國立中央研究院歷史語言研究所

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目　　錄

FORMULAE FOR THE DETERMINATION OF THE CAPACITY OF THE CHINESE SKULL FROM EXTERNAL MEASUREMENTS

By T. L. Woo

(I) *Introductory.* Various methods have been devised by physical anthropologists to measure the cranial capacity of the different races, but all of them can be applied only to intact specimens. When a skull is cracked, perforated or in any way defective, or very fragile as in the cases of many ancient specimens, none of these direct methods can be employed. However, an estimated value of the capacity can be obtained by the application of some mathematical equations which are derived from the external characters taken on a large number of specimens. Lee and Pearson[1] were the first to introduce the intra-and inter-racial formulae for predicating the estimated capacities of various races. Isserlis[2] and Tildesley[3] presented the intra-racial equations for the African negroes of both sexes in general. Hook[4] provided similar

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1. A. Lee and K. Pearson: "On the Reconstruction of the Capacity of the Skull from External Measurements," *Philosophical Transaction*, London, Vol. CXCVI, A, pp. 225-264, 1901. See also K. Pearson and A. Lewenz: "On the Measurement of Internal Capacity from Cranial Circumferences," *Biometrika*, Vol, III, pp. 366-397, 1904, and K. Pearson: "On the Reconstruction of Cranial Capacity from External Measurements," *Man*, Vol, XXVI, pp. 46-30, 1926.

2. L. Isserlis: "Formulae for the Determination of the Capacity of the Negro. *Biometrika*, Vol. X, pp. 183-193, 1914-15.

3. M.L. Tildesley: "Determination of the Cranial Capacity of the Negro from Measurements on the Skull or the Living Head," *Biometrika*, Vol. XIX, pp. 200-206, 1927.

4. B.G.E. Hooke: "A Third Study of the English Skull with Special Reference to the Farringdon Street Crania, "*Biometrika*, Vol. XVIII, pp. 33-35, 1926.

equations for three English series. The constants from which the estimated capacity is derived contain the product of three principal diametral or arcual measurements. Experience has shown that a satisfactory result can be gained by using the product formula of either kind.

With regard to the Chinese material, no such attempt has been made before in this respect, although many decent cranial studies have been published in recent years. The object of the present study is to provide some predicating formulae based on two Chinese cranial series available. As China has a long history and her area is immense and population enormous, the physical features of the cranium are probably not all of the same type. So the application of the proposed formulae deduced from such slender material will certainly be limited as to the factors of the period and locality.

(II) *Material.* The material on which the present investigation is based comprises two Chinese cranial series, one being excavated from the Houchiachuang site near An-yang, Honan, and the other collected in the suburbs of Kunming, Yunnan. A brief account of the origins of these crania is given below:

(*a*) Houchiachuang series. More than 400 Chinese crania of the Yin dynasty (ca. 1400-1100 B. C.) are available at present in the Anthropological Laboratory of this Institute. Unfortunately, the majority of them are either defective or much too fragile for the capacities to be determined so that the direct measurements of the cranial capacity can only be taken on one-seventh of the specimens. The specimens were excavated by Dr. Liang Ssŭ-yung in 1934-1936 at the site of Houchiachuang which is situated on the north bank of the Huan River, about half a mile north of the village of Houchiachuang and four miles northwest of the walled city of An-yang. There are only 61 male intact crania which are employed for the present purpose.

It is believed that they are the heads of individuals who had been decapitated and offered in sacrifice. They are all adults and extremely strong, massive and large in size. These most valuable specimens were kindly placed at the disposal of the Anthropological Section by Dr. Liang, to whom we are very much indebted for information concerning the source of the material. A detailed account of this excavation will be given in a special report on the subject.

(*b*) Kunming series. 500 modern adult Chinese crania with about 180 corresponding skeletons were collected by the Anthropological Section of this Institute at the beginning of 1938 from the unclaimed graves at Lean Hua Chih in the suburbs outside the northwestern gate of the city of Kunming. The specimens are the heads of people of the poor class who inhabited during their lifetime the vicinity of Kunming. According to the inscriptions on some of the gravestones, the majority of them were natives of Yannan although a few came from the neighboring provinces. Of the total number of specimens collected, there are 421 complete skulls (277 ♂ and 144 ♀) from which the proposed measurements could be taken. Besides the two series referred to, there are a few short series of Chinese crania of different periods preserved in our museum. Owing to the smallness of the samples represented, none of these are included in the present study.

