Papers and Originals

Medical Significance of Finger-prints and Related Phenomena*

L. S. PENROSE,† M.D., D.SC., F.R.C.P., F.R.S.

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History

In 1684 a learned and ingenious physician, Nehemiah Grew, published the first description of the epidermal ridges which make characteristic patterns when prints are taken of finger-tips. These "innumerable little ridges of equal bigness and distance, and everywhere running parallel one with another," contain the pores of the sweat glands. Grew also noted that they were disposed into "ellipticks" and "triangles." Grew's paper was followed by the publication in Amsterdam of a brief account in Bidloo's (1685) *Anatomia Humani Corporis*. In the year after that, 1686, a comparable description was given by Malpighi in *De Externo Tactus Organo*.

For nearly a century and a half there were no notable advances, but in 1823 Purkinje, in a thesis, again written in Latin, described nine types of patterns (or varieties of curvature) on the fingers. The first systematic study of the whole subject, however, was carried out by Francis Galton (1892) around the year 1890. His early interest was in the value of finger-prints for personal identification, for they persist throughout life. The chief use of identification was, he remarked, to benefit society by detecting rogues rather than to establish the identity of men who were honest. He made a thorough inventory of different kinds of pattern and drew attention to the fundamental formations—arches, loops, and whorls (Fig. 1). He also made numerous inquiries concerning the origins of the variations between different individuals; he showed that farm labourers and professors (who included many distinguished people, among them the famous A. E. Garrod) had similar ranges of distributions, but he found that there were significant likenesses within families.

I should make it clear that there are three separate fields of study, all connected yet providing quite distinct information. (1) The fine details of ridge formation, known as minutiae, are of special significance in identification; their clinical uses are restricted. (2) The arrangement of the "flexion" creases has some value in diagnosis of malformation syndromes, but creases are structures which are not always clearly defined; there is room left for the imagination in recording them—a circumstance used to great advantage by practitioners of the art of cheiromancy. (3) By far the most advantageous field for biological and medical investigation is that concerned with the topography of the systems of parallel ridges at the macroscopic level—that is, as seen fairly easily by the naked eye or with a hand lens with magnification of two to four diameters. This is called the science of "dermatoglyphics," a name coined some 50 years ago by the anatomist Harold Cummins, of Tulane University in the United States.

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† Research Director, Kennedy-Galton Centre, Harperbury Hospital, near St. Albans, Hertfordshire.

Anatomy

In attempting to explain this subject it is necessary first to draw attention to a few elementary anatomical facts and descriptive terms (Cummins and Midlo, 1943). The ridge configurations are formed by elevated parallel rows, each about half a millimetre in breadth, of sweat gland orifices and are laid down at an early stage in foetal life, probably by the tenth week. Complex patterns are formed by the systems of parallel lines because two kinds of discontinuity occur. These singularities, as the mathematicians would call them, are now known as loops and triradii. A loop (what Grew called an elliptick) occurs when the direction of ridges turns through an angle of 180°. Two loops opposing one another can form a spiral or circular system, and this is called a whorl. On a finger-print a loop whose core points to the ulnar side of the hand is called an ulnar loop and one whose core points the other way is called a radial loop.

Triradius is the modern name for the central point of the triangular singularity recognized by Grew. The ridges which radiate from this centre can be traced to their exits at the boundaries of the ridged surface on fingers, toes, palms, and soles. These radiants are called "main lines," and it is from their arrangement that the characteristic pattern is generated which is used in anthropological and clinical investigations, comparing one person with another.

The triradii situated at the bases of digits 2, 3, 4, and 5 are, respectively, called *a*, *b*, *c*, and *d* (Fig. 2). Another important triradius, *t*, occurs in the hypothenar region of the palm, and its position is often of clinical significance. Similar nomenclature applies to the soles of the feet.

