OBSERVATIONS ON HALLUX VALGUS

Based on a Controlled Series

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In view of the varied accounts of the natural history of hallux valgus in man it seemed worth while to attempt a series of exact observations on established cases together with a comparable number of controls. While any marked differences between the two groups might be merely accidental, it is likely that a predisposing factor, if any such exist, would either be found among them, or at least closely related to such differences.

CLINICAL MATERIAL

The material of the survey was drawn from three sources: morbid material from the Royal National Orthopaedic Hospital; controls from University College and Hospital, and from the Royal Naval Barracks at Portsmouth.

Morbid group—In May 1949 there was a list of 250 patients waiting for Keller's operation at the Royal National Orthopaedic Hospital. A letter was sent to each one, asking him to attend this department for an investigation, the nature and purpose of which was briefly explained. Of the 101 persons who presented themselves for examination, eighty-nine were suffering from uncorrected hallux valgus (affecting one or both feet) with symptoms of pain and deformity in the region of the first metatarso-phalangeal joint. Of the 250 patients written to, only twenty-nine (12 per cent) were males; and of those who attended for investigation only three were males. Eight (42 per cent) of nineteen patients with hallux rigidus examined in a similar manner were men; the proportion of men in the total list of 250 awaiting Keller's operation who were suffering from hallux valgus should therefore be rather less than 12 per cent. The ages of those examined ranged from twenty to sixty-six years with a preponderance between the ages of thirty-five to fifty-one years (Fig. 2). Of the women examined forty-seven (54 per cent) had borne one or more children.

Twelve of the 101 patients who attended were excluded from the investigation: eleven were suffering from bilateral hallux rigidus and one had already had bilateral operations without benefit.

The remaining group of eighty-nine patients with hallux valgus was, of course, highly selected and the following selecting factors are set down in a suggested order of importance: 1) Occurrence of symptoms. 2) Environment making operation preferable to a continuance of symptoms (the influence of fashion in shoes should be included here). 3) Suitability of case for operation as judged in orthopaedic out-patient department. 4) Willingness to submit to a lengthy investigation for purposes of research. 5) Ability to reach University College, London, at stated times.

An attempt was made to meet, so far as possible, all types of person by offering a choice of morning, afternoon and evening times of attendance. Fares were paid for all who attended, except in the few instances of those who refused payment.

Control group—Eighty-four persons were investigated in the same way as the morbid group. They were drawn from among the staff and students of University College and the nurses' preliminary training school at University College Hospital. Fifty-two (62 per cent) were

women. One nurse was found to be suffering from advanced bilateral hallux rigidus; otherwise there was no marked morbidity. Their ages were not closely comparable to those of the hallux valgus group, and ranged from sixteen to sixty-five years with a large preponderance between the ages of sixteen and twenty years (Fig. 1). In addition to these persons who were investigated fully, forty-two naval ratings of the Royal Naval Barracks, Portsmouth, were submitted to a brief clinical examination and a standard plantar radiograph. These were mostly young recruits between seventeen and nineteen years of age; the total range was from seventeen to forty-five years.

Of the London controls, those from University College were volunteers of whom only one or two expressed any concern with the condition of their feet and none with any emphasis, so that a desire for diagnosis or advice does not appear to have been a strongly selective factor. The nurses were all those available from the training school at the relevant moment. The naval recruits were selected by a Chief Petty Officer according to their freedom from

FIG. 1

FIG. 2

Histograms of distribution of age of subjects in two groups. Figure 1—Control group. Figure 2—Morbid group.

other commitments, and only one showed any interest in his feet; advanced osteoarthritic changes were present in the region of the first metatarso-phalangeal joint which gave rise to slight symptoms; these were unilateral and attributed to a single instance of severe trauma.

METHODS OF INVESTIGATION

In addition to a full history and clinical examination four methods of collecting data were used.

