



1979

Probabilities and Proof: Can HLA and Blood Group Testing Prove Paternity?

David H. Kaye
Penn State Law

Ira Mark Ellman
Arizona State University

Follow this and additional works at: http://elibrary.law.psu.edu/fac_works



Part of the [Evidence Commons](#), and the [Science and Technology Law Commons](#)

Recommended Citation

David H. Kaye and Ira Mark Ellman, *Probabilities and Proof: Can HLA and Blood Group Testing Prove Paternity?*, 54 *NYU. L. Rev.* 1131 (1979).

This Article is brought to you for free and open access by the Faculty Works at Penn State Law eLibrary. It has been accepted for inclusion in Journal Articles by an authorized administrator of Penn State Law eLibrary. For more information, please contact ram6023@psu.edu.

PROBABILITIES AND PROOF: CAN HLA AND BLOOD GROUP TESTING PROVE PATERNITY?

IRA MARK ELLMAN*

DAVID KAYE**

INTRODUCTION

Rabelais tells the story of Judge Bridlegoose, who appeared in his own defense before the High Court of Mirelinguais to clarify his grounds for a doubtful decision. The judge explained that he always decided cases by casting dice for plaintiff and defendant and awarding judgment to the party with the higher score. He conceded that in the questioned case, because of failing eyesight in his advancing years, he may have misread the dice, especially since they were very small. Still, he urged, in his forty years on the bench the High Court had never failed to uphold his judgments.¹

Judge Bridlegoose's jurisprudence has the virtue of being easily understood. Nor can one quarrel with an appropriate application of probability theory to decisionmaking. The problem, of course, is that Judge Bridlegoose's use of the laws of chance is neither appropriate nor fair.² For one thing, it assumes that the evidence in every case is evenly balanced.³

One might suppose that this sixteenth century satire would have no counterpart in the modern operation of the law. Yet, a growing number of courts appear to be making the same sort of error. For example, in *Cramer v. Morrison*,⁴ a paternity action, a California

* Associate Professor of Law, Arizona State University. B.A., 1967, Reed College; M.A., 1969, University of Illinois; J.D., 1973, University of California, Berkeley.

** Professor of Law, Arizona State University. S.B., 1968, Massachusetts Institute of Technology; M.A., 1969, Harvard University; J.D., 1972, Yale University. The authors wish to thank Tara Ellman, H. Robert Horvitz, and Dennis Young for reviewing earlier drafts of this article. They are especially indebted to Dennis Karjala for many helpful discussions of the problems raised by probability calculations and their use at trial.

¹ F. RABELAIS, GARGANTUA AND PANTAGRUEL 288-321 (1928) (1st ed. Paris & Lyons 1532-1564). Our attention was called to Rabelais' account by Sir Richard Eggleston's book, EVIDENCE, PROOF AND PROBABILITY, which opens with a similar synopsis of Judge Bridlegoose's travails. R. EGGLESTON, EVIDENCE, PROOF AND PROBABILITY 1 (1978).

² See generally R. DWORKIN, TAKING RIGHTS SERIOUSLY 31-39 (1978); Raz, *Legal Principles and the Limits of Law*, 81 YALE L.J. 823, 847-48 (1972).

³ See generally Kaye, Book Review, 89 YALE L.J. 601, 609-10 (1980) (reviewing M. FINKELSTEIN, QUANTITATIVE METHODS IN LAW: STUDIES IN THE APPLICATION OF MATHEMATICAL PROBABILITY AND STATISTICS TO LEGAL PROBLEMS (1978)).

⁴ 88 Cal. App. 3d 873, 153 Cal. Rptr. 865 (1979).

court of appeals held that the trial court erred in excluding expert testimony that "there was a 98.3 percent chance" that the defendant was the father.⁵ This calculation was based on results obtained from a tissue typing test for Human Leucocyte Antigen (HLA), and the appellate court was obviously impressed with the underlying science.⁶ Nevertheless, the testimony in *Cramer* and other cases⁷ suffered from the same methodological flaw which afflicted Judge Bridlegoose's application of probability theory. That testimony presupposed that the evidence, apart from the HLA test, was evenly balanced. Unlike Judge Bridlegoose's error, however, the mistake in *Cramer* and comparable cases is far from transparent. Indeed, it requires no small effort to unearth it and still more study to correct it.

The problem merits study, however, for at least two reasons. The first is eminently practical. The biology underlying the statistical evidence in such cases offers a wealth of previously unavailable information which is certain to revolutionize the adjudication of paternity disputes. Accordingly, it is important that the courts not become so mesmerized by these new sources of evidence that they neglect to subject them to traditional principles of evidence applicable to all testimony. Assuring such consistency requires a more sophisticated understanding of the new evidence than has thus far been exhibited by the courts, the commentators, and even the expert witnesses themselves.

The second reason this problem deserves serious attention has less immediate practical significance but may be more important in the long run. For some time, scholars have disagreed on the proper application of the laws of probability, and more particularly, a proba-

⁵ *Id.* at 878, 153 Cal. Rptr. at 867-68. The trial judge granted defendant's motion to exclude this testimony on the ground that "there was a possibility that statistical evidence of this nature would have a prejudicial effect on the jury which would outweigh its probative value." *Id.*, 153 Cal. Rptr. at 868.

⁶ *See id.* at 884-85, 153 Cal. Rptr. at 871-72.

⁷ HLA tests have been accepted as evidence of paternity by trial courts in Minnesota, New Jersey, and Oregon. *See Hepfel v. Bashaw*, 279 N.W.2d 342, 347 (Minn. 1979) (dictum); *Malvasi v. Malvasi*, 167 N.J. Super. 513, 515-16, 401 A.2d 279, 279-80 (1979); *Cannady, Tissue Typing Narrows Odds in Paternity Cases*, 39 OR. B.J. 18 (1979). *See also Lascaris v. Lardeo*, 100 Misc.2d 220, 227, 417 N.Y.S.2d 665, 669 (Fam. Ct. 1979) (ordering Department of Social Services to pay for HLA testing in paternity suit). *Cramer* was followed by another court of appeals in California. *County of Fresno v. Superior Court*, 92 Cal. App. 3d 133, 136-38, 154 Cal. Rptr. 660, 662-63 (1979). At least one state recently amended its statute to permit proof of paternity by blood group tests. ARIZ. REV. STAT. ANN. § 12-847(c) (West Supp. 1979).

The traditional rule in paternity actions in the United States is that the results of blood tests are admissible solely to exclude the possibility that the defendant is the father of the child in question. Serologic tests, in other words, cannot be introduced to prove paternity. *See, e.g., J.B. v. A.F.*, 92 Wis. 2d 696, 699-705, 285 N.W.2d 880, 881-84 (Ct. App. 1979); H. KRAUSE, ILLEGITIMACY: LAW AND SOCIAL POLICY 127-31 (1971).

bility formula called Bayes' Theorem, to questions of proof.⁸ The development of HLA and other serologic tests appears to mark the first time that probabilistic evidence will so dominate a field of law that virtually all future adjudication will depend on the resolution of these long debated questions. The evidence yielded by modern serologic tests is inherently quantitative and probabilistic, and the accepted method for calculating these probabilities involves Bayes' formula. Questions concerning the use of Bayesian calculations in the trial setting will thus have to be decided in these paternity disputes. Such rulings will undoubtedly influence judicial reaction to offers of similar probability evidence in other substantive fields.

This Article, therefore, undertakes a critical analysis of the use of probability calculations in paternity cases and of the broader issues implicit in this growing practice. Briefly stated, although we believe that the statistical information derived from HLA testing should be admissible in paternity cases, we doubt that any expert—no matter how skilled in biochemistry or biostatistics—can correctly testify to any quantified probability that the defendant in a given case is in fact the father.⁹ To explain our misgivings about such testimony, we first review the difficulties associated with traditional evidentiary techniques in paternity cases. We next discuss the nature and appeal of HLA and other modern serologic techniques for resolving paternity disputes. Then, we explore the statistical reasoning which necessarily underlies the expert testimony in cases like *Cramer*. Finally, we review the problems associated with statistical identification evidence and conclude by endorsing more suitable alternatives to the methodology currently used in paternity litigation.

I

TRADITIONAL MODES OF PROOF

In this age of pocket calculators, systems analysis, and occasional numerology, it should come as no surprise to hear courts and commentators lament that paternity is typically determined by

⁸ See, e.g., R. EGGLESTON, *supra* note 1, at 145-47; M. FINKELSTEIN, *QUANTITATIVE METHODS IN LAW* (1978); Brillmayer & Kornhauser, *Review: Quantitative Methods and Legal Decisions*, 46 U. CHI. L. REV. 116 (1978); Finkelstein & Fairley, *A Bayesian Approach to Identification Evidence*, 83 HARV. L. REV. 489 (1970); Tribe, *Trial by Mathematics: Precision and Ritual in the Legal Process*, 84 HARV. L. REV. 1329 (1971); Wagner, Book Review, 1979 DUKE L.J. 1071.

⁹ We are speaking of probability estimates tending to confirm paternity. In cases in which the medical evidence is inconsistent with the defendant's being the father, testimony to the effect that the probability of paternity approaches zero is not subject to the abuses we identify.

“extraordinarily flimsy evidence for which there is no quantitative measure of value.”¹⁰ A paternity suit is often a battle of conflicting stories told by persons obviously hostile to one another. Since the relevant acts have ordinarily been carried on in private, directly corroborating testimony is rare. Perhaps in desperation, judges have been known to permit exhibition of the child to the jurors, so that they may assess his resemblance to the defendant.¹¹ In this absence of more probative evidence, most jurisdictions allow a defense known as *exceptio plurium concubentium*, under which the defendant may escape liability by showing that the mother had sexual relations with some other man during the possible period of conception.¹² Of course, were he then charged, the other man could use the same defense, relying upon the testimony of the prior defendant. The temptation to perjure oneself to help out a friend may be too great to resist. In an often cited Chicago study,¹³ an attempt was made to measure the incidence of perjury in paternity cases through the use of lie detectors. When confronted with the machine, 57% of the male witnesses who had testified, for the purpose of establishing an *exceptio plurium* defense, that they had had intercourse with the complainant during the conception period, admitted to the examiner that they had lied.¹⁴ On the other hand, 48% of the mothers were shown to have lied when they denied having had intercourse with another man during the period of conception, and 88% of the defendants admitted having lied in court about the number of times they had had intercourse with the mother.¹⁵ A reliable scientific test determining paternity would provide welcome relief.

¹⁰ Beautyman, *Paternity Actions—A Matter of Opinion or a Trial of the Blood?* J. LEGAL MED., Apr. 1976, at 20, quoted in *Cramer v. Morrison*, 88 Cal. App. 3d 873, 885, 153 Cal. Rptr. 865, 872 (1979). For a general discussion of problems in proving paternity, see Holz, *The Trial of a Paternity Case*, 50 MARQ. L. REV. 450 (1967).

¹¹ See J. MAGUIRE, J. WEINSTEIN, J. CHADBOURN & J. MANSFIELD, *CASES AND MATERIALS ON EVIDENCE* 102-03 (6th ed. 1973).