(III) *Methods of measuring external characters and the cranial capacity.* The characters which are customarily employed to determine the cranial capacity are of two groups: diametral and arcual. For comparative purposes, the measurements of both groups have been adopted in the present study. The definitions of measuring external characters as well as cranial capacity are given below:

(1) Maximum cranial length (L): the greatest length taken in the median sagittal plane from glabella to opithocranium.

(2) Maximum cranial breadth (B): the greatest breadth taken transversely from the right euryon to the left one. It should be measured at right angles to the preceding length.

(3) Basio-bregmatic height (H′): the direct diameter of the head taken from bregma to basion.

(4) Auricular height (OH): the vertical height from the apex to the point where it meets the line between two poria, taken along a plane at right angles to the Frankfort Horizontal. It is measured with the aid of the Mollison-Black improved craniophone.

(5) Sagittal arc (S): the median sagittal are taken from nasion to opisthion.

(6) Horizontal circumference (U): measured directly above the superciliary ridges and around the most projecting sagittal part of the occiput;

i.e., the most projecting part between the inion and lambda.

(7) Transverse arc (Q'): taken perpendicular to the horizontal plane, passing through the apex, and terminating on both sides at the poria.

(8) Cranial capacity (C)[1]: found by the "crâne étalon" method first described by Macdonell in the journal *Biometrika*, Vol. III, 1904. One standard skull was used in comparison with the volumes of the individual skulls and its average water capacity was found to be 1360 cm.[3]

Measurements (1) to (7) are all read to the nearest one-tenth of a milimeter but the capacity can only be recorded in cubic centimeters.

The product of the three external characters of the same group or two products of the characters of different groups may be used to construct the regression equations. The possible arrangements of the products of the first seven characters in question are made as follows:

(1) Product of maximum length×maximum breadth×basio-bregmatic height, i.e., L×B×H', or P_{d_1}.

(2) Product of maximum length×maximum breadth×auricular height, i.e., L×B×OH; or P_{d_2}.

(3) Product of sagittal arc×horizontal arc×transverse arc, i.e., S×U×Q', or P_a.

(4) Both P_{d_1} and P_a.

(5) Both P_{d_2} and P_a.

According to Pearson and Stoessiger's study,[2] product formulæ, whether they be diametral or arcual, both give the more satisfactory results, and a better formula for reconstruction might be obtained by correlating with a bivariate regression C with both P_d and P_a. For comparative purposes, all formulæ arranged in the above ways have been worked out for the two series used.

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1. L, B, H', OH, S, U, Q' and C denote the letters used by workers in the London Biometric Laboratory.

2. Karl Pearson and Brenda N. Stoessiger: "On Further Formulæ for the Reconstruction of Cranial Capacity from External Measurements of the Skull." *Biometrika*, Vol. XIX, pp. 211-214, 1927.

(IV) *Regression equations for the series represented.* Before obtaining the proposed formulæ for predicating or reconstructing purposes, it is necessary to work out first the requisite constants from which the equations are derived. The constants contain: (1) the means of measured capacity and of different products; (2) values of their corresponding absolute variabilities or standard deviations and (3) coefficients of correlation between the capacity and each product or two products. Table I provides the values of these constants for our series It will be seen that the variations and correlation coefficients for the two male series are not of the same order, the values of the Houchiachuang series being sensibly lower, but those for the Kunming male and female series are much closer. The simple regression equations for the purpose mentioned for the two male and one female series are shown below:

For the Houchiachuang male series:

$C = .248080P_{d_1} + 568.34 \pm 44.75 + /\sqrt{n}$ ....(I, a)[1]

$C = .326636P_{d_2} + 477.11 \pm 42.18/\sqrt{n}$ ....(I, b)

$C = .014350P_a + 557.90 \pm 41.97/\sqrt{n}$ ....(I, c)

For the Kunming male series:

$C = .339472P_{d_1} + 252.64 \pm 50.92/\sqrt{n}$ ....(II, a)

$C = .405056P_{d_2} + 267.25 \pm 48.99/\sqrt{n}$ ....(II, b)

$C = .018659P_a + 292.91 \pm 46.92/\sqrt{n}$ ....(II, c)

For the Kunming female series.