Radiographic examination—Standard medio-lateral and plantari-dorsal radiographs were taken, from which it was found possible to take measurements which were significant for the purpose of comparison. In a preliminary investigation (Venning and Hardy 1951) it was found that, under the conditions laid down, measurements in the lateral radiograph of "arch height" (from the head of the talus to a base line—usually about 45 millimetres in the adult) showed a standard deviation of ± 1.5 millimetres; in the plantar view measurements of angle between an axis of the second metatarsal and a transverse tarsal base line (usually about 100 degrees) showed a similar standard deviation of ± 1.5 degrees. Small departures from the standard conditions were found to lead to considerable errors in measurement

(Figs. 3 and 4). Ten measurements were made from each plantar and seven from each lateral radiograph in addition to general observations.

The standard position for the lateral radiographs was as follows: The subject stood erect on one leg with the knee fully extended; the other knee was flexed, with the toes off the ground. The cathode-film distance was 100 centimetres, and the distance from a plane of the foot, represented by a line joining the base of the first interdigital cleft to the mid-point of the back of the heel, to the film was 11.5 centimetres. The central ray passed just below the base of the fifth metatarsal.

FIG. 3

FIG. 4

Standard radiographs. Figure 3—Lateral view. *AB*, base line; *CD*, arch height; *EF*, arch length. Figure 4—Plantar view. *AB*, axis of second metatarsal; *CD*, transverse tarsal line.

For the plantar radiograph the subject sat on a stool with the trunk upright and the knee flexed to about 120 degrees; the sole of the foot rested on a perspex sheet overlying the film in such a way that the central ray passed through the head of the second metatarsal; the base of the first interdigital cleft, the apex of the knee and the eye of the same side were in a straight line. The cathode-film distance was 100 centimetres.

Photography—A multiple photograph was taken by means of an arrangement of mirrors and included plantar, medial, lateral and posterior views of the foot (Figs. 5 to 7). By means of incorporating scales, measurements were made directly from the enlarged prints. Twelve measurements and general observations were recorded from each photograph.

Goniometry and ergometry—By means of a simple mechanical device (Figs. 8 and 9) an approximate measure of the range of movement of the foot on the leg and of the great toe on the foot was made. The axis of movement in each case was taken to be at right angles to that of the leg, passing through the prominence of the lateral malleolus and the metatarsophalangeal joints respectively. Readings were also taken of the force exerted in pounds by the isometric contraction of different groups of muscles in executing certain movements of the foot on the leg, and of the toe on the foot, against a resistance (Fig. 10). The force was transmitted by a right-angled lever to a ground-steel bar, the deflections of which were measured in thousandths of an inch. The deflection of the bar was calibrated for the force exerted in pounds. A mean of three readings was taken for each observation. Four observations of range of movement and five of force exerted were recorded.

Footprinting—Two types of footprint were used: one produced by pressing a thin sheet

FIG. 5

FIG. 6

FIG. 7

Figure 5—General view of apparatus for taking multiple photographs. Figure 6—Detail of arrangement of mirrors. Figure 7—Specimen of multiple photograph.

FIG. 8

FIG. 9

The measuring apparatus in use. Figure 8—The goniometer in neutral position. Figure 9—The goniometer set to full flexion of ankle and first metatarso-phalangeal joints. Figure 10—The ergometer: the dial is calibrated to read deflection in thousandths of an inch.

FIG. 10

(0.5 millimetres) of plain inked rubber on to a sheet of paper; the other obtained by means of a rubber sheet similarly inked but bearing on its undersurface a set of intersecting rubber ridges of different heights designed to give an indication of the pressure over the sole of the foot.* Specimens of each kind of print are shown in Figures 11 and 12. Six measurements were taken from the plain footprint and an estimate of pressure distribution was made from the other.

FIG. 11

FIG. 12

Figure 11—Plain footprint with projection lines. *AB*, medial contact line; *EF*, lateral contact line; *DC*, midline. 180° minus angle θ = angle *A*. Figure 12—Weight distribution footprint. Maximum weight is under the head of first metatarsal.

Personal details—A detailed history of general health and of the feet in particular was taken, and a history of the family's feet so far as possible. A detailed clinical examination of each foot was made, together with a note of the distribution of wear on the bottom of the shoe.

Statistical method—All the data collected were recorded on a *pro forma* and subjected to statistical analysis, and a large number of correlations were tested by means of the correlation coefficient. Whenever possible objective measurements were correlated with facts in the history or subjective observations of the subject or observer by means of the Chi-square test. In general comparisons each foot was treated as a unit so that recorded figures refer to feet and not to subjects unless otherwise stated. Only those observations and correlations are recorded which appear to be of interest in relation to past observations or of high statistical significance themselves.

