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A FEW THINGS YOU SHOULD KNOW ABOUT PATERNITY TESTS (BUT WERE AFRAID TO ASK)

Robert W. Peterson*

I. INTRODUCTION

In The Merchant of Venice, Lancelot Gobbo remarks, "[I]t is a wise father that knows his own child." No doubt the Bard's treatment of this question has contributed to his time-less appeal. Consider jealous King Leontes' pique over the possible illegitimacy of his newborn child:

King Leontes:
This brat is none of mine;
It is the issue of Polixenes:
Hence with it! and, together with the dam,
Commit them to the fire.
Pauline:
It is yours!
and, might we lay the old proverb to your charge,
So like you, 'tis worse,—Behold, my lords
Although the print be little, the whole matter
And copy of the father,—eye, nose, lip,
The trick of his frown, his forehead, nay, the valley,
The pretty dimples of his chin and cheek; his smiles;
The very mould and frame of hand, nail, finger . . . .

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The author would like to acknowledge the kind assistance of Dr. Jack Valentin, who not only patiently spent a week with him in his government paternity testing laboratory in Stockholm, Sweden, but also took the time to correspond with the author through numerous letters. The author would also like to acknowledge the assistance of Dr. Herbert A. Perkins, of the Irwin Memorial Blood Bank in San Francisco, who spent time explaining and reviewing this material, reading the manuscript, and making numerous helpful suggestions.

No doubt similar scenes have played countless times since mankind first stepped from the Garden of Eden.

Even though all babies are said to look like Winston Churchill, comparing the child to the alleged father is still a common forensic device.\(^3\) Fathers are not the only ones who may not know their children. King Solomon is considered wise for resolving the dispute between two possible mothers by ordering the child divided by a sword.\(^4\) It is doubtful that the Commission on Judicial Performance would applaud the wisdom of a judge proposing his solution today. Fortunately, blood and tissue typing, combined with modern genetics, render the Solomonic disposition unnecessary.\(^5\)

Since 1975, the federal government has required state governments actively to pursue cases on behalf of mothers receiving Aid to Families with Dependent Children.\(^6\) States have increasingly looked to blood tests to help discharge this obligation. In 1981, California amended section 895 of the Evidence Code to provide, in pertinent part, that if genetic tests “show the probability of the alleged father’s paternity, the question, subject to the provisions of section 352, shall be submitted upon all the evidence, including evidence based upon the tests.”\(^7\) Because of this amendment, attorneys prosecuting

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3. Perhaps the most famous case using this technique is Berry v. Chaplin, 74 Cal. App. 2d 652, 169 P.2d 442 (1946), in which the court concluded that Charlie Chaplin was the father, even though such a conclusion was excluded by blood tests. See cases collected in Annot., 55 A.L.R. 3d 1087 (1974).


If the court finds that the conclusions of all the experts, as disclosed by the evidence based upon the tests, are that the alleged father is not the father of the child, the question of paternity shall be resolved accordingly. If the experts disagree in their findings or conclusions, or if the tests show the probability of the alleged father’s paternity, the question,
and defending paternity cases must familiarize themselves with these tests and the probability calculations based on them. Also, since the statute gives no guidance to courts in exercising section 352 discretion, judges must educate themselves in this area.

Probability statistics on blood group testing are undoubtedly the greatest forensic advance in paternity cases in centuries. Some of these statistics, however, can easily mislead because, like cotton candy, they appear to be more than they are, or they are based on assumptions which are easily overlooked. For example, the probability that a nonfather will be excluded by a certain set of tests does not equal the probability that the nonexcluded accused is the father. The probability of paternity, as reported by certain laboratories, is based upon the important assumption that the accused had intercourse with the mother and has at least a 50% chance of being the father. Moreover, laboratories commonly report their results in a format which makes it difficult to evaluate the relative importance of other evidence in the case. It is the purpose of this article to explain in fairly simple terms how these tests work, and what the calculations do and do not mean. This article also proposes a format to help unite the statistical evidence with other, less scientific, evidence in a case.

II. BACKGROUND

Geneticists now uniformly agree that, barring the extremely rare occurrence of a mutation, blood groups are inher-

subject to the provisions of Section 352, shall be submitted upon all the evidence, including evidence based upon the tests.


8. See infra note 42 and accompanying text.
9. See infra notes 55-59 and accompanying text.
10. See infra notes 68-81 and accompanying text.
11. Id.
ited according to well established Mendelian laws. The basic laws are (1) genes determine inherited characteristics; (2) genes occur in pairs on chromosomes; and (3) one gene of the pair is inherited from the father while the other is inherited from the mother.

Genes control blood groups and follow these Mendelian laws. If one knows the blood group (the phenotype) of a given mother, father, or child, it is possible to infer the genes giving rise to that blood group (the genotype). For example, a person who tests as AB in the ABO system has an A gene on one side of the chromosomes matched with a B gene on the other. The A type must have come from one parent and the B type must have come from the other.

Over the past few decades it has become commonplace to use these tests to exclude wrongly accused fathers. For example, if an O mother (genotype OO) has an O child, it is clear that the child must inherit one O from its mother. The child must also have inherited the other O from its father. An accused father who is AB cannot be the father of this child, because his children will inherit only an A or a B.

The ABO blood typing system is complicated by the fact that the systems are not codominant (i.e. not all genes present will express themselves). A and B genes (which are codominant) are both expressed when present as type AB. The O gene, in contrast, is “silent” in respect to the other two genes. Therefore a person who carries the genotype AO or BO will

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13. Id.
14. Id. at 489-99; S. SCHATKIN, DISPUTED PATERNITY PROCEEDINGS, §§ 5.03, 6.02 (4th rev. ed. 1980).
15. See CAL. EVID. CODE § 895 (West 1966 & Supp. 1982). If a child is born to a mother cohabiting with her husband who is not impotent or sterile, then the motion for a blood test must be made within two years of the child’s birth. Otherwise, the child is conclusively presumed to be fathered by the husband. CAL. EVID. CODE § 621 (West 1966 & Supp. 1982); In re Marriage of B., 124 Cal. App. 3d 524, 177 Cal. Rptr. 429 (1981); See Note, California’s Tangled Web: Blood Tests and the Conclusive Presumption of Legitimacy, 20 STAN. L. REV. 754 (1968).

The United States Supreme Court has held that paternal exclusions are so reliable that due process is violated if the state refuses to advance the costs of the tests in a suit brought by an indigent father. Little v. Streater, 452 U.S. 1 (1981). California is in accord: Michael B. v. Superior Court, 86 Cal. App. 3d 1006, 150 Cal. Rptr. 586 (1978). Indigent putative fathers are also entitled to appointed counsel. Salas v. Cortez, 24 Cal. 3d 22, 593 P.2d 226, 154 Cal. Rptr. 529 (1979).
16. In the ABO system, O is simply the absence of A or B.
have the phenotype A or B. An A father and an O mother could have an O child (genotype OO), or an A child (genotype AO), but not a B child (genotype BB or BO) or an AB child (genotype AB). Similarly, parents who test A and B respectively could have a child who tested as O, A, B or AB. A person who tests as A could have the genotype AA or AO, and one who tests as B could have a BB or BO pattern. There would be no impossible mother-father-child combinations, so the father could not be excluded.\textsuperscript{17}

Because of the utility of blood group information in paternity cases and organ transplantation, the number of immunological and biochemical genetic systems which can be tested has increased to over 60. For example, the A group has been divided into A\textsubscript{1} and A\textsubscript{2},\textsuperscript{18} and the Rh (Rhesus) factor also contains an impressive array of genetic markers.\textsuperscript{19} The same Mendelian laws govern all of these systems, and most systems are independent of one another (e.g., the fact that a person carries the genotype AB does not change the likelihood that that person will carry another genotype or phenotype, such as M, N, or MN). Therefore, the probability of excluding an erroneously accused father increases with the number and type of tests run. A properly equipped lab may, in a case justifying the expense, test enough systems to increase the probability of excluding a wrongly accused father to over 99%\textsuperscript{20}.

The accuracy of any exclusion or calculation based on blood groups is no better than the accuracy of the tests. While the tests themselves are routine, laboratories do not routinely perform these tests. Tests and calculations should be done by laboratories which have special competence in the area of paternity testing. In Sweden, where paternity testing has been performed for decades, a government licensed laboratory does all the testing. The laboratory tests approximately 50 persons per working day, runs each test at least twice on the same sample (either by different staff or at different times), blindly

\textsuperscript{17} Joint AMA-ABA Guidelines: Present Status of Serologic Testing in Problems of Disputed Parentage, 10 Fam. L.Q. 247, 263-65 (1976) [hereinafter cited as Joint Guidelines].

\textsuperscript{18} For a table showing paternal exclusions for given mother-child phenotypes in the A,A,BO system see Joint Guidelines, supra note 17, at 264 and Paternity Testing, supra note 5, at 76-79.

\textsuperscript{19} Joint Guidelines, supra note 17, at 265-67.

\textsuperscript{20} Paternity Testing, supra note 5, at 70.
includes known blood samples from staff members in each day's testing, and constantly monitors the exclusion of the mother (an impossibility indicating a possible false test result). Two or more staff members check all entries and calculations. Under these carefully controlled conditions, the laboratory has achieved better than 99.9% accuracy.\footnote{21}

Some tests may present special problems because they have little or no clinical significance. For purposes of transfusion, \(A_1\) and \(A_2\) are usually not incompatible, so a normal blood bank laboratory may only have occasion to run a handful of such tests a year. Laboratories doing paternity testing, however, would run an \(A_1\ A_2\) test in every case. In addition, some of the more sophisticated tests are not easily performed, or good antisera (chemicals used to test for specific blood groups) are not readily available. For example, the Dombrock system (Do), which has an 18% exclusion capability, is one for which good reagents are not yet readily available.\footnote{22} Also, not all routine tests can be performed in every case. Haptoglobin (Hp) is not always present in sufficient quantities for testing. Gamma-globulin (Gm) is usually not present in sufficient quantities until the child is one year old, and any amount present before that time may have been passed on entirely by the mother.\footnote{23}

### III. The Tests

The tests used normally fall into four categories: red cell antigens, red cell enzymes, serum proteins and HLA (Human...
Leukocyte Antigens or white cell antigens). Each group is tested differently.\(^{24}\)

A. Red Cell Antigens

Antigens are the proteins and sugars present on the surface of red blood cells. The genetic makeup of the cell determines the type of antigen present. Thus, if one can identify the antigens, the genotype of the cell may be inferred. To discover the presence of antigens, the laboratory mixes the blood with an antiserum containing known antibodies. (Antibodies are proteins which will combine with certain antigens, but not others.) If the antibodies combine with the antigens, the cells clump together or agglutinate in a visible manner. If agglutination occurs, the antigen for that specific antibody is present. If no agglutination occurs, it is absent.\(^ {25}\)

B. Red Cell Enzymes and Serum Proteins

Electrophoresis is a process which tests for genetically controlled enzymes and proteins. The laboratory places either the serum or the red material inside red blood cells on a specially prepared gelatinous membrane. A current is passed through the material, causing the enzymes or proteins to migrate into bands. The laboratory identifies the bands by using dyes, and the position of the bands, when compared with a known substance tested at the same time, identifies the particular enzyme or protein present.\(^ {26}\)

These genetically transmitted characteristics are used in paternity testing in much the same way as are the red cell antigen tests discussed above.\(^ {27}\) None is as powerful as the HLA system.

