THE THICKNESS OF THE SCALP

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CONTENTS

INTRODUCTION

A KNOWLEDGE of the thickness of the soft tissues of the scalp has often been sought because of its obvious importance in the computation of head measurements on the living from those of the dried skull or *vice versa.* No satisfactory agreement has been reached for the simple reason that great variation occurs in the thickness of these tissues and determinations have been complicated by the condition of the post-mortem or cadaveric material upon which estimates have been calculated.

The methods adopted have been two: first, direct measurement by penetration of a needle (Welcker (16), His (6), Kollmann und Büchly (8), Czekanowski (4)), and secondly, by subtraction of the measurements upon the fresh skull from those on the cadaver (Gladstone (5), Anderson (1)). Probably the latter method is the more reliable, especially for averages. The limitations of each method will be discussed later in this article. Although the subtraction method does not involve the error induced by deformation of the skin which can scarcely be avoided in direct determination, it is subject to instrumental error. This is especially true in the measurement of auricular height. Further on we shall show that it is essential to use an instrument of precision in making this observation.

Two other methods have been proposed but we cannot find that they have come into any general use. Nearly thirty years ago Welcker suggested radiographing the living head and measuring the thickness of soft parts directly upon the radiograms (17). He presented rather scanty data to indicate that the results of this method are quite comparable with those obtained upon cadavera. Later on we shall show reasons for believing that the soft tissues of the scalp are not quite the same in the dead as in the living and this alone makes us somewhat dubious of the value of measuring shadows until radiographic methods have been more accurately worked out. The other method is that adopted by Pearson in the superposition of cranial contours upon those of skulls (2). This involves the use of different individuals, perhaps belonging to quite different social grades, and was only employed in temporary default of a better mode of attack.

We have undertaken to revise the existing data upon this important problem because we feel the imperative need of conducting, upon a specific material, a complete investigation of the various features necessary for a survey of the relation between measurements upon the head and upon the skull. Although the variabilities and correlations may not differ significantly from sample to sample the means undoubtedly do vary. One may not safely compare the means obtained from a sample of heads belonging to a particular social grade with the averages of a sample of skulls drawn from another. Hitherto there has been no serious attempt to determine all the necessary data upon a single population sample. We admit that there are objections to any group which may be chosen and the population of a dissecting room is no exception. We have reason, however, to believe that there are no greater objections to a population thus selected than to any other, and this group has the apparent advantage that it can readily be worked out completely.

In previous communications the senior author has set forth the necessary reductions for skull measurements upon the Reserve material (13) and has also presented data upon shrinkage of the cranium in drying (15), a source of error which must be considered. It is true, as Czekanowski has stated (4), that the alterations due to shrinkage do not result in an individual error greater than the probable average error in any calculated determination of cranial capacity, but we cannot hold with him that the effect of shrinkage can therefore be ignored. Having then these preliminary data to hand it is plain that what we still need for a complete set of observations rendering possible the prediction of cranial diameters from the comparable diametral measurements upon the living are: first, a consideration of the thickness of the soft tissues of the scalp and, secondly, a determination of the relation between these diametral measurements taken upon the living and upon the dead. Neither problem is simple but the latter is infinitely the more difficult.

All the observations necessary for this research have been determined by the senior author in the course of our routine examination of the cadavera and skulls in the Reserve collection. The data have been collected and reduced by the junior author and checked by the senior, who is also responsible for the form of presentation of this joint communication and for all the deductions drawn.

By the method adopted in this work the personal error remains constant throughout the entire series of investigations upon cadavera and skulls and

