Med. & Biol. Eng. Vol. 10, pp. 762–775. Peter Peregrinus Ltd., 1972. Printed in Great Britain

AN INVESTIGATION OF THE SPHERICITY OF THE HUMAN FEMORAL HEAD*

D. H. BLOWERS
Sheffield Polytechnic, Sheffield, England

R. ELSON
Department of Mechanical Engineering, University of Sheffield, Sheffield, England
and
E. KORLEY
Department of Orthopaedics, Northern General Hospital, Sheffield, England

Abstract—The sphericity of a limited area of the surface of the human femoral head has been assessed using the Talyrond roundness-measuring instrument. It is argued that this area approximates sufficiently closely to the load-bearing surface during standing and walking to allow conclusions to be drawn as to the sphericity of the whole head. The degree of sphericity is less than that reported by WALMSLEY (1928), but asphericity does frequently exist. The axis of any ovality is highly variable in this range of specimens, and the significance of this in relation to other published work is briefly discussed.

1. INTRODUCTION

HAMMOND and CHARNLEY (1967) drew attention to the previously unquestioned work of WALMSLEY (1928) concerning the shape of the human femoral head, with particular reference to its sphericity. They evaluated the problems in estimating the sphericity of this part on account of its irregular margins, geometrically incomplete surfaces and softness. Of seven techniques, a method was selected in which radiographs were projected onto a screen inscribed with a circle and calibrations, the latter marked on diameters drawn at 45° intervals; i.e. the circumference of the magnified image was measured at eight points and related to a true circle. The accuracy of this method was to within 0·0025 in on the specimen. Their results revealed a remarkable degree of sphericity in those specimens examined, some of which were affected by osteoarthrosis.

BULLOUGH *et al* (1968) examined a larger series for sphericity of both components of the human hip joint. Using a direct-measuring spherometer (a 3-legged gauge with a central probe controlled by a micrometer screw), they found that there was a departure from sphericity in both the head and articular surface of the acetabulum, that the radius of curvature of the acetabulum was less than that of the head, and that the departure from sphericity decreased with age of the specimen; note was made that HAMMOND and CHARNLEY (1967) had measured specimens from older subjects, and this was offered as an explanation for the discrepancy in the two sets of results. Subsequently, GREENWALD (1970) has studied the nature of the areas of contact between the femoral head and the acetabulum; a striking finding is that the arch of the acetabular surface (as viewed facing the mouth of the acetabulum) has a smaller radius of curvature than the adjacent femoral head which it caps, and consequently, between the

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* *First received 28th June 1971 and in final form 28th January 1972*

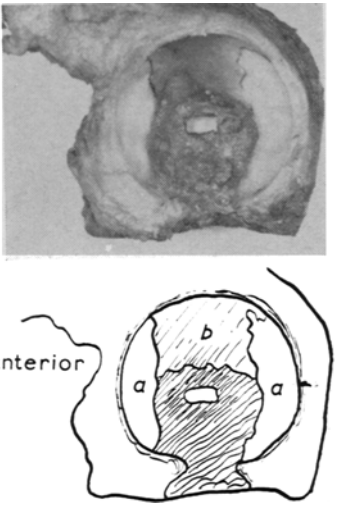

FIG. 1. Photograph of left acetabulum denoting contact areas (unstained) on the anterior and posterior surfaces. Letters *a* denote areas in contact at large and small loads while letter *b* denotes area in contact during large loads only.

two, there is a cleft (Fig. 1). With an increasing load, the cleft diminishes as the horns of the arch become progressively deformed; clearly, these are the sites of highest loading. If the femoral head were perfectly spherical, the contact pattern would remain unchanged during rotation while the load remained constant; any departure from sphericity would result in changes of the pattern during such motion.

The present study is concerned with the femoral head only, using the Talyrond. This machine enables specimens to be measured relatively easily, although the area of the surface which could be measured was limited. Other methods of measurement were tried but discarded.

2. INSTRUMENTATION

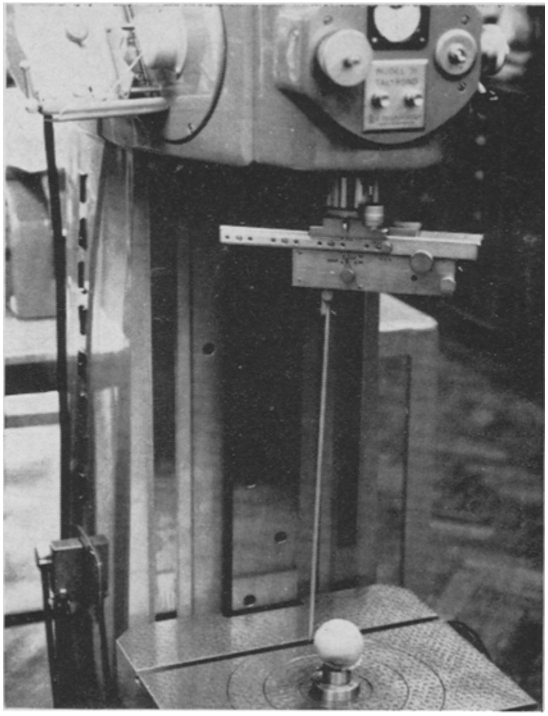

FIG. 2. The Talyrond machine. The long stylus was necessary to reduce the sensitivity of the machine to allow for the magnitude of deviations found in this sort of specimen. Although long, the stylus is both light and rigid. There was no significant deviation as a result of its length.

The measurements reported in this paper have been made with a Rank Taylor Hobson* 'Talyrond' roundness-measuring instrument normally used for the inspection of ball and roller bearings, pistons, cylinders etc. in the production-engineering industry. Electrical measurements are made of the motion of a fine stylus which is held against the specimen by a light spring, exerting a load of about $1 \cdot 5$ gf. The stylus is rotated about a vertical axis by a precision spindle. If the specimen is exactly circular, with its axis coincident with that of the instrument, there is then no relative deflection of the stylus as it rotates around the specimen. If, however, the specimen is not centrally placed or is not perfectly circular, the stylus moves relative to its carrier, and an electrical signal proportional to this relative movement is recorded. The output of the instrument is an irregular trace on a polar graph, typical examples of which are shown in Fig. 8.