C. White Cell Antigens—HLA

For an HLA test, the laboratory first isolates white blood cells (lymphocytes) from the blood sample. These are placed

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25. Stroud, Bundran, & Galindo, supra note 24, at 47.
26. Id.
in the wells of a plastic tray, each of which contains a different antiserum. When the antibodies in an antiserum combine with the antigens in the presence of a biologic agent known as a complement, the cell is killed and swells in size. Added chemicals stain the dead cells so that they may be seen through a microscope. Matching the well containing the stained cells with the antiserum introduced into that well indicates the antigen present on that cell.\textsuperscript{28}

D. Unique Factors of the HLA System

The HLA system can provide tremendous accuracy in paternity testing because each HLA type is fairly rare. The following explanation briefly describes the system: On the appropriate locus on the chromosome there is a gene which expresses itself as an HLA type A. There are many possible A types (e.g., A1, A2, A28, AW19, etc.), but each individual only has two of them (one on the chromosome inherited from the father and one on the chromosome inherited from the mother). Similarly, an individual has two HLA-B types. There are many different B types (e.g., B5, B14, BW35, BW40, etc.), and, again, an individual will have only two. The A locus on the chromosome and the B locus are so close to one another that the A and B genes are linked together in such a way that 99\% of the time the same AB combination which the mother or father inherited from a parent will be passed on to the child. If a person receives A28, B5 from one parent and A2, B8 from another parent, 99\% of the time that person will pass either A28, B5 or A2, B8 to his or her child. The HLA types will recombine in only one percent of the cases, so that this person could pass on A28, B8 or A2, B5.\textsuperscript{29}

HLA is a powerful paternity testing tool because of the large number of different A and B types which are characteristically passed as a linked pair (called a haplotype). If we assume that the frequency of finding A28 is .05 and the frequency of finding B5 is likewise .05,\textsuperscript{30} then, assuming that the A's and B's are independently distributed at random through-

\textsuperscript{28} See supra note 24.
\textsuperscript{29} Terasaki, supra note 5.
\textsuperscript{30} Paternity Testing, supra note 5, at 57, gives a table containing gene frequencies, as of 1978, for common HLA types. The frequency in caucasians for A28 is .0513, and the frequency for B5 is likewise .0513. In blacks the frequencies are: A28 = .100, B5 = .0253. There can, therefore, be significant differences among races.
out the population, one would expect the frequency of A1, B5 haplotypes to be .05 x .05 = .0025. Since an individual has two haplotypes, the frequency of finding A28, B5 in an individual would be 2 x .0025 = .005. Thus, only 5 persons in a thousand would have A28, B5. There are over twelve thousand different phenotypes using the A and B locus. Comparing this with type O blood (genotype 00), which occurs in about 45% of the population, one can easily see that HLA is a much more precise test than ABO.

Other blood types, of course, can be quite rare. Type AB in the ABO system is found only in 3% to 5% of the population, depending on race and geography, but the rarity of the blood type also limits the utility in paternity testing. Because it rarely occurs, seldom is it of any use. By contrast, the HLA system gives a rare blood type in virtually every case.

HLA testing is difficult and sophisticated. Only laboratories equipped and staffed to do paternity testing in the HLA system on a regular basis should do these tests. In a recent study of 1000 paternity cases, Dr. Paul Terasaki tested for 15 A locus and 17 B locus antigens in each individual. A total of 180 independent antisera were used to determine the HLA profile of each individual. Since three individuals must be tested in each case, HLA paternity testing is an area where great care and sophistication are required.

IV. THE CALCULATIONS

A. Calculating paternity probabilities in non-excluded men

Using statistics to prove historical facts is, like the sirens'
song, both alluring and dangerous. It is especially alluring when the burden of proof itself is cast in statistical terms—preponderance of the evidence (more-likely-than-not) or the somewhat vague "beyond a reasonable doubt and to a moral certainty" standard. There is a need for statistics, however, when the historical fact to be proven cannot be verified by independent, credible witnesses.\(^{35}\)

The California Supreme Court's famous opinion, *People v. Collins*,\(^{36}\) highlighted the dangers of using statistics. Although the court did not suggest any incompatibility between mathematics and the trial process, the court counselled caution: "Mathematics, a veritable sorcerer in our computerized society, while assisting the trier of fact in the search for truth, must not cast a spell over him."\(^{37}\)

The use of statistics in paternity cases presents a number of interrelated concerns: (1) Statistics can be very helpful in minimizing error, but they are misleading if manipulated or misunderstood; (2) we are wedded to jury trial, but we are concerned about the jury's ability to cope with sophisticated mathematics; (3) we would prefer to know the "facts" in an individual case, but we recognize that inevitably our beliefs about those facts are either covertly or overtly based on "the odds"; (4) we prefer the ritual of the adversary system, but we also recognize the value of the scientific method and the inherent incompatibility of the two; (5) we are uncomfortably aware that doing "justice" and finding "guilt" are not necessarily congruent. Certainly, before plunging ahead with pater-

\(^{35}\) In paternity cases "[t]here are seldom accurate or reliable eyewitnesses since the sexual activities usually take place in intimate and private surroundings, and the self-serving testimony of a party is of questionable reliability." Larson, *Blood Test Exclusion Procedure in Paternity Litigation: The Uniform Acts and Beyond*, 13 J. Fam. L. 713, 713 (1973-74).

Indigent mothers may feel coerced into providing the name of a potential father in order to receive Aid to Families with Dependent Children. See Cal. Welf. & Inst. Code § 11477(b) (Deering 1979).


nity statistics, judges and attorneys should first strap themselves to the mast and learn what the statistics mean, what they do not mean, and how they are calculated.

B. *The Probability of Exclusion*

One misleading statistic which must be put in proper perspective is the “probability of exclusion.” Calculations show that a certain test or series of tests should exclude a certain percentage of wrongly accused fathers. If, for example, one tests only the ABO system, the tests should exclude 13.42% of wrongly accused caucasian fathers. The Phosphoglucomutase (PGM) system (including subtypes) will exclude 25% of nonfathers. Since these blood groups are statistically independent (the existence of an ABO factor does

<table>
<thead>
<tr>
<th>ANTIGENS:</th>
<th>ABO</th>
<th>13.42%</th>
</tr>
</thead>
<tbody>
<tr>
<td></td>
<td>MNSs</td>
<td>30.96%</td>
</tr>
<tr>
<td></td>
<td>RHESUS</td>
<td>27.46%</td>
</tr>
<tr>
<td></td>
<td>Combined Antigens</td>
<td>56.63%</td>
</tr>
</tbody>
</table>

<table>
<thead>
<tr>
<th>ENZYMES:</th>
<th>GLO I</th>
<th>18.15%</th>
</tr>
</thead>
<tbody>
<tr>
<td></td>
<td>EoD</td>
<td>9.13%</td>
</tr>
<tr>
<td></td>
<td>PGM</td>
<td>25.00% (includes subtyping)</td>
</tr>
<tr>
<td></td>
<td>ADA</td>
<td>4.52%</td>
</tr>
<tr>
<td></td>
<td>EAP</td>
<td>23.23%</td>
</tr>
<tr>
<td></td>
<td>AK</td>
<td>4.28%</td>
</tr>
<tr>
<td></td>
<td>GPT</td>
<td>18.75%</td>
</tr>
<tr>
<td></td>
<td>Combined Enzymes</td>
<td>68.4%</td>
</tr>
<tr>
<td></td>
<td>Combined Antigens and Enzymes</td>
<td>86.3%</td>
</tr>
</tbody>
</table>

<table>
<thead>
<tr>
<th>SERUM PROTEINS:</th>
<th>Gc</th>
<th>16.61%</th>
</tr>
</thead>
<tbody>
<tr>
<td></td>
<td>Hp</td>
<td>18.34%</td>
</tr>
<tr>
<td></td>
<td>C 3</td>
<td>15.23%</td>
</tr>
<tr>
<td></td>
<td>GBG</td>
<td>14.43%</td>
</tr>
<tr>
<td></td>
<td>alpha,AG</td>
<td>17.73%</td>
</tr>
<tr>
<td></td>
<td>Combined Serum Proteins</td>
<td>59.4%</td>
</tr>
<tr>
<td></td>
<td>Combined Antigens, Enzymes and Serum Proteins</td>
<td>94.4%</td>
</tr>
</tbody>
</table>

<table>
<thead>
<tr>
<th>TISSUE TYPING:</th>
<th>HLA</th>
<th>90% (approx.)</th>
</tr>
</thead>
<tbody>
<tr>
<td></td>
<td>Combined Antigens, Enzymes, Serum Proteins and HLA</td>
<td>99.44%</td>
</tr>
</tbody>
</table>

The probability of exclusion will also vary because of the number of subgroups tested within a particular group. The difference may be illustrated by assuming these laboratories which all test the ABO, MNSs and Rh systems.
not affect the existence of any PGM factor), the combined probability of exclusion, when both systems are tested, is 35.07%.\(^4\) As each new system is tested, the probability of exclusion becomes higher. There is a point of diminishing returns because each new system, although fairly effective standing alone, only increases the overall probability of exclusion by a few percentage points.\(^4\)