* This type of footprinting mat was designed by Harris and Beath (1947) for the Royal Canadian Army Medical Corps foot survey, and kindly supplied through the Canadian High Commissioner in London.

OBSERVATIONS ON MORBID AND CONTROL GROUPS*

Degree of hallux valgus—An objective measure of valgus deformity on the plantar radiograph is the first requisite in defining the terms of reference of this paper. The measurement made is of the angle between the axis of the first metatarsal and that of the

FIG. 13

FIG. 14

FIG. 15

Figure 13—Radiographic measurement of hallux valgus. Angle X: between axes of first metatarsal and proximal phalanx. Figure 14—Distribution of hallux valgus in control group. Figure 15—Distribution in morbid group.

proximal phalanx; the first was obtained by bisecting the shaft of the metatarsal at two levels, joining the points of bisection and extending the line in both directions; the second was obtained by a line applied by visual estimation, because the irregular outline of the phalanx did not allow of geometrical division at two levels (Fig. 13).

* Statistical note—The term “statistically significant” is used conventionally throughout this paper, i.e., *not significant*, the probability of the findings being due to chance is more than one in twenty; *significant*, probability less than one in twenty; *highly significant*, probability less than one in a hundred; *very highly significant*, probability less than one in a thousand.

The correlation coefficient is used as a measure of the interdependence of two quantities. If the variables are independent, the correlation coefficient will be zero. If the interdependence is complete and the relationship linear the correlation coefficient will be ± 1 , the positive sign indicating that high values of one variable occur with high values of the other and a negative sign indicating that high values of one occur with low values of the other.

The distribution of the degree of valgus in the two groups is shown in the histograms (Figs. 14 and 15). The angle of valgus in the controls (252 feet) ranged from 0 to 36 degrees and in the morbid group (165 feet, operated cases excluded) from 12 to 60 degrees; the modes of the two groups lay at 12-16 degrees and 32-36 degrees respectively. The difference between the means ($32.0 - 15.7 = 16.3$ degrees) is very highly significant (probability estimated by the t-test $< .001$). The standard deviation of the control series is ± 6 degrees, and it is

FIG. 16

FIG. 17

FIG. 18

Figure 16—Radiographic measurement of metatarsal angle. Angle X: between axes of first and second metatarsals. Figure 17—Distribution of metatarsal angle in control group. Figure 18—Distribution in morbid group.

perhaps permissible to take "normal" distribution for the age group of the controls we are dealing with as $4-28$ degrees (the mean $\pm 2 \times$ standard deviation) for the purpose of analysis and reference.

First intermetatarsal angle—This angle was obtained by measuring the angle between the axes of the first and second metatarsals, obtained by the method given in the preceding section (Fig. 16). In the 252 feet of the control series this angle ranged from 0-17 degrees,

with the mode occurring at 8-9 degrees (Fig. 17). The mean intermetatarsal angle was 8.5 degrees. In the 177 defective feet the angle (measured in those cases that had been treated by Keller's operation, as well as in the 165 uncorrected feet of the preceding section) ranged from 4-27 degrees with a mode at 14-15 degrees (Fig. 18). The mean intermetatarsal angle in the morbid group was 13 degrees. There is a very highly significant difference between these means.

FIG. 19

FIG. 20

FIG. 21

Figure 19—Radiographic measurement of relative metatarsal protrusion. C, centre of circle of which A and B are arcs. Figure 20—Distribution of metatarsal protrusion in control group. Figure 21—Distribution in morbid group.

It will be observed that the distribution diagram of intermetatarsal angle in the control group is approximately symmetrical, with mean and mode coinciding. In the morbid group this is not so. It is to be expected that when symptoms are the chief selecting factor for inclusion in a morbid series the series will lack homogeneity. However, the departure from symmetry is not statistically significant.