¹² See, e.g., *Huntingdon v. Crowley*, 64 Cal. 2d 647, 657, 414 P.2d 382, 390, 51 Cal. Rptr. 254, 262 (1966) (dictum); *Holmes v. McLean*, 5 Conn. Cir. Ct. 476, 482, 256 A.2d 849, 853 (1969); *Yarmack v. Strickland*, 193 So. 2d 212, 214 (Fla. Dist. Ct. App. 1966); *Steed v. State*, 80 Ga. App. 360, 367, 56 S.E.2d 171, 176 (1949); *Bethel v. Todosijevic*, 141 Ind. App. 504, 506, 230 N.E.2d 107, 107-08 (1967); *Commissioner of Social Servs. ex rel. Debra M. v. James H.*, 65 A.D.2d 772, 773, 409 N.Y.S.2d 790, 790 (Sup. Ct. 1978); *Oregon ex rel. Leonard v. Hogan*, 32 Or. App. 89, 94, 573 P.2d 328, 329-30 (1978); *Jacobsen v. State*, 205 Wis. 304, 306, 237 N.W. 142, 143 (1931); see Note, *Liability of Possible Fathers: A Support Remedy for Illegitimate Children*, 18 STAN. L. REV. 859, 862-65 (1966).

¹³ Arthur & Reid, *Utilizing the Lie Detector Technique to Determine the Truth in Disputed Paternity Cases*, 45 J. CRIM. L.C. & P.S. 213 (1954).

¹⁴ *Id.* at 215.

¹⁵ *Id.* at 217.

The use of blood test evidence in paternity actions did not begin until the 1930's. Most frequently offered was a test based on the ABO blood typing system, but all such tests operate on the same basic principles. Human genes direct the expression of many easily identifiable characteristics. In particular, certain genes direct the synthesis of the chemicals, called antigens, which establish blood types.¹⁶ Since different versions, or alleles, as they are called, of these genes express distinct antigens, the presence of a specific antigen indicates a particular genetic composition, or genotype.¹⁷ Thus, the blood type antigens may be thought of as genetic markers.¹⁸

If one knows the father's genotype for a trait, such as blood type, then one also knows something about the child's. This is because humans, like many other organisms, possess genes in pairs, inherited one from each parent. If the putative father's pair of alleles for that characteristic are absent in the child—if neither of the child's pair is the same as either of the putative father's—then that man cannot be the father unless there has been a mutation. Mutations are sufficiently rare that they may be disregarded for the purpose of determining paternity.¹⁹ On the other hand, if the child and the putative father do share one allele of the gene pair in common, then it is

¹⁶ See HARRISON'S PRINCIPLES OF INTERNAL MEDICINE 1697 (8th ed. G. Thorn, E. Braunwald, K. Isselbacher & R. Petersdorf 1977).

¹⁷ A more comprehensive description of the mechanisms and terminology of inheritance can be found in any elementary text on biology or genetics. See, e.g., W. BODMER & L. CAVALLI-SFORZA, GENETICS, EVOLUTION, AND MAN 18-137 (1976).

¹⁸ More generally, antigens (also called immunogens) are large molecules (usually proteins, polysaccharides or nucleic acids) that, when introduced into an animal, are capable of eliciting the formation of antibodies. Antibodies are proteins synthesized by cells called lymphocytes and embedded in the cell membrane. An antibody coming into contact with its corresponding antigen binds to the antigen to form an antigen-antibody complex. See L. STRYER, BIOCHEMISTRY 732-52 (1975).

The antigens on the surface of red blood cells thus determine one's blood type. The introduction of red blood cells from one person into the blood of another person will stimulate the production of antibodies unless the foreign antigens are indistinguishable from the host antigens. Since the antigens are synthesized according to genetic instructions, they not only determine blood type, but also reveal something about the underlying genotype. See L. SUSSMAN, PATERNITY TESTING BY BLOOD GROUPING 3-13 (2d ed. 1976); Terasaki, *Resolution by HLA Testing of 1000 Paternity Cases Not Excluded by ABO Testing*, 16 J. FAM. L. 543 (1978). Antigens embedded in membranes of other cells can, in like fashion, be thought of as genetic markers pointing to other systems of genes, see text accompanying notes 37-44 *infra*, and any test that detects antigens by using antibodies (antisera) to form observable antigen-antibody complexes (agglutination) is called a serologic test. Even if these chemical tests are properly performed, however, confusion as to the alleles that correspond to the putative father's antigens can arise if more than one genotype could express the antigens that are detected. For simplicity of presentation, we shall assume that the types for antigenicity permit an unequivocal identification of genotypes.

¹⁹ See e.g., Neel, *The Study of Human Mutation Rates*, 86 AM. NATURALIST 129, 131 (1952); Zeisel, *The Uniqueness of Survey Evidence*, 45 CORNELL L.Q. 322, 332-33 (1960).

possible the accused is indeed the father. And if that shared allele were unique to them—if no other person had a genotype which includes it—paternity would be established. However, most alleles are hardly unique. Indeed, under the traditional ABO testing system, the failure to exclude the accused meant, on the average, that he was one of the 86.6% of the male population that might have the possible genotype.²⁰ Such evidence is obviously not very probative, and courts therefore have declined to admit it, since it is also deemed prejudicial.²¹

Even blood test evidence excluding the defendant was not admitted at first, though courts gradually became more confident of it.²² Yet once admissible, there remained the question of the weight of such evidence. For some time, courts were reluctant to make such evidence determinative. In a famous case brought against Charlie Chaplin the court sustained a jury verdict for the complainant, despite blood test evidence excluding Chaplin.²³ Even modern courts occasionally permit juries to find defendants liable despite serological evidence of nonpaternity.²⁴

The first attempt to resolve these questions comprehensively came with the Uniform Act on Blood Tests to Determine Paternity (UABT), proposed by the Commissioners on Uniform State Laws in 1952. It dealt with the *Chaplin* situation by making exculpatory blood

²⁰ *Joint AMA-ABA Guidelines: Present Status of Serologic Testing in Problems of Disputed Parentage*, 10 FAM. L.Q. 247, 257-58 (1976). Because of differing frequencies of the four blood types in the various racial groups, the probability of exclusion varies from group to group. *Id.* This percentage is lower than it might be because we do not ordinarily test directly for genotype. In the ABO system, for example, tests are made for the blood types of the parties, which yield only partial information about the genotypes. A person with Type A blood, for example, could have a genotype of either AA or AO, since "O" is a recessive trait that will manifest itself only if both alleles in the pair are Type O. See W. BODMER & L. CAVALLI-SFORZA, *supra* note 17, at 216, 247-49.

²¹ See, e.g., *Sheridan v. Curl*, 275 A.D. 966, 966, 86 N.Y.S.2d 785, 785 (1949); *State ex rel. Freeman v. Morris*, 156 Ohio St. 333, 337, 102 N.E.2d 450, 452 (1951).

²² Compare *Commonwealth v. Krutsick*, 151 Pa. Super. 164, 168-69, 30 A.2d 325, 326-27 (1943) and *State v. Damm*, 62 S.D. 123, 136-37, 252 N.W. 7, 12 (1933) with *Jordan v. Mace*, 144 Me. 351, 353-55, 69 A.2d 670, 672 (1949) and *State ex rel. Walker v. Clark*, 144 Ohio St. 305, 312-15, 58 N.E.2d 773, 776-77 (1944).

²³ *Berry v. Chaplin*, 74 Cal. App. 2d 652, 664-65, 169 P.2d 442, 450-51 (1946).

²⁴ See *State v. Camp*, 286 N.C. 148, 152-53, 209 S.E.2d 754, 756-57 (1974), in which the court sustained a conviction for failure to make child support payments of a man with Type O blood. The mother also had Type O, but the child had Type A. The jury heard expert testimony that correctly stated that it was not possible for the defendant to be the father. For a case which reviews the weight accorded exclusionary test results among the jurisdictions, see *Hanson v. Hanson*, 311 Minn. 388, 390-91, 249 N.W.2d 452, 453 (1977). See also Annot., *Admissibility and Weight of Blood Test Results in Immigration Preference or Derivative Citizenship Proceedings Under Immigration and Nationality Act*, 46 A.L.R. FED. 176, 190-93 (1980).

test evidence determinative.²⁵ In addition, it allowed the trial judge to admit evidence of nonexclusion "depending upon the infrequency of the blood type."²⁶ But while a number of states adopted the UABT, few included this provision.²⁷ This pattern continued when provisions similar to the UABT were incorporated into the Uniform Paternity Act, adopted by the Commissioners in 1960.²⁸

The more recent Uniform Parentage Act, adopted by the Commissioners in 1973, provides simply that "[e]vidence relating to paternity may include . . . blood test results, weighted in accordance with evidence, if available, of the statistical probability of the alleged father's paternity."²⁹ This entire section was omitted in California,³⁰ but was followed unchanged by the six other jurisdictions which adopted the Parentage Act.³¹ As regards confirmatory blood test results, therefore, the various Uniform Acts recognize that at some point the frequency of possible paternal blood type might be so low as to make the match between the defendant and the child so probative that evidence of the genetic similarity should not be suppressed.

II

THE NEW BIOLOGY

In the years following the discovery of the four blood types that comprise the original ABO system, more and more blood antigens have been recognized.³² With this proliferation of blood types has

²⁵ UNIFORM ACT ON BLOOD TESTS TO DETERMINE PATERNITY § 4 (1952).

²⁶ *Id.*

²⁷ A 1963 survey found only three of the seven jurisdictions that had adopted the UABT—Oregon, New Hampshire, and the Panama Canal Zone—had included this provision. Harris, *Some Observations on the Un-Uniform Act on Blood Tests to Determine Paternity*, 9 VILL. L. REV. 59, 70 (1963). By 1973, nine states had adopted the UABT. 9A UNIFORM LAWS ANN. 579 (1979).

²⁸ UNIFORM PATERNITY ACT § 10 (1960). The Act has been adopted officially by five states and substantially by one more. One state, however, did not incorporate this section. 9A UNIFORM LAWS ANN. 623, 625, 635-36 (1979).

²⁹ UNIFORM PARENTAGE ACT § 12(3) (1973).

³⁰ 9A UNIFORM LAWS ANN. 604 (1979).

³¹ *See id.* at 579, 604.