The probability of exclusion of a particular system or set of systems is a useful guide for determining how many different tests to run and at what point it is no longer cost effective to pay for further tests. If used as evidence of paternity against a nonexcluded man, however, it can be misleading. The probability that a nonfather will be excluded by a set of tests is not the same as the probability that the nonexcluded man is the father. While it is true that the higher the probability of exclusion, the higher the probability that the nonexcluded man is the father, "there is no direct relationship between the probability of exclusion and the likelihood of paternity. Likelihood of paternity cannot be extrapolated from the probability of exclusion."\(^4\)

Scientific literature documents the incorrectness of equating the probability of exclusion with the probability of paternity.\(^4\) In 1977 Hummel, one of the pi-

<table>
<thead>
<tr>
<th>Laboratory</th>
<th>ABO</th>
<th>MNS(_s)</th>
<th>Rh</th>
<th>Probability of Exclusion</th>
</tr>
</thead>
<tbody>
<tr>
<td>#1</td>
<td>A,B,O</td>
<td>M,N</td>
<td>D</td>
<td>.33</td>
</tr>
<tr>
<td>#2</td>
<td>A,A,B,O</td>
<td>M,N,S</td>
<td>D,C,E,c</td>
<td>.547</td>
</tr>
<tr>
<td>#3</td>
<td>A,A,B,O</td>
<td>M,N,S,s</td>
<td>D,C,C(^w),e,E,e</td>
<td>.614</td>
</tr>
</tbody>
</table>

\(^{40}\) This can easily be shown as follows: of 100 nonfathers, the ABO System will exclude 13.42. This leaves 86.58 nonfathers who have not been excluded. Of these 86.58 the PGM System will exclude 21.65 (25% of 86.58). The total excluded is 35.07 out of 100 (13.42 by the ABO System plus 21.65 by the PGM System), hence a probability of exclusion of 35.07%.

The formula for calculating the probability of exclusion (PE) for \(n\) systems is: \(PE = 1-(1-P_1)(1-P_2)(1-P_3)\ldots(1-P_n)\) where \(P\) is the probability of exclusion for each system (e.g., \(P\) for ABO = .1342; \(P\) for PGM=.25, etc.). \(\text{Paternity Testing, supra note 5, at 82.}\)


\(^{42}\) Stroud, Bundrant, & Galindo, \(\text{supra note 24, at 47.}\)

\(^{43}\) It is tempting to think of the complement of the probability of exclusion as being synonymous with the probability of paternity. A moment's reflection will dispel this notion. The probability of exclusion depends upon the genetic structure of a
Paternity testing, documented 13 actual cases from his own experience in which the probability of exclusion ranged from 80% to 96%, yet the probability of paternity ranged between 4.4% and 44%. It is quite easy to posit families with common blood groups where the probability of exclusion is below 50%, yet the probability of paternity is over 99%.

The probability of exclusion can be misleading for another reason. Generally a particular test carries a certain probability of exclusion, but the more correct probability of exclusion should be the probability given the mother-child combination in the specific case. For example, the basic Kell blood group system has a low probability of exclusion, only about 3.4%, but if the child is negative, or the child and mother are positive, the probability of exclusion with the Kell system is zero. If, however, the mother is negative and the population, whereas the probability of paternity is in reality a measure of our information with regard to a specific mother-child-putative father trio. Gene frequency data can enter into the calculation of both of these probabilities, but the nature of the computations are [sic] quite different.

Chakraborty, Shaw, & Schull, supra note 33, at 484.


45. The following is an example supplied by Dr. Valentin:

<table>
<thead>
<tr>
<th>Child</th>
<th>Mother</th>
<th>Father</th>
</tr>
</thead>
<tbody>
<tr>
<td>A_s</td>
<td>A_1</td>
<td>A_2</td>
</tr>
<tr>
<td>MNss</td>
<td>MNss</td>
<td>Mas</td>
</tr>
<tr>
<td>CcDee</td>
<td>CcDee</td>
<td>cde</td>
</tr>
<tr>
<td>K-</td>
<td>K-</td>
<td>K-</td>
</tr>
<tr>
<td>Fy(a-)</td>
<td>Fy(a-)</td>
<td>Fy(a-)</td>
</tr>
<tr>
<td>PGM:</td>
<td>1-1</td>
<td>1-1</td>
</tr>
<tr>
<td>EAP:</td>
<td>BA</td>
<td>AA</td>
</tr>
<tr>
<td>ADA:</td>
<td>1-1</td>
<td>1-1</td>
</tr>
<tr>
<td>Hp:</td>
<td>2-2</td>
<td>2-2</td>
</tr>
<tr>
<td>GC:</td>
<td>1-1</td>
<td>1-1</td>
</tr>
<tr>
<td>Ag:</td>
<td>x-</td>
<td>x-</td>
</tr>
</tbody>
</table>

The probability of exclusion using these specific mother-child-alleged father combinations is only 47%, yet the paternity index of the alleged father is 365.4 (for a discussion of the paternity index, see infra notes 56-57 and accompanying text), and his probability of paternity is 99.73%. Valentin Letter, supra note 33.

46. An exclusion occurs if both the mother and accused man lack this factor, but the child is Kell positive. The theoretical exclusion capability of the system is calculated as follows: PE = .92 (probability of mother being negative) x .92 (probability of the father being negative) x .04 (probability of a sperm being positive) = .034. Valentin Letter, supra note 33.
child is positive, the probability of exclusion is 93%.47

The probability of exclusion is, in a strict sense, relevant to the issue of paternity. It tells the trier of fact that the alleged father falls within the 1 to 10 percent (depending upon the number of tests) of the male population who could have fathered the child. Unfortunately, it does nothing to distinguish the true father from the perhaps millions of men who fall into this group. In addition, the probability of exclusion looks seductively like the probability of paternity so that there is patent potential to prejudice and mislead the fact-finder. There is also no straightforward way to integrate the probability of exclusion with the other evidence in the case, thus leaving the fact-finder to guess at its significance. It may be for these reasons that the 1981 amendments to section 895 of the Evidence Code did not provide for the admissibility of the probability of exclusion.48

Even if the probability of exclusion were considered relevant under traditional evidence standards, the potential for confusing and misleading the fact-finder is so great that the court should exclude it under its general power to exclude evidence which creates a substantial danger of prejudice, of confusing the issues, or misleading the fact-finder.49 This is especially true because there is no need for admitting the probability of exclusion in light of the current ability to calculate the more relevant and useful probability of paternity. If, however, the probability of exclusion were considered relevant enough to be admissible, the court should admit only the probability of exclusion based on the mother-child combina-

47. Id.

48. By implication, the 1981 amendments to § 895 of the Evidence Code do not authorize admission of the probability of exclusion. The section only authorizes admission if tests “show the probability of the alleged father's paternity.” The probability of exclusion does not “show the probability of the alleged father's paternity.” See supra note 41 and accompanying text. Moreover, the legislative history shows that the question of the admissibility of the probability of exclusion was before the Assembly Judiciary Committee from whence the bill originated, and the bill was not amended to authorize admissibility. The Bill Digest prepared for the Assembly Committee on the Judiciary by the Committee’s counsel, posed the following question: “Given the statistical nature of blood test evidence, should AB 123 require that both probability of exclusion and probability of inclusion be given to the trier of fact?”

tion in the case rather than the same probability based on a hypothetically random mother-child combination.

C. Calculating the Probability of Paternity

Fr. Bayes, an 18th century monk, derived a formula which tells a rational decision maker how newly discovered evidence should change a prior probability that a hypothesis is true. The formula is a mathematical way of expressing the intuitively obvious. If King Leontes had been persuaded that his queen's conduct with Polixenes created a 50% probability (or the odds were 1-to-1) that Polixenes had fathered the child, Leontes would have modified his opinion in favor of his own paternity if the child indeed had received Leontes' "eye, nose, lip." Similarly, he would have modified his opinion in favor of Polixenes' paternity if the child's physical features had favored Polixenes.

If Fr. Bayes had been in Leontes' court, he would have told the King that the proper formula to calculate the odds that the King was the father, given the new physical evidence is:

\[
O(F|E) = \frac{P(E|F) \cdot O(F)}{P(E|\text{not-F})}
\]

This means that the odds that Leontes was the father, given the new evidence, \(O(F|E)\), is equal to the probability of the existence of the evidence given that he was the father, \(P(E|F)\) divided by the probability of the existence of the evidence given that he was not the father, \(P(E|\text{not-F})\), multiplied by the prior odds that he was the father.

If it could be said that the observed features would resemble Leontes in 10 out of 100 cases if he were the father, but in only 1 out of 100 cases if Polixenes were the father, then the calculation would be as follows:

---

51. See supra note 2 and accompanying text.
0 (F|E) = \frac{10}{.01} \times \frac{1}{1} = 10. \quad \text{The new odds would be}

ten-to-one (10:1) that Leontes was the father. Stated another
way, in 10 out of 11 cases, where these facts were observed
and the prior odds were 1:1, Leontes would be the father.

The odds may be changed into a probability by dividing
all correct choices by the sum of all possible choices. In this
case ten out of eleven choices are correct, so the probability
of paternity is \frac{10}{11} = .91.\textsuperscript{53}

While there is no dispute over the mathematical correct-
ness of Bayes' Theorem, the difficulties in mathematically ex-
pressing the prior odds and the two probabilities in the ratio
limit its use as a forensic device.\textsuperscript{54} In 1938, however, Essen-
Möller published an article suggesting that the theorem could
be used to calculate paternity probabilities.\textsuperscript{56} Since gene fre-
quencies were being discovered, and the presence of one gene
was statistically independent of the presence of another, the
Mendelian laws of heredity could be used to calculate the
probability ratio

\[ \frac{a}{a+b} \]

53. Odds may always be changed into probabilities by dividing the numerator
of the odds by the sum of the numerator and the denominator. If the odds are a:b,
then the probability is \[ \frac{a}{a+b} \]

54. Whether or not Bayes' Theorem should be used by juries and judges to as-
sist in legal fact-finding is warmly debated. For criticisms of the practice see L. Co-
hen, The Probable and the Provable 79-120 (1977); Brilmayer & Kornhauser, Re-
view: Quantitative Methods and Legal Decisions, 46 U. CHI. L. REV. 116, 137-46
(1978); Callen, Notes on a Grand Illusion: Some Limits on the Use of Bayesian The-
ory in Evidence Law, 57 IND. L. J. 1 (1982). Supporters of the use of Bayes' Theorem
include Ellman and Kaye, supra note 5, at 1147-58; Fairley, Probabilistic Analysis of
Identification Evidence, 2 J. LEGAL STUD. 493 (1973); Finkelstein and Fairley, A
Bayesian Approach to Identification Evidence, 83 HARV. L. REV. 489 (1970); Kaye,
Bayes' Theorem may also be useful as a device to explain or derive other legal rules.
Kaplan, supra note 50, Kornstein, A Bayesian Model of Harmless Error, 5 J. LEGAL
STUD. 121 (1976); Lempert, supra note 52.