In addition to drawing the graph of raw data shown in Fig. 8C, the instrument also has the capability of calculating and drawing on the

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* The Rank Organisation, Rank Taylor Hobson Division, Leicester, England

Table 1. *Results of the study*

No.	Age	Sex	Side	Contour level 0 = lowest contour	Angle of inclination	Mean angle of inclination	Major axis deviation	Minor axis deviation	Measure of asphericity	Mean measure of asphericity	True / mean square ellipse agreement	
				in	deg	deg	in	in	in	in		
1	0	F	R	0	—	0	0	0	0	0	G	
				0·05	—		0	0	0		G	
			L	0	+44	+42	0·0030	0·0030	0·0060	0·0045	G	
				0·05	+40		0·0015	0·0015	0·0030		G	
2	0	M	R	0	−41	−57	0·0060	0·0075	0·0135	0·0135	E	
				0·05	−73		0·0060	0·0075	0·0135		E	
			L	0	+78	+79	0·0060	0·0075	0·0135	0·0143	G	
				0·05	+80		0·0075	0·0075	0·0150		F	
3	0	F	R	0	−15	−15	0·0113	0·0120	0·0233	0·0233	F	
			L	0	−21	−21	0·0105	0·0105	0·0210	0·0210	G	
4	1 day	M	R	0	−31	−31	0·0038	0·0038	0·0076	0·0076	G	
			L	0	+21	+21	0·0015	0·0015	0·0030	0·0030	E	
	1 day	M	L	0	−33	−33	0·0053	0·0053	0·0106	0·0106	G	R damaged 26/52 pregnancy
6	1 day	M	R	0	+25	+25	0·0023	0·0023	0·0046	0·0046	E	
			L	0	+5	+5	0·0015	0·0015	0·0030	0·0030	E	
7	5 days	M	R	0	+37	+37	0·0045	0·0045	0·0090	0·0090	E	
			L	0	−16	−16	0·0060	0·0060	0·0120	0·0120	E	
8	5 days	M	R	0	+27	+27	0·0060	0·0060	0·0120	0·0120	G	
			L	0	+15	+15	0·0045	0·0045	0·0090	0·0090	G	
9	3 weeks	F	R	0	+22	+22	0·0053	0·0060	0·0113	0·0113	G	
			L	0	+24	+24	0·0030	0·0030	0·0060	0·0060	G	
10	3 weeks	M	R	0	+10	+10	0·0060	0·0060	0·0120	0·0120	E	
			L	0	+15	+15	0·0075	0·0083	0·0158	0·0158	E	
11	3 months	F	R	0	+10	+10	0·0045	0·0045	0·0090	0·0090	F	
			L	0	−61	−61	0·0030	0·0030	0·0060	0·0060	F	
12	15 years	F	R	0	+47	+63	0·0030	0·0030	0·0060	0·0060	F	
				0·3	+78		0·0030	0·0030	0·0060		F	
			L	0·0	−76	−78	0·0038	0·0038	0·0076	0·0087	G	
				0·3	−80		0·0053	0·0045	0·0098		G	
13	16 years	M	R	0	−21	−21	0·0090	0·0090	0·0180	0·0180	P	
			L	0	+26	+35	0·0135	0·0135	0·0270	0·0240	F	
				0·2	+44		0·0105	0·0105	0·0210		F	
14	26 years	M	R	0	−50	−61	0·0038	0·0038	0·0076	0·0083	F	
				0·2	−71		0·0045	0·0045	0·0090		F	
			L	0	+40	+46	0·0030	0·0030	0·0060	0·0068	F	
				0·2	+52		0·0038	0·0038	0·0076		F	
15	26 years	F	R	0	+45	+51	0·0038	0·0045	0·0083	0·0095	F	
				0·3	+56		0·0053	0·0053	0·0106		P	
			L	0	−66	−70	0·0008	0·0008	0·0016	0·0031	F	
				0·1	−74		0·0023	0·0023	0·0046		P	
16	33 years	F	L	0	+33	+33	0·0128	0·0128	0·0256	0·0256		Right side too irregular