$C = .416642P_{d_1} + 46.05 \pm 47.15/\sqrt{n}$ ....(III, a)

$C = .474371P_{d_2} + 77.48 \pm 49.49/\sqrt{n}$ ....(III, b)

$C = .020143P_a + 202.26 \pm 52.06/\sqrt{n}$ ....(III, c)

In the first two equations of each series the estimation of the capacity is based on the diametral product, i.e., P_{d_1} or P_{d_2}, in the last case it is based on the arcual product, i.e. P_a. The letter C denotes the estimated capacity, n the number of specimens used in each series, while the value of the probable error for each equation is calculated by the usual notation of $.67449\sigma(1-r^2)/\sqrt{n}$.

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1. Units of both capacity and products in cm.[3]

It is clear that from the size of the probable error, the determination of the capacity from the arcual products for the two male series is slightly better than that from the diametral products but the reverse order is observed in the case of the female series.

It is supposed that a better estimation may be made by forming a bivariate regression equation, that is, the determination of C both from P_{d1} and P_a, or P_{d2} and P_a.

TABLE I. CONSTANTS REQUIRED FOR THE RECONSTRUCTION OF PREDICATING FORMULAE.

Series	*Mean capacity (C) in cm.*^{3}	*Mean product of* $L\times B\times H$ *or* P_{d1} *in cm.*^{3}	*Mean product of* $L\times B\times OH$ *or* P_{d2} *in cm.*^{3}	*Mean product of* $S\times U\times Q'$ *or* P_a *in cm.*^{3}
Houchiachuang (Male)	1439.7	3512.2	2946.8	61448.2
Kunming (Male)	1413.3	3330.7	2829.5	60048.9
Kunming (Female)	1278.8	2958.7	2532.4	53452.0

Series	*S.D.*[1] *of capacity in cm.*^{3}	*S.D. of product of* $L\times B\times H'$ *in cm*^{3}	*S.D. of product of* $L\times B\times OH$ *in cm*^{3}	*S.D. of product of* $S\times U\times Q'$ *in cm*^{3}
Houchiachuang (Male)	81.57	191.34	160.35	3676.30
Kunming (Male)	112.99	247.61	213.67	4771.53
Kunming (Female)	122.51	241.46	206.81	4722.88

1: S.D = standard deviation.

Series	$^{1}r_{c,\,pd1}$	$r_{c,\,pd2}$	$r_{c,\,pa}$	$r_{pd1,\,pa}$	$r_{pd2,\,pa}$
Houchiachuang (Male)	.582	.642	.647	.725	.807
Kunming (Male)	.744	.738	.788	.841	.897
Kunming (Female)	.821	.801	.777	.893	.920

By the method of determinants the bivariate equations for the series considered are led as follows:

For the Houchiachuang male series:

$$C=.101648P_{d1}+.010516P_{a}+436.51\pm36.53/\sqrt{n} \cdots\cdots\cdots (I,\ d)^{2}$$

$$C=.175366P_{d2}+.008178P_{a}+420.38\pm37.73/\sqrt{n} \cdots\cdots\cdots (I,\ e)$$

For the Kunming male series:

$$C=.126705P_{d1}+.013129P_{a}+202.92\pm44.87/\sqrt{n} \cdots\cdots\cdots (II,\ d)$$

$$C=.160503P_{d2}+.012214P_{a}+225.75\pm51.59/\sqrt{n} \cdots\cdots\cdots (II,\ e)$$

For the Kunming female series:

$$C=.320251P_{d1}+.000552P_{a}+301.75\pm41.38/\sqrt{n} \cdots\cdots\cdots (III,\ d)$$

$$C=.332615P_{d2}+.006752P_{a}+75.56\pm42.80/\sqrt{n} \cdots\cdots\cdots (III,\ e)$$

Judging again from the size of the probable error the equations (d) and (e) appear to be, in most cases, slightly better than those (a), (b) and (c) although they differ in some instances only to a small extent.