Whatever the merits of either side of this debate may be, in light of the recent
amendment of CAL. EVID. CODE § 896 (supra note 7), the use of Bayes' Theorem in
paternity trials seems inevitable in California.

55. Essen-Möller, Beweiskraft der Ähnlichkeit im Vaterschaftsnachweis; The-
oretische Grundlagen, 68 MITT ANTHROF GES 368 (1938); see Terasaki, supra note 5,
at 544 n.8.
where E is the blood group evidence and F is the fact of paternity. If the prior odds of paternity are assumed to be 1:1 (probability = .50), then the probability ratio becomes the new odds that the accused man is the father. In other words, the odds that the accused is the father compared to a random man, equal the probability that if the accused is the true, biological father, he would have passed on the genes which, from the mother’s and child’s blood types we know must have come from the true father, \( P(E|F) \), divided by the probability that in a mating between a random man and the mother, the random man would have passed on those same genes, \( P(E|\text{not-F}) \). The ratio

\[
\frac{P(E|F)}{P(E|\text{not-F})}
\]

is sometimes referred to as the paternity index (PI) of the accused.56

The index may be a number ranging anywhere from 0 to, theoretically, infinity. Studies in paternity cases show that the most frequently encountered indices for nonexcluded men in paternity cases range between 19 and 100.57 If the accused’s index is 19, the odds of the accused’s paternity as compared to an equally likely random man are 19:1. The probability of his paternity is:

\[
\frac{19}{19 + 1} + \frac{19}{20} = 95\%.
\]

It is not at all uncommon for nonexcluded men to receive indices in the hundreds, or occasionally even the thousands.

56. Paternity Testing, supra note 5, at 83-88. An alternative statement of the rule found in the scientific literature is

\[
(\text{PI}) = \frac{\text{frequency of accused man's phenotype among fathers in the current mother-child combination}}{\text{frequency of accused man's phenotype among nonfathers}}.
\]

Valentin Article, supra note 5, at 424. I find the statement of the rule in the text, however, intuitively easier to grasp.

57. Based only on HLA tests, the current arithmetical mean for nonexcluded men at the Irwin Memorial Blood Bank in San Francisco is 28. Interview with Dr. Herbert A. Perkins (October 27, 1981). An index of 28 yields a probability of 96.55%.
D. Understanding the Index

In a paternity trial, a fact-finder is naturally tempted to seize upon statistical figures, like the paternity index or the probability of paternity, as lifelines of objective truth in a sea of prevarication. "Soft" evidence involving difficult questions of credibility and other circumstantial matters may be submerged or lost because it appears unnecessary to resolve the questions in light of the hard, scientific, mathematical proof. Under these circumstances it is absolutely essential that the significance of the mathematical proof be clearly understood by both counsel and the fact-finder.

The paternity index, and the probability based upon it, can be easily misused. Returning to the example of the man with a paternity index of 19 (probability of paternity = 95%), it is clear that in a large population many men will have a phenotype compatible with fathering the child. If only one man in a thousand were to have the proper phenotype, there would be 1,000 men who could have fathered the child in an urban population containing only one million men. Bayes' Theorem cannot tell us which of these 1,000 men is the father. The most that the blood group evidence can tell us is that, assuming paternity is limited to the men in this city and the defendant is one of them, his probability of paternity is only one in a thousand, or .1%.

The reason for this apparent discrepancy between the relative probability of 95% and the actual probability of .1% is clear if we again consider Bayes' Theorem. The Theorem only tells us how to modify the prior odds of paternity in light of the new blood test evidence. The Theorem can do nothing to tell us what those prior odds are. Without the prior odds as a multiplier, Bayes' Theorem is virtually useless.

The paternity index merely represents the relative likelihood that a man with the phenotype of the accused father would contribute the required genes compared with the likelihood that a random man of the same ethnic group would do so. In order to convert this figure into the actual probability of

paternity, we must also know the probability that the accused father had intercourse at the right time, and the probability that a random man did likewise. If the accused had no intercourse, then, regardless of his index, his probability of paternity is zero. If the accused is the only man to have had intercourse then, regardless of his index, his probability of paternity is 100%. The paternity index equals the odds of paternity only if it is assumed that the prior odds of paternity are 1:1 (or the accused is already 50% likely to be the father). In other words, before the paternity index accurately represents the odds of paternity, one must assume that the defendant had intercourse with the mother and that a random man (whom we shall call Mr. X) also had intercourse with her. In addition, the calculation assumes that both had intercourse at a time, and under circumstances, in terms of timing, fertility, frequency of coition, and use of birth control, making them both equally likely to have fathered the child. If these assumptions are true, then, and only then, does Bayes' Theorem accurately reflect the odds that the accused is the father.

Since there is no way to calculate the prior odds of paternity, they must be inferred from the "soft" evidence—the testimony of witnesses, circumstantial evidence, admissions and all of the other evidence which the fact-finder may prefer to ignore in favor of the "scientific proof." Until the fact-finder, disregarding the paternity index, is persuaded that the above assumptions are true, use of Bayes' Theorem will yield a false result.

Time and again courts, commentators, and possibly

59. On this basis, one may quibble about whether Cal. Evid. Code § 895 authorizes the admissibility of this calculation. This calculation does not "show the probability of the alleged father's paternity" (supra note 7). It is only accurate if the assumption that the accused is already 50% likely to be the father is also accurate. Since the burden of proof in civil cases is only a preponderance of the evidence (50+%), the calculation is accurate only if most of the defendant's case is assumed to be invalid. Given the magnitude of this assumption, it is difficult to see how this calculation shows the probability of the alleged father's paternity.

Nevertheless, given the legislative history and case law background of Cal. Evid. Code § 895, it seems clear that this is the sort of calculation the legislature had in mind. See supra notes 7 & 48.


61. See, e.g., Cramer v. Morrison, 88 Cal. App. 3d 873, 153 Cal. Rptr. 865 (1979); Phillips v. Jackson, 615 P.2d 1228 (Utah 1980) (probability of paternity excluded because insufficient foundation that tests generally accepted in scientific community). The United States Supreme Court recently noted the continued importance
even experts have disregarded the importance of the soft evidence and jumped hastily to the conclusion that the paternity index represents the actual odds of paternity. As a practical matter it may well be that justice is usually done because the soft evidence would justify the conclusion that the above assumptions are satisfied. The danger is that the habit of incorrectly applying these statistics will mesmerize fact-finders to such an extent that the statistics will be improperly used in cases where the soft evidence is truly weak.

The coexistence of soft evidence and mathematical statistics presents the knotty problem of melding the two. Theoretically, it should be an extraordinarily rare case in which the fact-finder believes that the probability of the accused's paternity is exactly 50%, yet the calculations are correct only when that assumption is made. Consequently, in the vast majority of cases the fact-finder is left in the unsatisfactory position of either misusing or disregarding the statistics. Paternity statistics, however, can be presented in a way which makes it fairly easy for the fact-finder either to incorporate various degrees of persuasion into the calculations or to assess the importance of discrepancies or doubts left by the soft evidence.

It can be mathematically shown that the index of a random man is one. Since one random man is equally as likely as another random man to have fathered the child, this conclusion is also intuitively clear. It can also be shown that if more than one man is possibly the father, and if each man is equally as likely to have fathered the child as any other, then the probability that any one of the men is the father is equal to his paternity index divided by the sum of the indices of all of the possible fathers. If $P_{d}$ is the index of the defendant

---

62. Trueblood, *Paternity Blood Testing*, Prosecutor's Brief (June-July 1980) at 8; *Joint Guidelines, supra* note 17, at 278 (suggesting that the probability that a random sperm would contain the paternal haplotype equals the probability that the accused man is wrongly identified); *Schatkin, supra* note 14, at 66.

63. See the report of the expert witness' testimony in *Phillips v. Jackson*, 615 P.2d 1228 (Utah 1980); Konugres, *supra* note 5, at 220 ("[T]he accurate distinction between human beings on the basis of blood groups has become almost a surety and at present is only surpassed by finger printing."); *Joint Guidelines, supra* note 17, at 278.

64. Valentin Article, *supra* note 5, at 424.

65. Id. at 429. A variation on this formula is also used in Europe and the United States. The probability of paternity is expressed as
and

$$\sum_{1-n} P_{In}$$

is the sum of the indices of the other $n$ men, then the probability of the defendant's paternity is

$$\frac{P_{Id}}{P_{Id} + \sum_{1-n} P_{In}}.$$ 

Since all untested random men have an index of one, the following formula applies whenever the defendant was actually tested and the other men are unknown

$$\frac{P_{Id}}{P_{Id} + n}.$$ 

If we assume a defendant with an index of 19, then in a "one man case" (a case where we assume that there is only one Mr. X equally likely to be the father) the probability of paternity is

$$\frac{19}{19 + 1} = \frac{19}{20} = 95\%.$$ 

If the case involves relative promiscuity, we may infer three Mr. X's. The defendant's probability of paternity would then be

$$\frac{19}{19 + 3} = \frac{19}{22} = 86.36\%.$$ 

The fact-finder can also use this simple formula to test different conclusions with respect to the prior odds that the defendant or Mr. X is the father. Assume, for example, that the mother had frequent sexual relations with Mr. X. The fact-finder may conclude that, under the circumstances, Mr.

$$\frac{1}{1 + \frac{1}{P_{I}}}.$$ 

*Paternity Testing, supra* note 5, at 86. If the numerator and denominator of this fraction are multiplied by $P_{I}$, it becomes

$$\frac{P_{I}}{P_{I} + 1},$$

the formula in the text. The formula in the text is a better expression of the probability because it is easier for judges and juries to work with.
X is 10 times more likely to be the father than the defendant. The defendant's probability of paternity would be

\[
\frac{19}{19 + 10} = \frac{19}{29} = 65.52\%
\]

(scientists consider this figure statistically insignificant). Conversely, Mr. X's probability of paternity would be

\[
\frac{10}{19 + 10} = \frac{10}{29} = 34.48\%.
\]

However, if the circumstantial evidence showed the defendant 5 times more likely than Mr. X to be the father, then the probability of his paternity would be

\[
\frac{5 \times 19}{5 \times 19 + 1} = \frac{95}{96} = 98.96\%.
\]

In short, if the circumstantial evidence justifies enhancing the prior odds of a particular person's paternity, then the effect on the calculations is shown by merely multiplying that person's index (wherever it is found in the equation) by the fact-finder's assessment of that person's odds of paternity.