17	41 years	M	R	0	+3	+3	0·0090	0·0090	0·0180	0·0173	F	
				0·2	+3		0·0090	0·0075	0·0165		F	
			L	0	−3	+17	0·0045	0·0053	0·0098	0·0079	G	
				0·3	+37		0·0030	0·0030	0·0060		F	
18	43 years	M	R	0	−67	−59	0·0045	0·0053	0·0098	0·0094	P	
				0·2	−50		0·0045	0·0045	0·0090		F	
			L	0	+52	+63	0·0038	0·0038	0·0076	0·0068	F	
				0·2	+74		0·0030	0·0030	0·0060		P	
19	43 years	M	R	0	+12	+17	0·0068	0·0068	0·0136	0·0013	F	Amputee left hip
				0·2	+21		0·0030	0·0060	0·0090		F	
20	48 years	M	R	0	0	−13	0·0030	0·0030	0·0060	0·0045	G	
				0·3	−26		0·0015	0·0015	0·0030		G	
			L	0	+3	+1	0·0038	0·0038	0·0076	0·0061	G	
				0·2	−2		0·0023	0·0023	0·0046		G	
21	50 years	M	R	0	−60	−56	0·0090	0·0090	0·0180	0·0188	P	
				0·2	−51		0·0098	0·0098	0·0196		P	
			L	0	+49	+49	0·0105	0·0105	0·0210	0·0210	P	
22	51 years	M	L	0	−37	−36	0·0038	0·0045	0·0083	0·0095	G	
				0·3	−34		0·0030	0·0030	0·0060		G	
			L	0	+38	+53	0·0060	0·0060	0·0120	0·0080	F	
				0·2	+57		0·0030	0·0030	0·0060		G	
				0·3	+84		0·0030	0·0030	0·0060		G	
23	52 years	M	R	0	−27	−35	0·0060	0·0060	0·0120	0·0100	F	
				0·2	−37		0·0060	0·0060	0·0120		P	
				0·4	−42		0·0030	0·0030	0·0060		F	
			L	0	+18	+48	0·0030	0·0030	0·0060	0·0050	G	
				0·2	+48		0·0015	0·0015	0·0030		F	
				0·4	+79		0·0030	0·0030	0·0060		P	
24	53 years	M	R	0	−32	−29	0·0045	0·0045	0·0090	0·5010	F	
				0·3	−26		0·0060	0·0060	0·0120		F	
			L	0	+61	+47	0·0045	0·0045	0·0090	0·0090	F	
				0·2	+53		0·0045	0·0045	0·0090		F	
				0·3	+26		0·0045	0·0045	0·0090		F	
25	56 years	F	R	0	−4	−4	0·0075	0·0075	0·0150	0·0150	P	No other readings possible
			L	0	+30	+30	0·0075	0·0075	0·0150	0·0150	G	
26	57 years	M	R	0	0	−13	0·0030	0·0030	0·0060	0·0045	G	
				0·3	−26		0·0015	0·0015	0·0030		G	
			L	0	+3	0	0·0038	0·0038	0·0076	0·0061	F	
					−2		0·0023	0·0023	0·0046		P	
27	60 years	M	R	0	−29	−29	0·0098	0·0098	0·0196	0·0196	P	
			L	0	+39	+48	0·0120	0·0120	0·0240	0·0176	P	
				0·2	+44		0·0075	0·0090	0·0167		F	
				0·3	+62		0·0060	0·0060	0·0120		F	
28	61 years	M	R	0	−48	−48	0·0060	0·0060	0·0120	0·0120	F	
				0·2	−56		0·0060	0·0060	0·0120		F	
				0·3	−63		0·0060	0·0060	0·0120		P	
			L	0	−5	+4	0·0060	0·0060	0·0120	0·0113	P	
				0·1	+13		0·0045	0·0060	0·0105		P	
29	61 years	M	R	0	−17	−23	0·0075	0·0075	0·0150	0·0128	G	
				0·2	−17		0·0060	0·0060	0·0120		F	

Table 1.—*Continued.*

No.	Age	Sex	Side	Contour level 0 = lowest contour in	Angle of inclination deg	Mean angle- of inclination deg	Major axis deviation in	Minor axis deviation in	Measure of asphericity in	Mean measure of asphericity in	True/ mean square ellipse agreement	
30	63 years	M	L	0·4	−34	+32	0·0053	0·0060	0·0113	0·0113	P	
				0	+37		0·0060	0·0075	0·0135		G	
				0·2	+27		0·0045	0·0045	0·0090		G	
			R	0	−40	−41	0·0060	0·0060	0·0120	0·0135	P	
				0·2	−41		0·0075	0·0075	0·0150		P	
			L	0	+19	+18	0·0090	0·0090	0·0180	0·0185	P	
				0·2	+12		0·0090	0·0090	0·0180		P	
				0·4	+5		0·0105	0·0090	0·0195		P	
31	63 years	F	L	0	+32	+33	0·0038	0·0038	0·0076	0·0068	G	Right side too irregular
				0·2	+34		0·0030	0·0030	0·0060		G	
32	65 years	M	R	0	−56	−35	0·0060	0·0068	0·0128	0·0068	P	
				0·2	−80		0·0015	0·0015	0·0030		F	
				0·3	+31		0·0015	0·0030	0·0045		P	
			L	0	0	−86	0	0	0	0·0050	E	
				0·2	−89		0·0030	0·0030	0·0060		E	
				0·3	−83		0·0060	0·0030	0·0090		G	
33	65 years	M	R	0	−54	−58	0·0030	0·0030	0·0060	0·0060	F	
				0·2	−63		0·0030	0·0030	0·0060		G	
				0·4	−56		0·0030	0·0030	0·0060		E	
			L	0	+38	+60	0·0060	0·0060	0·0120	0·0080	F	
				0·2	+57		0·0030	0·0030	0·0060		F	
				0·3	+84		0·0030	0·0030	0·0060		P	
34	66 years	M	R	0	0	0	0	0	0	0		No other readings possible. Left side —Moore's arthroplasty
35	71 years	M	R	0	+35	+23	0·0038	0·0045	0·0083	0·0102	G	
				0·1	+10		0·0060	0·0060	0·0120		F	
			L	0	−33	−27	0·0045	0·0045	0·0090	0·0113	F	
				0·2	−22		0·0053	0·0060	0·0113		P	
				0·3	−26		0·0075	0·0060	0·0135		P	
36	74 years	M	R	0	−52	−57	0·0023	0·0023	0·0046	0·0053	F	
				0·3	−62		0·0030	0·0030	0·0060		G	
			L	0	+8	+14	0·0023	0·0023	0·0046	0·0046	G	
				0·2	+19		0·0023	0·0023	0·0046		G	
37	80 years	F	R	0	−58	−46	0·0060	0·0060	0·0120	0·0124	F	
				0·2	−27		0·0060	0·0068	0·0128		P	
			L	0	−84	−54	0·0053	0·0053	0·0106	0·0106	P	
				0·2	−23		0·0053	0·0053	0·0106		G*	
38	86 years	F	R	0	−15	−15	0·0030	0·0030	0·0060	0·0060	P	

graph the 'best' circle and 'best' ellipse to fit the recorded data. A typical best circle and best ellipse are each shown in Fig. 8D. A reference computer coupled to the Talyrond calculates the polar co-ordinate of a circle and an ellipse which conform as closely as possible to the actual trace, and the instrument then traces these contours onto the output graph. Statistically, the 'best' circle and ellipse are calculated according to a 'least-squares' formula as described in the manufacturer's literature for the equipment.