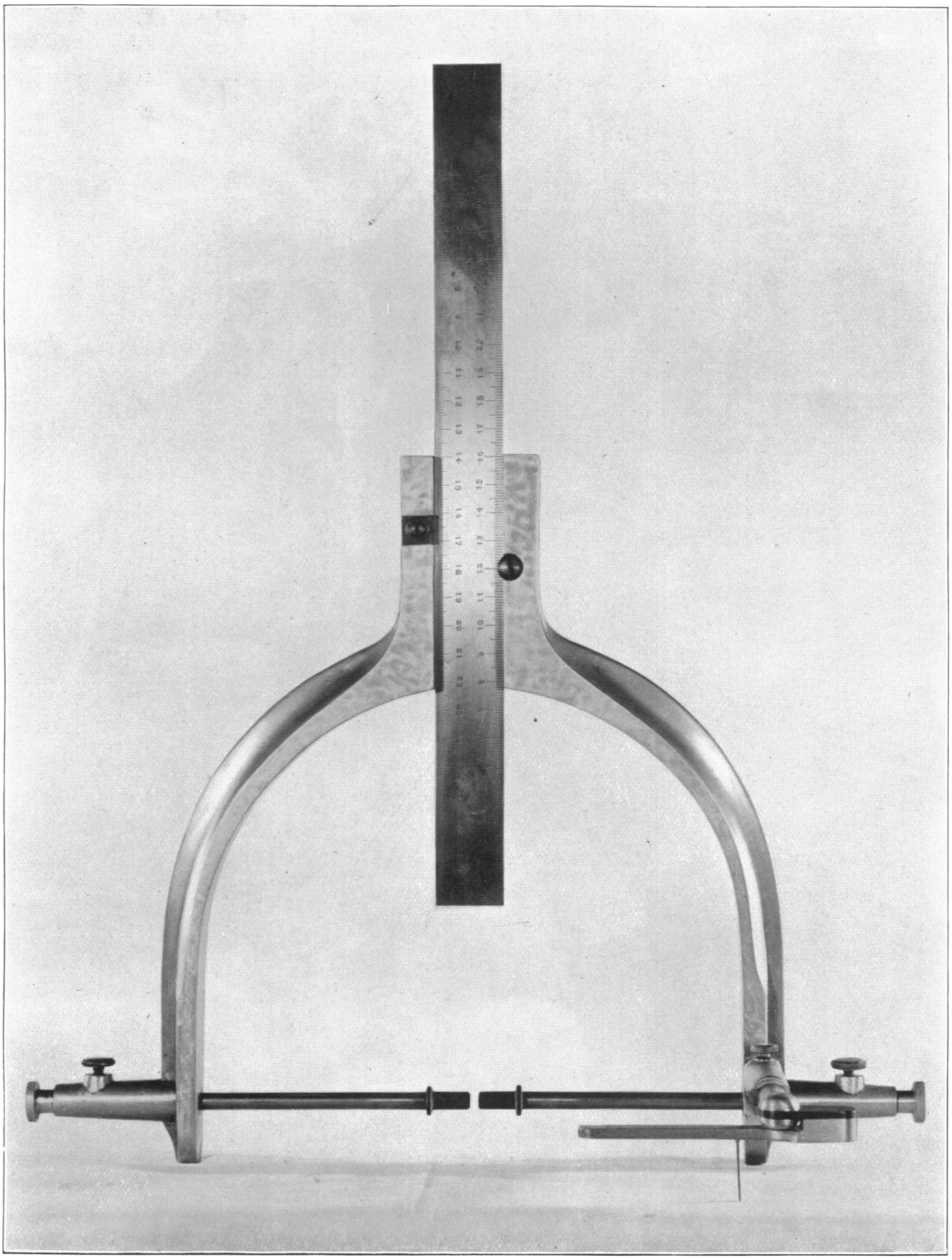

Fig. 1. The Reserve Head-spanner from the front. The ear rods are fibre tipped; the shoulders prevent the rods from penetrating too far into the ear passages. The infra-orbital gauge permits an accurate adjustment of the instrument in the Frankfort plane.

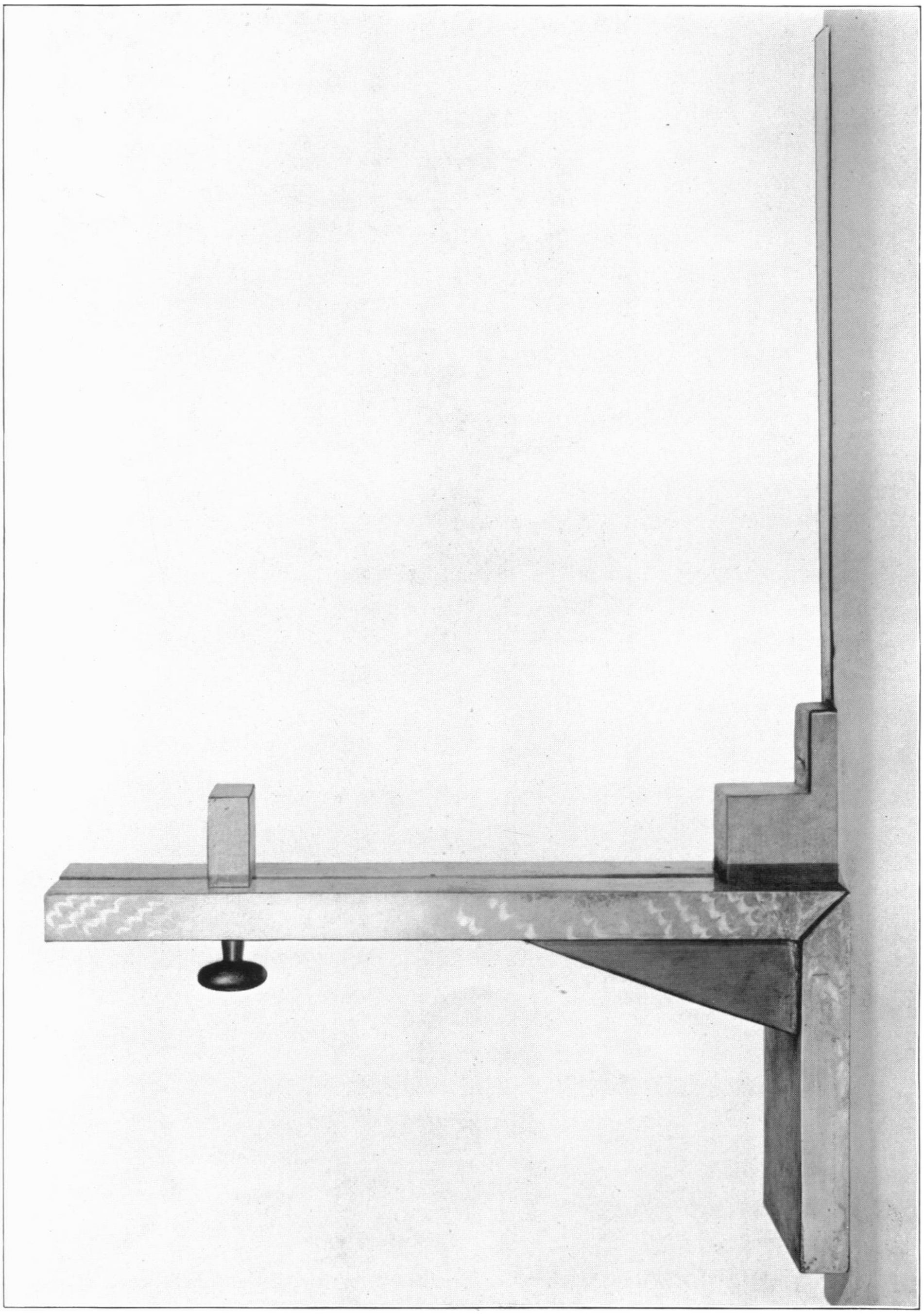

Fig. 2. The recently modified forward Cambridge Block used with the Reserve Craniostat.

A figure of the craniostat was published in this Journal, 1923, vol. LVII, p. 339. The base scale does away with the necessity of using millimetre paper. Zero on the scale is precisely under the free face of the upper measuring block. The craniostat and the hinder Cambridge block are slotted to permit the free passage of the scale. Length is read off on the scale at the point where it is covered by the free face of the hinder Cambridge block.

may therefore, for practical reasons, be discounted. For the most part the instrumental errors are known and have already been set forth. It is necessary, however, to discuss the error for an instrument which has not yet been described, namely the Reserve head-spanner.