Relative metatarsal protrusion—This is a somewhat vexed question because the definition

of terms is difficult and, even when defined, the relevance and interpretation of the terms are obscure. However, for the purpose of the survey the measure was made in the following way. The axes of the first and second metatarsals were drawn as described above; a transverse tarsal line was drawn so as to touch the posterior articular surface of the cuboid and the posterior aspect of the tuberosity of the navicular. At the point of intersection of this line with the axis of the second metatarsal one point of a pair of dividers was placed; arcs were then drawn with the other so as to touch the articular surfaces of the heads of the first and second metatarsals (Fig. 19). The radial distance (in millimetres) between the arcs was taken as the measure of relative metatarsal protrusion. For the purpose of recording this measure the distance between the arcs is preceded by a sign: a positive sign indicates that the first is greater than the second, and a negative sign that the second is greater than the first.

The histograms of this measure indicate a "shift to the right" in the morbid group as compared with the control group (Figs. 20 and 21); that is, the mode of the morbid series falls at +5 millimetres to +7 millimetres (mean measure +4 millimetres) and the mode of the control group falls at +2 millimetres to +4 millimetres (with a mean +2 millimetres). This amounts to a statement that in the cases of hallux valgus the first metatarsal is longer than in the controls. The difference between the two means is statistically very highly significant, although arithmetically small.

Mention must be made at this point of the work of Morton (1935). He used as an estimate of relative protrusion a perpendicular to the axis of the second metatarsal at the point of intersection of the distal articular surface, and measured the distance from this perpendicular to the head of the first metatarsal. His measure is based on his conception of the functional mechanics of the foot, of which no criticism is offered; but it is nevertheless open to the objection that any increase in the intermetatarsal angle will lead to an apparent shortening of the first metatarsal. While it may be true that widening of the intermetatarsal angle is dynamically equivalent to shortening of the first metatarsal, it is clearly redundant to measure both and regard each as a separate factor. In the Canadian Army survey (Harris and Beath 1947) this measurement was made as a radial distance between arcs of circles centred on the mid-point of the posterior aspect of the calcaneum, a point which was not accurately identifiable by the methods here described. Ideally these arcs should be of circles centred on the intersection of the radii represented by the metatarsal axis, but in practice their convergence is, in cases of small intermetatarsal angle, so far distant from the metatarsal heads as to make the measure inconvenient.

It is, of course, not possible—even if it were desirable—to measure the absolute lengths of the first two metatarsals because of the irregularity of their proximal joint surfaces. It must be pointed out that the method of comparison here suggested contains an inherent bias, in that those subjects with a larger metatarsal angle will be compared by means of arcs of circles of approximately the same radius as those with a smaller intermetatarsal angle. Thus there will be a tendency slightly to underestimate the relative protrusion of the first metatarsal in cases of metatarsus primus varus.

Sesamoid displacement—The position of the sesamoids in relation to the head of the first metatarsal was measured by relating the medial sesamoid to the metatarsal axis. Seven degrees of position are recorded in this way (Fig. 22). Thus, in the first position, the medial sesamoid is entirely on the medial side of the axis and not in contact with it and, in the seventh position, it is entirely lateral to the axis. In the 252 controls the spread is from 1 to 6 degrees of displacement, with 90 per cent showing 3 or less degrees of displacement; in the morbid series (174 readings) from 1 to 7 degrees of displacement, with 88 per cent showing 4 or more degrees of displacement (Figs. 23 and 24).

Rotation of the hallux about its long axis—It was not found possible to make an objective measure of this observation. Rotation was therefore said to be present or absent. It was found that the estimate of rotation from the radiograph and from the medial photograph

corresponded closely (Figs. 4 and 7). Rotation was found only in the morbid group and it was observed that of those subjects who showed rotation of the hallux the average degree of hallux valgus was 36 degrees, and of those who did not show such rotation the average valgus was 19 degrees.

Mobility of the first tarso-metatarsal joint—Again no objective measure of the observation was possible. It was estimated clinically as follows: the whole tarsal area of the foot was firmly grasped in one hand while the fingers of the other grasped the head of the first metatarsal and attempted to flex and extend it in the vertical plane. The findings were recorded as

FIG. 22

FIG. 23

FIG. 24

Figure 22—Displacement of medial sesamoid of first metatarso-phalangeal joint—seven positions in relation to the axis of the first metatarsal. Figure 23—Distribution of sesamoid displacement in control group. Figure 24—Distribution in morbid group.

free mobility, limited mobility, no mobility. In the 168 members (sailors excluded) of the control group 59 per cent showed free mobility, 29 per cent limited mobility, and 13 per cent no mobility. The figures for the morbid group were 63 per cent, 18 per cent and 19 per cent (185 feet) respectively. The difference between the distributions of the control group and the morbid group is statistically significant.