³² The definitive reference on human blood types is R. RACE & R. SANGER, *BLOOD GROUPS IN MAN* (6th ed. 1975). Useful elementary descriptions of the genetics of blood types can be found in W. BODMER & L. CAVALLI-SFORZA, *supra* note 17, at 215-17, 329-42, and in M. FARNSWORTH, *GENETICS* 50-57 (1978). The underlying biochemistry and genetics of several of the blood group systems is summarized in more detail in Watkins, *Genetics and Biochemistry of Some Human Blood Groups*, 202 PROC. ROYAL SOC'Y LONDON 31, 31-53 (series B 1978). Several "blood type" antigens occur as cell surface antigens on many cells outside the blood stream. *Id.* at 32.

come the possibility of testing for some relatively uncommon genetic markers.³³ As already observed, when the defendant is randomly selected from the white population, the chance that he will be excluded by ABO typing alone has been calculated to be only .134, or 13.4%.³⁴ Testing for the three MN types and the Rh-Hr system raises the cumulative "probability of exclusion" for all three typing systems combined to .566, or 56.6%.³⁵ With additional tests, which are not routinely done in paternity cases but are technically feasible, the cumulative probability of exclusion approaches .75, or 75%.³⁶

In addition to the numerous blood tests, the recently discovered HLA system provides a rich source of genetic information about those accused of paternity and their putative offspring.³⁷ The HLA system is the most complex genetic system known in man.³⁸ It consists of, at a minimum, hundreds of closely linked genes³⁹ that function in determining the susceptibility to certain diseases,⁴⁰ the immune re-

³³ The chemical and physical techniques used to ascertain blood types are described by A. DELATT, *PRIMER OF SEROLOGY* (1976); G. GRANT & W. BUTT, *IMMUNOCHEMICAL METHODS IN CLINICAL CHEMISTRY* 383-466 (O. Bodansky & C. Stewart eds. 1970).

³⁴ See text accompanying note 20 *supra*.

³⁵ Weiner, *Likelihood of Parentage*, in *PATERNITY TESTING BY BLOOD GROUPING* 124, 129 (2d ed. L. Sussman 1976).

³⁶ P. Terasaki, *HLA Testing, A New 95% Paternity Exclusion Test 1* (unpublished pamphlet) (n.d.).

³⁷ See A. SVEJGAARD, M. HAUGE, C. JERSILD, P. PLATZ, L. RYDER, L. STAUB NIELSEN & M. THOMSEN, *THE HLA SYSTEM: AN INTRODUCTORY SURVEY* 67 (L. Beckman & M. Hauge eds. 1975) [hereinafter A. SVEJGAARD, *THE HLA SYSTEM*]; Terasaki, *supra* note 18.

Two additional approaches that have not yet been used in paternity cases promise to supply even more information about human genotypes. One of these, chromosome banding, is already under study for use in paternity testing. This procedure involves the application of certain dyes to generate distinctive staining patterns, or bands, that can be observed when chromosomes are viewed under a microscope. The other approach is farther from implementation, but it may prove to be the most discriminating test for paternity. It would entail the application of recombinant DNA techniques to analyze the nucleotide sequence of the DNA that constitutes the genes themselves. Interview with H. Robert Horvitz, Department of Biology, Massachusetts Institute of Technology (May 25, 1980).

³⁸ Terasaki, *supra* note 18, at 8; see W. BODMER & L. CAVALLI-SFORZA, *supra* note 17, at 346; Bodmer & Bodmer, *Evolution and Function of the HLA System*, 34 *BRIT. MED. BULL.* 309, 309-16 (1978); Bodmer, Jones, Barnstable & Bodmer, *Genetics of HLA: The Major Human Histocompatibility System*, 202 *PROC. ROYAL SOC'Y LONDON* 93 (series B 1978) [hereinafter Bodmer, *Genetics of HLA*]; Boettcher, *Immunogenetics*, in *TEXTBOOK OF HUMAN GENETICS* 326, 353 (G. Fraser & O. Mayo eds. 1975).

³⁹ See A. SVEJGAARD, *THE HLA SYSTEM*, *supra* note 37, at 8. The genetic loci carrying the HLA alleles are in four regions (denoted A, B, C, and D) of chromosome six. They have been estimated to represent 1/1000th of the human genetic material. *Id.* at 9; Bodmer & Thompson, *Population Genetics and Evolution of the HLA System*, in *HLA AND DISEASE* 280 (J. Dausset & A. Svejgaard eds. 1977).

⁴⁰ See, e.g., W. BODMER & L. CAVALLI-SFORZA, *supra* note 17, at 352-53; Bodmer, *Genetics of HLA*, *supra* note 38, at 102-03; Cudworth & Festenstein, *HLA Genetic Heterogeneity in Diabetes Mellitus*, 34 *BRIT. MED. BULL.* 285 (1978); Motulsky, *The HLA Complex and Disease*,

sponse,⁴¹ and the rejection of transplanted tissue.⁴² Despite the name "leucocyte antigen," the factors expressed by the HLA genes are present in most cells,⁴³ and HLA testing can be thought of as tissue typing rather than blood group typing.⁴⁴

Since many combinations of the numerous antigens, or genetic markers, in the HLA system are observed to occur very infrequently in the population at large,⁴⁵ HLA typing excludes a high proportion of falsely accused defendants. A man is excluded if he and the mother both lack an antigen which the child has, or if the child lacks an antigen which any offspring of the defendant and the mother would necessarily possess.⁴⁶ Given the statistics on the prevalence of the various antigens, it has been said that typing for HLA alone provides about as much information as can be obtained by the investigation of all the genetic markers routinely used in blood tests for paternity.⁴⁷ Indeed, some proponents argue that HLA testing is even more valuable.⁴⁸ Used in this exclusionary fashion and employed with proper sensitivity to the risk of false test results,⁴⁹ the new blood tests and

300 NEW ENGLAND J. MED. 918, 918-19 (1979); Rosenberg & Kidd, *HLA and Disease Susceptibility: A Primer*, 297 NEW ENGLAND J. MED. 1060, 1061-62 (1977).

⁴¹ See W. BODMER & L. CAVALLI-SFORZA, *supra* note 17, at 352; A. SVEJGAARD, THE HLA SYSTEM, *supra* note 37, at 20-21; Crumpton, Snary, Walsh, Barnstable, Goodfellow, Jones & Bodmer, *Molecular Structure of the Gene Products of the Human HLA System: Isolation and Characterization of HLA-A, -B, -C and Ia Antigens*, 202 PROC. ROYAL SOC'Y LONDON 159 (series B 1978).

⁴² See W. BODMER & L. CAVALLI-SFORZA, *supra* note 17, at 343-45; F. POLACK, CORNEAL TRANSPLANTATION 75 (1977); A. SVEJGAARD, THE HLA SYSTEM, *supra* note 37, at 40-50; Bodmer, *Genetics of HLA*, *supra* note 38, at 97-98; McDevitt & Bodmer, *HLA, Immune-response Genes, and Disease*, 1 LANCET 1269 (1974); Mittal, Ruder & Green, *Matching of Histocompatibility (HLA) Antigens for Platelet Transfusion*, 47 BLOOD 31, 31-41 (1976).

⁴³ J. BARRETT, TEXTBOOK OF IMMUNOLOGY 386-87 (3d ed. 1978). Cells called lymphocytes are typically used in HLA testing. See, e.g., *id.* at 391-93; Bodmer, *Genetics of HLA*, *supra* note 38, at 96; Boettcher, *supra* note 38, at 353-54.

⁴⁴ Consequently, it can be argued that HLA typing is not covered by statutes that preclude the admission of "blood tests" into evidence for the purpose of proving paternity. See *J.B. v. A.F.*, 92 Wis. 2d 696, 698-705, 285 N.W.2d 880, 881-84 (Ct. App. 1979).

⁴⁵ See Bodmer, *Genetics of HLA*, *supra* note 38, at 97, 100.

⁴⁶ A. SVEJGAARD, THE HLA SYSTEM, *supra* note 37, at 67. The second possibility can be explained most easily with an example. Restricting our attention to antigens expressed at the A and B loci, consider a defendant whose two haplotypes are A1,B17 and A3,B14. Ordinarily, one or the other of these haplotypes must be passed on to any offspring of this defendant. If the child who is tested has the haplotypes A11, B12, and A1,B8, and thus lacks both the defendant's haplotypes, he cannot be the defendant's progeny. For a fuller description of HLA nomenclature, see *id.* at 12-16; note 52 *infra*.

⁴⁷ See A. SVEJGAARD, THE HLA SYSTEM, *supra* note 37, at 67.

⁴⁸ The chief proponent in this country of HLA testing for paternity has claimed, for that procedure alone, probabilities of exclusion exceeding 90%. P. Terasaki, *supra* note 36; *accord*, Bias, 27 AM. J. HUMAN GENETICS 243 (1975) (letter to the editor).

⁴⁹ See Weiner, *supra* note 35, at 129-31.

the HLA tests plainly have much to offer in disproving false claims of paternity.

It would be wonderfully convenient if these same techniques could be used to confirm, as well as to negate, accusations of paternity, if forensic medicine by itself could supply the judge or jury with impersonal, objective, meaningful, accurate, and comprehensible calculations of the probability that an accused is actually the father. Medical experts now claim the ability to deduce this probability of paternity,⁵⁰ and, in cases such as *Cramer*, the courts have accepted their claims.⁵¹ These experts believe that HLA testing, for example, provides positive, quantifiable evidence of paternity when the man and the child share a set of HLA alleles not found in the mother. The logic of this argument is deceptively simple. Since most of these HLA haplotypes,⁵² as they are called, are rare, the chance is small that a randomly chosen man will possess the haplotypes of the true father.⁵³ Just how rare the haplotype is determines how small the chance of a random match is. If, for instance, the haplotype shared by child and father is known to be present in only 5% of the relevant population, the probability that a randomly chosen defendant would possess it is only .05, or 5%. We may call this figure the "genetic frequency"⁵⁴ or "probability of a random match." We might then be

⁵⁰ E.g., A. SVEJGAARD, *THE HLA SYSTEM*, *supra* note 37, at 67 ("when the information obtained by all these markers and HLA is pooled, it usually becomes possible to 'prove' with a significant probability that a particular man is indeed the true father"); Chakraborty, Shaw & Schull, *Exclusion of Paternity: The Current State of the Art*, 26 AM. J. HUMAN GENETICS 477, 484-85 (1974); Lee, *Current Status of Paternity Testing*, 9 FAM. L.Q. 615, 630-33 (1975); Shaw & Kass, *Illegitimacy, Child Support, and Paternity Testing*, 13 HOUS. L. REV. 41, 59-60 (1975); Terasaki, *supra* note 18, at 543-44.

⁵¹ See *Goodrich v. Norman*, 100 Misc. 2d 33, 36-39, 421 N.Y.S.2d 285, 287-89 (Family Ct. 1979); cases cited in note 7 *supra*. Many legally trained commentators have been effusive in their praise of the new technology. See, e.g., 1 S. SCHATKIN, *DISPUTED PATERNITY PROCEEDINGS* §§ 8.01-.04 (rev. ed. 1977); Beautyman, *supra* note 10, at 19-25. The exception is Jaffe, *Comment on the Judicial Use of HLA Paternity Test Results and Other Statistical Evidence: A Response to Terasaki*, 17 J. FAM. L. 457 (1979), who has the surprising belief that reliance on any statistical evidence to prove an "ultimate fact" is "illogical" and "procedurally irrational." *Id.* at 458.