THE RESERVE HEAD-SPANNER

The Reserve head-spanner, a modification of Gray's apparatus, is an all-metal instrument the principle of which is measurement of auricular height from the roof of the external auditory passage at right angles to the Frankfort plane. The instrument is illustrated in fig. 1. Zero on the scale is shown when the lower end of the scale is in contact with the upper aspect of the ear rods. The frame of the instrument is aluminium, the scale and rods are of steel, the tongue of the Frankfort gauge is of brass, and the rod tips of fibre. At first we made the rod tips of steel but these proved very uncomfortable in the ear passages. We next tried rod tips made from tooth brush handles but these were too brittle. The fibre tips can scarcely be called pleasant in the ear but they are the least objectionable. It is essential that the tips penetrate the ear passages sufficiently to rest against the roof of the bony canal; otherwise there is a large individual error. They cause actual distress if they penetrate too deeply. Consequently we constructed a shoulder 13 mm. from the extreme end. In using the instrument the tips should penetrate the canals sufficiently to rest in contact with the bony roof; they should not be pushed further in. The precise distance must be ascertained for each individual; the shoulder itself is not a sufficient guide. It is quite important to adjust the instrument correctly in the ear passages for the principle of our craniostat also is measurement from the roof just within the bony meatus.

The tongue of the Frankfort gauge was first made entirely of aluminium, but this metal proved too brittle. The antero-posterior rod is flattened on one side to prevent rotation and is held in position by a screw. The transverse limb moves freely in a horizontal direction by a joint permitting no vertical wobble. It is long enough for all practical purposes: if made too long it becomes inconvenient for use on narrow-faced individuals.

Once the ear rods are in position they are held securely in their bearings on the frame by the screws. The Frankfort gauge is adjusted to the lower border of the left orbit. The scale is then settled down upon the vertex and the auricular height read off directly. This instrument, like all others designed and made in the Anatomical Laboratory of Western Reserve University, may be purchased at cost on application.

RELATIVE ACCURACY OF INSTRUMENTS

The instrumental error for Flower's craniometer has previously been calculated (13) so that there is no necessity to engage in a new discussion of this instrument. For the measurement on hard surfaces the average error has been shown to amount to about 0·3 mm. either for length or breadth (13, p. 156) but in the former dimension there is a further source of error in the difficulty of orienting the head of the cadaver exactly in the Frankfort plane. This difficulty adds about 0·2 mm. to the average error in length (13, p. 156). Assuming then that it is possible to measure the dimensions as accurately upon the soft tissues of the head as upon the hard skull, an assumption perhaps scarcely justifiable but yet necessary in the circumstances, we must admit that the average dimensions in the cadaver will not be more accurate than to 0·3 mm. for breadth and 0·5 mm. for length. The error in individual cases may be five or six times that amount.

In measurement of auricular height the standard of accuracy is the dimension as ascertained on the Reserve craniostat, the average error for which instrument amounts to 0·2 mm. (13, p. 156). When first employed, our craniostat had rounded rods for the ear passages but later we gave a knife-edge to those parts of the rods entering the external auditory meatus because the constricted orifice of certain skulls failed to permit the rounded rod quite to reach the roof of the passage. For a head-spanner to be employed upon the living it is not practicable to use knife-edges and therefore the Reserve head-spanner, as designed and made by our Mr Cherney, possesses ear rods with rounded fibre ends and in addition a shoulder the object of which is to prevent the rod from penetrating too deeply into the auditory passage. In those infrequent cases in which the upper part of the meatus suddenly narrows it has not yet been ascertained whether, on the living, the knife-edge would give a smaller measurement than the rounded rod. The cases cannot be diagnosed clinically. The difference rarely amounts to more than 0·25 mm. which is within the limit of personal error. It follows therefore that any difference between the two instruments in measurement of auricular height should result in the larger figure being derived from the head-spanner.

Table I. *Accuracy of Reserve head-spanner checked against Reserve craniostat*

Auricular height in millimetres			
1	2	3	4
Date	June 2	June 1	
Skull	Head-spanner	Craniostat	Deviation cols. 3 and 4
901	107·25	107·25	0·0
910	125·0	125·0	0·0
918	108·0	107·75	0·25
926	118·5	118·25	0·25
927	106·0	106·0	0·0
928	113·75	113·75	0·0
932	110·75	110·5	0·25
951	112·0	112·0	0·0
953	110·0	110·0	0·0
996	114·0	113·75	0·25
Total deviation ...	...	...	... 1·00
Average deviation ...	...	...	... 0·1 mm.

The skulls are drying unmacerated but no appreciable change in dimensions would occur in the 24 hours between measurements.

The slight difference between results is undoubtedly due to the fact that the craniostat has knife-edges whereas the head-spanner has round rods.

Table I gives the data for measuring the accuracy of the Reserve head-spanner. The skulls used in the investigation were in process of drying and not yet macerated but no appreciable change in dimension would occur in the 24 hours between measurement with the two instruments. The table shows that the average difference in auricular height as ascertained with the two instruments is 0·1 mm. less than the instrumental error of the craniostat. Consequently the head-spanner may be regarded as accurate within the limits of possibility of the measurements. The individual difference is 0·25 mm. and in each case the larger figure is obtained on the head-spanner. This is explained by the fact that the head-spanner necessarily possesses rounded ear rods whereas the craniostat is provided with knife-edge rods. Estimating the maximum individual error as five or six times the average error, as was done in the case of Flower's craniometer, an instrument essentially less accurate than the head-spanner, the maximum would scarcely ever exceed 0·6 mm.

RELATIVE ACCURACY OF VARIOUS METHODS OF MEASURING AURICULAR HEIGHT

In measuring auricular height, three methods have been adopted. The first is a very simple one which calls for no special instrument and is a modification of the method described fully in Hrdlička's *Anthropometry* (7). A Tasterzirkel is adjusted on the head so that the bulbous extremities of its limbs rest upon the roof of the external auditory passages just within the meatus and the stem of a Gleitzirkel is used to measure the distance from skull vertex to a fixed point on the Tasterzirkel. This dimension, subtracted from the vertical distance between the horizontal passing through the upper aspects of the bulbous extremities and the fixed point mentioned above, gives the auricular height. In this method the adjustment of instruments is done by estimation so that a dimension is obtained at right angles to the Frankfort plane.

The second method is described in Martin's *Lehrbuch* (10, p. 163). One limb of the Stangenzirkel is adjusted to the roof of the left auditory passage and the other, to which the Ohrhöhenadel is affixed, is laid upon the head vertex, the relation of the stem of the Stangenzirkel again being adjusted by eye with reference to the Frankfort plane.

The third method is that described above in connection with our head-spanner.