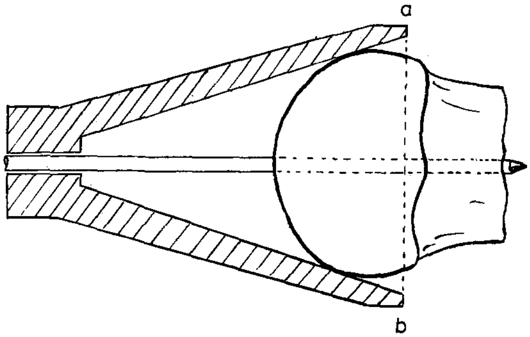


FIG. 3. Template used for mounting the femoral-head specimens. This was funnel shaped and the irregular margin of the articular cartilage was aligned by eye with the plane of the mouth ab.

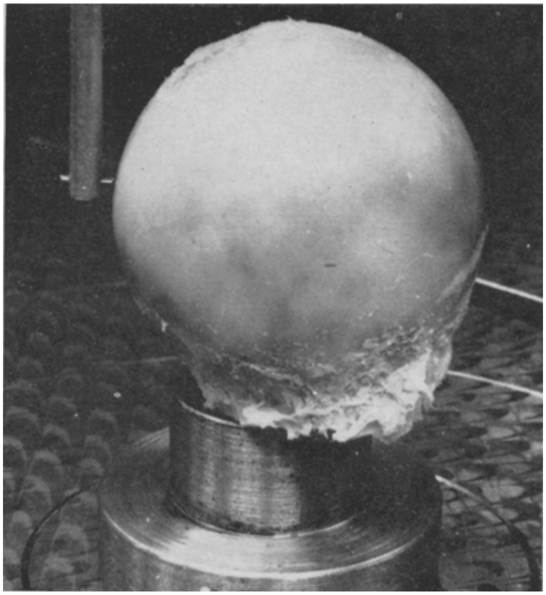


FIG. 4. Femoral-head specimen mounted on plinth.

A possibly confusing feature of the graphical output from the instrument is that the scale of radial deviations from circular form is greatly magnified on the polar traces. As a result of this distortion, an ellipse loses its geometical form and may become dumbbell shaped, as shown in Fig. 8A. A circle always remains truly circular, however, although its centre may be offset from the axis of the machine, and therefore the centre of the graph, as also shown in Fig. 8D.

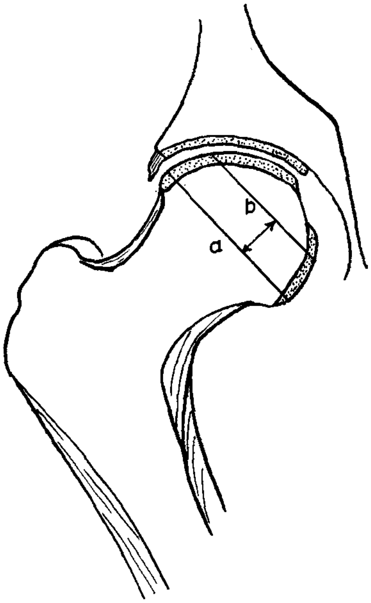
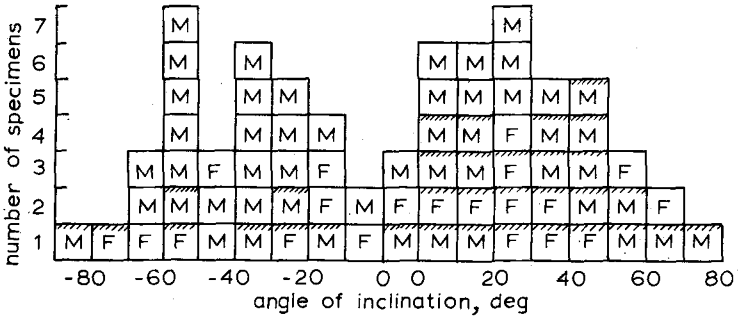


FIG. 5. Coronal section of the hip joint showing the band (ab) of femoral-head articular surface which was estimated in this study.

In describing the geometrical forms of the specimens measured, a difficulty arises over terminology, and particularly the word 'ovality'. It has become customary in engineering applications to use 'ovality' to describe the dimensional difference between the least-squares circle and the least-squares ellipse. Thus, in Fig. 6, where the semimajor axis of the ellipse exceeds the radius of the circle by distance e, and the semiminor axis of the ellipse is less than the radius of the circle by distance f, then the ovality is said to be the dimension (e+f). Since the least-squares ellipse must be symmetrically located with respect to the least-squares circle, the ovality will be the same whichever semiaxes are chosen for this measurement.

To reduce the sensitivity of the instrument, an extended stylus rod was used, as shown in Fig. 2. To maintain accuracy, the dynamic deflection of this rod must be small compared with the surface irregularities being measured. It should be explained that the long stylus rod was essential because the lack of roundness of the specimens had to be scaled down to fall within the bandwidth of the instrument, and the flexibility and weight of the rod are not believed to have been sufficient to distort the results to any significant extent. This belief was substantiated by testing a steel ball on the surface of which had been machined a flat, resulting in a sudden change of contour. It was found that the sharp changes in profile were faithfully reproduced without detectable distortion which would have occurred if dynamic effects from such a long stylus had been significant.

Table 2. Distribution of examples showing angles of inclination (boxes with cross-hatching indicate left specimens)

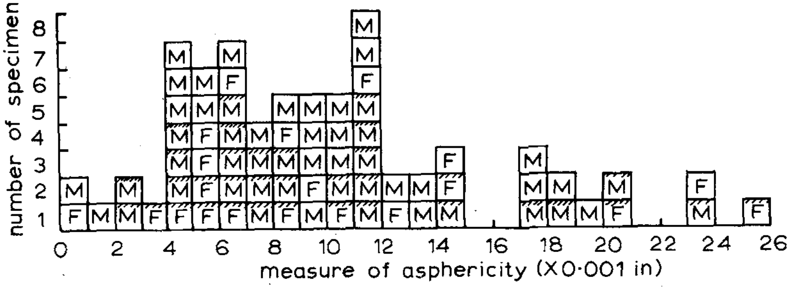


3. METHOD

Femoral heads were removed from fresh cadavers through an anterior incision. The anterior capsule was removed and, after the lower limbs had been placed in the neutral or anatomical position relative to the trunk, the most anterior aspect of the femoral neck was marked with a V-shaped cut using a sharp osteotome. The base of the neck was then sectioned using a saw and, following complete division of the remaining capsule, the joint was disarticulated and the ligamentum teres was removed. Care was taken that the articular cartilage was not bruised.