⁵² Haplotype refers to the set of genes found on one and the same of the two homologous chromosomes of a diploid cell. In the absence of genetic aberrations, such as recombination, one of these chromosomes is inherited from one parental sex cell, and another chromosome comes from the other parent. Recombination (the breakage and crossing over of chromosome segments) interfering with the pairwise transmission of the HLA alleles that constitute a haplotype is fairly rare. See W. BODMER & L. CAVALLI-SFORZA, *supra* note 17, at 347-50. Thus, an individual's genotype is almost always the combination of two haplotypes, one from each parent, see J. BARRETT, *supra* note 43, at 387; Terasaki, *supra* note 18, at 545, and the term haplotype serves as a shorthand for "haploid genotype." See W. BODMER & L. CAVALLI-SFORZA, *supra* note 17, at 343.

⁵³ A. SVEJGAARD, *THE HLA SYSTEM*, *supra* note 37, at 67.

⁵⁴ By "genetic frequency," we mean the total frequency within the relevant male population of all those genotypes that the father could have had, given the antigens detected in the child

tempted to regard the probability of paternity as being the probability that the match is not mere coincidence, or one minus the probability of a random match. For the genetic frequency of 5% the corresponding probability of paternity calculated in this way is $1 - .05 = .95$, or 95%.

This is the technique which the court of appeals in *Cramer* erroneously believed had been used to arrive at the probability of paternity in that case.⁵⁵ Such a technique, however, is not typically employed in forensic medicine, and its use in *Cramer* would have been quite incorrect.⁵⁶ The 95% figure just calculated is merely the probability that a man selected at random from the relevant population would be excluded by the test. This probability is more appropriately called the "probability of exclusion." It is *not* the probability of paternity—the probability that an individual whom the test does not exclude is the father.

An example helps to illustrate the difference between the probability of exclusion and the probability of paternity. Suppose it is known only that the mother lived in Los Angeles at the time of the child's conception, and that mother and child are Caucasian. One might assume that the actual father must also have lived in Los Angeles, but of course that is far from certain. He might have been visiting from elsewhere, or the mother might have become impregnated on a weekend trip to San Diego. But if we ignore those possibilities and limit our universe of possible fathers to Caucasian males past the age of puberty who resided in the Los Angeles area at the time of conception, we have a suspect list of about two million. A test which eliminates even 95% of the suspects would still leave 100,000 possible fathers. The fact that the defendant was one of the remaining 100,000 is hardly overwhelming evidence. Although the test has a probability of exclusion of 95%, the probability of paternity in this example is only one in 100,000.⁵⁷

and the mother. This genetic frequency thus specifies how rare the genotypes not excluded by the serologic examination are. It should not be confused with the "gene frequency." The latter phrase is used in population genetics to denote the frequency with which a particular allele occurs out of all the alleles for the gene in question. See M. FARNSWORTH, *supra* note 32, at 511. When the rates of mutation and recombination are negligible, however, the "genetic frequency" that is crucial in confirmatory use of blood or HLA test results can be derived readily from the pertinent gene or haplotype frequencies.

⁵⁵ 88 Cal. App. 3d at 867, 153 Cal. Rptr. at 877-78.

⁵⁶ See, e.g., Weiner & Socha, *Methods Available for Solving Medicolegal Problems of Disputed Parentage*, 21 J. FOR. SCI. 42, 61-62 (1976). A more refined but ultimately no more satisfactory method was actually used by the expert in *Cramer*. See text accompanying notes 90-92 *infra*.

⁵⁷ The point made by this example is effectively made in another context by Tribe, *supra* note 8, at 1355.

Of course this example has some unlikely features. Perhaps the most questionable aspect of our hypothetical is the assumption that our knowledge is strictly limited to the test results. Few defendants are chosen randomly from the population. We ordinarily know more, sometimes much more. In a typical case, the mother may testify that she had intercourse with the defendant, and only the defendant, during the period of conception, while the defendant might produce evidence that she had other lovers, and that he was out of town in the critical period. The problem is to determine how to combine our statistical information based on genetic frequency with the other evidence available. Only then can a number be produced which can sensibly be called the probability of paternity in that particular case. Mathematically, the problem is solved with probability calculations explained more fully in the next section. That discussion will reveal two points: first, that the approach actually used in *Cramer* is erroneous,⁵⁸ and second, that a mathematically correct approach raises important policy questions regarding the kind of presentation which should be made to a jury.⁵⁹

What should now be apparent, however, is that the use of sophisticated medical tests to prove paternity is simply an instance of the more general problem of presenting quantified identification evidence to a judge or jury. In this respect, it is no different in principle from proof of identity by coincidences in fibers from clothing,⁶⁰ hair samples,⁶¹ dental characteristics,⁶² fingerprints,⁶³ traces of paint,⁶⁴ handwriting or typewriter peculiarities,⁶⁵ and so on.⁶⁶ Although not

⁵⁸ See text accompanying notes 90-98 *infra*.

⁵⁹ See text accompanying notes 99-131 *infra*.

⁶⁰ See *People v. Trujillo*, 32 Cal. 2d 105, 112-13, 194 P.2d 681, 685-86, *cert. denied*, 335 U.S. 887 (1948).

⁶¹ See *United States v. Massey*, 594 F.2d 676, 679-81 (8th Cir. 1979); *State v. Smiley*, 27 Ariz. App. 314, 317, 554 P.2d 910, 913 (1976).

⁶² See *State v. Garrison*, 120 Ariz. 255, 258-59, 585 P.2d 563, 566-67 (1978), I. GLADFELTER, *DENTAL EVIDENCE: A HANDBOOK FOR POLICE* (1975).

⁶³ See Osterburg, Parthasarathy, Raghavan & Sclove, *Development of a Mathematical Formula for the Calculation of Fingerprint Probabilities Based on Individual Characteristics*, 72 J. AM. STATISTICAL A. 772 (1977).

⁶⁴ See *People v. Woodward*, No. 108551 (Cal. Super. Ct., San Mateo County, July 7, 1964), *criticized in Comment, The Evidentiary Uses of Neutron Activation Analysis*, 59 CALIF. L. REV. 997, 1014-20 (1971); D. CROWN, *THE FORENSIC EXAMINATION OF PAINTS AND PIGMENTS* (1968).

⁶⁵ See *People v. Risley*, 214 N.Y. 75, 86-87, 108 N.E. 200, 203 (1915).

⁶⁶ See *State v. Coolidge*, 109 N.H. 403, 417-23, 260 A.2d 547, 558-61 (1969) (matching of particles of clothing), *rev'd on other grounds*, 403 U.S. 443 (1971).

fully appreciated by the courts,⁶⁷ the dangers associated with the introduction of such statistical identification evidence have been amply discussed in the literature,⁶⁸ and familiarity with the more general problem is necessary to deal adequately with paternity cases. In the next section, we discuss some of the concerns that have been voiced and canvass some of the methods that have been proposed to deal with them. We conclude that the method by which HLA and blood test evidence has been presented in recent paternity cases is one of the more unsatisfactory approaches for using quantified probability estimates in litigation, and we identify two more suitable alternatives.

III

THE NEW MATH

The issues posed in paternity litigation by the HLA system and the extension of blood typing are easily stated: first, should serologic evidence tending to confirm paternity be admissible?, and second, if so, how should it be presented? The first question is relatively easy to answer. Given the low genetic frequencies and correspondingly high probabilities of exclusion characteristic of HLA and blood typing, the failure of these tests to exclude a defendant is usually important in evaluating the allegation of paternity. Unless the test results are remarkably prejudicial, they are, as both the *Cramer* court and the drafters of the Uniform Acts have recognized, simply too probative to withhold from the jury.⁶⁹

We turn, therefore, to the second question: how can the medical evidence be presented so as to minimize prejudicial impact and enhance the accuracy of the factfinding process?⁷⁰ By "prejudice," we

⁶⁷ See, e.g., *State v. Garrison*, 120 Ariz. 255, 585 P.2d 563 (1978); *People v. Trujillo*, 32 Cal. 2d 105, 194 P.2d 681, cert. denied, 335 U.S. 887 (1948).

⁶⁸ See, e.g., Finkelstein & Fairley, *A Comment on "Trial by Mathematics,"* 84 HARV. L. REV. 1801 (1971); Tribe, *A Further Critique of Mathematical Proof,* 84 HARV. L. REV. 1810 (1971); Tribe, *supra* note 8.

⁶⁹ See text accompanying notes 5-6 & 25-31 *supra*.

⁷⁰ By "accurate factfinding" we mean that resolution of the facts which is most likely to correspond to the true state of affairs. Erroneous findings are those that are contrary to the true state of affairs. We realize, of course, that the "true state of affairs" is rarely known in litigation, but we believe that by and large juries do their best with the limited resources society allocates to trials to ascertain what "really" happened in a given case. Strict pursuit of the goal of minimizing total errors implies that civil cases should be decided for plaintiffs whenever the relevant probability exceeds one-half. M. FINKELSTEIN, *supra* note 8, at 66-67; Kaye, *supra* note 3, at 604-05.

mean the danger that the jury will be so awed by the evidence that it will give it more weight than it logically deserves. This is surely the fear which prompted the traditional rule excluding any presentation of blood tests tending to confirm paternity.⁷¹ The task, then, is to develop a method of presentation which accurately communicates the meaning of the test evidence so that the jury can give it proper weight. The ease with which the probability of exclusion and the probability of paternity can be confused suggests that this may not be a simple task.

In this section, we consider a variety of approaches, differing in the reliance they place upon numerical evidence. In assessing their relative merits, we must give due weight to psychological as well as strictly logical or mathematical considerations. The most mathematically precise and sophisticated statement of the test's meaning might be entirely incomprehensible to a judge or jury. Alternatively, the most accessible statement of the evidence may be too inaccurate or misleading to allow. What is required is a method of presentation which is at once accurate and intelligible.

A. *The Data Approaches*

One of the methods placing only minimal reliance on statistical calculations can be called the data approach. Strictly speaking, the only medical evidence useful in confirming paternity consists of testimony as to the alleles shared by the child and the defendant and the frequency with which corresponding possible paternal genotypes are found in the pertinent racial and geographic population. Any further statements, such as calculations of the probability of paternity, are necessarily derived from these facts and are, in effect, attempts to tell the judge or jury what conclusions to draw from this data. Therefore, to prevent the expert testimony from invading the province of the finder of fact, the data approach would eschew calculations of the probability of paternity and would confine the expert to presenting

In criminal nonsupport actions, on the other hand, simple minimization of total errors is inappropriate, since a mistaken verdict for the state may be more objectionable than an erroneous acquittal of the defendant. See, e.g., Friedman, *Trial by Jury: Criteria for Convictions, Jury Size and Type I and Type II Errors*, AM. STATISTICIAN, Apr. 1972, at 21; Kaplan, *Decision Theory and the Factfinding Process*, 20 STAN. L. REV. 1065, 1073-82 (1968). Whatever the optimal burden of proof, however, the problem with which we are concerned is essentially unchanged. The statistical evidence should be introduced in a fashion which enables it to make its maximum contribution to the accurate resolution of controverted facts.