In order to ascertain the reliability of the several methods I have arranged the following experiment. Using 25 fresh cadavera of a mixed population of Whites and Negroes and of both sexes I have measured the auricular height upon the head-spanner and also by the methods discussed above in association with the names of Hrdlička and Martin. In addition I have measured the height by what I shall call the "old" method. It is based on Hrdlička's method but the measurement is taken from the roof of the ext. aud. meatus, a pelvimeter is substituted for the Tasterzirkel and the third segment of a

Martin's anthropometer for the Gleitzirkel. The measurement simply provided a check upon the Hrdlička method.

Table II *a*. *Comparison of methods*

Auricular height: 25 fresh cadavera; mixed population

	Average	Standard deviation	Coeff. of variability
"Old" method ...	121·0 ± ·666	4·94 ± ·471	4·09 ± ·391
Hrdlička	121·1 ± ·666	4·94 ± ·471	4·08 ± ·390
Martin	121·2 ± ·688	5·10 ± ·486	4·20 ± ·401
Reserve head-spanner	122·1 ± ·595	4·41 ± ·421	3·61 ± ·345

Table II *b*. *Deviations of methods from results by head-spanner in mm.*

	"Old" method	Hrdlička	Martin
Total deviation	36·5	34·5	60·5
Average „	1·46	1·38	2·42
Maximum „	8·0	6·0	7·0

Table II *b* gives the results of this experiment. The total deviation of each method from the height ascertained by the head-spanner is recorded without regard to sign. These give average deviations of 1·46 mm. for the "old" method, of 1·38 mm. for Hrdlička's method, of 2·42 mm. for Martin's method. There is no doubt from practical experience that Martin's method is the most difficult to carry out, the most uncomfortable for the individual being measured, and the least satisfactory in result. The exact instruments used are less important than the method employed. This is shown by the fact that our "old" method and that of Hrdlička give practically identical results. The precise maximum deviation is a matter of accident but shows that each of the three methods may be quite unreliable compared with the much more accurate head-spanner.

It has been shown that, so far as individual measurements are concerned auricular height cannot be measured with that degree of accuracy which we should reasonably expect unless a specially designed instrument is used. Anthropologists should therefore not encourage field workers to employ haphazard methods to ascertain auricular height. In justification of this view I present the results of a comparison of reliability of the various methods when applied to a population and not to individuals. Table II *a* gives the averages, standard deviations and coefficients of variability of the three methods checked against the results obtained on the head-spanner. The small variability as ascertained on the head-spanner is intrinsic evidence of the relatively greater accuracy of this instrument and the differences between this coefficient of variability and those of the other methods are measures of the inaccuracy of these methods due to instrumental error. Once again it is apparent that there is no essential difference between our "old" method and that of Hrdlička, the precise type of instrument being less important than the nature of the method employed. It is now plain that, for a population sample, no one of the three methods under examination gives better results than the other two and any one of them gives an appreciable error in the final result. One cannot too strongly insist upon the standardisation and unification of anthropometric instruments and methods.

THE PROBLEM OF SOURCE OF MATERIAL

About ten years ago Pearson drew attention to the fact that a general hospital population cannot be considered representative of the general population of the district (3). Although there may be an obvious difference between the means of these two groups the difference does not extend to the variabilities or correlations. This latter observation might be reasonably inferred. From very numerous series of properly reduced records in this laboratory and from the comparison of these reductions with those made upon similar material by others, notably the Staff of the Biometric Laboratory at University College, we have come to the conclusion that variabilities and correlations have a very distinct "human" value, affected relatively little by stock and only slightly or not at all by sex, age and other features usually emphasised by anthropologists.

The social stratum from which a material is drawn may very readily affect the dimensions, and in certain respects even the proportions of the skeleton. It is therefore unwise to use means obtained from one class in arguments upon another social grade without careful reservations. In the present communication we are concerned, not alone with measurements upon the bony frame, but in addition with determinations upon the soft parts, which, at least in their water and fat content, may be subject to considerable variation. The problem of source of material, therefore, becomes quite important.

The cadavera upon which this investigation is based should be classed as a general hospital population with a distinct criminal and pauper bias. The mean age at death is even less than that for the hospital population given by Blakeman, Lee and Pearson. This is doubtless due in part to the number of deaths from violence (see polygon of age frequency, (12), p. 290)). But this very fact indicates that the material must not be considered as a pure hospital sample; it is a peculiar group characteristic of the anatomical laboratory. Probably the measurements on the skeleton are somewhat under those of the population at large but not so far below this standard as would be those of a pure hospital sample. The same is true of the averages deduced from the soft tissues.

Pearson has drawn particular attention to the effect of want of nourishment and "shrinkage" due to chronic disease (3) in such samples. The "shrinkage" is caused by emaciation which is usually interpreted as loss of weight. The "shrinkage" associated with increasing age, however, probably involves change in the colloidal constitution of the tissues which becomes coarser and expresses water. I feel strongly that in chronic disease such a dehydration also takes place and though I cannot enlarge upon the problem at this time it is of such paramount importance in this work that we must glance in passing at its probable effect upon the subcutaneous tissues.

THE SUBCUTANEOUS TISSUES IN THE LIVING AND THE DEAD

In previous investigations such as those of Czekanowski (4), Anderson (1) and Gladstone (5), it has been either definitely asserted or tacitly assumed that the thickness of the subcutaneous tissues is the same after death as during life. Since the results of this research are to be applied to healthy living persons one must emphatically affirm that the cadaver, in most instances, is not simply the individual after the circulatory and respiratory systems have ceased to function. This communication is not the place in which to enlarge upon this very significant problem which, by its nature, must receive adequate attention upon another occasion. One ought, however, to make passing reference to the matter.

Our interest was aroused in the relation between the healthy individual living and the same person dead by the important fact that the weights of our cadavera almost always are considerably less than those which our experience of the living stripped weight would lead us to expect. Our estimates have been nearly always between 20 and 30 pounds in excess of those revealed by the cadaver scales, a marked exception being the cadaver obtained after a death of violence not involving external haemorrhage. It is apparent that a lingering illness results in emaciation but this emaciation does not appear to explain adequately the considerable loss of weight which our investigation shows. In brief there seems to be a dehydration of the subcutaneous tissues in the last stages of illness. The process of embalming restores the features to a condition more nearly resembling those of life. The amount of fluid used in our embalming method weighs from 16 to 24 pounds according to the size of the cadaver. So far as the scalp is concerned our embalming makes an important difference to the thickness of the soft tissues and this should not be ignored in the present investigation.