After removal, the specimen was preserved in a 4% formaldehyde in saline solution until measurement. To assess any change in dimension, especially in the infantile specimens which comprise such a large proportion of cartilage compared with bone, two specimens were measured immediately and again after one week

Table 3. Distribution of examples showing measures of asphericity (boxes with crosshatching indicate left specimens)



in the solution. There were minor changes of less than 0·001 in, but there was no change in the gross measurements afforded by this technique. The minor errors were, in part, due to slightly different positioning of the specimens during the two measurement procedures. Changes due to drying, which might have occurred during the period of each measuring procedure, were not detected.

The section of the femoral-head surface which could be evaluated by this method is bounded distally by the irregular margin of the articular cartilage adjacent to the neck. This line was estimated by eye using the funnel-shaped template (Fig. 3). Once aligned, the specimen was drilled perpendicular to the margin and then mounted on a plinth supporting a woodscrew (Fig. 4).

After adjustment, it was possible to stand the specimen on its plinth centrally under the axis of the spindle, and a series of contours could be measured by raising or lowering the table. The lowest contour was located and determined in position by the irregularities of the irregular margin of the cartilage; the highest contour depended for its position on the fovea (Fig. 5). In each case, the orientation was such that the anterior aspect, as indicated by the osteotome cut on the neck (which had been carefully related to the anatomical position at the time of removal), could be indicated on the tracings, thereby enabling any long axis of ovality to be related to the standing human subject.

The lowest contour was found by trial, and subsequently further contours were selected so that as large a depth of surface as possible could be examined. At first, several contours were measured (these were located with reference to the lowest contour), but after it had been found that these corresponded well in terms of axis and asphericity, only two were explored; in very small specimens (infantile) only one contour was measured, located approximately in the mid-position of the available depth.

A typical result is shown in Fig. 6, where the dotted lines indicate the construction used to obtain an axis of ovality. Deviations on the chart of 0·1 in correspond to 0·003 in on the specimen. The following parameters were measured:

(*a*) For each contour, the major axis of a mean-square ellipse was obtained and the following convention adopted: each specimen was viewed as if from within the pelvis. If, from this aspect, irrespective of right or left sides, the upper half of the ellipse axis inclined forwards, this was called ‘positive’, and the number of degrees of inclination were measured; the converse applies for negative inclinations (see Fig. 6).

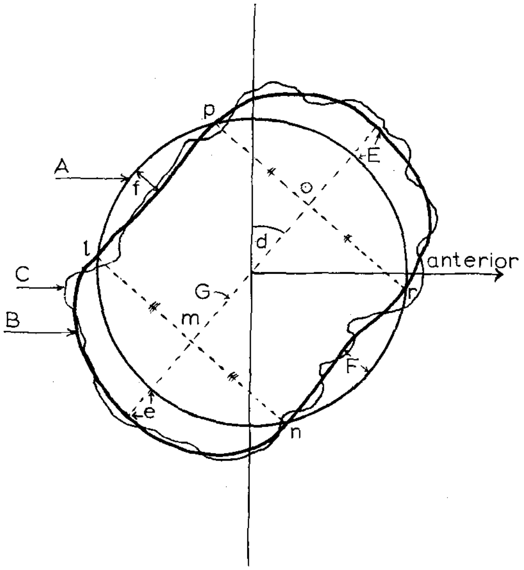


FIG. 6. Method of construction to obtain angle of inclination and measures of asphericity from each record as determined by the Talyrond. Line A is the least-squares mean circle, line B is the least-squares mean ellipse, and line C is the path representing the actual surface from which B and A are computed by the machine. The anterior aspect of the specimen is known and, from the construction shown, the angle *d* which, in this example, is positive, can be measured directly as the angle of inclination. Distance E is the major-axis deviation and distance F is the minor-axis deviation. On each chart, radial deviations of 0·1 in represent 0·003 in on the specimen. Note: (i) Line C, the outline of the specimen as interpreted by the Talyrond, may appear as shown because of the great magnification of departures from true sphericity. In this example, the longer segments of the oval shape are represented by concave segments in line C and, consequently, in line B. (ii) Distance E always equals distance e and, similarly, F equals f.

(*b*) The difference between the positions of the mean circle and mean ellipse shape, on the major and minor axes of the latter, were measured, added, and this sum regarded as an estimate of ovality of the specimen concerned. Referring again to Fig. 6, distances *e* and *f* were the measurements concerned.

(*c*) The maximum deviations outside and inside the mean circle were selected by inspection and measured; these were regarded as less important than the outline of the mean ellipse.

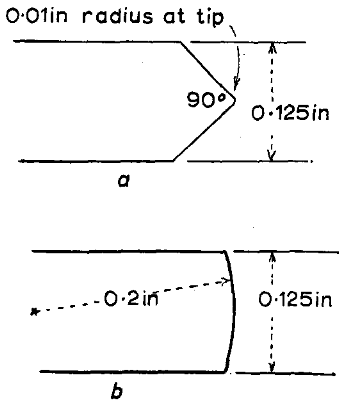


FIG. 7. Dimensions of probe. Aspect *a* is from above, and aspect *b* is from the side.