(V). *Testing of the formulae.* The next important question to be considered is the accuracy of these proposed formulæ when applied to the intra-group specimens or to those of more related inter-group series of the same race. The validity of equations depends wholely upon the closeness of the directly observed (or measured) value and the estimated (or computed) one. Let us examine this point based on some materials at hand:

1, r=correlation coefficient.

2, I, II and III denote the three series used and a, b, ... , e different forms of equations calculated.

(1) Application of equations to some intra-group specimens.

For the purpose of illustration four cranial specimens were chosen at random. The first three specimens belonging to the period of the Yin dynasty were collected by Dr. Liang in the same region as the series (*a*) described above. But they were repaired and put in good condition after the series (*a*) were measured. The last is one of the male heads of the Sui-T'ang dynasties (581-899 A.D.) obtained by Dr. Li Chi some years ago in the neighboring region of Hsiao T'un, only 1.5 miles southeast of the Houchiachuang site. Eight direct measurements including the capacity were taken on four specimens and their values are shown in Table II. Their estimated capacities were computed by all the equations of the Houchiachuang series. The differences between the observed and estimated values of the capacity, and the percentages expressing the excess (with+sign) and defect (with—sign) of the estimated or predicating values were also calculated throughout and are given in the same table. If we compare the average percentages[1] of excess or defect yielded by adopting different formulæ, it is clear that the estimated values computed by the equations (*b*) and (*e*) are closer to the observed one than those computed by the remaining 3 equations. That is to say, other things being equal, the formulæ containing the character of auricular height are better for predicating purposes.

(2) Application of the equations to other Chinese cranial series.

Although several anthropological studies of Chinese cranial have appeared, the majority of them are of little use for the purpose of testing formula owing to the absence of the direct measurement of the capacity.[2] There are only five larger series which may serve the purpose. They are:

1. See the percentages given in the last column of the lower part of Table II.

2. For instance, two longer series, prehistoric and North China, measured by D. Black, can not be used here due to the fact that their observed capacities have not been taken by the author.

TABLE II. COMPARISON OF MEASURED AND COMPUTED CAPACITIES FOR FOUR INTRA-GROUP SPECIMENS (ALL MALES)

Series		1 *Houchiachuang*	2 *Houchiachuang*	3 *Houchiachuang*	4 *Hsiao T'un*
Specimen No.		4: 202 HPKM 1542(5)	4: 25 *HPKM* 1477(3)	*HPKM* (1)	*Hsiao* 4.17
Measurements: in mm. Length (L)		174.0	194.0	171.0	177.0
Breadth (B)		131.0	147.0	142 0	151.0
Basic-bregmatic height (H′)		130.0	145.0	137.0	141.0
Auricular height (OH)		115.5	120.0	119.0	116.5
Sagittal arc (S)		360.0	397.0	373.0	369.0
Horizontal arc (U)		493.0	514.0	495.0	522.0
Transverse arc (Q′)		310.0	331.5	325.0	348.0
Measured capacity in cm.[3]		*1335.0*	*1617.5*	*1450.0*	*1498.3*
Computed capacities in cm.[3] found by formulæ[4]	(I, a)	1354.3	1591.2	1393 6	1503.2
	(I, b)	1337.1	1594.9	1420.9	1494.2
	(I. c)	1350.6	1585.2	1430.5	1519.8
	(I, d)	1330.5	1609.7	1414.1	1524 5
	(I. e)	1333 8	1606.0	1424.4	1514.6

Excess or defect of capacity-prediction in cm.[3]		1		2		3		4		*Average*[3] *percentage*
		Δ[1]	%[2]	Δ	%	Δ	%	Δ	%	
Found by formulæ:[4]	(I, a)	—19.3	—1.45	+23.3	+1.44	+36.4	+0.89	— 4 9	—0.33	1.78
	(I, b)	— 2.1	—0.16	+22.6	+1.40	+29.1	+2.01	+ 4.1	+0.27	0.96
	(I, c)	—15.6	—1 17	+32.3	+2.00	+19.5	+1 31	—21.5	—1.43	1.49
	(I, d)	— 4.5	—0.31	+ 7.8	+0.48	+35.9	+2.41	—26.2	—1.75	1.26
	(I, e)	+ 1.2	+0.09	+11.5	+0.71	+25.6	+1.77	—16.3	—1 09	0.92

1. Δ=measured capacity-computed capacity.
2. Percentage=Δ/measured capacity.
3. Average percentage is computed without regarding the sign.
4. See equations in the text.