The mechanism by which these patterns are produced is obscure, but their alignment suggests that compression forces have acted at right-angles to the ridges and tensions along them. Consequently, the ridge directions tend to take the shortest routes on the embryonic surface, encircling the fingers and also the pads which are present in the limb buds. These matters have been investigated by studying the hands of apes, by searching for other systems of parallel lines in living organisms, and by experiments with artificial materials. A natural example is the striped skin, as on the zebra, and wrinkles on cellophane subjected to heat in restricted space can provide an equivalent experimental result.

Topology

The features which are common to all these widely different systems are the loop and triradius. These are inevitable topological consequences of the attempt to lay down a carpet of equidistant parallel lines—that is, lines parallel in small fields—over a surface which is not flat (Penrose, 1965).

The mathematician Littlewood (1953) conceived a similar problem, as that of combing a surface covered with hair. He pointed out that when combing a spherical dog at least four loops (or two whorls) would have to be produced. The lines of latitude on the earth have the same characteristic and show one solution. A little knowledge of elementary topology tells us how many loops or triradii are essential on any specified kind of surface. From these basic mathematical truths, combined with the principle that, on the whole, ridge lines take the shortest routes and allowing for the fact that only one aspect of the hands and feet is covered with these ridges, I have devised a simple arithmetical rule. This rule enables us to check, on any limb, whether all the triradii have been recorded or not. In practice this is very often necessary, particularly on the feet, where experts as well as novices are surprisingly negligent.

Clinical Uses of Topological Approach

The formula which emerges is simply that, on any limb, the number of triradii plus one is equal to the number of loops plus the number of digits (or, more accurately, nails), which is normally five. Examples of this rule, which applies to normal as well as to abnormal hands and feet, can be multiplied at leisure (Fig. 3). Since an extra digit implies the existence of an extra triradius, the history that a supernumerary or a malformed finger has been amputated can sometimes be inferred from the dermatoglyphic pattern. There are, however, some notable exceptions to the basic formula. One of these occurs if there is anonychia. The nail is replaced then by two loops,