As the paternity index increases, the magnitude of the prior odds of paternity may decrease substantially and the accused father will still score over 95%. If the accused has an index of 200 or more, which is not uncommon, and we assume that there are 10 Mr. X's, or one Mr. X who is ten times more likely than the accused to have fathered the child, then the probability of paternity is

\[
\frac{200}{200 + 10} = 95.23\%.
\]

If the identity of Mr. X is known and his blood may be sampled, then, assuming he is not excluded, one may use the same formula to compare the relative probabilities of paternity of Mr. X and the defendant. Again, assuming that the "soft" evidence indicates an equal probability of paternity, the probability of the accused's paternity is

\[
\frac{P_{Id}}{P_{Id} + P_{Ix}}.
\]

66. See infra notes 89-90 and accompanying text.
The probability of Mr. X’s paternity is
\[ \frac{PI_x}{PI_d + PI_x} . \]

Again, if the circumstantial evidence shows that the odds of one man’s paternity is greater than the other’s, then the probability of paternity is calculated by merely multiplying that person’s index by those odds wherever the index appears in the formula.

It is clear, then, that a fact-finder should not attempt to use these statistics unless fully informed with respect to the assumptions underlying the calculations—particularly the assumption of intercourse and the assumption of a 50% prior probability of paternity. It verges on the inevitable that a paternity index yielding 95% probability will be mistakenly confused with a 95% probability of intercourse or paternity. If, in a jury trial, these assumptions are not made absolutely clear by the experts, then the court should either instruct the jury on the assumptions66 or seriously consider excluding the evidence under California Evidence Code section 352 or the equivalent section in another jurisdiction. Any expert who understands and candidly explains these calculations will, if asked, undoubtedly explain the underlying assumptions.

In addition, the fact-finder should be given the paternity index of the accused and of a random man, the probability of the accused’s paternity based on the 50% prior probability assumption, and the simple formula for recalculating the probability of paternity based on the fact-finder’s own assessment as to the prior odds of paternity.

In Swedish courts where there are no juries, and judges are well informed as to the meaning of these statistics, the evidence is presented in this manner. The need for a thorough explanation is even more acute when jury trial is the mode of fact-finding. Currently there is no uniformity in the way pa-

68. In TV star Chad Everett’s recent paternity trial, the trial judge suggested that the jury decide the issue of intercourse prior to using the statistics. The jury found for the defendant in spite of a 95% probability of paternity. San Francisco Chronicle, Nov. 4, 1981, at 2, col. 1. The propriety of this instruction may be tested on appeal. The L.A. Daily Journal, Jan. 5, 1982, § 2, at 1, col. 3.
ternity probabilities are presented. For example, until recently, the Irwin Memorial Blood Bank in San Francisco presented the paternity index, while the HLA Tissue Typing Laboratory at U.C.L.A. presents only the probability. Now the Irwin Memorial Blood Bank presents both the paternity index and the probability of paternity based on different assumed prior probabilities of paternity. Neither laboratory reports the simple formula for melding the blood group evidence with the soft evidence in the case. In addition, the U.C.L.A. practice can be very misleading because percentages alone do not, to the lay person, accurately reflect the differences in probabilities on which they are based. For example, 10:1, 100:1, and 1000:1 all translate into percentages over 90% (91%, 99%, and 99.9% respectively), yet there are vast differences between these probabilities. It is also easy to forget that the comparison is being made to a single random male, not the entire male population.

Unless the evidence is presented in the format suggested above, the fact-finder will have no reliable way to evaluate the statistics in light of the other evidence in the case. In

\[
P(E|F) = \frac{1}{1 - \frac{1}{PI} + \left(\frac{1}{P(F)}\right)}
\]

In a case where the paternity index is 19, and P(F) is assumed to be 1/2, then this becomes:

\[
P(E|F) = \frac{1}{1 - \frac{1}{19} + \left(\frac{1}{19}\right)} = \frac{1}{\frac{18}{19} + \left(\frac{2x1/19}{19}\right)} = \frac{19}{20} = .95.
\]

As can be seen, this gives the same result as the formula suggested in the text accompanying note 65, supra. While the above formula has the advantage of dealing only with probabilities rather than a mixture of odds and probabilities, it has the disadvantage of involving more arithmetical steps which may be confusing or difficult for jurors to manipulate. For this reason, the format suggested in the text seems preferable.
cases where different prior odds of paternity are indicated, this formula will be an essential tool for synthesizing the soft
and scientific evidence. Some scientists may shrink at the no-
tion of mixing objective scientific evidence with subjective
non-scientific evidence, but, unfortunately, a trial is a forum
in which society has no choice but to do the best it can in
accommodating the scientific method to the adversary system
of the courtroom. There is simply no sensible alternative.

To be sure, the fact-finder in a given case may not be able
to assign prior odds of paternity to the various participants,
but in such a case the fact-finder is hardly any worse off with
this information. The formula would at least be a useful guide
to the fact-finder when the fact-finder comes to the difficult
task of applying common sense to uncommon and complex
scientific facts. If the evidence is not presented in this or a
similar format, then the court should seriously consider ex-
cluding it under its general discretion to exclude confusing
and prejudicial evidence.

It makes little sense in a civil case to assume a prior probability of more than
50% because the burden of proof is preponderance of the evidence. An assumption of
more than 50%, then, assumes that the defendant loses and merely calculates by
how much.

The propriety of the preponderance-of-evidence standard for civil paternity cases
may itself be open to question. In In re Angelia P., 28 Cal. 3d 908, 623 P.2d 198, 17
Cal. Rptr. 637 (1981), the California Supreme Court, arguing that parenting is a "fund-
amental right," held that due process requires application of the "clear and convinc-
ing evidence" standard to parental termination proceedings. In Salas v. Cortez, 24
Cal. 3d 22, 593 P.2d 226, 154 Cal. Rptr. 529 (1979), the same court, arguing that
freedom from imposition of a parent-child relationship is equally as compelling an
interest as maintaining the relationship, required appointment of counsel for accused
indigent fathers in civil paternity cases. It would seem a logical extension of these two
cases to require clear and convincing evidence to impose a parent-child relationship.
In light of blood test evidence, this would not be an unrealistic standard of proof.

73. See supra note 54.
74. The French paternity expert Denise Salmon shows the results of the probability calculation assuming several different prior probabilities—e.g. 10%, 50%,
and 90%. D. Salmon and C. Salmon, Blood Groups and Genetic Markers Polymor-
phism and Probability of Paternity, 20 TRANSFUSIONS 694 (1980). The Irwin Memo-
rial Blood Bank recently began reporting calculations based on assumptions of prior
probabilities ranging from 10% to 90% in increments of 10%. At least one other
California laboratory does likewise. (Sample reports on file with the Santa Clara Law
Review). These practices are variations of the "chart" or "modified chart" approaches
suggested by Ellman and Kaye, supra note 5, at 1152-53.
75. See, e.g., FED. R. EVID. 403; CAL. EVID. CODE § 352 (incorporated by refer-
ence in CAL. EVID. CODE § 895). See supra note 7.
E. Calculating the Paternity Index

Bayes' Theorem can be applied successively to each new piece of evidence. If we call the probability ratio in Bayes' Theorem for the first item of newly discovered evidence $PI_1$, then the odds of the fact being true given this evidence are $PI_1 \times O(F)$. This is the prior odds when the next piece of evidence is discovered. Thus, the odds that the fact is true given the second piece of evidence are $PI_2 \times PI_1 \times O(F)$. If there are $n$ pieces of evidence in the case, then the odds that the fact is true given all this evidence are $PI_1 \times PI_2 \times PI_3 \times \ldots \times PI_n \times O(F)$. This formula is correct only if the existence of each piece of evidence is statistically independent of each other piece of evidence.\(^7\)

With few exceptions, each blood group is statistically independent of every other blood group. (The one important exception among systems used in paternity work is HLA, which is composed of several tightly linked subsystems. Calculations can be adjusted accordingly.\(^7\)) In other words, whether a person is A, B, AB, or O will not increase or decrease the probability of his being Kell, M, N, or MN, or any other blood group. Moreover, the paired genes on the chromosome are statistically independent from one another. Thus, the existence of an A gene does not increase or decrease the probability that an A, B, or O gene will pair with it; and the existence of an M gene does not increase or decrease the likelihood that an M or N gene will pair with it.

Given the statistical independence at these two levels, it is possible to calculate a paternity index for each blood group tested. These indices may then be multiplied together to arrive at the overall index for the accused man. The equation becomes the product of $PI_1$ through $PI_n$ multiplied times the prior odds of paternity. Since the prior odds of paternity are assumed to be 1:1, the paternity index is simply the product

\(^7\) See Joint Guidelines, supra note 17, at 261; Paternity Testing, supra note 5, at 85. Hummel's method of calculation, which is explained in Joint Guidelines, can be a bit confusing because, instead of working directly with $PI$, he uses the log of $1/PI$. Use of logs facilitates hand calculation because it is easier to add logs than to multiply indices. The use of $1/PI$ seems a needless confusion and it is not used in Scandinavian countries. See Valentin, Bayesian Probability of Paternity When Mother or Putative Father are not Tested: Formulas for Manual Computation, 91 Hereditas 163 (1979).

\(^7\) Valentin letter, supra note 33.
of the indices for each system.