(*a*) Northern Chinese, the mean measurements of which were pooled together from three short series.[1]

(*b*) Northern Chinese measured by Koganei.[2]

(*c*) Southern Chinese, whose means were combined together by Morant and Tildesley.[3]

(*d*) Southern Chinese from Fukien measured by Harrower.

(*e*) Formosa Chinese measured by Koganei.[5]

The required constants[5] and their products for these series are given in the upper part of Table III. In the lower part are provided the differences

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1. The specimens of this series are combined together by the following short series: (1) Reicher. Untersuchungen über die Shädelform der alpenländischen und mongolischen Brachycephalen," *Zeitchrift für Morphologie und Anthropohogie*, Bd. XV, p. 421, 1913. Measurements of 13 male adult Northern Chinese skulls are given in Table 6 A. (2) Halerer: *Schädel und Skeletteile aus Peking*, Bd. I, 1892. 27 male adult skulls from Peking are described. (3) Quatrefages and Hamy: Les Crânes des Races Humaines, p. 434, 1882. Means of 6 male Northern Chinese are given.

2. In 1902 Koganei gave measurements of the skulls of 70 Chinese soldiers from Hopei, Shantung, and Liaoning, but the regions from which the soldiers came are unknown. Characters of 14 male Formosa Chinese from the North of the island were also measured by the same author. See *Internationales Centralblatt für Anthropologie und Verwandte Wissenschaften*, Bd. VII, p. 130, 1902.

3. The measurements of this series had been collected by M. L. Tildesley from the German Anthropological Catalogues and Flower's and Barnard Davis' Catalogues, and were said to represent the inhabitants of South China. No specimens obtained in Peiping and the North of the country had been consciously included. The 18 male crania of Southern Chinese measured by Quatrefages and Hamy have also been added to them by G. M. Morant. See *Biometrika* Vol. XVI, pp 48-49 and p. 55, 1924.

4. Measurements are given of 36 male skulls of unclaimed coolies from the province of Fukien. See Gordgen Harrower: "A study of the Hokien and the Tamil skull," *Transactions of the Royal Society of Edinburgh*, Vol. LIX, Part III. (No. 13) pp. 573-599, 1926.

5. Methods of measuring 8 characters adopted by different observers are practictically similar to those used by the writer.

between the mean observed capacity and the predicating one, and the percentages of excess or defect of the predicating value, The estimated figures were computed by all equations for both series. It will be seen that differences between two values of capacities for the first four series are all positive while those for the last series are all negative. The range of excessive or defective percentages varies from .30 to 4.76. The average percentage, disregarding the signs, is 2.73. In other words, when various formulæ are applied to those cranial materials there is 2.7% of average error which is likely to be made in predication. In Table III we have 42 comparisons altogether. It is not without interest to compare the average size of percentages in the same way as made above in accordance with different equations to be applied.

Equations used	(a)	(b)	(c)	(d)	(e)
Average percentages	3.67(6)[1]	1.79(10)	3.15(10)	3.61(6)	2.57(10)

It is clear that in both series, the use of equations (*b*) and (*c*) involving the measurement of auricular height tends again to contain less error than the use of other 3 equations. i. e. (*a*), (*c*), and (*d*), although in the latter cases the values of probable error are smaller. On the whole, the application of predicating equations of the Kunming series is slightly better[2] than that of the Houchiachuang series, possibly due to the fact that the five series examined are all of modern date. Judging from the average percentages again, all equations seem to be better fitted to the nothern Chinese cranial materials.[3] It is especially so in the case of the Houchiachuang equations. The results arrived at accord well with the nature of the data under consideration.