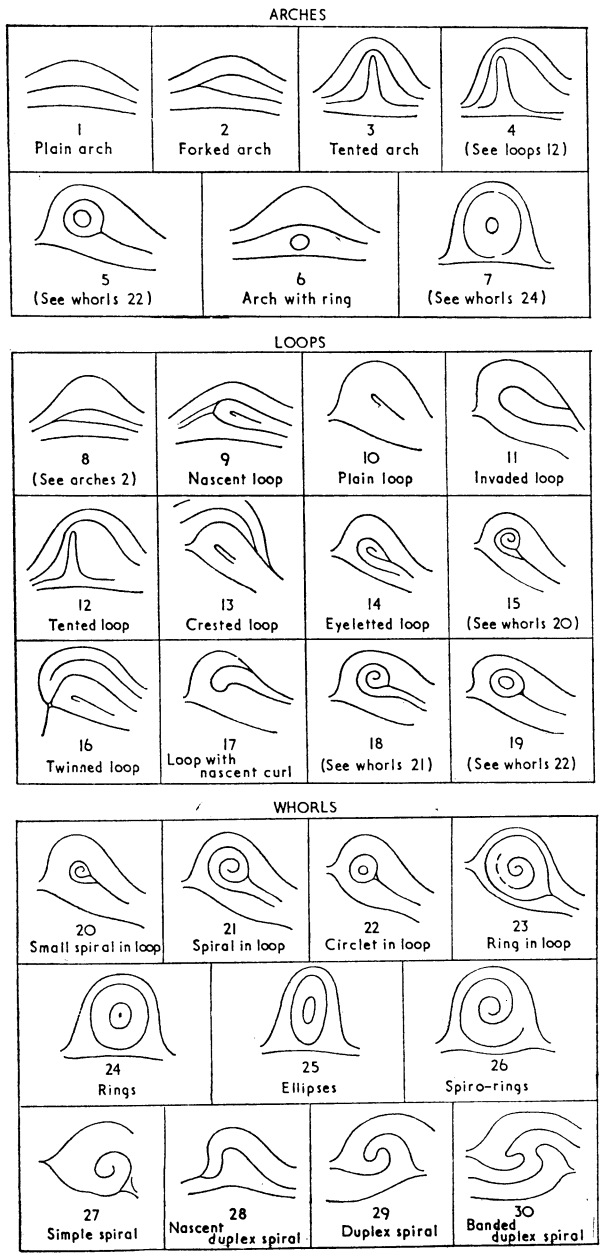

FIG. 1.—Types of finger-print patterns as classified by Galton.

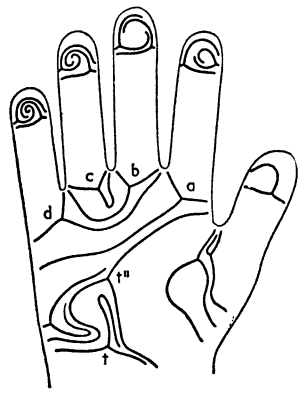

FIG. 2.—Radiants of all triradii on a normal hand. Note positions of a, b, c, d, t, and t''. There are nine triradii on the fingers and nine on the palm. There are nine loops on the fingers (a whorl contains two loops) and five on the palm. The rule is that the number of triradii, T, plus 1 is equal to the number of loops, L, plus the number of digits. Here, 18+1=14+5.

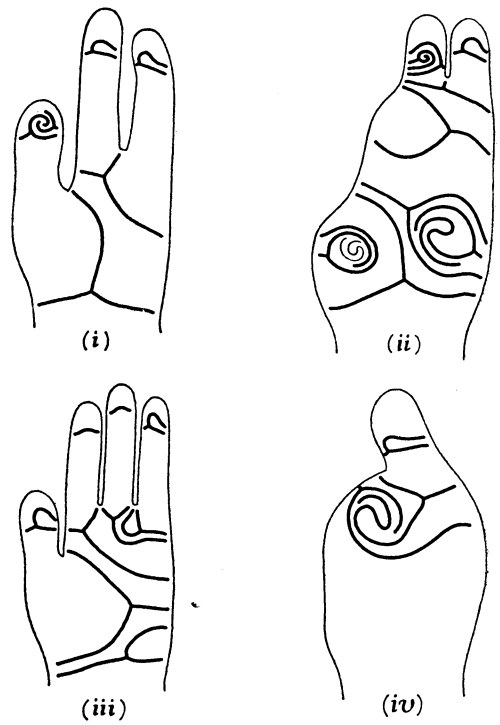

FIG. 3.—Radiant lines from all triradii on four malformed hands. On all of them the rule holds, T+1 =L+D. For (i) 6+1=4+3, for (ii) 9+1=8+2, for (iii) 7+1=4+4, and for (iv) 3+1=3+1.

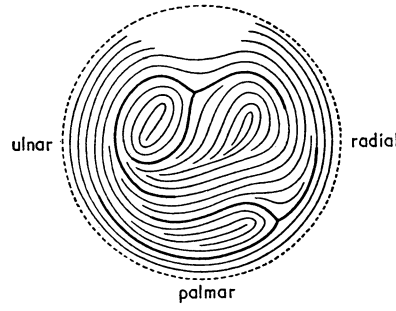

FIG. 4.—Diagram in conical projection of the ridge formations on the tip of the right thumb in a case of anonychia.

and the ridges continue until many of them encircle the finger-tip. (In the example shown (Fig. 4) there is also an extra loop and triradius.)