(*d*) Deviations of the true outline from the least-squares ellipse were examined to gain some idea of the minor irregularities of the surface. These are demonstrated only as detected by the probe at the end of the stylus (Fig. 7), and then as deviations in a radial direction. Agreement between the true path and the mean-squares ellipse was graded for convenience as:

excellent (E) if deviations were less than 0·003 in
good (G) if between 0·003 in and 0·006 in
fair (F) if between 0·006 in and 0·012 in
poor (P) if exceeding 0·012 in

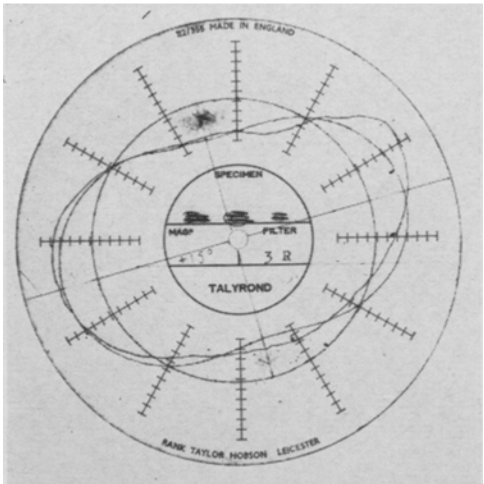
(These estimations were approximate but, nevertheless, indicative of the surface irregularities.)

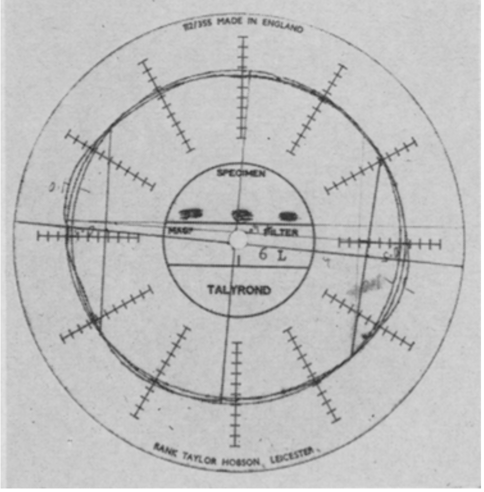
4. RESULTS

Table 1 shows the results of the study. The histograms in Tables 2 and 3 demonstrate the frequency of the measurements and the sex distribution (of the 70 specimens recorded, 19 were from females and 51 from males).

The average measurement of ovality was calculated for each specimen from whatever readings were available (the results from individual contours of the same specimen often differed widely). The mean was about 0·009 in, and the extremes were 0·026 in and 0·001 in. In particular, infantile specimens of small diameter showed remarkably varying measurements.

The angle of inclination varied from +80° to −86°. Means of forward and backward inclination were +31° and −55°, respectively. The





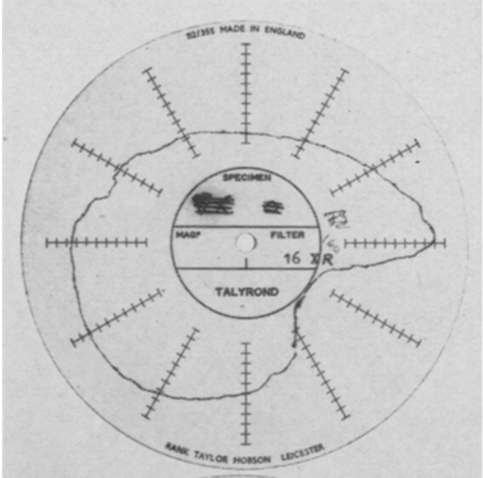
Above: FIG. 8A. Specimen 3 right (female—stillborn, full term).

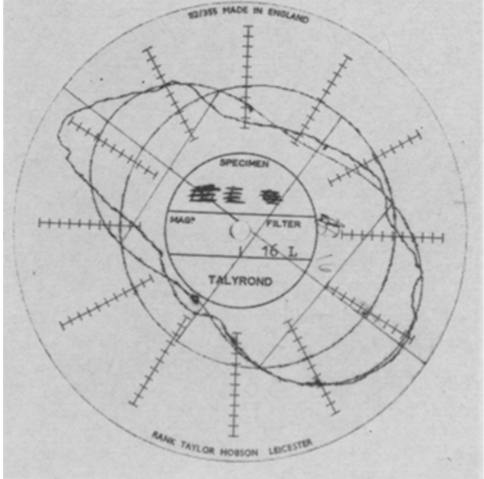
Below: FIG. 8B. Specimen 6 left (male—age 1 day).

angle was positive (forward inclination) in 36 examples, negative (backward inclination) in 31 examples, and neutral in three.

No correlation with age could be found in this series, nor with the mean diameter of the actual specimen as obtained using a pair of outside calipers.

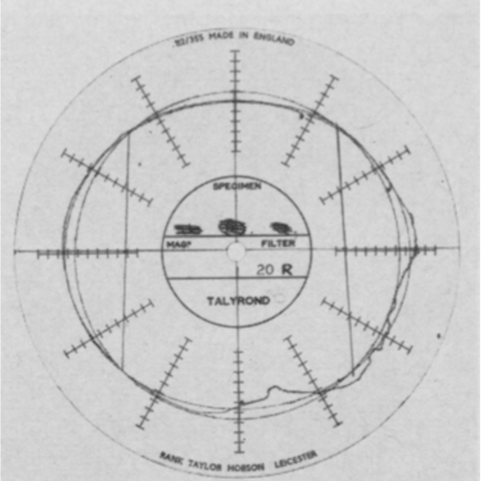
The major axes of the mean-squares ellipses and the dimensions of the deviations from the true circle from the several contours of one specimen usually show a trend, and occasionally there was a change from positive to negative in the angle of inclination. When the sign changed, it was usually in examples in which the major axis was more vertically disposed (specimen 28L)—an exception was specimen 32R.

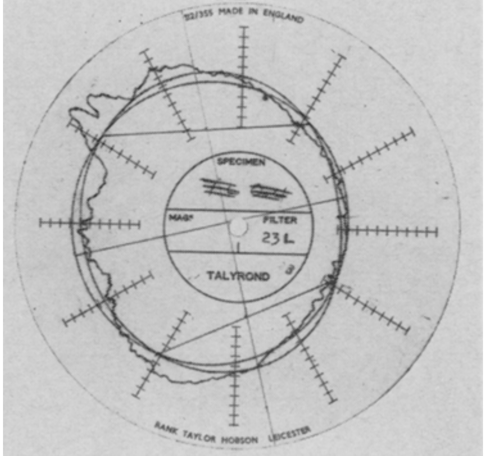




Above: Fig. 8c. Specimen 16 right (female—age 33 years). (Too irregular for Talyrond to measure mean square ellipse).