(VI). *Adaptation of the formulae for use on the living head.* It should be noted that among the five predicating formulæ formed for each series only the second one, which is determined from the produet of L×B×OH, can be

1. Figures in brackets indicate the number of comparisons made.

2. The average percentage of error by using the Kunming equations is 2.43 (21) and that by using the Houchiachuang equations 3.03 (21)

3. When all equations are applied to the northern series, the average percentage of error is 3.26 (16); and to the southern seris, it is 4.24 (20).

TABLE III. COMPARISON OF MEASURED AND COMPUTED CAPACITIES FOR SOME OTHER CHINESE CRANIAL SERIES (ALL MALES)

Series		1 Northern Chinese		2 Northern Chinese		3 Southern Chinese		4 Southern Chinese		5 Formosa Chinese	
Observors		various authors		Koganei		various authors		Harrower		Koganei	
Mean measurements in mm.: Length (L)		177.9(46)[1]		180.1(70)		177.6(102)		179.9(36)		179.9(14)	
Breadth (B)		133.8(46)		140.5(70)		139.4(120)		140.9(36)		139.4(14)	
Basio-bregmatic height (H)		133.7([illegible]6)		—		137.1(89)		137.8(36)		—	
Auricular height (OH)		118.1(27)		117.0(70)		119.2(33)		119.[illegible](36)		117.1(14)	
Sagittal arc (S)		370.3(45)		373.2(69)		369.5(96)		377.0(36)		374.1(14)	
Horizontal arc (U)		504.6(46)		511.6(70)		509.3(100)		510.5(36)		509.5(14)	
Transverse arc (Q)		317.6(40)		325.2(70)		321.2(39)		322.0(36)		325.1(14)	
Measured mean capacity in cm.^{3}		*1454.7*(40)		*1485.5*(69)		*1480.9*(64)		*1496.6*(36)		*1408.9*(14)	
Computed capacities in cm.^{3}											
Found by formulae:[2]	(I, a)	1405.7		—		1410.4		1434.9		—	
	(I, b)	1429.6		1444.1		1441.0		1464.9		1436.6	
	(I, c)	1409.5		1448.9		1425.3		1447.2		1447.1	
	(I, d)	1403.7		—		1417.2		1443.3		—	
	(I, e)	1417.1		1447.3		1432.2		1457.5		1442.1	
	(II, a)	1428.5		—		1434.9		1468.4		—	
	(II, b)	1448.5		1466.4		1462.6		1492.1		1456.8	
	(II, c)	1400.2		1461.4		1420.7		1449.2		1449.1	
	(II, d)	1409.8		—		1426.6		1459.1		—	
	(II, e)	1418.6		1459.3		1437.7		1463.0		1453.9	
Excess or defect of capacity-predication in cm.^{3}		Δ	%	Δ	%	Δ	%	Δ	%	Δ	%
Found by formulae:[2]	(I, a)	+49.0	+3.37	—	—	+70.5	+4.76	+61.7	+4.12	—	—
	(I, c)	+25.1	+1.73	+41.4	+2.79	+39.9	+2.69	+31.7	+2.12	−27.4	−1.94
	(I, c)	+45.2	+3.11	+35.6	+2.46	+55.6	+3.75	+49.4	+3.30	−38.2	−2.71
	(I, d)	+51.0	+3.51	—	—	+63.7	+4.30	+53.3	+3.56	—	—
	(I, e)	+37.6	+2.58	+38.2	+2.57	+48.7	+3.29	+39.1	+2.61	−33.2	−2.36
	(II, a)	+26.2	+1.89	—	—	+46.0	+3.11	+23.2	+1.83	—	—
	(II, b)	+6.2	+9.43	+19.1	+1.29	+18.3	+1.24	+4.5	+0.30	−47.9	−3.40
	(II, c)	+54.5	+3.76	+34.1	+2.30	+60.2	+4.07	+47.4	+3.17	−40.2	−2.85
	(II, d)	+44.9	+3.00	—	—	+54.3	+3.67	+37.5	+2.51	—	—
	(II, e)	+36.1	+2.48	+26.2	+1.76	+43.2	+2.92	+23.6	+1.91	−45.0	−3.19

1. Figures in brackets indicate the number of cases measured.
2. See equations given in the text.