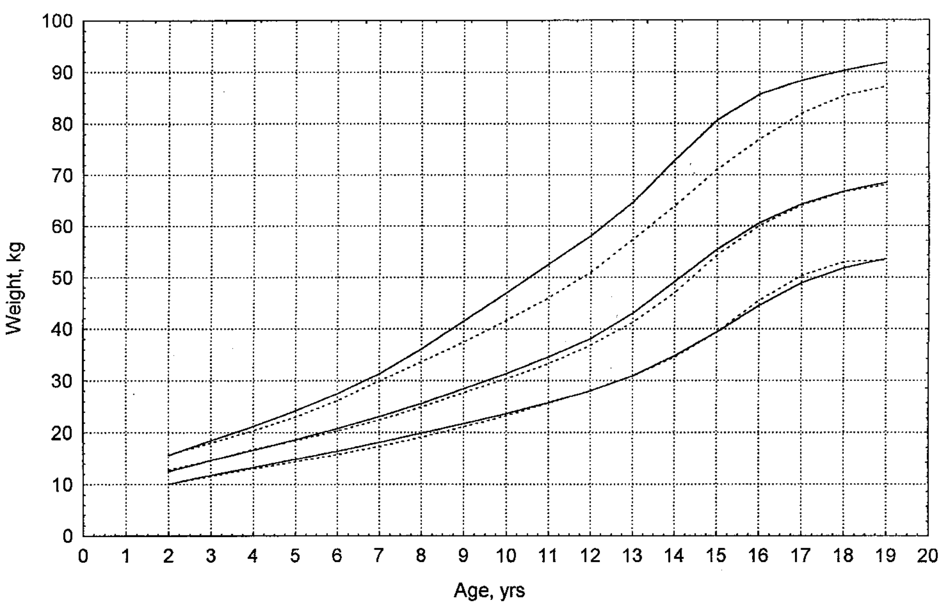

Figure 3. Comparison of the 3rd, 50th and 97th centiles from the Buckler–Tanner 1995 chart (– – –) with the 2nd, 50th and 98th centiles from the Freeman *et al.* 1995/1 chart (—); boys' weight.

psychosocial, etc. and thus in a situation in which the child's weight can be contextualized. However, it may be of far greater significance in a research setting in which the area of interest is that of the normal variation in weights for a given gender and age. In this situation the Freemen chart will classify the limits of 'normal' weight

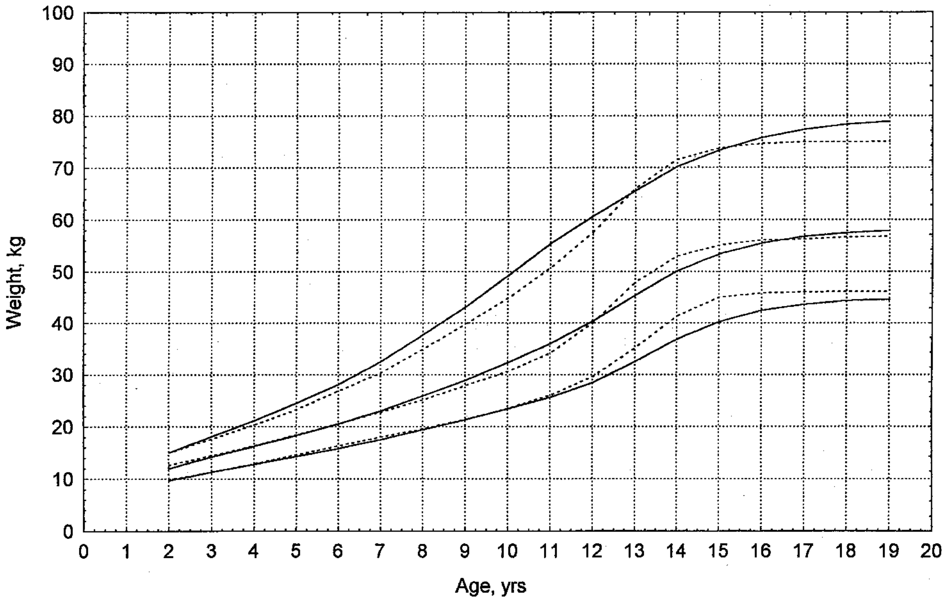

Figure 4. Comparison of the 3rd, 50th and 97th centiles from the Buckler–Tanner 1995 chart (– – –) with the 2nd, 50th and 98th centiles from the Freeman *et al.* 1995/1 chart (—); girls' weight.

as up to 8 kg greater during adolescence than the Buckler–Tanner charts. A difference of that magnitude does not seem to be appropriate and will lead to dramatic differences in the estimation of the prevalence of overweight in a sample or population. Based on the documented reference data it would seem that the Freeman chart is more likely to be externally valid in identifying the appropriate prevalence of overweight (i.e. > 98th centile) than the Buckler–Tanner chart. The comparison in girls identifies greater centile values for the Freeman *et al.* data up to 13 years of age and then again after 15 years.