Below: Fig. 8d. Specimen 16 left (female—age 33 years).





Above: Fig. 8e. Specimen 20 right (male—age 48 years).

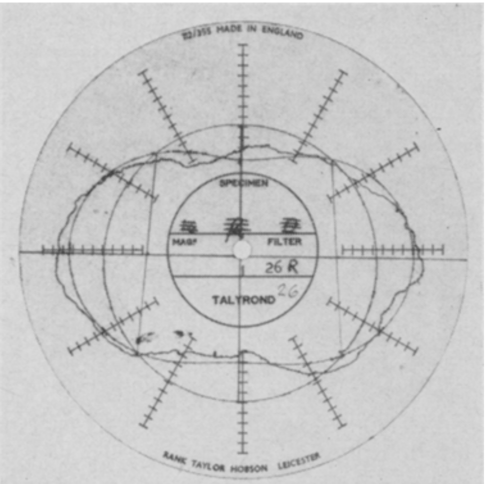
Below: Fig. 8f. Specimen 23 left (male—age 52 years).

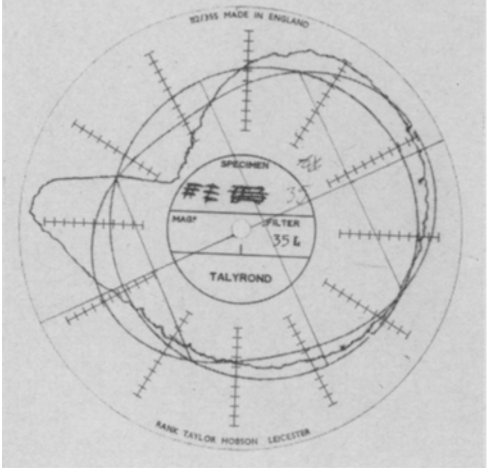
The changes between contours on the same specimen, which occurred although the position on the table was not altered, indicate that, if we possessed a device that would measure the relevant surface perpendicular to the direction explored by the Talyrond, comparable irregularities would be expected over the whole surface of the femoral head.

Examination of individual records was of interest:

(*a*) The finer irregularities of the surface, with which this study was not particularly concerned, and the detection of which depended on the nature of the stylus probe (Fig. 7), were variable. In general, as might be expected, the older specimens showed a more granular texture (specimen 20L, from a 48-year-old male, and specimen 23L, from a 52-year-old male, contrast in this respect—see Figs. 8E and F. Infantile specimens were very smooth.

(*b*) Gross irregularities, as well as the finer ones just mentioned, were smoothed by the reference computer (specimen 35L, Fig. 8H). An assessment of the sphericity of an irregular surface must involve some averaging process, and clearly, even if associated with blunt points, calipers applied to specimen 35L could give measurements indicating marked ovality of about 0·05 in difference between major and minor axes. The appearance on this record shows how the Talyrond exaggerates the irregularities; only the radial deviations can be regarded dimensionally.





Above: FIG. 8G. Specimen 26 right (male—age 57 years).
Below: FIG. 8H. Specimen 35 left (male—age 71 years).

(*c*) Differences between right and left hips in the same subject were common. In 23 of the 34 subjects of whom both hips were assessed, the directions of the axes of ovality were of opposite sign. In another respect, three of the specimens which were too asymmetrical for the machine to tolerate had very smooth surfaces; one of these (specimen 16R, from a 33-year-old female) is shown in Fig. 8C; on the opposite side, 16L, there was marked ovality but a much more symmetrical shape (Fig. 8D). The angle of inclination only occasionally changed its sign from contour to contour on the same specimen when the long axis of the ellipsed shape was disposed towards the vertical (0°), as in specimen 26R (Fig. 8G). Here again, there were exceptions, and, in specimen 10, measurement was checked and confirmed. Clearly, any marked depression in the surface will influence the shape of the mean ellipsoid and, if the latter is already fairly circular, a change in sign is more likely.

(*d*) Specimens 3R and 6L (Figs. 8A and B) demonstrate contrasting oval and circular contours from infantile specimens.

(*e*) The vertically disposed long axis of specimen 26R (Fig. 8G) contrasts with the usually expressed view that this is normally horizontal.

5. DISCUSSION

The measurement of the femoral head presents technical problems as outlined by HAMMOND and CHARNELY (1967). We attempted several methods but abandoned them because of various difficulties. For example:

(*a*) Direct measurement using a spherometer (a displacement gauge, having a linear accuracy of 0·005 in, mounted on a tripod) which was stood repeatedly on successive areas of the specimen to be examined. Although different-shaped probes and supporting feet were tried, it was found impossible to obtain accurately repeatable results even over limited areas. For example, any of the four points of support could be located in a pit on the surface of the articular cartilage; also, creep introduced another variable.

(*b*) Measurement of co-ordinates using a travelling microscope which traversed over the mounted specimen. After recording *x* and *y* values for the whole available circumference, the shape was plotted on graph paper. Different views of the specimen were recorded. The result was superimposed onto true circles and, while comparison was possible, the irregularities seemed so gross that, at this early stage of our study, conclusions were very uncertain. Further, the time taken to plot and record the co-ordinates was considerable. Finally, because the microscope afforded a tangential view of the surface, some lesser irregularities were not perceived.

(*c*) A projection technique in which the femoral-head specimen was photographed onto high-contrast film which was projected very accurately using a Taylor Hobson toolroom optical projector. Twelve attitudes of the head were examined and the projected outlines were compared with a series of concentric circles on the screen. In our hands, it was difficult to centre the projected outlines despite the facility of *x* and *y* controls of the table; this was partly because of incompleteness of the images (due to interruption by the femoral neck). It is now apparent, from the results using the Talyrond, that, between contours which are as little as 0·2 in apart, considerable variation in shape occurs, and any projection technique must entail some smoothing of detail and a tendency to apparent sphericity.