In order to calculate the index for a particular system, one must know the frequency of the particular genes giving rise to the blood type in the relevant racial and geographic population. Because of extensive studies, the gene frequencies are published. Once the gene frequencies are known, and the blood group of the mother, child, and father are known, the index can be calculated.

The PGM system is a good example because it is a straightforward codominant system. A person is either PGM 1-1, 1-2, or 2-2. If the frequency of the "1" gene is \( p \) and the frequency of the "2" gene is \( q \), then the frequency of a 1-1 person would be \( p^2 \) (the probability of a gene being "1" is \( p \); the probability of finding two "1" genes is \( p \times p = p^2 \)), the frequency of a 1-2 person would be \( 2pq \) (i.e., \( pq + qp \)), and the frequency of a 2-2 person would be \( q^2 \). The following chart illustrates all possible combinations:

---

78. The frequency may vary dramatically according to race, and usually less dramatically according to geography. See supra notes 22 and 25. Gene frequencies are published in A. Mourant, A. Kopec, K. Domanska-Sobczak, The Distribution of the Human Blood Groups and Other Polymorphisms (1976). This book has been updated once, and it may continue to be updated in future years. Moreover, laboratories engaged in the relatively new HLA testing are in constant contact with one another sharing data on gene and haplotype frequencies.

79. It is also possible to calculate the paternity index when the mother or father is unavailable. The formulas are fairly complex, but the technique may be critical in heirship cases. Valentin, Bayesian Probability of Paternity When Mother or Putative Father are not Tested: Formulas for Manual Computation, 91 Hereditas 463 (1979).

Highly polymorphic systems, such as Rh, involve more complex equations. Formulae for the Rh system may be found in M. Okajima, Probability of Paternity in Rh Blood Groups, 7 Acta Gen. Med. et Gemell 321 (1958). These must be inverted because they have been calculated as \( \frac{1}{P} \).

80. The author is grateful to Dr. Jack Valentin for suggesting this example and checking the calculations.
Assume the following mother, child, father constellation: Mother 1-1; Child 1-1; Alleged Father 1-1. Since the mother is homozygous for “1”, she must have given an “1” gene to the child. The child must have received the other gene from its father. The probability that a paternal “1” gene would be found if the accused is the father is \( P(E|F) \) in Bayes’ Theorem. Since the alleged father is also homozygous for “1”, he can give only “1” genes. The probability of his transferring a paternal “1” gene if he is the father is 100%, or 1. \( P(E|F) \), the numerator for the ratio in Bayes’ Theorem, is 1.

The denominator, \( P(E|\text{not-F}) \), is the probability that a random man who fathered the child would have passed a paternal “1” gene. This probability is equal to the frequency of encountering the “1” gene in a random sperm of the relative racial and geographic population. Since a sperm carries only one gene of each pair, the probability simply equals the gene frequency for “1” genes + \( p \).

The paternity index for the PGM system in this mother, child, father constellation is, then, \( \frac{1}{p} \).

Assuming that the accused father in the same example were 1-2, then, because there is a 50% chance of passing the “1” and a 50% chance of passing the “2”, the probability he would pass the “1” gene if he were the father would be .5. Therefore, the numerator of the Bayesian ratio is .5, and the paternity index is: \( \frac{.5}{p} = \frac{1}{2p} \).

In other words, when compared to a random man, the odds that the 1-1 man fathered the child in this mother-child combination are twice those of the 1-2 man.

The following charts give the formula for calculating the paternity index for each mother, child, father constellation in this simple, codominant system:
To calculate the index, one simply inserts the gene frequencies for the relevant racial and geographic group. (The blanks are paternal exclusions.)

81. Calculating the index for a system with dominance is slightly more complex. Assume that the system has two phenotypes, + and -. A person who tests "+" could have the genotype ++ or +-. A person who tests "-" can only have the genotype --.

The index in the following family constellation would be calculated as follows:

<table>
<thead>
<tr>
<th>Phenotype</th>
<th>Genotype</th>
</tr>
</thead>
<tbody>
<tr>
<td>Mother</td>
<td>--</td>
</tr>
<tr>
<td>Child</td>
<td>+</td>
</tr>
<tr>
<td>Alleged</td>
<td>++ or +-</td>
</tr>
<tr>
<td>Father</td>
<td>++</td>
</tr>
</tbody>
</table>

*Because must have inherited a - from the mother, therefore cannot be ++.

Because the child must have received the + gene from its father, we must first calculate the likelihood that the accused man would pass a + gene given that he has a "+" phenotype. This likelihood equals the probability that he would be ++ and pass the gene, plus the probability that he would be a + and pass the + gene. The frequency of ++ men is $p^2$, and the frequency of + men is $2pq$ (he could be +- or -+). Therefore, the relative frequency with which a + man passes a + sperm becomes

$$\frac{p^2 + \frac{1}{2}pq}{p^2 + 2pq} = \frac{p(p+q)}{p(p+2q)}$$

Since $p+q = 1$, this becomes $1/(1+q)$.

The probability that a random man would pass the + gene is equal to the frequency of the + gene in the population, $p$. Therefore, this accused father's paternity index is: $\frac{1}{1+q} = \frac{1}{(p+pq)}$.

The calculations are more complex when the mother, child and father all test for the dominant gene because the probability of each possible maternal contribution must also be calculated.
F. Calculating the Paternity Index in HLA

In the HLA system, A and B types (called alleles) are linked together and passed along in packets. A person will have two A's and two B's, but a blood test of the person cannot show which A's are linked with which B's. If the mother, for example, has phenotype A2, A25, B7, B18, her haplotypes may be A2, B7/A25, B18, or A2, B18/A25, B7. If she has a child with phenotype A1, A25, B18, BW35, the child must have inherited the A25, B18 from the mother (since the mother did not have A1, BW35 to give). We can, then, infer that A25 and B18 are linked in a haplotype in both the mother and child. Therefore, the father must have passed the haplotype A1, BW35.

If the father does not have the antigens A1, BW35, he is excluded as the father of this child. Assume, however, that the father has the following antigens +A1, A28, BW35, BW51. He cannot be excluded because he has A1, BW35.

We do not know, however, whether this man has haplotypes A1, BW35/A28, BW51 or haplotypes A28, BW35/A1, BW51. In the latter case, he could not, barring a 1% chance of recombination, father the child. The first step in calculating this man's paternity index is to calculate the probability that his alleles are linked +A1, BW35/A28, BW51, or A28, BW35/A1, BW51. To calculate this, the frequency of this linkage is compared with the frequency of the A28, BW35/A1, BW51 linkage in the population. The calculation would look like this:

\[
\begin{align*}
\text{A1, BW35} & \quad \text{A28, B51} \\
\text{frequency 60.1} & \quad \text{frequency 31.6} \\
& \quad 60.1 \times 31.6 = 1899.16 \\
& \quad \text{(relative frequency)} \\
\text{A28, BW35} & \quad \text{A1, B51} \\
\text{frequency 36.1} & \quad \text{frequency 11.5} \\
& \quad 36.1 \times 11.5 = 415.15 \\
& \quad 2314.31 \\
& \quad \text{(relative frequency)}
\end{align*}
\]

82. See generally, Paternity Testing, supra note 5.

83. In 1% or less of the cases, the HLA alleles will switch chromosomes. Thus, an A28, BW35/A1, BW51 person could pass A28, BW51 or A1, BW35. Valentin Letter, supra note 25. Paternity Testing, supra note 5, at 55.

84. The author is grateful to Dr. Herbert A. Perkins, of the Irwin Memorial Blood Bank, for supplying the following examples and checking the calculations.

85. The frequencies are expressed per 10,000. Thus, there are 60.1 A1, BW35 haplotypes per 10,000 haplotypes.
This indicates that the A1, BW35/ A28, B51 haplotype will occur in 1899.16 of the cases and the converse haplotypes in 413.15 2314.31 2314.31 of the cases. The accused man's probability of being linked in a way to possibly father this child is: \[
\frac{1899.6}{2314.31} = .82.
\]

If the accused were linked A1, BW35/A28, BW51 and he fathered a child, he would pass on the A1, BW35 haplotype in only one-half of his matings. The probability that, if he were the father, he would pass on the paternal haplotype found in the child is therefore \( .50 \times .82 = .41 \). The probability that a random man would pass on the A1, BW35 haplotype is equal to the frequency of finding that haplotype in a random sperm of the relevant population. In this particular case, it would be found in .00601 random sperm. The accused father's paternity index is: \[
\frac{.41}{.00601} = 68.22 = 98.55\%.
\]

If the accused man's parents are available for testing, it is very possible that the accused man's actual haplotype configuration could be inferred in the same way the child's was inferred in the above example. If his mother gave A28, BW51, and his father gave A1, BW35, then the accused father would be A1, BW35, rather than just being 82% likely to be A1, BW35. Conversely, if one of his parents gave A1, BW51, and the other gave A28, BW35, then because of the 1% chance of recombination, the accused would have only a \( \frac{1}{2} \% \) chance of passing an A1, BW35 haplotype. In an appropriate case jus-

---

86. The accused's paternity index would, then, be
\[
\frac{.50}{.00601} = 83.19 = 98.81\%.
\]

Note also that the accused's father would have a 98.81% probability of being the father. This underscores the importance of the assumptions underlying these calculations, see supra notes 55-59 and accompanying text.

87. The accused's paternity index would, then, be
\[
\frac{.005}{.00601} = .83 = 45.46\%, \text{ a statistically insignificant probability.}
\]

A proper calculation of the paternity index should include the possibility of recombination. While in most cases the small possibility of recombination makes only an insignificant difference in the paternity index, in some cases it can make a tremendous difference. If we assume a Central European population, and a child \( (A_1, A_2, \)
tifying the expense, this kind of further testing might be indicated.\(^8\)

An HLA case can be more complex when the paternal and maternal haplotypes cannot be clearly determined. The following example from an actual case demonstrates the point:

<table>
<thead>
<tr>
<th></th>
<th>Mother</th>
<th>Child</th>
<th>Father</th>
</tr>
</thead>
<tbody>
<tr>
<td></td>
<td>A2</td>
<td>AW24</td>
<td>BW50</td>
</tr>
<tr>
<td></td>
<td>BW35</td>
<td>A2</td>
<td>A2</td>
</tr>
<tr>
<td></td>
<td>B40</td>
<td>A2</td>
<td>--</td>
</tr>
</tbody>
</table>

In this case the mother could have given either the A2, B40 (in which case the alleged father would be excluded) or the AW24, B40 (in which case the alleged father could not be excluded). First, the probability that the mother is linked AW24, B40 must be calculated. This is calculated in the same manner as for the father in the first example.