Table III. *Effect of embalming upon auricular height*

Nine heads of general population measured fresh and after embalming

	Mean	Standard deviation	Coeff. of variability
Fresh	$122{\cdot}1 \pm {\cdot}798$	$3{\cdot}55 \pm {\cdot}564$	$2{\cdot}91 \pm {\cdot}463$
Embalmed	$124{\cdot}7 \pm {\cdot}832$	$3{\cdot}70 \pm {\cdot}588$	$2{\cdot}97 \pm {\cdot}472$

Table III gives the result of an enquiry into the difference in auricular height induced in the cadaver by embalming. Nine fresh cadavera of our mixed population were measured on admission and again 24 hours after the embalming fluid was introduced into the right brachial artery. Auricular height was chosen because it presents the least disadvantage. Head breadth tends to be exaggerated since the fluid travels up the temporal arteries and often greatly increases this measurement. Head length was discarded because the cadaver is embalmed while lying upon its back and a relatively small amount of fluid, in consequence, percolates into the tissues over the opisthion which is compressed between the subjacent board and the heavy skull. The vertex of the head, on the contrary, has no large vessels and is subjected to no compression. The second measurement was deferred 24 hours to ensure even percolation of the embalming fluid. As one might expect, the table shows a somewhat greater variability of the measurement in the embalmed cadaver owing to variation in the actual amount of fluid which finds its way to the vertex. But the table also shows that this divergence may safely be ignored in our argument. The difference between the means is 2·6 mm. which represents the increase in auricular height consequent upon embalming. Double this amount should be added to head breadth and head length to indicate the probable true effect of embalming upon these dimensions. The reason for doubling the amount becomes apparent from a study which will be made later in this paper of the variabilities of breadth and length.

A rough check upon this amount of 2·6 mm. is provided in the following manner. We may assume that the total area of the adult male body is in the neighbourhood of two million square millimetres, a figure obtained from Vierordt's quotation from Meeh (14, p. 51). A layer of our embalming fluid 2·6 mm. deep, spread over an area of this size corresponds to a weight of about 13 pounds. Allowing for the fluid which naturally finds its way into the organs and deeper tissues of the body this agrees roughly with our total weight of embalming mixture. It also seems to be warranted by the dehydration of the subcutaneous tissues assumed in our hypothesis.

Of course one may ask why I have not taken a sample of the presumably healthy living population which ultimately finds its way into the dissecting room and checked this up against the dimensions ascertained on our cadavera. Apart from the inherent difficulties of carrying out such an investigation the possible variability of the means of small samples precludes any greater weight being given to the result of work along such lines. Another method would involve measuring the actual thickness of the scalp in the living by a calibrated needle. But this alternative is alike impracticable on account of pain, wounds and deformation of the skin.

For the present then we must rest content with the results now given. The mean auricular height, as ascertained on the cadaver, must be increased by 2·6 mm. to give the probable true mean living auricular height. Breadth on the cadaver must be increased by 5·2 mm. to give the comparable field dimension. Length is the most difficult of all to estimate for the expression of fluid from the soft tissues over the opisthion undoubtedly reduces this dimension. I am inclined to add a further amount of 2·6 mm. (i.e. 7·8 mm. total) to the cadaveric head length in order to obtain the probable true living length.

THICKNESS OF THE SCALP ON RESERVE MATERIAL

In order to obtain the actual thickness of the soft tissues of the scalp the dimension measured upon the green skull is subtracted in each individual from the corresponding dimension on the cadaver. Mathematical reduction of the remainders so obtained gives the results presented in Table IV. In a former communication I have shown how much the skull shrinks in each of these dimensions in consequence of drying (15). Therefore the figures in this table must not be applied to measurements of the dried skull unless these measurements are corrected for drying.

Table IV. *Thickness of scalp on Reserve fresh material in millimetres*

Type	Number	Dimension	Mean	Standard deviation	Coeff. of variability
Mixed population	69	Length	$4{\cdot}88 \pm {\cdot}233$	$2{\cdot}87 \pm {\cdot}165$	$58{\cdot}81 \pm 4{\cdot}392$
	71	Breadth	$7{\cdot}29 \pm {\cdot}230$	$2{\cdot}87 \pm {\cdot}162$	$39{\cdot}31 \pm 2{\cdot}545$
	21	Aur. height	$6{\cdot}06 \pm {\cdot}177$	$1{\cdot}12 \pm {\cdot}124$	$19{\cdot}82 \pm 2{\cdot}141$
Male White	43	Length	$5{\cdot}07 \pm {\cdot}324$	$3{\cdot}15 \pm {\cdot}229$	$62{\cdot}13 \pm 6{\cdot}014$
	43	Breadth	$7{\cdot}02 \pm {\cdot}224$	$2{\cdot}80 \pm {\cdot}158$	$40{\cdot}00 \pm 3{\cdot}343$
	14	Aur. height	$5{\cdot}80 \pm {\cdot}234$	$1{\cdot}30 \pm {\cdot}166$	$22{\cdot}41 \pm 3{\cdot}144$

The actual number of individuals utilised differs in the several dimensions owing to the fact that certain obvious errors had crept into the records and could no longer be corrected at the time when the statistics were gathered. This accounts for the differences in number of cadavera in the length and breadth series. Since the material obtained during one year is not usually worked up till the following year, and because the Reserve head-spanner was not manufactured until September of 1922, the number of measurements of auricular height is relatively very small. The skulls of the majority of the individuals on which this dimension was obtained with the head-spanner while the cadaver was still fresh and not yet embalmed will not be available until the summer of 1924. At that date it will be possible to review the figures relating to auricular height. But small as the number may be at this time, the averages are not likely to be altered to any practical extent and therefore, instead of holding the entire paper over for two years, it is worth while to publish these results at once. The variability in thickness of the soft tissues involved in the measurement of auricular height is much less than the variability of the soft parts in either length or breadth. This is due, of course, to the fact that only one variable quantity is present, namely the scalp at the vertex. For one could not claim the existence of any practical magnitude in variability of thickness of the soft tissue in the roof of the auditory passage.