It should be pointed out that for a given age and degree of valgus, the partial correlation

between stiffness of this joint and lowering of the "arch height" dimension is significant, but that the partial correlations between the degree of valgus and stiffness, and between age and stiffness are not significant. That is, for a given "arch height" there is no correlation between stiffness and valgus or between stiffness and age.

No radiological estimate of this observation was possible because it was found that in almost any foot an apparent gap between the two medial cuneiforms could be made by altering the relation of the foot to the film.

Age of onset of symptoms—Of those who were able to give a definite estimate of the age of onset of their valgus condition (either as onset of pain or deformity—usually the latter) twenty-four out of fifty-two (46 per cent) gave an age of onset less than twenty years and, of these, sixteen (30 per cent) gave an age of onset of less than fifteen years.

Family history—Of the ninety-one cases in the morbid group with a degree of hallux valgus less than 25 degrees, there was a positive family history in fifty-seven (63 per cent)—that is, at least one of the following relations suffered from "bunions": grandmother, grandfather, mother, father, uncle, aunt (consanguineous), brother, sister (siblings), children. Only a limited significance can be attached to these reports because of lack of definition of the term "bunion" and inaccessibility of most of the relations in question for examination. They are nevertheless of some interest in comparison with the eighty-four control subjects of whom only one gave a positive family history of "bunions."

There are at least two highly selective factors here; namely the interest aroused by a complaint similar to the sufferer's own, combined with a natural desire of a rational being to attribute a cause to an observed fact, for which purpose heredity is a favourite choice. It is perhaps worth observing that of the fifty-seven who avowed a family history of bunions 77 per cent implicated the mother, 16 per cent the father, 33 per cent brother(s) or sister(s) and 4 per cent children. There were no statistically significant differences between the mean degree of hallux valgus occurring in each of the four groups.

Sex differences in the control group—Of the 125 cases in the control group, seventy-three were men and fifty-two women. Sex differences were investigated for the three measures, degree of hallux valgus, intermetatarsal angle and relative metatarsal protrusion. The results are shown in Table I.

TABLE I
DIFFERENCES ACCORDING TO SEX: CONTROL GROUP

Measure	Mode of distribution		Mean measure		Standard error of difference	Value of t (123 degrees of freedom)	Probability
	Male	Female	Male	Female			
Degrees of valgus	11°	14°	14.5°	15.4°	±0.78	1.21	>0.2 (not significant)
Inter-metatarsal angle	7°	10°	8.3°	9.6°	±1.09	3.77	<.001 (very highly significant)
Relative metatarsal protrusion	3 mm.	2 mm.	2.8 mm.	2.7 mm.	±1.28	0.35	>0.7 (not significant)

It appears, then, that there is no significant difference between the means of the male and female controls in the case of severity of hallux valgus and relative protrusion of the first metatarsal, but there is a mean increase of intermetatarsal angle of 1.3 degrees in the females over the males, and this difference is statistically highly significant.

CORRELATIONS

All the large amount of data collected for each subject of this investigation, comprising 175 entries, was transferred to a punched card system. Although no attempt was made to intercorrelate all items of data many correlations were tested. Where objective measurements were used the correlation coefficient can be quoted, whereas the χ^2 test is used to test the significance between subjective observations of a "yes, no or somewhat" variety. It is to be expected that a large number of apparently irrelevant correlations will appear in such a blunderbuss method, and it is of interest to note that in many observations there is a departure from the control observations in the morbid group. For instance there is a lowering of the head of the talus towards the base line in the lateral radiograph in the morbid group, which correlates fairly well (correlation coefficient from the combined series, -0.3) with the severity of hallux valgus. Similarly there is a correlation between advancing age and the occurrence of foot symptoms. In fact the apparent correlation between lowering of the "arch height" and degree of valgus is statistically attributable solely to age (see page 385—*mobility of tarso-metatarsal joint*). It is not necessary to record more than a few of these correlations. Those that are recorded are set down in order of significance.