The alleged father has two "blanks." This means that either he is homozygous (i.e., the genes on both sides of the chromosome are identical) at that locus, or he has an undiscovered or silent allele. In the latter case if the undiscovered or silent allele were coupled in a haplotype passed to the child, the child should also have a blank. The father's possible haplotype arrangements are:

A. If blanks in both an A and B locus:
   1. A2, BW35/--
   or

\(B_5, BW50\), mother \((A_2, A_3, B_5, B_7)\) and a putative father \((A_1, AW_23, B_8, BW50)\), a calculation ignoring the possibility of recombination yields a probability of paternity of only 9.8%. When recombination is considered, the probability jumps to 97.2%! J. Conradt, J. Valentin, K. Hummel, & P. Ihm, An Algorithm to Evaluate HLA Results Taking into Account Recombination Between the A and B Loci, BIOMATHEMATICAL EVIDENCE OF PATERNITY 151, 156-57 (Hummel & Gerchow, ed. 1981).

88. If the parents were cooperative, no court order would be necessary, and, if the information were not informative or were damaging, the test results may be protected by the work product privilege. See Sanders v. Superior Court, 34 Cal. App. 3d 270, 109 Cal. Rptr. 770 (1973); Scotsman Mfg. Co. v. Superior Court, 242 Cal. App. 2d 527, 51 Cal. Rptr. 511 (1966); Swartzman v. Superior Court, 231 Cal. App. 2d 195, 41 Cal. Rptr. 721 (1964). It is unlikely that relatives who are not parties or under the control of parties would be ordered to take blood tests. The opposite party might, therefore, be able successfully to argue that the work product privilege should give way in light of the need for the information and the inability of the party to get the substantial equivalent. See CAL. CIV. PROC. CODE § 2016(b), (g) (West Supp. 1981). Moreover, great care must be taken not to waive the privilege. Williamson v. Superior Court, 21 Cal. 3d 829, 582 P.2d 126, 148 Cal. Rptr. 39 (1978).
2. --BW35/A2--

B. If homozygous at A2, but blank at one B locus:
3. A2, BW35/A2,--

C. If homozygous at BW35, but blank at one A locus:
4. A2, BW35/--BW35

D. If homozygous at both the A and B locus:
5. A2, BW35/A2, BW35

In case 2, he could not be the father. In case 5 he would have a 100% chance of passing on the A2, BW35 haplotype. In cases 1, 3, and 4 he would have a 50% chance of passing on the A2, BW35 haplotype. The probability that the father could pass on A2, BW35 is one-half times the probability that he is either 1, 3, or 4 above, plus the probability that he is 5. The probability that he could have fathered the child is the probability he could have passed on the A2, BW35 haplotype multiplied by the probability that the mother is AW24, B40/A2, BW50. This is the numerator in the probability ratio.

The denominator equals the probability that a random man could father the child. This would equal the probability that the mother is A2, B40/AW24, BW50 multiplied by the probability a random sperm is AW24, BW35, plus the probability the mother is AW24, B40/A2, BW50 multiplied by the probability that a random sperm is A2, BW35.

In this particular case, the paternity index is 40.15 and the probability is 91.57%. Again, a study of the HLA types of the mother's and alleged father's parents could remove some of the ambiguities and either raise or lower the probabilities. For example, if the studies showed the child's mother carried an A2, B40 haplotype or the alleged father carried the—BW35/A2—haplotypes, then, barring the 1% chance of recombination, the alleged father would be excluded. On the other hand, if the mother were shown to be A24, B40/A2, BW50 then the denominator in the probability ratio simply would be the frequency of the A2, BW35 haplotype.

G. Statistical Significance

At present there is disagreement in the scientific community about the level of significance of different paternity indices. The Nordic countries presently use the following signifi-
The 1976 AMA-ABA Joint Guidelines, however, suggest that significance limits proposed by Hummel, a German paternity researcher. These are:

Index =

5 or less (prob. 83% or less) no significance
6 to 10 (prob. 83% to 91%) undecided
11 to 20 (prob. 92% to 95%) paternity likely
21 to 100 (prob. 96% to 99%) paternity very likely
101 to 200 (prob. 99% to 99.5%) paternity extremely likely
over 200 (prob. over 99.5%) paternity practically proven

The Nordic guidelines are more conservative in assigning a positive likelihood of paternity to the paternity index. While Hummel ascribes a likelihood of paternity at index 11, the Nordic countries do so only when the index reaches 19. Since both agree that an index of 19 (corresponding with 95%) is

89. Valentin Article, supra note 5, at 429-30.
90. See Joint Guidelines, supra note 17, at 262; Explanation of Paternity Test Report, Irwin Memorial Blood Bank of the San Francisco Medical Society (on file with the Santa Clara Law Review). There are even slight differences in the way Hummel's table is interpreted. The Joint Guidelines use the following break points: Below 80%, 80-90%, 90-95%, 95-99%, 99.1-99.75%, and over 99.80%. The Irwin Memorial Blood Bank expresses the significance in terms of the indices listed in the text accompanying this footnote. These indices yield the percentages accompanying them in the text. As can be seen, these are slightly different from those used by the Joint Guidelines. In Paternity Testing, supra note 5, at 87, a slightly different modification of Hummel's table is given:

<table>
<thead>
<tr>
<th>Probability of Paternity</th>
<th>Likelihood of Paternity</th>
<th>Paternity Index</th>
</tr>
</thead>
<tbody>
<tr>
<td>99.8-99.9%</td>
<td>practically proven</td>
<td>&gt; 399 to 1</td>
</tr>
<tr>
<td>99.0-99.7%</td>
<td>extremely likely</td>
<td>95 to 1</td>
</tr>
<tr>
<td>96.0-99.3%</td>
<td>very likely</td>
<td>90 to 1</td>
</tr>
<tr>
<td>90.94.9%</td>
<td>likely</td>
<td>89 to 1</td>
</tr>
<tr>
<td>80.89.9%</td>
<td>certain hint</td>
<td>80 to 1</td>
</tr>
<tr>
<td>less than 80%</td>
<td>not useful</td>
<td>&lt; 40 to 1</td>
</tr>
</tbody>
</table>
significant, the better practice would be to follow this level as the one generally accepted in the scientific community. Moreover, ninety-five percent is a commonly accepted level of significance, and it is also the one accepted by the EEOC and courts when statistical analysis is used to show discrimination in Title VII cases.

The highly skewed nature of the distribution of paternity indices of nonexcluded men also suggests the appropriateness of the Nordic standard. One study found that of the nonexcluded men tested in the HLA system alone, 67% scored over 19 (prob. 95%), and 86% scored over 9 (prob. 90%). Only two cases out of 1000 scored below 1 (prob. 50%).

Once the accused is not excluded as the possible father of the child, he is in a group which includes nonexcluded fathers and nonexcluded nonfathers. The fact-finder must determine into which of these categories the accused falls. Ironically, nonexcluded nonfathers frequently score impressively high probabilities. In fact, the geometric mean for the paternity index of nonexcluded nonfathers appears to be between 3.15 and 5.65 (76%-85%). Nonexcluded fathers also score high indices, with the mean somewhere between 19 and 100. Since a nonexcluded nonfather is more likely to score 85% than a true father, such a score not only does little to differentiate nonexcluded fathers from nonexcluded nonfathers, but it may, if anything, be more probative of nonpaternity than paternity.

Simply stated, the biologic father is likely to achieve a very high index (19 or more). If he does not score an index higher than one would expect a nonexcluded nonfather to score, however, then we cannot say whether he is more likely to be a nonexcluded father or a nonexcluded nonfather. Since this conclusion is counterintuitive, a high index in the range commonly received by nonexcluded nonfathers has a positive tendency to mislead the fact-finder. Therefore, the “significance” level should be kept high and indices below 19 should

---

91. Paternity Testing, supra note 5, at 86.
93. Terasaki, supra note 5, at 552-53.
94. Valentin Article, supra note 5, at 425. Plotting the frequency with which fathers and nonexcluded nonfathers obtained different log index values, Dr. Valentin came out with the following curves:
either be excluded as evidence or, if admitted, should be spon-

The Irwin Memorial Blood Bank has begun a more sophisticated study. Interview with Ms. Fonna Cronin, Irwin Memorial Blood Bank, April 28, 1982. 345 acknowledged caucasion families were tested to see what the known father’s paternity index would be using the HLA system. The median index (i.e., there were as many above the index as below the index) was 50 (probability 98.04%). The paternity indices ranged from .03 (probability 2.9%) to 5795 (probability 99.98%).

The same 345 mother-child combinations were then matched with 345 randomly chosen men (who presumably, were not fathers of the children). The HLA test excluded all but 18 of these men. These 18 men would, then, be nonexcluded nonfathers. The median paternity index for these nonexcluded nonfathers was 8 (probability 88.89%), and the range was 1.7 (probability 62.96%) to 57.3 (99.83%). Four of these men had the most common haplotype (A1, B8), and two of them carried another very common haplotype (A2, B44).

Tentative as these results are, they illustrate several important things. Nonexcluded nonfathers will often score impressive probabilities, particularly if translated into percentages. One half of these 18 nonfathers scored percentages of 88.89% or higher, and the top score was an impressive 99.83%. This is contrary to the common assumption that a nonfather, if not excluded, should at least score a low probability. At the same time, the median for fathers was 98.04%. While one would expect fathers to score higher than nonfathers, these calculations are important because they illustrate in a rough way how much higher the score should be.

The second important point is that men with common haplotypes are more likely to be nonexcluded than ones with rarer haplotypes. Common sense suggests this, and this experiment bears it out. In the event that an accused father bears a common haplotype, testing in other systems should be seriously considered.

This small group of 345 families is probably not large enough to yield firm data. For example, the theoretical exclusion rate for HLA is about 90%, yet the tests failed to exclude only 18 rather than 34 nonfathers. This might be some indication that the group was not large enough.