Standard Types of Pattern Distortion

The study of dermatoglyphs has received a considerable stimulus from the tardy recognition that, in developmental defects, especially those associated with generalized dysplasias as can happen when there is a chromosomal anomaly, the ridge patterns are distorted (Penrose, 1963). As far back as 1935, Cummins (1936) noticed that, in mongolism (Down's syndrome in Russia), most of the finger-print patterns were ulnar loops. Ten ulnar loops, in fact, occur in 32% of mongols but in only 4% of normal people. Furthermore, the direction of the lines across the distal area of the palm tends to be more horizontal in mongolism than normally, and this distortion is quickly recognized by noting the central position of triradius *t*, known in that position as *t''*. It is important to remember that although some 80 out of every 100 mongols show this peculiarity so also do about 7 out of every 100 normal people. So it is unwise to rely solely upon this feature for purposes of diagnosis. However, there is always the rare possibility to be considered that such a sign, in a normal person, may indicate mosaicism for an extra G (21 or 22) chromosome and increase the risk of having a mongol child. There are also other characteristic peculiarities, the most noteworthy of which is the absence of pattern on the hallucal area of the sole in a large proportion of mongols.

Two other autosomal trisomic conditions also have characteristic dermatoglyphs. These are the 18 and D (13, 14, or 15) trisomies (Uchida *et al.*, 1962). In 18-trisomy the most striking feature is the lack of pattern on the fingers: over 80% of all fingers in this disease carry arches. The palmar patterns show little abnormality, but the soles tend to have a peculiar central loop.

The D (13–15) trisomics, who are likely to have much malformation including polydactyly, not unexpectedly show several dermatoglyphic peculiarities (Penrose, 1966). On the fingers radial loops appear in unusual places, as on digit 5. The alignment of ridges on the palm is more transverse even than in Down's syndrome and the *t* triradius is even more distal. The thenar area configuration is quite specific, however, for the main line A exists usually on the radial side of the palm and patterns tend to occur at the base of the thumb. On the feet the most characteristic feature is a tibial loop on the hallucal area of a kind which is normally very rare.

Peculiarities are noteworthy in almost all cases of chromosomal error, though they are not always very specific. Remarkable patterns occur on hands of patients who have polyploid chromosome counts in all or in some of their cells. One patient, who was noted by a keen-eyed paediatrician to have a "funny triradius" on one hand, actually turned out, on skin culture, to have 69 chromosomes in a large proportion of the cells (Ellis *et al.*, 1963).

Almost every kind of early growth disturbance which affects the limbs produces some dermatoglyphic effect. This applies equally to embryonic traumata, such as those related to poisons like thalidomide, and to hereditary errors which determine limb defects, as in ectrodactyly. It also applies to the large class of malformations of hands and feet with unknown origin. It is important to notice that the converse principle holds good—namely, that hereditary or environmental defects which do not affect early limb growth do not change the dermatoglyphics. Thus we find nothing characteristic of phenylketonuria or other biochemical errors. Claims have been made that finger-prints are peculiar in schizophrenia, for example. Such inferences have almost always been drawn from material with inadequate control populations for comparison. The enormous natural variation in finger-print pattern, as well as main-line palmar configuration, should make us cautious in accepting results of inquiries into pathological types. There are many so-called racial differences also which must be taken into account.

Quantitative Methods

The collection of data on dermal ridge patterns in diseased or in healthy populations is made more valuable when metrical methods are introduced. Numerous measurements are in use. The commonest are concerned with counting the number of ridges between specified triradii and pattern cores. One great advantage of these quantitative studies is that they can be used for accurate comparison of abnormal with normal. Another is that they can be conveniently used for genetical investigations. The most generally used measurement is the "ridge-count," or number of ridges between the triradius and loop core on a finger-print (Fig. 5). This number is used regularly in identification by the police (Henry, 1901). It has also important clinical implications. The number of ridges between triradii *a* and *b* on the palms is also useful.

FIG. 5.—Diagram to show how ridge-counting is used to measure pattern size. The arch (i) scores zero; the loop (ii) has 10 lines between the triradius and pattern core and scores 10; the whorl (iii) has two counts, 12 and 10: only the larger one, 12, is scored.