⁷¹ See, e.g., *People v. Nichols*, 341 Mich. 311, 329-31, 67 N.W.2d 230, 231-32 (1954); *State ex rel. Freeman v. Morris*, 156 Ohio St. 333, 337, 102 N.E.2d 450, 452 (1951).

the underlying data itself. Two such data approaches can be specified. Under a strictly qualitative presentation of the data, the expert would simply tell the jury that the test evidence reveals that the defendant could have been the father as alleged, and that the alleles or haplotype the child and the father have in common are rarely found in the population at large. In contrast, under a quantitative presentation, a statistical statement of precisely how rare the genetic characteristics in question are would be included—one out of twenty, one out of a hundred, one out of a hundred thousand, or whatever figure is appropriate. That figure, the genetic frequency, is, as already remarked, the probability of a random match.⁷²

The difficulty with the purely qualitative presentation is that it fails to give the jury a clear indication of the probative force of the test data. Any verbal description of the genetic frequency is necessarily a translation from the numerical, and precision is inevitably lost in that translation. One expert, for instance, might regard a haplotype frequency as "rare," while another may call it "uncommon." If quantification is precluded, the jury has no way of knowing whether their disagreement is over the distribution of genes, the use of words, or some combination of the two. Clarity requires that the expert quantify his estimate.

Nevertheless, in other areas of litigation involving identification evidence, a quantitative presentation has been criticized as tending to misdirect the jury's attention from important, nonquantifiable matters and as conveying a false sense of certainty.⁷³ In *People v. Collins*,⁷⁴ the leading case concerning quantified probability estimates, the Supreme Court of California held that the trial court erred by admitting testimony that only one out of twelve million randomly selected couples would be expected to fit the witnesses' description of the couple that robbed a woman in Los Angeles.⁷⁵ The state supreme court warned that "[m]athematics, 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."⁷⁶ Presumably, this generalized concern for the undue impact of statistical evidence lay behind the rejection by the trial court in *Cramer v. Morrison* of the 98.3% figure as "prejudicial."⁷⁷

⁷² See text accompanying notes 52-54 *supra*.

⁷³ The most penetrating critique is Tribe, *supra* note 8.

⁷⁴ 68 Cal. 2d 319, 438 P.2d 33, 66 Cal. Rptr. 497 (1968).

⁷⁵ *Id.* at 332-33, 438 P.2d at 41-42, 66 Cal. Rptr. at 500-02.

⁷⁶ *Id.* at 320, 438 P.2d at 33, 66 Cal. Rptr. at 497.

⁷⁷ 88 Cal. App. 3d 873, 877, 153 Cal. Rptr. 865, 867 (1979).

Although this problem is also present in paternity litigation, it should be possible to overcome it so that the statistical information, clearly of probative value, can be admitted. The conventional approach would be to rely on counsel⁷⁸ to place the test evidence in its proper context along with direct testimony as to the sexual relationships of the mother. The success of this approach requires avoiding the error made in *Cramer*, namely, confusing the probability of exclusion with the probability of paternity. An example such as the one in section II concerning our hypothetical Los Angeles mother,⁷⁹ might suffice in clarifying the meaning of the probability of exclusion for the jury. Similarly, counsel could explain that a genetic frequency of, say, .05, or 5%, implies that, on the average, every twentieth person tested at random would be identified as the father.⁸⁰

B. The Probability of Paternity Approaches

A more mathematically advanced way to utilize statistical evidence is to go beyond a quantified and suitably explained statement of the probability of exclusion, and to calculate the probability of paternity itself. The argument for proceeding with the probability presentation is clear: if done properly, it is the most accurate way of conveying the significance of the test data. The data is itself statistical in nature—the defendant is one of a measured percentage of the population which possess a trait that the true father necessarily has—and its meaning is most precisely expressed in probabilistic terms. Moreover, once it has been explained to the jury that the probability of exclusion is not the probability of paternity, the question arises of what the probability of paternity is. In this section, therefore, we discuss various methods (including the one currently accepted and utilized in forensic medicine) for calculating and presenting to the jury the probability of paternity.

⁷⁸ See Finkelstein & Fairley, *supra* note 68, at 1806-07. In *People v. Collins*, however, the court noted that "few defense attorneys . . . could be expected to comprehend th[e] basic flaw" in the prosecution's use of probabilistic evidence. 68 Cal. 2d at 331, 438 P.2d at 41, 66 Cal. Rptr. at 505. Nevertheless, it is hard to see why the rudiments of statistical reasoning should remain so intimidating and inaccessible to practicing lawyers, and there are signs that legal education can adapt to advances in other disciplines. See, e.g., D. BALDUS & J. COLE, STATISTICAL PROOF OF DISCRIMINATION (1980); M. FINKELSTEIN, *supra* note 8; R. LEMPERT & SALTZBURG, A MODERN APPROACH TO EVIDENCE 998-1034 (1977).

⁷⁹ See text accompanying note 57 *supra*.

⁸⁰ If p is the probability of a random match, then it can be shown from sampling theory that one would expect, on the average, every $1/p$ th person in the relevant population tested at random to show a match. In *Cramer v. Morrison*, for example, it appears that the paternal haplotype found in the child had been observed in only 1.73% of the white male population. Hence, one would expect, on the average, every $1/0.0173$ or every 58th, Caucasian male tested to be identified by his HLA type as a possible father.

1. The Binomial Calculation

In our Los Angeles hypothetical, we calculated a probability of paternity of one in 100,000 by simply applying the probability of a random match—.05—to the local white adult male population.⁸¹ This calculation rests on what is technically called a binomial probability distribution model.⁸² This model was employed by the court in *People v. Collins*⁸³ to conclude that even with the 1 in 12,000,000 figure—analogue to a probability of exclusion of practically one—the conditional probability that there existed in the Los Angeles area at least one couple in addition to the one apprehended fitting the robbers' description was about .41, or 41%.⁸⁴

As mentioned earlier, this method of transforming the genetic frequency statistic into a probability of paternity is not at all suitable.⁸⁵ It requires an accurate specification of the relevant population size—a figure which ordinarily is not available.⁸⁶ Moreover, it presupposes that every man of the right race, location, and genotype is equally likely to be the true father. Hence, the very phrase probability of paternity as applied to the product of such calculations is misleading, since the number arrived at ignores all the nonquantitative evidence in the case. For these reasons, no probability of paternity derived using the binomial model should be put before the jury.

2. Bayesian Calculations

To overcome the defects in the binomial model, so-called Bayesian techniques could be used to combine the quantitative medical evidence with all the other evidence in the case to deduce one overall probability of paternity. Bayes' Theorem, a basic formula of

⁸¹ See text accompanying note 57 *supra*.

⁸² See Fairley & Mosteller, *A Conversation About Collins*, 41 U. CHI. L. REV. 242, 250 n.13 (1974).

⁸³ 68 Cal. 2d 319, 438 P.2d 33, 66 Cal. Rptr. 497 (1968).

⁸⁴ 68 Cal. 2d at 333-35, 438 P.2d at 42-43, 66 Cal. Rptr. at 506-07 (appendix). The *Collins* court's mathematical demonstration is based on an approximation of the binomial distribution with the population size taken to be the reciprocal of the frequency of the identifying characteristics. This assumption about the population size is artificial, and a number of refinements and improvements of the court's mathematical model have been proposed. See, e.g., Charrow & Smith, *A Conversation About "A Conversation About Collins,"* 64 GEO. L.J. 669 (1976); Smith & Charrow, *Upper and Lower Bounds for Probability of Guilt Based on Circumstantial Evidence*, 70 J. AM. STATISTICAL A. 555 (1975).

⁸⁵ See text accompanying notes 55-57 *supra*.

⁸⁶ See, e.g., M. FINKELSTEIN, *supra* note 8, at 83; Fairley & Mosteller, *supra* note 82, at 250. But see text accompanying note 123 *infra*. In our example, we somewhat arbitrarily excluded males living outside Los Angeles and included all those inside the region.

probability theory,⁸⁷ can be used to describe the way new statistical information alters a previously established probability.⁸⁸ Suppose the probability that a defendant is the father somehow has been established without regard to any serologic testing, and let us denote this prior probability by $P(F)$. Bayes' formula can then be used to state how the statistical evidence alters this prior probability. If we designate the probability as revised by the HLA or blood test statistics as $P(F|M)$ (denoting the probability of fatherhood *given* the genetic match between the defendant and the child), then Bayes' formula connects the posterior or conditional probability $P(F|M)$ with the prior probability $P(F)$ as follows:⁸⁹

$$P(F|M) = \frac{1}{(1-f) + fP(F)} \quad (1)$$

where

$$f = \frac{P(M|\text{not-F})}{P(M|F)} \quad (2)$$

These equations, in other words, say that the prior probability of paternity should be revised according to a fraction—given in equation (2)—whose denominator is the likelihood of positive test results given that the defendant is the father, and whose numerator is the probability the tests would show a match between the defendant and the child given that the defendant is not actually the father. If the tests have no false positives, that is, if they never show a genetic match when none is present, and if defendants are not preselected according to blood or HLA type, then $P(M|\text{not-F})$ is our probability

⁸⁷ For elementary derivations of Bayes' Theorem, see H. BRUNK, AN INTRODUCTION TO MATHEMATICAL STATISTICS 35-37 (3d ed. 1975); M. DEGROOT, PROBABILITY AND STATISTICS 55-60 (1975). For more extended treatments of Bayesian methods, see G. BOX & G. TIAO, BAYESIAN INFERENCE IN STATISTICAL ANALYSIS (1973); R. WINKLER, INTRODUCTION TO BAYESIAN INFERENCE AND DECISION (1972). Bayes' original paper, "An Essay Towards Solving a Problem in the Doctrine of Chances," dated 1763, is reprinted in STUDIES IN THE HISTORY OF STATISTICS AND PROBABILITY 134-53 (E. Pearson & M. Kendall eds. 1970).

⁸⁸ To avoid any possible confusion over the point, see Brilmayer & Kornhauser, *supra* note 8, at 135 n.68, it may be advisable to state the obvious: no knowledgeable student of probability theory denies that Bayes' formula is mathematically correct. It is part and parcel of the theory of probability presented in every elementary text on the subject.

⁸⁹ It is more common to write Bayes' formula in a slightly different form:

$$P(F|M) = \frac{P(F)P(M|F)}{P(F)P(M|F) + [1-P(F)] P(M|\text{not-F})}$$

Dividing numerator and denominator of the right side by $P(F)P(M|F)$ gives the version presented here.

of a random match—the probability that a male selected at random from the relevant population would have a genotype consistent with the child's.

Thus, if these assumptions hold, $P(M|\text{not-F})$ —the probability of a match, given that the male is not the father—is simply the genetic frequency statistic. If mutation rates are negligible and the test shows no false negatives, then $P(M|F)$ —the probability of a match (M) given that the defendant is the father—is one. The ratio f thus reduces to the genetic frequency statistic alone—it is the proportion of men in the relevant population whose genotypes are consistent with those found in the child.