---

Distribution of the paternity index $L$ in logarithmic scale among 1,371 one-man cases 1973-1974. Three of the men were outside limits of graph (log $L = -2.5$, $+4.7$, and $+4.9$). Stippled area under fine line contains presumed nonfathers. Log $L = 0$ corresponds to a probability of paternity of 50%; log $L = 1.28$, to 95%; and log $L = 2$, to 99%.

---

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sored by a witness familiar enough with the statistics, computations, and literature to explain the indices' significance or lack thereof.95

H. Beyond the Paternity Index

Recall that the paternity index equals the probability of paternity only when the man selected is 50% likely to be the father. Can statistics tell us anything about the correctness of this basic assumption?

Assume that the probability is 1/100 that in a given case a randomly chosen man would have the proper blood groups to father the child. The mother cannot see or know the serological profile of the alleged father. If he has the blood groups necessary to father the child, it might appear that the probability that the mother did not choose him randomly (i.e., the probability that she knew he was the father) would be 1-1/100 or 99%. This, however, would be incorrect. The probability that a single choice was made non-randomly cannot be calculated from the probability that it could be made randomly. If it were otherwise, then no race track or gambling house would ever have to pay a player who wins a long-shot bet. The improbability of the player choosing the correct result would be almost conclusive evidence that the player cheated. This is intuitively obvious, because many extremely rare occurrences happen randomly every day.

If, however, many selections are made and the results deviate from the distribution one would expect from random selection, then statistics can tell us the probability that the selections are not being made randomly.96 If, for example, the gambling house knows that the odds in roulette favor the house, but the results over a substantial series of plays favor the gamblers, then the house may properly infer that the game is, for some reason, not random.

In the paternity context, there are tens of thousands of mothers picking men as the fathers of their children. Obvi-

95. In a recent case the court gave little weight to 98.95% probability of paternity, in part because the testimonial sponsor was a medical technologist. "She did not know the extent or nature of the other evidence to be introduced at trial and she was not in a position to weigh the evidence and make a mathematical determination of the probability of paternity." Alanda V., a minor v. Alfredo V., 125 Cal. App. 3d 98, 101, 177 Cal. Rptr. 839, 840 (1981).

96. Braun, supra note 92, at 68-74.
ously, some of these mothers, even if picking randomly, would choose men with the appropriate blood groups. If, out of every 100 mothers, 99 choose men who could not be the father and only one chose a man who could be the father, there would be no reason to conclude that the selection of a nonexcluded man was anything other than a random guess. On the other hand, if 99 mothers choose men who could have fathered the child, and only one chose an impossible father, then one could at least say that mothers, in general, know who the father is and are not choosing randomly.

It is possible to draw the curve of the expected distribution of paternity indices if men were being chosen randomly and compare it with the actual distribution of paternity indices of men accused by mothers. The government licensed laboratory in Sweden has completed a preliminary study along these lines. The laboratory, which had investigated about 75,000 paternity cases, focused its study on 3,913 of those cases. The number of blood systems tested gave a probability of exclusion for nonfathers of 86.6%. The actual rate of exclusion in the tested cases was only 30-35%. This result is not surprising to the extent that it shows that by-and-large mothers pick the right man. The 30-35% exclusion included exclusions in both one-man cases and cases where more than one man was accused and tested. In one-man cases (those in which the mother claimed that only one man could possibly be the father), it is perhaps surprising that the man was excluded in 22.6% of the cases. This exclusion often leads to a refreshed memory on the part of the mother as to other possible fathers.

The Swedish study estimated the frequency of accused nonfathers by comparing the observed and theoretical exclusion rates. In one-man cases it was 26.1%. Thus, women in general accused the right man in approximately 73.9% of the one-man cases. Paradoxically, if the mother initially had named several possible fathers, the true father was less likely to be among them. At least in one-man cases, these results

97. Valentin Article, supra note 5.

98. In a similar study done by Dr. Paul Terasaki, 25% of the cases tested resulted in exclusions. He does not state whether these were all "one man" cases. Terasaki, supra note 5, at 552. Tests done by others (sometimes using a less impressive array of genetic markers) have excluded from 16% to 26.5%. Paternity Testing, supra note 5, at xi-xii.
strongly suggest that the mothers are more than 50% likely to be correct. Thus, the Bayesian prior odds of paternity could be adjusted upwards.

Although a fact-finder may intuitively arrive at a similar conclusion, there are some serious obstacles to the introduction of this sort of statistical evidence. Many scientists generally consider polygraph evidence to be 95% accurate, but the courts, with a few exceptions, do not consider it sufficiently reliable to be admitted absent a stipulation. Scientists base this estimate on the test's ability to detect falsehood in the large group of people who have been tested. Similarly, the paternity statistics are based on inferences about the truth and falsity of accusations made by a large group of people. If polygraph results are inadmissible even though they are based on more or less involuntary responses to prevarication and may be able to detect falsehood with a 95% degree of accuracy, a statistical "polygraph," which generally tells us only that mothers are correct in 70-75% of the cases, should likewise be excluded. Moreover, the veracity of mothers may vary from place to place and time to time. In fact, the very existence of paternity testing should, if it becomes common knowledge, affect the general level of veracity.

In addition, there have not been enough studies here or abroad to justify generalizations about the veracity of mothers. At best, the current studies are tentative, suggesting that further study may be interesting and helpful.

The existing studies are not helpful in litigation for another reason: The wrong group was studied. After the paternity tests are completed the majority of accused men who score high indices admit paternity. Less than one-fourth of the Swedish cases required further legal action. One might suspect that a higher percentage of nonfathers would be found


100. Valentin Article, supra note 5, at 421. This would undoubtedly be true in the United States because many men, knowing full well the possibility of their paternity, really only want some assurance that the child is actually theirs. Even King Leontes finally relented. See supra note 2 and accompanying text.
among the group of men who persistently claim nonparentage throughout litigation. This smaller group must form the basis for generally assessing the credibility of mothers.

Courts have used similar statistical analysis in other contexts. For example, courts have admitted statistical analysis in discrimination cases to show that a pattern, such as hiring, is not one which can be explained by random or nonbiased selection. Racial or sexual motivation may be inferred if the pattern deviates significantly from that which has occurred with respect to another race or sex. There are significant differences, however, between using statistics to infer the state of mind of a defendant in a discrimination case and using them to infer knowledge of the mother in a paternity case. The plaintiff in a discrimination case offers statistics against the party who engaged in the conduct giving rise to the statistic. The statistics are based on conduct of either the party or others for whom the party may be charged. It is not unfair to place the burden on the defendant to explain the conduct of these people. Therefore, the conduct giving rise to the statistic operates very much like an admission of a party opponent. By contrast, statistics in paternity cases share none of these characteristics. The mother is often a witness rather than a party, and the statistics are not based on her conduct, but on conduct of other mothers. The alleged father cannot explain that conduct, nor could the mother if the statistics were offered against her.

If, in the future, there are enough studies on the proper group, and mothers consistently identify fathers in contested cases well above 50% of the time, the legislature might consider enacting a presumption shifting the burden of production, or possibly the burden of proof, to defendants in paternity cases. In any event, these sorts of statistics are much

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101. Braun, supra note 92.
103. E.g., Connecticut law provides that if the mother "continues constant in her accusation," then the burden of proof on the question shifts to the accused father. CONN. GEN. STAT. § 46b-160 (1981); Kelso v. Green, 6 CONN. Cir. Ct. 516, 519-20, 276 A.2d 909, 911-912 (1971); Mosher v. Bennett, 108 Conn. 671, 674, 144 A. 297, 298 (1929). The United States Supreme Court discusses the Connecticut rule in Little v. Streater, 452 U.S. 1, 9-12 (1981).
more useful in adopting overall policies towards paternity cases than they are in resolving any particular case.

V. Conclusion

If, in the California Supreme Court's words, mathematics is a sorcerer in our society, the bench and bar must learn about the forensic use of mathematics in order to avoid the fate of the hapless sorcerer's apprentice. In the paternity area, courts must familiarize themselves with paternity statistics in order to exercise wisely their discretion under California Evidence Code section 352 in weighing the probative value and prejudicial impact of this evidence. Attorneys must also become sufficiently versed in the area to guide fact-finders and judges in the proper use of paternity statistics.

Paternity statistics are particularly vulnerable to criticism because the calculations are based on the hidden assumption that the accused father is as likely as not to have fathered the child. If the paternity calculations are reported in the format currently used in Sweden, the fact-finder should be able to test this assumption against the actual evidence in the case and arrive at an accurate understanding of how the other evidence in the case affects the overall probability of paternity.

Paternity statistics are no more reliable than the data on which they are based. Reputable and experienced laboratories will rarely make a typing error, but some of the data about HLA haplotype frequencies is still very sketchy. Actual observation of some haplotypes is rare, so their frequency is based on the product of the frequency of the A or B alleles. When the actual haplotype is observed, its frequency may be significantly different from this product. Testing of the mother's and alleged father's parents can be very helpful in resolving some ambiguities.

The "probability of exclusion" is a troublesome statistic because it invites the inference that the probability of exclusion equals the probability of paternity for a non-excluded man. This is incorrect and, more importantly, misleading. Thus, the probability of exclusion should be excluded as evidence in favor of the probability of paternity.

The significance of a "high" probability of paternity is difficult to evaluate. It is clear that nonexcluded nonfathers can score comparatively high probabilities of paternity (since most nonfathers are excluded, the rest must of necessity "fit"
reasonably well). In one study, as many nonexcluded nonfathers scored over 88% as scored under 88%. On the average, fathers have higher probabilities of paternity than nonexcluded nonfathers (in the same study, the mean for fathers was 98.04%), so a paternity index must be rather high before it really differentiates the nonexcluded nonfathers from the (obviously nonexcluded) fathers. There is no general agreement in the scientific community that a probability below 95% has significance. Scientists generally agree that a probability greater than 95% (Paternity Index 19) is significant, so significance should be attached only to those probabilities exceeding 95%. Courts should weigh this factor in exercising their discretion when the probability is below 95%, and counsel should take care to insure that the fact-finder is aware of the importance of this significance level.

In the future it may be possible to bring statistical analysis to bear on the question of the credibility of the mother. It is unlikely, however, that the statistics would be suitable as a forensic tool. They might, however, be useful to legislators when setting policy in this troublesome area of family law.

104. See supra note 94.