The statement just made needs some explanation since it is absolutely opposed to descriptions given by Pearson (2) and Parsons (11) of the relation of the soft tissues to the bony external auditory meatus. The former writer, after an examination of three sections of heads through the meatus concludes that when the ear plug is properly inserted it can scarcely be more than

3 to 4 mm. below the bone. The latter author, on the basis of four tracings of the same region believes that the skin opening is always below the bone but that its distance below varies from 3 to 8 mm. I am not here concerned with head-spanners which give the auricular height from the axis of the ear plug: our instrument determines the height from the upper aspect of the rod. It is well, however, to point out that the material upon which the estimates just quoted are based, was embalmed or at least was dead and that the area is one very frequently distorted by unavoidable post-mortem measures. The finger inserted into the meatus can quite plainly feel the bony margin and the soft tissues are certainly not so thick as either author would lead us to expect. As a matter of fact it is a principle of the use of our head-spanner to draw the rods up to the bony meatal roof immediately within the orifice and it is difficult to believe that the thickness of intervening soft tissues is more than 1 to 2 mm. At any rate the thickness is so small that no appreciable change could occur either in embalming or in emaciation. By far the greatest thickness of soft tissues concerned in auricular height is at the vertex. This is again indicated by the fact that variability in thickness of the soft parts in auricular height is about one half that of the thickness of the soft parts in breadth.

Our results show that the soft parts concerned in breadth are distinctly thicker than those in length. This may be due to the bulk of the temporal muscle which, in certain cases, overlies the Euryon. At least such an explanation has been given by others. I am not convinced that it really has any bearing upon the case for the site of the Euryon is not at all constant and consequently the temporal muscle cannot invariably be included in the dimension. Hence this fact should tend to increase the variability in breadth but the figures show that variability in breadth is much less than variability in length. Nothing is proved by this argument but it at least casts doubt upon the validity of the temporal muscle explanation of the relatively great thickness in breadth. A more reasonable cause for the relatively considerable thickness of soft tissues in breadth compared with length, so far as our cadavera are concerned, is the fact that the body lies upon its back and in consequence there is a tendency for the expression of fluid from the soft parts at the back of the head owing to compression of those tissues between the underlying board and the skull the weight of which, with its contained brain, is considerable.

Again it must be remembered that we cannot give dimensions of the head in the living and we do not know how far these are represented by the dimensions in the cadaver. This problem has been taken up in a separate section of our communication.

For each dimension we have calculated the mean and the variability in a mixed population of both sexes and of White and Negro stocks (Table IV). This is more of theoretical than of practical value. When we have sizeable groups of the female sex and of Negro stock we shall submit figures appropriately dissected. Until then we can give merely the figures for the male

Whites. These, checked up against the corresponding figures for the general population, indicate the effect of admixture of sex and stock together upon average and variability. The general population figures are therefore simply temporary.

It is unnecessary, we think, to compare in detail the results obtained in this work with those given by previous authors for the methods utilised by the different writers vary quite considerably and are often not clearly stated. We must also warn the reader not to accept without caution the quotations of one author from another's work as quite frequently errors seem to have crept into the quotations. Further divers complicating factors enter such as age, sex, state of nourishment of the body, condition of the cadaver, whether fresh or embalmed, and sample of population. We shall content ourselves with comparing the average results for male Whites obtained by us with those given by Czekanowski in his complicated but important communication.

Todd and Kuenzel:	length	5·07;	breadth	7·02;	auricular height	5·80.
Czekanowski:	,,	7·25;	,,	6·91;	,, ,,	3·43.

Czekanowski does not state from what type of population he derived his data but his methods differ fundamentally from ours. In no case did Czekanowski measure the skull directly: all his skull measurements are hypothetical and are obtained by subtracting the thickness of the soft parts from the directly ascertained dimension on the cadaver. We have already pointed out the danger of error from deformation of the skin in direct determination of thickness of soft parts. Further Czekanowski derived his determination of auricular height from measurements with Martin's method which we have shown to be the most difficult and least dependable of all the methods so far utilised. It is essential, we believe, at this stage to confine attention to a particular sample upon which a complete survey can be made.

DIMENSIONS OF THE HEADS AND CRANIA

It will still be many months before the fully dried crania belonging to the series of heads used in this work are all set out ready for service on the Museum shelves. Hence, in emergency, I desire to present for comparison the dimensions with their variabilities ascertained upon the fresh heads and compare them with those of a former standard series of male White dried crania. These figures are gathered together as Tables V and VI. Elsewhere I have commented upon the relatively stable character of human variabilities and the very slight degree in which these differ from sample to sample in spite of statistically significant differences in the means. In actual fact the averages of the 25 crania of our recent series which are now fully dried (shown in Table VII) do differ somewhat from those of Table V but there is no reason to anticipate a corresponding difference in the variabilities.

Now, comparing Tables V and VI, one notes the significant fact that variabilities are less in the dimensions of the cadaver head than in the measurements on the skull. One cannot assume this to be an accident of the samples since it occurs in many different phases of our work where we are comparing the variabilities of any bodily unit with those of the constituent parts of the unit. We are accustomed to speak of this phenomenon in the laboratory as the compensation of the parts in the whole. Its relation to measurements of

Table V. *Reserve cranial dimensions; 167 male White skulls* (13)

	Mean	Standard deviation	Coeff. of variability
Length	181·42±·427	8·191±·302	4·514±·166
Breadth	144·28±·296	5·675±·209	3·933±·147
Aur. height	116·41±·252	4·822±·178	4·142±·152

Table VI. *Cranial dimensions; fresh cadavera; male White only*

Dimension and number		Mean	Standard deviation	Coeff. of variability
Length	43	188·73±·797	7·75±·564	4·11±·299
Breadth	43	153·64±·590	5·74±·417	3·74±·272
Aur. height	16	123·59±·695	4·12±·491	3·33±·397

the skull is demonstrated in an article now being prepared for the press by Dr Pitkin. It is also evident in the precisely comparable figures given by Czekanowski (4) and by Blakeman, Lee and Pearson upon head and skull measurements (3). The paradox is vividly presented by Pearson as a negative correlation between skull diameters and amount of covering flesh.

THE COMPUTATION OF DIMENSIONS AND CAPACITY

We originally undertook this work in order to compute cranial dimensions from those of the living head or *vice versa*. In this calculation it is necessary to allow for shrinkage of the skull in drying after maceration as well as for thickness of soft tissues. Corrections for shrinkage have been set forth in a recent communication (15). We shall consider first the computation of average dimensions in a population sample and secondly the calculation of dimensions for individual skulls.