Sometimes it is convenient to measure an angle, though when this is done the age of the subject needs to be specified. The maximal *atd* angle can be used as a measurement of the degree of distal deviation of the *t* triradius. There is some change from the average normal position in Turner's syndrome, more change in Down's syndrome, and even more in D-trisomy.

Genetics

It is natural to ask how far these traits are hereditary and how far they are environmentally determined. If we limit the question, in the first place, to the normal population, much can be learned by examining families. In Germany there is a strong belief that several types of minutiae are specifically inherited and that paternity can be proved by examining hands carefully from this point of view. At present this activity, though lucrative, is not based on scientific genetical principles and is suspected to be unreliable. There is, however, good evidence of hereditary influence on the number of separate minutiae, and some people are constitutionally disposed to have their ridges more broken up than others (Okajima, 1967).

More exact studies, using both main-line configurations and quantitative measurements, are of value as an aid to the diagnosis of zygotic type in twins. In one recent example, where the success of a kidney transplant would depend on proof that the donor was the identical twin of the recipient, the hand prints were used to help to establish identity. Correspondence between identical twin patterns is by no means perfect, but knowledge of the limits of error can be made precise by the inclusion of metrical data. Such comparisons were used to prove the probability of identity of genetical origin in a remarkable case of a normal brother and a sister (albeit with Turner's syndrome) (Dent and Edwards, 1963). They could have been used as a true example for Shakespeare's Sebastian and Viola in *Twelfth Night*, and they prove that fact can be as strange as fiction.

Perhaps even more extraordinary to modern ways of thinking are extremely rare instances of identical twins, one normal and the other with Down's syndrome (Penrose and Smith, 1966). Here an extra chromosome must have slipped in or out in the very first division of the zygote which formed two individuals. The dermatoglyphic patterns show that in the mongol there has been a simplification and rearrangement, characteristic of that disease, which has taken place on the background of a normal pattern variant.

Analysis of the mode of inheritance of normal variations has been carried out by studying parents and children and by comparing brothers and sisters. The maximal degree of hereditary likeness, which is one-half in all these types of pair, is closely approached by the character "total ridge-count," the sum of the values on all 10 fingers. This result can be interpreted as indicating that this trait is determined almost entirely by one or more additive or co-dominant genes (Holt, 1961). The high correlation for identical twin pairs supports this view, and no evidence of sex-linked inheritance has been found. That is to say, the trait is not determined by genes on the sex chromosomes and environment has, in general, very little effect on it. Other traits, like the *a-b* ridge number (Pons, 1964) and the maximal *atd* angle are less directly caused by genes, and there is much room for accidental influences to affect these formations.

Sex Chromosome Effects

Though the dermatoglyphic patterns are not appreciably influenced by genes on the sex chromosomes, X and Y, paradoxically, distinctive peculiarities are found on the hands of cases of Turner's, Klinefelter's, and other syndromes caused by sex chromosome aberrations. I will confine the demonstration to the finger-prints (Penrose, 1967). The patterns on the finger-tips of normal males have, on the average, slightly more ridges—that is to say, they are slightly larger than those on the finger-tips of females. This is shown by the total values, from all 10 fingers, which add up, on the average, to 145 in males and 128 in females, or 12% less. Now, in Turner's syndrome, in a female with only one sex chromosome instead of two, the "total ridge-count" as it is called, tends to be much increased above the normal male level, and in 54 cases the average was 178, an increase of 23% above the male average. Reducing the number of sex chromosomes, then, seems to increase the size of the finger-print patterns.

What happens then if there are too many sex chromosomes, as in Klinefelter males, double-Y males, and triple-X females? Astonishing though it may seem, the pattern size on the finger-print is actually reduced. This reduction is more marked when there are two extra sex chromosomes than when there is only one such interloper, and it goes even further in the more extreme cases which have three too many. Indeed, many of the patients of the extreme types have nothing on their fingers but arches, which contribute no score at all to the total ridge-count. It is also demonstrable that the presence of an X chromosome has approximately twice the effect on pattern size reduction as the Y chromosome. A fascinating thought is that, since it is known now that an extra Y chromosome may predispose its possessor to commit crimes, finger-print clues could be used simultaneously for detection and diagnosis of the thief—at least in science fiction.