Correlation of degree of hallux valgus with size of intermetatarsal angle—Of all the correlations recorded this is by far the most striking. Over the whole series of cases, control and morbid groups together, there is a correlation coefficient between them of 0.71 . It is

FIG. 25

Correlation diagram—hallux valgus in degrees correlated with intermetatarsal angle in degrees. An arrow has been placed at the level of suggested division into two groups (control and morbid groups combined).

perhaps worth noting that the correlation between the angle between first and fifth metatarsals and hallux valgus is 0.62 , and that this correlation is almost entirely accounted for by the first and second intermetatarsal angle. Thus the partial correlation coefficient is only 0.3 : that is, for a given first-to-second angle the correlation between valgus and the first-to-fifth angle is low. The second-to-fifth angle in the morbid group is only 0.3 degrees higher than the average value in the control series whereas the first-to-second is 4.5 degrees higher. Hence, if "splay-foot" is equivalent to a radial divergence of the metatarsals, there is no significant association of hallux valgus and "splay-foot."

The correlation between hallux valgus and intermetatarsal angle is shown on the accompanying correlation diagram (Fig. 25). It can be seen that there appears to be a natural division of the observations in the diagram in the region of 25 degrees. Before this point the slope is less steep than after it, and the respective correlation coefficients for the two divisions are 0.36 and 0.53. There is some agreement here with the theoretical division of the hallux valgus measure into "normal" and "abnormal" constituents at 28 degrees of valgus as suggested above. It is therefore possible to speak hesitatingly of a "critical angle" of hallux valgus occurring at approximately 25 degrees, but any attempt to interpret this in terms of etiology or pathology is not yet justified.

An additional confirmation of the constancy of this association is obtained from looking at pairs of feet which show a discrepancy in this respect between the two sides; in such cases it is found that a high difference in valgus between the two sides is associated with a high difference of intermetatarsal angle (correlation coefficient of the two differences, 0.59).

Angulation of the whole metatarsus in relation to the tarsus correlated with hallux valgus—A further association immediately suggests itself, namely the relation of "metatarsus omnis varus" (Fig. 26) and hallux valgus, without a widening of the angle

FIG. 26

Metatarsus omnis varus—axis of second metatarsal displaced to indicate that in such a case the angle between the axis of the first and the base line (X) will be small, but that the intermetatarsal angle will also be small.

between the first and second metatarsals. This measure was estimated by observing the angle of the axis of the first metatarsal to the transverse tarsal base line described above. While it is true that for a given intermetatarsal angle there is a correlation between a low angle of metatarsal to base and severity of hallux valgus, nevertheless the correlation (coefficient, 0.71) between valgus and intermetatarsal angle is higher than that between valgus and the angle of metatarsal to base (coefficient, 0.61).

Age correlation—These considerations immediately lead to an inquiry after a correlation of the two members of the correlation (hallux valgus and intermetatarsal angle) with age. If, for instance, hallux valgus were the determining factor causing a widening of the intermetatarsal angle, a high correlation between this angle and advancing age would be expected. The results of these correlations are unfortunately equivocal. The correlation of hallux valgus with age is not high in the morbid group (correlation coefficient, 0.10); the correlation of intermetatarsal angle with age is not significant (correlation coefficient, 0.01). The correlation of general significance here would be that between intermetatarsal angle and the onset of the deviation of the hallux. All the cases in the morbid group are, in a sense, in the same stage of the disease (that is, the symptomatic stage) so that the correlation with the age of the subject is of only limited significance.

Relative metatarsal protrusion—There is a low correlation (0.16) between relative protrusion of the first metatarsal and the severity of hallux valgus. However, for a given intermetatarsal angle there is a higher correlation in the valgus (coefficient, 0.33) and for a given degree of valgus a negative correlation with intermetatarsal angle which is also significant (coefficient, 0.31). Thus, for a high valgus and a low intermetatarsal angle, the first metatarsal tends to be greater than the second, while for a low degree of valgus and a high intermetatarsal angle the second tends to be the greater. There was no instance of the "atavistic foot" with severe valgus, wide intermetatarsal angle and short first metatarsal.