An example may help to clarify all this terminology. Suppose it is agreed that the non-medical evidence establishes a .50 probability that the defendant is the father. The medical evidence proves the following: that the child's blood is type A_1 ; that the mother's blood is type O, that the defendant's blood is type A_1 ; and that the frequency of type A_1 blood in the relevant population is .20. With the previously stated assumptions, if the defendant were the father, the probability of a match between defendant and child is one. The probability that the blood would be type A_1 if someone else selected at random from the relevant population were the father is one-fifth, since one-fifth of these men have type A_1 blood. The fraction f is therefore $1/5 \div 1 = 1/5$, and formula (1) indicates that after the evidence on the blood is received the paternity probability should be evaluated as:

$$P(F|M) = \frac{1}{(1 - 1/5) + (1/5)/(1/2)} = 5/6$$

The blood type evidence has raised the probability in favor of paternity from .50 to .83.

a. Present Practice—Since Bayes' Theorem is the accepted mathematical technique for calculating conditional probabilities, it is not surprising that it has been employed by experts testifying in recent paternity disputes. It is surprising, however, that the currently accepted technique allows the expert to make his own undisclosed estimate of the prior probability in order to arrive at the probability of paternity he presents to the jury. For instance, the expert who testified for the prosecution in *Cramer v. Morrison* routinely calculates his "probability of paternity" by assuming that the non-test evidence establishes a 50% chance that the defendant is the father.⁹⁰

⁹⁰ Letter from Ray Mickey to David Kaye (Mar. 19, 1979); see Terasaki, *supra* note 18.

This is equivalent to supposing that the universe of possible fathers is already reduced to two equally likely suspects before considering the HLA test results. As the application of Bayes' Theorem shows, making such an assumption ensures that in every case in which any recognized blood test does not exclude the defendant, one will find that he is probably the father, thus satisfying the burden of proof in civil cases.⁹¹ It is apparent from the court's opinion in *Cramer* that it did not understand that such an assumption had been made.⁹² Nor have other courts displayed awareness of this point.⁹³

There seems to be no basis for the blanket assumption that the prior probability is one-half. One might try to justify this assumption by pointing to objective statistics about the probable accuracy of plaintiffs' accusations of paternity. For instance, if 50% of paternity cases are decided for defendants, one might think that the prior probability should be taken to be .50.⁹⁴ A more refined and somewhat less objectionable method of calculating a prior probability is based upon 1,515 Polish paternity cases from the early 1950's, in which serologic tests revealed that, overall, the frequency of a "true" accusation (one consistent with the blood tests) was about 70%.⁹⁵

⁹¹ See M. FINKELSTEIN, *supra* note 8, at 93 n.58. Under the preponderance of the evidence standard, a probability greater than one-half in favor of a disputed fact ordinarily justifies a finding that the fact exists. See note 70 *supra*. If one starts with $P(F) = \frac{1}{2}$, one will arrive at a $P(F|M)$ in excess of $\frac{1}{2}$ whenever the probability of exclusion is not one and the prior probability $P(F)$ is not zero.

⁹² See 88 Cal. App. 3d at 884, 153 Cal. Rptr. at 871-72.

⁹³ Opinions concerning the admissibility of HLA tests typically rely on statements or publications of experts who claim to be able to derive high probabilities of paternity through the use of HLA tests. Such opinions evidence little understanding of the method by which the experts calculate the probabilities. See *County of Fresno v. Superior Court*, 92 Cal. App. 3d 133, 137, 154 Cal. Rptr. 660, 662-63 (1979); *Malvasi v. Malvasi*, 167 N.J. Super. 513, 515, 401 A.2d 279, 279-80 (1979); *Lascaris v. Lardeo*, 100 Misc. 2d 220, 222-27, 417 N.Y.S.2d 665, 666-69 (Fam. Ct. 1979); *Goodrich v. Norman*, 100 Misc. 2d 33, 38-39, 421 N.Y.S.2d 285, 288 (Fam. Ct. 1979) (reluctantly concluding that admission of the test results is barred by statute). Since few judges would even know what a Bayesian calculation is, they can hardly be expected to see that the expert's proposed use of this method involves legally improper assumptions.

⁹⁴ See Weiner, *supra* note 35, at 125.

⁹⁵ Steinhaus, *The Establishment of Paternity*, PRACE WROCLAWSKIEGO TOWARZYSTWA NAUKOWEGO 5 (series A, no. 32 1954). Steinhaus' method is described in "slightly simplified" terms in M. FINKELSTEIN, *supra* note 8, at 74-75 & n.25, as follows:

The background or prior probability computed by Steinhaus was the probability that the accused was the father after intercourse had been established but before the serological test. The posterior probability was the probability of paternity after the test

Different blood types occur with different frequency in the population. Let the type in question be called "A" and have the frequency f ; the frequency of those who do not have this type is $1-f$. Consider the group of accused fathers who take a serological test because the child has the blood type "A," one not shared by the mother. If the mothers'

Similarly, a 1963 study of 1,000 paternity cases in New York City found a figure of about 60%.⁹⁶ But even assuming perfect accord among studies using the more discerning serologic techniques now available, the prior probability these tests would yield would necessarily be an average figure for paternity cases generally. Hence, the propriety of its application to individual cases with varying degrees of probative, non-test evidence is surely debatable.

To see why this is so, consider a case in which the mother testifies to having had intercourse with two men, and admits that the intercourse had been more frequent with the one who is now outside the jurisdiction and unavailable for testing. A prior probability of less than .50 would seem appropriate here, the average statistic from all paternity cases notwithstanding. The credibility of the mother's testimony and of the defendant's denials, as well as other particularized considerations, may suggest still other departures from the .50 figure.⁹⁷ In short, even the use of a well-founded prior probability derived from general experience in other paternity litigation yields a "probability of paternity" figure that excludes consideration of all the non-statistical evidence in that particular case. To label such a figure the "probability of paternity" is surely misleading, especially when the jury is not informed that the expert's calculation is based on such background statistics. One can imagine a case in which the defendant has produced credible evidence that the mother had

accusations were always right, the serological test would show every member of this group to have type "A" blood (although the converse of course is not true). If the mothers' accusations were always wrong, the members of this group would be a random sample from the population, and the expected frequency of those with other than type "A" blood would be $1-f$. The difference between the actual rate of "A" blood in this accused group and the population rate can be used to measure the accuracy of the accusations as a group. The more "A" blood, the more correct the accusations. [In particular,] [l]et p be the proportion of the accused group who are the fathers. Then $1-p$ is the proportion of innocents and $(1-p)(1-f)$ is the expected proportion of those accused who will be exonerated by the test. The ratio of the expected proportion of the accused group who will be exonerated to the proportion of those in the general population who do not have the blood type in question is $(1-p)(1-f)/(1-f)$. This ratio, however, is simply $1-p$, the prior probability of a false accusation. The key fact is that both numerator and denominator of the foregoing ratio can be estimated from objective sample and population statistics.

For an elaboration of the technique and its application to calculating the probability of paternity, see Fairley, *Probabilistic Analysis of Identification Evidence*, 2 J. LEGAL STUD. 493, 493 (1973).

⁹⁶ See Sussman, *Blood Grouping Tests: A Review of 1000 Cases of Disputed Paternity*, 40 AM. J. CLIN. PATH. 38 (1963).

⁹⁷ The mean figure derived from the type of analysis used by Steinhaus, *supra* note 95, is optimal only in the sense that it can be expected to produce fewer errors than any other single prior probability used in every paternity case.

had intercourse with other men, but not with him, during the conception period. Indeed, even had the defendant in *Cramer* shown that he was imprisoned in another state during the critical period, the expert's calculation of a 98.3% chance of paternity would not have been affected.

Furthermore, even if it were possible to convey the limited character of this "probability of paternity" to the jury, use of this figure would still be problematical for the very reason that its calculation relies upon such general information from other cases. We surely would not allow the plaintiff in a civil case to present evidence that, for example, most people sued for breach of contract are found liable. Similarly, it seems doubtful at best that in a paternity case we should or would admit evidence of the frequency with which accusations of paternity were ultimately sustained in court. Such an offer of proof would undoubtedly be rejected as both irrelevant and prejudicial, since it is not based on facts sufficiently connected with the case at bar.⁹⁸ It is thus hard to see how these same statistics can be introduced by way of calculating a probability, whether done explicitly or *sub rosa*.

b. The Chart Approaches—To avoid the presentation of a probability of paternity arrived at via undisclosed or arbitrary estimates of the prior probability, each juror could be asked to consider all the nonquantitative evidence in the case—to evaluate all the non-expert testimony, making appropriate adjustments for the witnesses' apparent credibility, *et cetera*—and to summarize his view of the case in the form of an estimate of the probability that the defendant is the father. Bayes' formula could then be used to show how the quantified medical evidence should alter the estimates of the prior probability applicable to the case at bar. To implement such a scheme, it has been proposed that experts testifying about rare, identifying traits should present a chart showing a range of hypothetical prior probabilities and specifying the posterior probability associated with each one.⁹⁹ In the hypothetical involving the subgroup A₁ agglutino-gen,¹⁰⁰ for instance, the expert might testify that if the jurors believe, apart from the statistical evidence, that there is a 10% chance

⁹⁸ The use of a single number for P(F) also could lead to possible feedback effects, distorting the accuracy of verdicts. If P(F) is taken to be large, say .70, based on past experience, then potential plaintiffs may come to realize that any evidence of nonexclusion, no matter how weak, will produce expert testimony that the probability of paternity P(F|M) exceeds .70. See note 91 *supra*. This might encourage less meritorious suits, thereby lowering P(F).

⁹⁹ This proposal is most fully developed in M. FINKELSTEIN, *supra* note 8, at 85-104, and Finkelstein & Fairley, *supra* note 8. See also I. GOOD, *PROBABILITY AND THE WEIGHING OF EVIDENCE* 66-67 (1950); Cullison, *Identification by Probabilities and Trial by Arithmetic*, 6 HOUS. L. REV. 471, 484-502 (1969).

¹⁰⁰ See section IIIB2 *supra*.

that the defendant fathered the child, they should believe that the probability increases to 36% if they accept the statistical evidence; that if they believe the non-test evidence shows a 25% chance, they should conclude there is a 63% chance if they believe the statistical evidence, and so on. This method of presentation will be called the chart approach.

At this point, however, two versions of this chart approach can be distinguished: one which places great emphasis on quantifying the force of the evidence and one which allows more leeway for qualitative evaluations. Under the former, each juror might be instructed to choose the prior estimate that most closely matches his own view of the strength of the non-test evidence and to gauge the impact of the statistical evidence according to the chart. Further, the juror might also be instructed to find that the defendant is the father whenever Bayes' Theorem prescribes a probability of paternity in excess of .50, or 50%.¹⁰¹

Such reliance on statistical reasoning has been severely criticized on both practical and theoretical grounds.¹⁰² We believe the practical objections are well founded. First, instructing the jury to follow the chart may be asking it to do something it cannot: to translate a subjective opinion about the non-test evidence into a single probability figure. Few people are accustomed to thinking in this numerical manner; many jurors may be uncomfortable with it and unsure of how to begin.¹⁰³ Second, in many instances, the instruction is unlikely to be followed. Consider a juror who has no difficulty estimating the prior probability but finds that his initial assessment yields a posterior probability of paternity that departs from his intuitive judgment of the entire package of evidence. For example, Bayes' Theorem tells him that the probability of paternity is 65%, but he does not really believe that the defendant is the father. This juror might lower his estimate of the prior probability to reach an intuitively attractive final result. Since experimental studies suggest that

¹⁰¹ But see text accompanying notes 122-31 *infra*.