I find the regularity of the effects produced by the number of sex chromosomes most remarkable (Fig. 6). One must, however, not forget that for the most part these figures represent average values. The finger-tip patterns in a given case are chiefly dependent on those of the parents. The disturbance caused by the chromosomal errors is superimposed on the natural variation. Thus a few with Turner's syndrome have quite normal counts and the majority of triple-X females are normal in this respect, and these peculiarities can only be convincingly demonstrated after assembling large amounts of material (Holt and Lindsten, 1964). You cannot make the chromosomal diagnosis on finger-prints alone, though sometimes they help to suggest it.

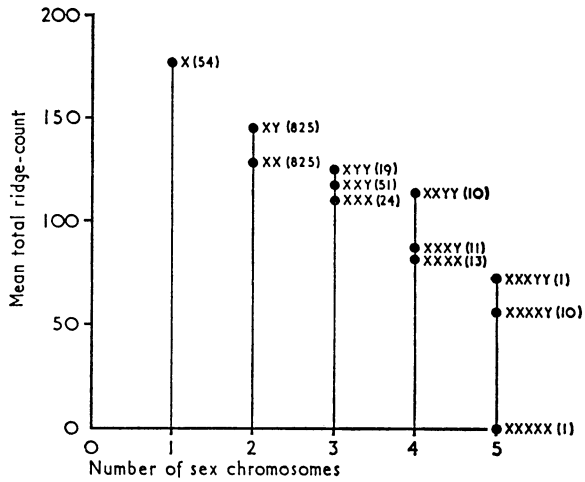

FIG. 6.—Mean total ridge-count is shown for cases with different numbers of sex chromosomes. Figures in parentheses show the number of cases in each group.

Pathology in Chromosomal Aberration

There are several known examples of patients who have one of the small acrocentric autosomes deleted or missing in most of their cells. These patients have a condition which is in some respects the reverse of Down's syndrome, and it has been termed anti-mongolism; by French paediatricians it is called a "syndrome réciproque." It is certainly not fully reciprocal, otherwise such patients would all be geniuses instead of being somewhat mentally retarded. However, it does appear that to some extent the effects of having too few chromosomes can be the reverse of those which result from having too many chromosomes. Such morphological reciprocity is well known between monosomic and trisomic specimens of *Datura stramonium* from the work of Blakeslee (1923). The queer thing is that the effect is produced by the whole chromosome, or a large segment, rather than by its constituent genes. Thus the disturbances produced by the absence or excess of sex chromosomes, in Turner's, Klinefelter's, and related syndromes, seem to have little or nothing to do with sex-linked genes.

To what then are these morphological peculiarities to be attributed? In my view one of the factors to be considered here is an alteration in fluid balance at an early embryonic stage. It is known that in plants and in amphibia such changes occur when the number of chromosomes is aberrant. Disturbance of the aqueous equilibrium in early stages of development may explain why defects of the vascular system, including heart malformations, are so common in patients with chromosomal aberrations. It is also established that in Turner's syndrome the occurrence of foetal oedema is typical; the oedema gradually subsides during extrauterine life. If this oedema affects the finger-tips at the time of their formation it may account for the large patterns required to cover them and consequently the high total ridge-count. Possibly, in the converse anomalies, where there are too many sex chromosomes, there may be dehydration of the finger-tips at the same developmental stage, which results in diminution in pattern size and ridge-count.