To ascertain what reliance can be placed upon our results for a population sample one must know the dimensions of a series of heads and also the dimensions of the fully dried skulls from the same heads. One can then check the computed cranial dimensions by actual observations. Table VII gives the computed figures for male Whites together with the directly ascertained averages upon the 25 male White crania of our present series which are already fully dried. The greatest difference between calculated and directly determined averages is in breadth, the divergence being 0·9 mm. For length the difference is 0·1 mm. and for auricular height 0·4 mm. One must remember that there will be a slight further shrinkage of these skulls during the coming year for I now find that there may be, though not invariably, a slight shrinkage going on in our crania even after the 12 weeks which we have come to use as a standard drying period. This would reduce still more the discrepancy for breadth but would rather increase it for height.

Table VII. *Calculation of average head dimensions from measurements on dried skulls—male Whites only*

Average	Length	Breadth	Aur. height
Dimension on 25 dried skulls ...	181·9	145·4	115·7
Shrinkage	1·8	2·1	1·7
Thickness of soft tissues	5·1	7·0	5·8
Computed head dimension (cadaver)	188·8	154·5	123·2
Actual " " "	188·7	153·6	123·6
Amount to be added to cadaveric dimension in order to reproduce living dimension	7·8	5·2	2·6

In order to reconstruct the dimensions of the living head one must add to the cadaveric measurements 2·6 mm. for auricular height, 5·2 mm. for breadth and probably 7·8 mm. for length.

The surprising accuracy with which average dimensions can be computed must not engender a false optimism in results for individual cadavera. We have already shown the great variability in thickness of the scalp. This permits a very considerable deviation between actual dimensions and those calculated from our averages. So long as we deal only with the averages of samples of reasonable size it is probable that the method will be fairly satisfactory. The moment, however, we apply our figures to individual heads, the effect of great individual variability is vigorously demonstrated, even if the individuals are grouped into a series.

From the cadaveric measurements we have calculated the dimensions of the 25 male White crania already dried. Taking round figures we have subtracted from the cadaveric diameters the following amounts for thickness of soft tissues and cranial shrinkage in drying, the figures being based upon Table VII.

Length 7·0 mm.; breadth 9·0 mm.; auricular height 10·0 or 7·5 mm. In auricular height 7·5 mm. is deducted if the cadaveric dimension was ascertained when the body was fresh: 10·0 mm. (i.e. 7·5 + 2·5) if the body was already embalmed, 2·5 mm. being approximately the increase due to embalming as shown in Table III. The average deviations calculated without regard to sign in these 25 examples are:

L + B + AH 8·8 mm. Length 3·4 mm.; breadth 2·5 mm.; auricular height 2·9 mm.

and the individual ranges are very great:

L + B + AH	ranges	from	− 15·25	to	+ 11·0
Length	"	"	− 7·25	"	+ 5·75
Breadth	"	"	− 6·0	"	+ 8·0
Aur. height	"	"	− 6·5	"	+ 4·5.

When we come to calculate cranial capacity from the computed dimensions we must not even be misled by the L + B + AH discrepancy of 6·6 mm. This would result in an error of about 50 c.c. in the computation of capacity by any proper regression formula (13, pp. 181-182). We should be quite satisfied if the result were no worse than this. Unfortunately the different diameters are not of equal value in regression formulae and therefore errors of opposite sign in different diameters do not rule each other out but greatly increase the discrepancy of the result. The L + B + AH figure is naturally obtained by addition of the several deviations having regard to the sign: it therefore gives a fictitious indication of the accuracy to be attained by a regression formula. A truer forecast would be given by addition of the three diametral errors, namely 3·4 + 2·5 + 2·9. This sum of 8·8 mm. error in the average diameters would presage an average error of about 90 c.c. in the calculation of cranial capacity, an error which robs our results of all confidence. On the other hand, by the use of a least square formula, we might hope to attain an average error of about 50 c.c. for in this type of formula the diameters are of more nearly equal value and errors of opposite sign tend to rule each other out. The objection which I have to the least square formula is that it tends to eliminate the essential differences in crania and whereas it should give better average results in principle in a very heterogeneous collection of skulls the individual results would be worse and, if the sample were not very heterogeneous, might be exceedingly bad. To assert that any given sample of skulls is really unselected in any way is to assume a heavy responsibility. The du Chaillu group of West African skulls was selected by the collectors on account of size: that is an easy inference. The Egyptian collections have all been selected in an intangible manner, important factors being the circumstances of exhumation and the necessity of utilising native help. One cannot put one's finger readily upon the influences in this case though there is no doubt of their presence. At an earlier stage of our investigations I was strongly of the opinion that our Reserve male White crania are just about as heterogeneous as they could be, drawn as they are from all the countries of Europe. But our intensive studies of the material from year to year have shattered that illusion completely; we now find that they are indeed quite rigidly selected but by influences entirely unthought of, as I shall demonstrate elsewhere. If then, on the basis of non-selection, one use a least square formula one is apt to encounter quite discouraging results without warning.

In Table VIII I have attempted to illustrate the essential truth of the foregoing statements. Taking a group of ten of the crania of this series we have calculated capacities from linear dimensions using for this purpose the diameters both of the fully dried skulls and of the fresh heads. In the latter calculations the necessary corrections have been made for thickness of the soft parts and for shrinkage during drying. Using Lee and Pearson's least square formula male White reconstructed No. 9 (9), a suitable formula for a heterogeneous collection, we get an average deviation of over 100 c.c. with either cranial or head diameters. This is unquestionably so inaccurate as to be useless. That is not the fault of the formula, the value of which has been demonstrated by the authors and confirmed in our laboratory (13); it is the logical result of using a general formula upon a selected unsuitable material.

Table VIII. *Calculation of cranial capacity from linear dimensions*

Mean errors in c.c.