The Talyrond offers a simple method of estimating the sphericity, or more strictly the circularity, of a very limited slice of the femoral head. In fact, it records with known accuracy the shape of a series of contours of this slice, amplifying both minor and major irregularities. Comparison of contours of the same specimen reveals the trend of any departures from circularity, and accordingly, it is reasonable to make some estimation of the surface under consideration. The narrow band which has been assessed has some approximation to the weight-bearing part of the femoral head during standing and walking (Fig. 5). It is considered useful to make this approximation since the section is so near to that referred to by workers who claim to detect the screwing-home effect in a position of maximum congruency. We found that, in testing each specimen for this sensation, sometimes there *is* a change in the texture of motion palpable to the examiner and in some instances a sensation of screwing-home. Measurements using the Talyrond certainly show ovality of many contours of the specimens examined, and therefore these irregularities in the texture of the quality of motion between the head and acetabulum would be expected. However, the variability of this texture is comparable to the widely differing amounts and axes of any elliptical shape in the range of specimens.

Certainly, the gross differences recorded by Walmsley between the major and minor axes of the femoral head (0·066 in) and the horizontal disposition of the major axis are not confirmed.

Any consideration of the congruence of two mating surfaces must include both components. From our measurements of the femoral head alone, whether or not the related acetabular articular surface is spherical, it may be concluded that, during rotation in most instances (i.e. excluding the infrequent examples where a close approximation to sphericity was demonstrated, e.g. Fig. 8B), there must have been changes in the nature of the contact pattern, even allowing for the compliance of healthy articular cartilage, and variation in loading.

We have not attempted to measure the curvature of the acetabular articular surface to confirm GREENWALD'S (1970) claim that there is a smaller radius of curvature here compared with that of the femoral head. His tests show that, because of this incongruence, there is a cleft due to lack of contact between the superior aspects of the joint components. During loading, the cleft narrows as the articular cartilage in the regions of the horns of the acetabular bearing surface deforms. Whenever the cleft exists, it must presumably be filled with synovial fluid (unless gas bubbles form, as may be the case in one variety of clicking hip) and, during intermittent loading of the joint, the fluid will be alternately expressed from and sucked back into the cleft. During ordinary function, it is probable that the cleft exists during periods of low loading as occur during relaxed recumbency and part of the swing phase of walking.

The irregularities demonstrated in the present limited study are of two magnitudes: first, gross asphericity exists in many specimens and during flexion–extension movements, even under constant loading, changes in the cleft as demonstrated by Greenwald must occur, depending on the axis of such asphericity. Secondly, the lesser surface irregularities present in many specimens, young and old, which vary in site between the contours we have measured, must act as pools or traps for smaller collections of synovial fluid. These will be situated, in some instances, in load-bearing areas, or become thus associated during flexion–extension motion of the hip joint.

At the extreme, the demonstration of microscopic irregularities by WALKER *et al.* (1969) completes a spectrum of irregularities.

It is probable that the captive hip joint, in which large ares of contiguous joint surfaces are deprived of easy access to synovial fluid, utilises these incongruities as a device to introduce synovial fluid with its lubricative, nutrient and load-bearing functions between the joint surfaces. Such considerations are probably involved in the anatomically curious shape of the acetabular articular surface. The cleft described by GREENWALD (1970) and the shape of the acetabular articular surface are regular in position, but the axes of any asphericity and the lesser surface irregularities are not critical in this respect, as are the microscopic details photographed by WALKER *et al* (1969).

In a plane fairly related to the contours we have been able to examine, HAMMOND and CHARNLEY (1967) found, using the radiograph-projection technique, that the curvature did not deviate by more than 0·001 in. Our results do not confirm such small deviations from sphericity in most instances, although we are not able, using the Talyrond, to examine as many planes as these workers.

Acknowledgments—We wish to thank the Principal of the Sheffield Polytechnic for measuring facilities, Prof. B. DOWSON (Leeds) for advice, Prof. B. RAWLINGS and Mr. D. TROTT for early assistance in measuring techniques. Dr. A. S. GREENWALD of Imperial College, London, kindly supplied the photograph in Fig. 1.

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UNE INVESTIGATION DE LA SPHERICITE DE LA TETE FEMORALE HUMAINE

Sommaire—La sphéricité d'une partie limitée de la surface de la tête fémorale humaine a été évaluée à l'aide de l'instrument de mesure de rondeur de Talyrond. Il est débattu que cette partie se rapproche suffisemment de la surface porteuse pendant la position debout et la marche pour permettre de tirer des conclusions concernant la sphéricité de toute la tête. Le degré de sphéricité est plus faible que celui rapporté par WALMSLEY (1928), mais la non sphéricité est fréquente; l'axe de toute ovalité est très variable dans cette gamme de spécimens, et la signification de ceci en rapport à d'autres travaux publiés est discutée brièvement.

EINE UNTERSUCHUNG DER KUGLIGKEIT DES MENSCHLICHEN OBERSCHENKELKOPFES

Zusammenfassung—Unter Verwendung des Rundungsmeßgeräts Talyrond wurde die Kugligkeit eines begrenzten Teils der Oberfläche des menschlichen Oberschenkelkopfes bestimmt. Es wird behauptet, daß diese Fläche der beim Stehen und Gehen lasttragenden Oberfläche ähnlich genug sei, um Schlußfolgerungen in bezug auf die Kugligkeit des ganzen Kopfes zuzulassen. Der Kugligkeitsgrad ist geringer als von WALMSLEY (1928) angegeben, und oft tritt eine asphärische Form auf: Die Achse jedes ovalen Körpers ist in diesem Probenbereich sehr variabel, und es wird kurz erörtert, was das im Zusammenhang mit anderen veröffentlichten Arbeiten zu bedeuten hat.