¹⁰² See L. COHEN, *THE PROBABLE AND THE PROVABLE* (1977); R. EGGLESTON, *supra* note 1, at 146-47; Brilmayer & Kornhauser, *supra* note 8, at 135-52; Tribe, *supra* note 8, at 1354-68; Tribe, *supra* note 68.

¹⁰³ A juror's estimate of the prior probability might therefore be unreliable. See Tribe, *supra* note 8, at 1348-49. To accommodate this uncertainty in the estimation of P(F), one could use Bayes' formula to calculate the effect of the medical evidence on a distribution of prior probabilities rather than a point estimate of P(F). See, e.g., H. BRUNK, *supra* note 87, at 175-76. Asking jurors to specify a probability density function (or merely a range of values for P(F)), however, would only magnify the difficulty many jurors might experience in stating a single estimate of P(F).

people intuitively process information differently than Bayes' formula states they should,¹⁰⁴ this prospect is not unlikely. Nor is there any practical way to preclude jurors from adjusting their prior probabilities in this circular fashion.¹⁰⁵

Rejecting the chart as a device for instructing jurors as to what verdict to reach, however, does not preclude introducing the chart into evidence for the purpose of educating or informing the jury.¹⁰⁶ We are still left with the problem of helping the jurors to appreciate the meaning of the statement that the defendant possesses alleles which the father must have and which only some specified percent of the population share. The most accurate way of displaying the significance of this number is through a probability calculation. We might, therefore, allow an expert to employ a chart solely as a pedagogical technique. Under this modified chart approach, the jurors would be cautioned that the chart is intended merely to aid them in understanding the significance of the medical evidence and that they are in no sense bound to follow it.

This version of the chart approach has a number of advantages over the binding use of Bayes' formula as well as over the alternative methods of presenting the statistical evidence. Use of the chart as a heuristic device does not purport to require the jurors to employ formal statistical methodology.¹⁰⁷ Neither would it compel resisting jurors to commit themselves to any prior probability. Since the jurors

¹⁰⁴ See, e.g., C. COOMBS, R. DAWES, & A. TVERSKY, *MATHEMATICAL PSYCHOLOGY: AN ELEMENTARY INTRODUCTION* 145-47 (1975); M. FINKELSTEIN, *supra* note 8, at 92 n.57; Slovic, Fischhoff & Lichtenstein, *Behavioral Decision Theory*, 28 ANN. REV. PSYCH. 1 (1977); Underwood, *Law and the Crystal Ball: Predicting Behavior with Statistical Inference and Individualized Judgment*, 88 YALE L.J. 1408, 1428 & n.54 (1979) (citing authorities).

¹⁰⁵ In theory, one could force compliance with Bayes' formula by not revealing the chart to the jury and asking the jurors to deliberate until they agree upon an estimate of the prior probability. The court could then consult the chart and return the indicated verdict. So radical a restructuring of the trial process is most unlikely. In addition, "any method that is profoundly counterintuitive inspires suspicion and distrust, and detracts from [one's] sense that he has been evaluated by a legitimate process." Underwood, *supra* note 104, at 1429.

¹⁰⁶ It might be argued that introduction of the probabilities with instructions to follow the chart might still induce many jurors to deviate at least slightly from their untutored, intuitive judgments, even if the instructions are not strictly obeyed. But, if this is what is desired—and it should be remembered that we first turned to Bayes' Theorem only to find a workable device for revealing the logical import of the statistical data now available in many paternity cases—it is preferable to use a candid, straightforward approach.

¹⁰⁷ We recognize that one function of the jury may be to inject certain nonrational considerations into the trial process. Indeed, that is one reason we are wary of demanding rigorous compliance with Bayesian analysis. See note 105 *supra*. Nonetheless, we believe jurors should be given the opportunity, if it is feasible to do so, of appreciating the logical import of the statistical evidence. See text accompanying note 71 *supra*.

are not so constrained, the objection that they may be unable to quantify their subjective beliefs with much precision is also less telling. It is enough that they can scan the chart to see the impact the test data logically should have across a range of starting points.

We do not advance this chart approach with any unrealistic expectations of jurors' abilities to comprehend Bayes' Theorem or probability theory, for such mathematical acumen is not required. Nor do we believe that all jurors will necessarily appreciate what the chart really means. Undoubtedly, many will not. But no reasonably accurate method of introducing tissue typing or blood test evidence can avoid this problem of complexity. A strictly qualitative presentation is, as we have seen, fraught with difficulties.¹⁰⁸ Overtly quantitative statements of the genetic frequency statistic, standing alone or accompanied with an explanation of why the probability of exclusion is not the same as the probability of paternity, also have potential for confusion. In fact, many jurors may find such testimony more perplexing than a well-presented chart of the resulting probabilities. We can only speculate as to which presentation will be, on balance, more comprehensible to juries. In the absence of strong evidence that the more accurate and complete presentation is somehow more likely to confuse, it should be regarded as the preferable method for presenting the statistical information.

Nevertheless, commentators have voiced a variety of other criticisms of the chart approach. First, a Bayesian (or any other) probability calculation involving statistical identification evidence can only tell the jury the likelihood that the defendant committed the act in question; it cannot supply any information about his state of mind during the commission of the act.¹⁰⁹ This is an important point in considering the use of statistical evidence in a criminal case. For example, discovering that the defendant's palm print matches the unusual print left at the scene of the crime may persuade us that he committed the act, but it cannot tell us whether he acted with malice, a point that may be crucial to the verdict. Such questions of intent do not customarily arise in paternity suits, however, where the issue is whether the defendant is the biological father of the complainant's child.¹¹⁰

A second criticism concerns the possibility of a frame-up. It is always possible that the evidence that will be reflected in the statistical computation has been created for the very purpose of implicating

¹⁰⁸ See section IIIA *supra*.

¹⁰⁹ See Tribe, *supra* note 8, at 1365-66.

¹¹⁰ This point would be relevant, however, if the same blood test evidence were offered in a rape prosecution, where the alleged rapist impregnated the victim who then bore his child.

the defendant. Someone could plant a fragment of another's hair or an item containing another's fingerprint, for example, at an incriminating location. The Bayesian calculation does not take this into account, although in theory it could.¹¹¹ Yet, this concern would rarely arise in paternity litigation, since it would be most unusual for the defendant's genetic endowment to be planted without his cooperation. Although the frame-up problem thus may not be directly applicable to paternity cases, it does suggest a parallel concern: if the probability of false test results is, contrary to our assumptions, not negligible, the calculations implicit in the chart should incorporate the probabilities of such errors.¹¹² If sloppy laboratory work makes it difficult to quantify the probabilities of mistakes in the clinical tests, defense counsel should make it plain by cross-examination or argument that the numbers in the chart overstate the probability of paternity.

Third, it is conceivable that some jurors faced with a chart might give undue weight to the statistical evidence by unconsciously allowing these figures to influence their assessment of the prior probability. Adhering to the chart in arriving at the probability of paternity, they would unjustifiably count the same evidence a second time.¹¹³ This problem might be minimized by presenting the chart only after all the other evidence has been received.¹¹⁴ In addition, "double counting" is a less weighty objection to the modified chart approach which does not require jurors to plug their own numbers into the probability equation. Consequently, this last criticism provides another reason for preferring a modified use of the chart method over a more rigorous application of Bayes' Theorem.

In addition to these practical objections—which do not seem to supply compelling grounds for dismissing the modified chart approach—several rather theoretical challenges to using Bayesian calculations in legal factfinding have been advanced.¹¹⁵ Some of these arguments dispute the appropriateness of using *any* of the accepted

¹¹¹ See Fairley, *supra* note 95, at 493; Tribe, *supra* note 8, at 1363-64.

¹¹² Cf. Lempert, *Modeling Relevance*, 75 MICH. L. REV. 1021, 1024 n.19 (1977) (expressing concern over uncertainty in the values of the conditional probabilities that determine the value of the quantity *f* defined by equation (2) at text accompanying note 89 *supra*).

¹¹³ See Tribe, *supra* note 8, at 1366-68.

¹¹⁴ See Finkelstein & Fairley, *supra* note 68, at 1807.

¹¹⁵ See L. COHEN, *supra* note 102, at 34-37; Brilmayer & Kornhauser, *supra* note 8, at 135-48; Nesson, *Reasonable Doubt and Permissive Inferences: The Value of Complexity*, 92 HARV. L. REV. 1187, 1199 n.27 (1978).

techniques of probability and statistics in the legal realm.¹¹⁶ However, the primary objection to employing Bayes' formula at trial does not deny that the equation produces mathematically correct results.¹¹⁷ It asserts instead that the prior probability one proposes to use is somehow not a "true" probability and that this subjectively ascertained number cannot be combined meaningfully by Bayes' Theorem with an objectively derived figure like the genetic frequency. That is, this objection contends that even in theory jurors cannot produce by subjective methods a number which obeys the probability axioms. Whether or not this view is convincing,¹¹⁸ it is of little consequence as applied to the modified chart approach. That approach does not ask the jurors to produce such a number. It merely shows them how a correctly ascertained probability would be altered, if one were in fact available. In this way it accurately communicates the significance of the admittedly probabilistic scientific evidence, without requiring the remaining evidence to be expressed as a probability.¹¹⁹ Hence, we conclude that the use of the modified chart approach to show the probative force of the statistical evidence derived from HLA or other tests meets the criteria of mathematical accuracy and general intelligibility. The approach is defensible on both practical and theoretical grounds, and it may well represent the best single method for explaining what the medical evidence proves.

In sum, while modern medical techniques can produce relevant evidence of paternity, the method by which recent cases have allowed such evidence to be presented is unsatisfactory. Two alternative methods, the data approach and the modified chart approach, are clearly preferable. The data approach prevents the expert from testifying to the probability of paternity, but gives the jury little guidance in evaluating the statistical evidence. The approach is consistent with the use of statistical identification evidence outside the

¹¹⁶ See L. COHEN, *supra* note 102, at 49-120; Brilmayer & Kornhauser, *supra* note 8, at 137-46. These authors suggest that jurors should weigh evidence according to a fundamentally different mathematical structure—one in which the probability that an event will happen and the probability that it will not do not necessarily add up to one. Their arguments in favor of such a system are criticized in Kaye, *The Laws of Probability and the Law of the Land*, 47 U. CHI. L. REV. 34 (1979); Kaye, *The Paradox of the Gatecrasher and Other Stories*, 1979 ARIZ. ST. L.J. 101; Williams, *The Mathematics of Proof I*, CRIM. L. REV., May 1979, at 305; Schum, Book Review, 77 MICH. L. REV. 446 (1979); Wagner, Book Review, *supra* note 8.

¹¹⁷ See note 88 *supra*.

¹¹⁸ For a detailed analysis of this issue, see Kaye, *The Laws of Probability and the Law of the Land*, *supra* note 116, at 41-47.