Sesamoid displacement—There is a high correlation between the degree of sesamoid displacement (measured in seven degrees of displacement (Fig. 22)) and the severity of hallux valgus. The coefficient is 0.8 (morbid group only).

Mobility of first tarso-metatarsal joint—There is an association between limitation of movement in this joint and hallux valgus. Those feet with limited movement show a mean hallux valgus of 24.7 degrees and those with a mobile joint a mean valgus of 21.7 degrees. This difference is statistically highly significant. As has been pointed out above the correlation of valgus and stiff joint for a given arch height is low. Arch height is the determining factor in the correlation.

Rotation of hallux—There is an association between rotation of the hallux and degree of valgus; those feet which show rotation have an average valgus of 35.8 degrees, and those which do not show rotation an average valgus of 18.5 degrees. This difference is statistically very highly significant.

Age of onset—There is only a barely significant association between the severity of hallux valgus and the history of an early onset of symptoms.

Wearing of high-heeled shoes—There is a significant ($X^2=11.08$) negative correlation between the severity of valgus and the history of having worn high heels. There is a tendency for those with severe valgus never to have worn high-heeled shoes.

SUMMARY AND CONCLUSIONS

A survey of this type cannot be used to point to any definite factor or factors predisposing to the development of hallux valgus. Nevertheless, a comparison of measurements in the morbid and control groups shows several outstanding differences:

- 1) There was a high degree of correlation between valgus and intermetatarsal angle in the two groups combined (coefficient, 0.7) but the correlation was higher in those cases with a degree of valgus greater than 25 degrees than in the remainder (coefficients, 0.36 and 0.53).
- 2) In the control group the first metatarsal was longer than the second by a mean measure of 2 millimetres; in the morbid group by a mean measure of 4 millimetres. For a high degree of valgus and a low intermetatarsal angle the first metatarsal tends to be longer than the second by a significantly greater amount than when the high valgus is associated with high intermetatarsal angle.
- 3) In 90 per cent of the control cases there was a lateral displacement of the medial sesamoid of the first metatarsal of 3 degrees or less, whereas 88 per cent of the morbid group showed a displacement of 4 degrees or more. There was very little overlap in the distributions of this observation in the two groups. There was a high correlation between the degree of this displacement and the severity of hallux valgus.
- 4) Rotation of the hallux was not observed among the controls; in the morbid group those cases showing rotation had an average degree of valgus of 36 degrees while the rest had an average of 19 degrees. The mean degree of valgus in the morbid group was 32.0 degrees and that of the controls 15.5 degrees. The mean angle between the axes of the first and second metatarsals was 13.0 degrees in the morbid group and 8.5 degrees in the controls.

Since the morbid group consisted largely of women (98 per cent) it is important to know that in the control group the only measure showing a statistically significant sex difference is that of intermetatarsal angle, but that, even so, the mean difference is only 1.3 degrees. Thus the sex difference between the two groups is probably only of minor importance. The role of age in influencing the observations cannot be clearly elucidated from the data at present available. It can only be stated that there is no positive indication that age is a controlling factor in the departure observed in the morbid group from the control observations.

APPENDIX

This appendix contains a brief résumé of observations incidental to the hallux valgus survey which are either of general interest or give a lead to future lines of inquiry.

Use of footprints in further surveys—Correlation between hallux valgus as measured on the footprint (Fig. 11) and the radiograph (Fig. 13) is high (coefficient, 0·8). Correlation between "Angle A" (Fig. 11) and intermetatarsal angle is not sufficiently high to be of any practical value (coefficient, 0·5) and this is almost entirely due to the correlation with valgus. Correlation between pressure distribution under metatarsal heads (Fig. 12) and relative metatarsal protrusion is of the following order:

For feet with maximum pressure under the first metatarsal the first metatarsal is longer than the second by 4·2 millimetres (average).

For feet with maximum pressure *not* under the first metatarsal the first metatarsal is longer than the second by 2·6 millimetres (average).

The difference is statistically very highly significant. There is no correlation between maximum pressure under the second metatarsal in the footprint and a relative protrusion of the second metatarsal beyond the first as measured radiographically.