L. and P. Reconstr. male White No. 9	10 heads	Fresh	102·8
	skulls	Dried	104·8
W. R. U. Regression male White No. 5	25 heads	Fresh	101·0
	skulls	Dried	63·0
L. and P. Regression male German No. 8	25 heads	Fresh	64·6
	skulls	Dried	40·8
β-group W. R. U. male White No. 5	5 heads	Fresh	31·5
	skulls	Dried	12·1
γ-group L. and P. male German No. 8	12 heads	Fresh	57·2
	skulls	Dried	11·1

I have next presented the results given by regression formulae, using for this purpose our own male White No. 5 (13) and Lee and Pearson's male German No. 8 (9). Now we find that Lee and Pearson's formula gives a much better result than our own. The average error of the Lee and Pearson formula for dried skull dimensions is only 41 c.c., a strikingly good result. The average error of the same formula for fresh head dimensions is only 64 c.c. If we could always obtain this accuracy we should be entirely content. Turning to the results of our own male White formula we find an average error of 63 c.c. for dried skull dimensions and of 101 c.c. for fresh head diameters. At first sight this is very discouraging for it seems to indicate that the formula worked out with the greatest care upon our own material is less serviceable even for our own material than a formula devised from an entirely different population in which the safeguards emphasised in our work were not attainable. But the problem is not so readily disposed of.

In another communication I shall be able to demonstrate that the material upon which these observations have been made is not the material used as the basis for calculation of our formula; different selective influences have been at work. The social turmoil after the war, industrial depression, the subversion of certain social orders, the prohibition amendment to the American constitution, and perhaps most important of all, restriction of immigration and the actual exodus from this country during the past four years have combined to alter the character of our dissecting material. The year 1922 in which all these 25 cadavera, with one exception, were admitted, has brought us a material more closely related on the whole to the crania upon which Ranke made the observations utilised by Lee and Pearson, than to the crania characteristic of the war and pre-war years in this laboratory. This is a bold assertion, and I must ask the reader's indulgence, pending publication of the complete series of observations upon which the statement is made. The material is indeed almost ready for the press. At this time I would mention that the basic principle upon which it now appears possible to segregate crania is not cephalic index or race but the definite relation of cranial capacity to the several dimensions of the cranium. We have divided our crania into α, β, γ and δ groups. During and before the war the β group was greatly predominant and thus influences most markedly our formula male White No. 5. In 1922 the γ group appears in much larger numbers. This is also the dominant group in Ranke's Altbaerische collection. Hence the better results given in our 1922 material by Lee and Pearson's formula male German No. 8.

Among the 25 crania there are only five of the β group but twelve of the γ group. At the end of Table VIII I have set out the average errors in computation of capacity of these groups, using for the β group our formula male White No. 5, and for the γ group Lee and Pearson's formula male German No. 8. Regression formulae for the other groups have not yet been worked out as we are still in process of identifying the examples. At once the accuracy of the mathematical method of computing capacity is apparent. The error for calculation from dried cranial diameters is well within that of individual direct determination and the error for the calculation from fresh head dimension is small enough to justify further research into the method. The day is not distant when we shall be able to form a fairly exact idea of cranial capacity from head diameters. That reasonable accuracy should be attainable is evident from the demonstration by Blakeman, Lee and Pearson of reasonable probability that the brain-weight of living individuals can be calculated with a mean error of not more than 50 gms. (3).

TRANSFERENCE OF OUR RESULTS TO OTHER POPULATION SAMPLES

The next logical stage of this investigation would be the transference of our results to other population samples, a step which cannot be undertaken, as we have shown, without very careful safeguards. It will not suffice to say that, since we have obtained certain results upon a dissecting room population, these dimensions of soft parts can be directly used for the prediction of head dimensions upon, say, a grave-yard sample of skulls. We have confirmed Pearson's assertion of a negative correlation between skull diameters and the amount of covering flesh. When we shall have amassed a considerably larger amount of data it will be possible to compute formulae for deriving skull measurements from those on the cadaver and *vice versa*. Although the formulae will be obtained upon specific populations it should be possible, within limits, to utilise the formulae for other populations. At a later date this will be carried out and we shall be able to test its value by checking very diverse samples against others.

Until such time as this procedure becomes feasible we consider it wise to refrain from any predictions as to the value of the formulae. We content ourselves then with the presentation of such facts as we have so far obtained. These are the necessary preliminary to the further work which has been outlined and we hope that meantime others will endeavour to carry out check series of observations by which the accuracy of prediction will ultimately be enhanced.

SUMMARY

1. We have described a form of head-spanner for obtaining auricular height upon the cadaver and in the living. The instrumental error of this apparatus, as checked against the Reserve craniostat, is 0·3 mm.

2. The instrumental errors have been reviewed for the several instruments necessary to measurement of greatest length and greatest breadth upon the head and upon the skull.

3. The relative accuracy of various instrumental methods of obtaining auricular height are shown in detail.

4. Although full presentation of the thesis must be postponed, it is indicated that the subcutaneous tissues of the cadaver do not accurately represent the condition of the soft tissues during life. The average difference in auricular height between the cadaver fresh and embalmed is 2·6 mm. Consideration of the variabilities of length and breadth suggests that the probable true difference in each of these dimensions is 5·2 mm. This amount should be added to the dimension in the fresh cadaver in order to obtain the approximate breadth in life but for reasons stated in the text 7·8 mm. should be added to length to obtain the real living value.

5. The average thickness of the soft tissues of the scalp has been ascertained for small samples of a general population and for male Whites alone. For male Whites these averages are: height (vertex) 5·8 mm., length (glabello-opisthion) 5·1 mm., breadth (Euryon) 7·0 mm.

6. Shrinkage of the skull in drying having already been ascertained, it is possible, from the measurements on the dried skull, to compute the probable dimensions of the head in the fresh cadaver or in the living. The accuracy for a small sample of male Whites is within 0·9 mm. of the directly ascertained average for each dimension.

For individuals the deviation is naturally greater, but the average accuracy is within 6·6 mm. of the total of the three dimensions as directly determined. This has been shown to correspond to an accuracy in cranial capacity of within 50 c.c.

From the magnitude of the variabilities in thickness of the scalp it is desirable, in the calculation of cranial capacity from head dimensions, to use a formula in which the diametral errors of opposite sign will tend to eliminate each other. It is probable that ultimately least square formulae will give better results than regression formulae because the former tend to diminish differences in the comparative value of the several diameters. It is not possible at the present time to devise such formulae since we have not yet clearly differentiated the various types of skull upon a basis of the relation of capacity to diameters. When this shall have been done and the appropriate least square formula can be applied, there is reasonable probability that we may hope for an average individual error of not more than 50 c.c.

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