¹¹⁹ Cf. Sprott & Kalbfleisch, *Use of the Likelihood Function in Inference*, 64 PSYCH. BULL. 354 (1965) (advocating that the likelihood ratio be used in evaluating scientific hypotheses even if prior or posterior probabilities are not computed).

context of paternity. The modified chart approach, on the other hand, is more innovative. It is mathematically more appealing and, we believe, no less practicable. It would represent a marked improvement over the status quo in two respects. First, it would result in a figure more aptly called the probability of paternity and the meaning of which is more readily apparent to the jury. Second, it would preclude the expert from imposing his own view of the prior probability—a view that is necessarily founded on ad hoc assumptions or inadmissible background statistics derived from earlier paternity cases. Although this method of presentation may seem to depart from traditional evidentiary techniques, such novelty, in and of itself, cannot count as a serious argument against the approach. Novel and unfamiliar types of evidence frequently are viewed, at first, with suspicion. For example, it was only a few decades ago that the Pennsylvania Supreme Court held that annuity tables could not be shown to a jury because “[t]he less jurors are burdened with complicated tables and the necessity for complex calculations, the more likely they will be to do substantial justice.”¹²⁰ Today, such views seem quaint, for we have become familiar with the concept of discounting to present value, and the courts have become comfortable with such tables. In terms of courtroom procedure and practice, there seems to be no reason why probability charts could not enjoy similar acceptance.¹²¹

However, we cannot unconditionally endorse the use of confirmatory HLA or blood test evidence, even when it is suitably explained and presented via the data or modified chart approach. One final issue, which concerns the sufficiency of the evidence, must be attended to.

c. The Problem of Insufficient Evidence—Although modern serologic testing can often provide highly probative evidence of paternity which can be usefully expressed as a final probability of paternity, it does not follow that such evidence should always be admitted, even if the correctly calculated probability of paternity is

¹²⁰ *Moore v. Leininger*, 299 Pa. 380, 385, 149 A. 662, 664 (1930). In response to *Moore*, McCormick wrote in 1935 that “the courts should shift from the present extreme emphasis upon caution in the use of the tables to a willingness for actuarial witnesses in their testimony and counsel in argument to develop the application of these statistical methods . . . to their full limits of usefulness.” C. MCCORMICK, *HANDBOOK ON THE LAW OF DAMAGES* § 86, at 307 (1935).

¹²¹ Blood testing based on the ABO system, it will be recalled, met with strong judicial resistance. See text accompanying note 22 *supra*. Similarly, the now commonplace techniques of statistical inference in jury selection and employment discrimination cases lagged far behind the recognition of the validity of these tools by academics and practicing lawyers.

quite high. The reason is not that the probability calculation is defective, but rather that the policy of promoting accurate verdicts may be furthered in the long run by barring plaintiffs from recovering when they choose not to introduce more revealing evidence which is reasonably available to them.¹²²

A simplified version of a typical fact pattern in paternity litigation illustrates how this rationale limits the overenthusiastic use of serologic test results. Suppose it is known that the mother has had sexual relations with approximately equal frequency with each of three men and only these three during the time period in which conception almost surely occurred. For reasons not disclosed at trial, only the defendant was given an HLA test, the results of which do not exclude him as the father. Suit was therefore brought against him. The expert testifies that the probability of a random match—the haplotype frequency—in this particular test is .30, or 30%. The result of a Bayes' calculation shows that if the prior probability of paternity is taken to be one-third, on the ground that defendant is one of the only three equally likely suspects, the HLA test results increase the probability of paternity to .63, or 63%.¹²³ No other information is presented. Should the jury be permitted to find for the plaintiff on this evidence? At first blush, the probability seems sufficient to meet the burden of proof ordinarily imposed in civil cases,¹²⁴ suggesting that a verdict for the plaintiff is justified. The problem, however, is the plaintiff's failure, without explanation, to test any of the other defendants. The probability that the test would implicate at least one of the other two men is actually quite high.¹²⁵ At the same time, it would not seem difficult for plaintiff to eliminate this substantial and lingering doubt. Unless the plaintiff produces some satisfactory explanation for her failure to obtain such test results, her case should not be allowed to go to the jury.

The most obvious explanation which might be offered, of course, is that the two other men cannot be found. This is usually satisfactory

¹²² See Kaye, *supra* note 3; Tribe, *supra* note 8, at 1349 (to create "an incentive for plaintiffs to do more than establish the background statistics," verdicts should be directed against plaintiffs who rely exclusively on statistical evidence).

¹²³ This probability is obtained from equations (1) and (2), with $f=.30$ and $P(F)=1/3$.

¹²⁴ The preponderance of the evidence standard can be interpreted quantitatively to mean evidence establishing that the probability in favor of a proposition exceeds .50, or 50%. See note 70 *supra*.

¹²⁵ This probability is easily calculated from the definition of conditional probability. Assuming that the selection of the three men is random as regards HLA haplotypes, the probability that neither the second (M₂) nor the third (M₃) man tested will have the paternal haplotype for the child in question given the fact that the defendant (M₁) does match is given by:

if true.¹²⁶ But when the other men are available, and no other satisfactory explanation for the incomplete testing appears, the plaintiff should be barred from relying on the HLA evidence until more comprehensive testing has been performed. It is poor policy to encourage plaintiffs to stop testing at the first lucky strike.¹²⁷

$$P(\text{not-}M_2 \ \& \ \text{not-}M_3 | M_1) = \frac{P(\text{not-}M_2 \ \& \ \text{not-}M_3 \ \& \ M_1)}{P(M_1)}$$

Since the events in the numerator of the right hand side are independent, we have

$$\begin{aligned} P(\text{not-}M_2 \ \& \ \text{not-}M_3 | M_1) &= \frac{P(\text{not-}M_2)P(\text{not-}M_3)P(M_1)}{P(M_1)} \\ &= P(\text{not-}M_2)P(\text{not-}M_3) \\ &= (1-f)(1-f) = (1-.30)^2 = .49 \end{aligned}$$

where f is the frequency of the particular HLA haplotype in the relevant population. The probability that at least one of the two untested men will match is therefore given by

$$\begin{aligned} P(M_2 \ \text{or} \ M_3 | M_1) &= 1 - P(\text{not-}M_2 \ \& \ \text{not-}M_3 | M_1) \\ &= 1 - .49 = .51 \end{aligned}$$

More generally, where the number of possible fathers is N (in our example, $N = 3$), the probability that at least one of the $N - 1$ untested men would match if tested is

$$P(M_2 \ \text{or} \ M_3 \ \text{or} \ \dots \ \text{or} \ M_N | M_1) = 1 - (1-f)^{N-1}$$

These results can also be derived starting with Bayes' Theorem rather than the definition of conditional probability. See Kaye, *The Paradox of the Gatecrasher and Other Stories*, *supra* note 116, at 104-08.

¹²⁶ See generally W. RICHARDSON, EVIDENCE § 92 (10th ed. 1973); 2 J. WIGMORE, EVIDENCE § 286 (3d ed. 1940); Comment, *Drawing an Inference from the Failure to Produce a Knowledgeable Witness: Evidentiary and Constitutional Considerations*, 61 CALIF. L. REV. 1422 (1973). Even when a particular person is not available for testing, however, his genotype can sometimes be deduced from tests performed on his relatives. See W. BODMER & L. CAVALLI-SFORZA, *supra* note 17, at 248.

¹²⁷ Even when the genetic frequency and the number of realistic suspects are small, so that the probability of paternity is quite high and the likelihood that one of the untested suspects will also match is low, plaintiff should be required to act, if feasible, to minimize doubt. Weiner, *supra* note 35, provides a case in point. He describes an instance in which "there . . . were two and only two men either one of whom, the mother stated, could be the father of her child." *Id.* at 127-28. However, only one of the two men was available for testing, and the series of blood tests performed showed that the probability of a random match was about .01, or 1%. Since there were two possible fathers, and Dr. Weiner had no reason to think one was more likely than the other to be the father, he applied Bayes' Theorem to a prior probability of one-half. The resulting posterior probability was 74/75, or nearly .99. He informed the court that the blood test results established a probability of paternity of this magnitude. Two and a half years later, the court sent the second man for testing. As Dr. Weiner put it: "The second man was not excluded either, contrary to expectations. Thus, in the final report to the court, the authors had to point out that the likelihood of paternity was almost the same for the two men, and that the completed findings were inconclusive as to paternity." *Id.* at 128.

The same logic also bears on how extensive a battery of serologic tests should be performed on a particular suspect in order to establish an adequate foundation for the admissibility of the medical evidence. When paternity is not excluded after searching for one genetic marker, the laboratory can almost always look for another.¹²⁸ Each additional test, however, adds to the cost, and the point of diminishing returns is quickly reached.¹²⁹ As a rough guide, we recommend that, for confirmatory test data to be admissible under any of the approaches we have listed, testing be continued until the probability of exclusion for the battery of tests performed exceeds .95, or 95%.¹³⁰ Although there is nothing magic about this particular figure, testing to establish such probabilities should usually be available at a reasonable cost¹³¹ and yields results too probative to withhold from the jury.

CONCLUSION

Advancing medical technology has produced tests which offer the opportunity to resolve paternity disputes with more accuracy than unaided traditional evidentiary techniques are likely to obtain. Proper understanding of the test results, however, requires statistical reasoning with which courts are typically unfamiliar. As a result, recent cases have allowed experts to state probabilities of paternity which have had little relevance to the cases at bar. Nevertheless, such misuse of available techniques should not preclude their proper application, since they can produce results highly probative of paternity. It

¹²⁸ There are hundreds, if not thousands, of genetic markers in the HLA system alone. See text accompanying note 39 *supra*.

¹²⁹ As an illustration, suppose that four tests have been done which, in combination, exclude 90% of falsely accused men, and it is proposed to do another test offering a 10% exclusion rate. Of the men excluded by this additional test, 90% will already have been excluded by the prior tests. Hence, the new test would raise the probability of exclusion from 90 to only 91%. Weiner, *supra* note 35, at 128-29.

An additional test also would increase the likelihood of a false negative, or spurious exclusion. As the number of independent tests approaches infinity, the probability of this type of error approaches one.

¹³⁰ The problem of defining an appropriate "stopping rule" and analyzing its implications is quite complex. See generally A. WALD, *SEQUENTIAL ANALYSIS* (1947); Cornfield, *Sequential Trials, Sequential Analysis and the Likelihood Principle*, 20 AM. STATISTICIAN 18 (1966). The rule suggested here is meant to be illustrative rather than definitive.

¹³¹ HLA testing involving about 50 antigens can be completed within a day and costs about \$300 when administered to mother, child, and one man. Cannady, *supra* note 7, at 18. Tests for red blood cell antigens cost about \$50 per person. *Lascaris v. Lardeo*, 100 Misc. 2d 220, 223, 417 N.Y.S.2d 665, 667 (Fam. Ct. 1979).

is possible to convey the meaning of the test results to the jury most accurately through the use of probability charts which preserve the jury's role of resolving the disputed factual claims present in particular cases. A more restricted presentation of the statistical information, focusing exclusively on the underlying statistical data, also would be preferable to existing methods. Care should be taken, however, to ensure that plaintiffs who seek to introduce such tests employ them with adequate thoroughness to justify judicial reliance on them.