Occurrence of flattening of the first metatarso-phalangeal joint—An apparent flattening of this joint surface at the head of the first metatarsal is strikingly observable in the radiographs and is characteristically associated with hallux rigidus. Observations of its occurrence were made throughout the 450 odd radiographs and compared with the goniometric measurement of the total excursion of the great toe and with the clinical observation of limited mobility at the metatarso-phalangeal joint. The following observations were made: In those feet in which a clinical assessment of limited mobility was made 14 per cent had a flat joint. In those where no such assessment was made 1 per cent had a flat joint. Those feet in which a radiological assessment of flat joint was made show an average total excursion of the great toe (goniometer) of 64 degrees. Those without flat joint show an average total excursion of 87 degrees.

These differences are statistically very highly significant. This finding is of some interest in view of the work of Harris and Joseph (1949) on the metacarpo-phalangeal joint of the thumb, where they observed an association between flat joint and limitation of movement.

Observations on the medial longitudinal arch—The arch height was measured as the vertical distance from the lowest point on the head of the talus to a base line joining the lowest points of the calcaneum and the sesamoids of the first metatarso-phalangeal joint. In order to relate the absolute measurement to the relative size of the foot under consideration, this observation is expressed as the *per cent arch height/arch length* (Fig. 3). If in fact the lowering of an arch also induces its lengthening this ratio will tend to lose some of its significance, but it is by no means clear that this is the case.

There is a high correlation between "arch height" and the slope of the first metatarsal—that is, the angle between a line extending the superior surface of the first metatarsal, as seen in the lateral view, and the base line; the correlation coefficient is 0·8; there is thus an association between lowering of the head of the talus and lowering of the inclination of (at least) the anterior member of the medial longitudinal arch.

There is a very highly significant correlation between a lowering of the per cent arch height/arch length ratio and the following clinical assessments: "pronation" of the foot; subcutaneous prominence of head of talus; tilting of the calcaneum as looked at from behind; and there is a negative correlation with the appearance of a cavus foot. It therefore appears that it is worth using these radiographical measures further in any inquiry into "flat foot."

Age—As well as the correlation between hallux valgus and increasing age there is also a positive correlation between age and the following clinical assessments: "pronation"; tilt of the calcaneum; callosities of the plantar skin; anterior metatarsalgia; "overcrowding" deformity of the toes; hallux rigidus; and a number of other deformities of the foot. It is perhaps worth noting that of the total number of subjects in whom multiple ossific centres of the first metatarsal sesamoids were observed (thirty-six subjects) only nine were over the age of twenty-five years. In the control group there was only one such—a woman aged twenty-seven years. In the morbid group, in every one of the eight cases the condition was unilateral. It is therefore possible to suggest that in general there is a union of the multiple centres of ossification during the third decade.

Degree of valgus—Mention has been made of the association of a high degree of hallux valgus and various other foot deformities. The following clinical assessments show a statistically very highly significant correlation with the severity of hallux valgus: "pronation" of the foot; subcutaneous prominence of the head of the talus, plantar callosities; "overcrowding" deformity of the toes; limitation of mobility in the "transverse tarsal joint"; hammer toe.

Range of movement of ankle joint—There is no correlation between a low arch height/arch length ratio and limitation of extension at the ankle joint (goniometric measurement). (Contrast Harris and Beath 1948.)

Child-bearing—Those women who had borne one or more children showed a statistically significant lowering of the arch height/arch length ratio.

Pain in the foot attributable to the longitudinal arch region—Those who complained of such pain had an arch height/arch length ratio of 19.4 per cent, while those who did not complain showed a ratio of 20 per cent. This difference is statistically significant.

Anterior metatarsalgia (in the general sense of localised pain beneath metatarsal heads)—This condition showed a low correlation with numerous other departures from "normality." The force of the isometric contraction of the toe flexors (ergometric measure) in those cases with anterior metatarsalgia was 20 lb. (average). In those without metatarsalgia it was 28 lb. (average). This difference is very highly significant.

Plantar callosities—The average force of isometric contraction of the toe flexors in those with plantar callosities was 26½ lb. In those without it was 30 lb. This difference is on the border line of statistical significance.

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