6. Concluding remarks

Charts pre-dating the Freeman *et al.* 1995/1 chart and the Buckler–Tanner 1995 chart should be considered as obsolete for the purposes of growth assessment. Prior to the adolescent growth spurt the centiles of both the Buckler–Tanner 1995 and Freeman *et al.* 1995/1 height charts are so closely superimposed that no obvious practical gain results from using one chart in favour of the other. Clear differences between the Buckler–Tanner 97th centile and the Freeman 98th centile with regard to weight-for-age are disturbing in the light of concern over adolescent obesity and the recognition that adolescence is a critical period for the acquisition of obesity. It seems reasonable to suggest that there should be agreement as to the variability in weight-for-age that is deemed to be acceptable in that it is not associated with a significantly increased risk of morbidity. In any event, screening for obesity should include a combination of Body Mass Index and measures of body fat, rather than simply weight-for-age, but if the latter is to be used then the Freeman charts are the most appropriate. However, the Freeman *et al.* 1995/1 chart should be the choice as a single growth chart for the purpose of the screening and surveillance of samples of children on the grounds of larger source samples and appropriate data analysis.

Which chart to use for the purpose of monitoring the normality of an individual's adolescent growth is the most contentious of the issues with regard to the choice of chart. Cole *et al.* (1998) view the Freeman chart as being a cross-sectional reference and expect an individual's growth curve to cross centiles. Tanner and Buckler (1997) also expect centile crossing, but in addition they expect a degree of parallelism between the individual's growth curve and the early, average or late centiles depicted in their chart, i.e. they expect their tempo-conditional charts to accurately reflect the normality of the timing and magnitude of growth at adolescence. Preece (1998) and Cole (1998) quite rightly maintain the view that regardless of what chart is being used an individual's growth curve will cross the centile lines. The question, therefore, is whether the tempo-conditional centiles depicted by Tanner and Buckler are clinically helpful in identifying the child at risk of abnormal growth.

The risk of false positives is greater with the Buckler–Tanner charts. However, the collection of familial, physiological, endocrine, genetic and historical data to contextualise the growth data will reduce these risks. Proper use of the Buckler–Tanner tempo-conditional centiles requires the clinician to correctly identify the tempo of the child's development, i.e. the child must be known to be within the adolescent growth spurt and thus approaching or actually beyond the point of peak height velocity. Such a categorization is possible with supportive evidence of pubertal development having begun. Thus an adolescent curve that falls through the centiles and is not accompanied by pubertal development would be characteristic of either a late developer, or a child with abnormal delay. The actual diagnosis would only be possible from anthropometric data following continued monitoring. The early developer accelerates upwards through both the Buckler–Tanner and Freeman centiles and would display pubertal development appropriate for that timing. When comprehensive growth and development data are available the proper use of the Buckler–Tanner chart as a diagnostic and monitoring tool has significant advantages over the Freeman *et al.* 1995/1 chart during adolescence.

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Zusammenfassung. *Zielstellung:* Überprüfung der Eignung gebräuchlicher britischer Wachstumscharts für Körperhöhe und Körpergewicht.
Methodik: Überprüfung ihrer Struktur und Funktion in Hinblick auf Probleme, welche resultieren aus (1) der durch den säkularen Trend bedingten Größenzunahme, (2) der äußeren Validität der Ursprungsstichproben, (3) Unterschieden im Design und in der Anwendung von Querschnitts- und Längsschnittcharts und (4) der klinischen Bedeutung von Unterschieden zwischen den gebräuchlichen Charts.
Ergebnisse: Charts, die vor den Charts von Freeman *et al.* 1996 und Buckler-Tanner 1995 erstellt wurden, sollten hinsichtlich der Beurteilung des Wachstums von Probandengruppen oder Einzelindividuen als veraltet angesehen werden. Sowohl die Freeman Charts als auch die Buckler-Tanner Charts sind zum Screening, zum Überwachen oder zur Kontrolle vor der Adoleszenz geeignet. Die Freeman Charts werden jedoch zum Screening und zum Überwachen von Stichproben von Kindern während der Kindheit und der Adoleszenz empfohlen. Wenn umfassende Daten zu Wachstum und Entwicklung verfügbar sind dann ist es von Vorteil, die Buckler-Tanner Charts während der Adoleszenz zur Diagnose und Kontrolle bei einzelnen Kindern zu verwenden.

Resumé. *Objectif premier:* Evaluer la justesse des standards de croissance britanniques pour les courbes de stature et de poids.
Méthodes et procédures: On revoit leur structure et leur fonction dans le cadre de problèmes posés par (1) l’accroissement séculaire de format, (2) la validité extérieure des échantillons d’origine, (3) les différences de construction et d’application des courbes longitudinales et transversales et (4), la signification clinique des différences entres les courbes actuellement en usage.
Résultats principaux : L’utilisation des courbes antérieures à celles de Freeman *et al.* 1996 et de Buckler-Tanner 1995 devrait être considérée comme obsolète s’il s’agit de contrôler la croissance sur la base d’un individu ou d’un échantillon. Les courbes de Freeman comme celles de Buckler-Tanner sont valides pour contrôler, surveiller ou guider la croissance avant l’adolescence, mais celles de Freeman sont recommandées pour le contrôle ou la surveillance d’échantillons d’enfants tout au long de l’enfance et de l’adolescence. Lorsque des données complètes de croissance et de développement sont disponibles, il est avantageux d’utiliser les courbes de Buckler-Tanner pendant l’adolescence pour le diagnostic et l’accompagnement individuel des enfants.