Conclusion

I must apologize for presenting these views, which are heretical at the present time, but I believe that they may contain

the germ of an idea for explaining how malformations are produced by chromosomal aberrations. Otherwise this branch of pathology is shrouded in complete darkness. I must also apologize for presenting so many peculiar and mysterious diagrams. However, if they have been entertaining, though incomprehensible, I shall feel that I have been excused for asking your attention for such a long time on subject matter which may seem remote from medicine. At one of the best meetings of the Harveian Society that I ever attended, the chief performer was an expert in prestidigitation, and I only wish that I could have been as entertaining as he was on that occasion: only very modest conjuring can be performed with dermatoglyphics.

To demonstrate this perhaps I may be permitted to end up with an anecdote. Some years ago a stranger from an eastern country came to my room at University College. He produced, rather furtively, some palm prints and asked me to give an opinion about the person from whom they had been taken. I explained that I did not tell fortunes or estimate character; but I said that they probably came from a normal male, and I assured him that they were not the prints of a certain well-known type of imbecile. "That is good," he said, "because he is our prime minister."

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Further Information on the Identity of 47,XYY Males

W. M. COURT BROWN,* M.B., B.SC., F.R.C.P.ED.; W. H. PRICE,* M.B., B.SC., M.R.C.P.ED.
PATRICIA A. JACOBS,* D.SC.

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Since the report by Jacobs *et al.* (1965) of an unusual number of males with the chromosome complement of 47,XYY at the Scottish State Hospital, considerable interest has been taken in the frequency of such males among men in maximum security hospitals and in prisons. Jacobs *et al.* drew attention to the unusual distribution of height of males with two Y chromosomes. Taking advantage of this, Casey *et al.* (1966) showed 12 out of 50 males of 183 cm. (6 ft.) or more in height from the English maximum security hospitals of Moss Side and Rampton to have a 47,XYY complement, 4 out of 50 similar males to have this abnormality from the maximum security hospital at Broadmoor, and 2 out of 24 males of 183 cm. or more who were serving intermediate term sentences (six months to five years) in Nottingham Prison also to have this complement.

The study at the Scottish State Hospital showed the XYY males to have no obvious abnormality of sexual development or any other important physical abnormality save perhaps for a tendency to myopia (Price *et al.*, 1966; Jacobs *et al.*, 1968). Our more recent experience of such males, ascertained among penal groups or in hospitals for the mentally subnormal, has been that these men also are normally developed sexually. It is necessary, however, to add the caveat that, from the very nature of the groups in which they are found, these men are often single and it is seldom that there is information on their fertility.

By the end of 1967 we had identified 25 men who either had a 47,XYY complement or were chromosome mosaics in whom this cell line predominated in lymphocyte cultures. One was a man referred to hospital with hypogonadism and bilateral talipes equinovarus, and the information on him was published by Court Brown *et al.* in 1964 (Case 82/62). The next nine cases came from the State Hospital at Carstairs, and the details of these are given by Jacobs *et al.* (1968). This communication deals with the remaining 15 males with a 47,XYY sex chromosome complement or who are mosaics in whom the XYY cell line is the dominant one. Its primary intent is twofold—to underline the apparently normal sexual development of these individuals and to emphasize that they are found in various groups and not just in maximum security hospitals or in prisons. This paper shows that while many of those described have a criminal record, a finding biased by the method of ascertainment of some of them, the XYY male may not have such a record though he may pose behavioural problems.

* Medical Research Council, Clinical and Population Cytogenetics Research Unit, Western General Hospital, Edinburgh 4.

Patients

The 15 abnormal males have been identified in various groups, and with one exception (Case 289/67) all have been found in chromosome surveys. These surveys include studies of liveborn male babies, of new entrants to the Scottish Borstals, of men in the Scottish prisons and in one Young Offenders Institution, of males in an epileptic colony, and of men in hospitals for the mentally subnormal and for mental disease, while one case (364/67) was found in a survey of men who had been given thorotrast intra-arterially for diagnostic purposes many years ago. Formal reports of these surveys will be published later, and this paper deals specifically with the physical and mental features of the abnormal males and gives information on their behaviour. The only male not identified