How Well Does Paternity Confidence Match Actual Paternity? Evidence from Worldwide Nonpaternity Rates

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Note: this version contains the sidebars that are available only in the electronic edition of the paper.

The issue of paternity—whether a man really is the biological father of his supposed children—has long been a topic of interest to anthropologists. Evolutionary theory predicts that males will provide less parental investment for putative genetic offspring who are unlikely to be their actual offspring (e.g., Alexander 1974; Trivers 1972). Actual genetic paternity may differ from paternity confidence (a man's assessment of the likelihood that he is the father of a putative child), which must be assessed through indirect cues such as mate fidelity or child resemblance. There is great variation across cultures in beliefs about paternity (e.g., Beckerman et al. 1998; Hrdy 2000; Levine 1987), but cross-culturally, paternity confidence is positively associated with men's involvement with children or with investment or inheritance from paternal kin (e.g., Flinn 1981; Gaulin and Schlegel 1980; Greene 1978; Hartung 1985).

This paper draws on 67 studies reporting nonpaternity to examine the relationship between paternity confidence and actual paternity and to look for global variation in this relationship. I test the hypothesis that men with high paternity confidence will have higher rates of actual paternity than men with low paternity confidence by comparing nonpaternity rates from two groups of men: one biased toward high paternity confidence and the other toward low paternity confidence. The relative frequencies of men with high and low paternity confidence are generally unknown, making it difficult to estimate true nonpaternity rates for human societies.

Nonpaternity in Cross-Cultural Perspective

Nonpaternity rates in human societies are often cited as being 10% or greater in general populations (e.g., Alfred 2002; Cervino and Hill 2000; Stewart 1989), though little or no empirical support is generally provided for this assertion (MacIntyre and Sooman 1991). Baker and Bellis (1995) report a worldwide median nonpaternity rate of 9% from a sample of ten studies. While little is known about global variation in nonpaternity, even less is known about cross-cultural patterns of paternity confidence. Gaulin and Schlegel (1980) used three variables measuring the degree of female sexual promiscuity among 135 societies to create a dichotomous measure of paternity confidence, and estimated that only 55% of cultures in their sample have high paternity confidence. Huber et al. (2004) used four measures of extramarital sexual activity from 57 cultures to create a 16-level measure of paternity confidence. Their results indicate that 63% of societies have paternity confidence levels at or above the median. Thus, while paternity confidence is high for many societies, a substantial minority appear have reduced levels of paternity confidence.

In recent years, the determination of nonpaternity has become a science. Modern paternity tests cannot prove paternity; instead they prove nonpaternity, by excluding men whose genotype is incompatible with that of the child in question (Pena and Chakraborty 1994; Wilson 1987). Failure to exclude a man as the father can be taken as proof of paternity if the probability of excluding non-fathers is extremely high; the probability that a man is likely to be the father is calculated using Bayesian logic, based on assumptions of the frequencies of the genotypes under consideration in the general population (for further details see Mickey, Gjertson, and Terasaki 1986; Pena and Chakraborty 1994). Contemporary paternity tests, which use DNA polymorphisms to determine nonpaternity, have probabilities of exclusion in excess of 99.99%, so that out of 10,000 paternity tests the true non-father will be excluded as a potential father 9,999 times (Helminen et al. 1988; Jeffreys, Turner and Debenham 1991; Pena and Chakraborty 1994). Older (pre-1985) paternity tests, based on blood type or HLA antigens, had lower probabilities of exclusion, ranging from 18% (if using only the ABO blood types) to 95% or more. A lower probability of exclusion means that nonpaternity will not be established for some non-fathers, even though they are not the actual father of the child. (For example, a man may have a blood type that is compatible with being the father of the child, even though he is not the father.) Many older studies therefore report two nonpaternity rates: the observed nonpaternity (the proportion of men excluded in the study), and the actual nonpaternity (the proportion of men who *should have been* excluded, not all of whom were due to limitations of the test). For example, if the probability of exclusion in a study is 50%, and the study finds a 5% nonpaternity rate in the sample, then the actual nonpaternity rate is 10%.

Methods

For the present study, published data on nonpaternity rates were gathered through extensive literature searches, using online databases, bibliographies, and journal indices, resulting in a sample of 67 nonpaternity rates. While this list cannot be considered complete, it is the most extensive published list of nonpaternity rates assembled to date, far exceeding pre-existing lists (e.g., Baker and Bellis 1995; James 1993; Lucassen and Parker 2001; MacIntyre and Sooman 1991; Sasse et al. 1994).

The measures of nonpaternity used in this study were estimated in many different ways. Because older methods of establishing nonpaternity had lower probabilities of exclusion (i.e., were less likely to detect nonpaternity), the proportion of men actually excluded in older (pre-1985) papers is always less than the number of non-fathers in the sample who should have been excluded. Most researchers adjust for this accordingly, presenting both the observed nonpaternity and the actual (adjusted) nonpaternity; in a few cases, actual nonpaternity was not stated, and I calculated actual nonpaternity from the stated probability of exclusion. More recent references, with greater probabilities of exclusion (greater than 95% and typically exceeding 99.99%), do not distinguish between observed and actual nonpaternity, as the difference is minimal. In a few cases where nonpaternity is estimated through other methodologies (for example, Mendelian inconsistencies), there is no difference between observed and actual nonpaternity. Where possible, the actual nonpaternity rate will be used for the analysis.

On the basis of the level of presumed paternity confidence within each group, the dataset is divided into three groups: (1) men with relatively high paternity confidence, (2) men with relatively low paternity confidence, and (3) men whose paternity confidence is unknown.

1. *High paternity confidence*. This group includes 22 data points from genetic studies or other sources that are likely to bias the sample toward high paternity confidence (see table 1). None of these studies come from random samples. The nature of these studies (especially the genetic and lineage studies) will bias the samples toward men with high paternity confidence because men who do not believe they have fathered their putative children will be less likely to participate in the research. Most of these studies include mother/father/child trios, and many contain primarily or exclusively married couples. Since men in marriages are likely to have higher paternity confidence than men who father children outside of marriage (Anderson, Kaplan and Lancaster 2006a, 2006b), this will further bias the sample toward men with high paternity confidence. Some men in this sample undoubtedly do not have high paternity confidence; additionally, the studies may have included covert adoptions, misidentified stepchildren, etc., for whom paternity confidence is zero. Overall, however, these studies are likely to include men whose paternity confidence is relatively high.

[Table 1 about here]

2. *Low paternity confidence*. All of the 31 data points in this group come from studies of disputed paternity (for example, from paternity testing laboratories) (see table 2). The men in this

sample were sufficiently doubtful of their paternity to participate in laboratory tests to determine if they were the fathers of their putative children; thus, this sample is categorized as having low paternity confidence.

[Table 2 about here]

3. *Unknown paternity confidence*. This group contains 14 data points for which no conclusion can be drawn regarding the paternity confidence of the men involved (see table 3). Many are from unpublished or secondhand sources, and therefore we do not know whether the reported nonpaternity reflects observed or actual nonpaternity, or if the rates have been adjusted for laboratory error.[1] One study (Baker and Bellis 1990) estimates nonpaternity through women's reports of sexual behavior; they present no data on whether the women's partners had high or low paternity confidence in any resulting pregnancies.

[Table 3 about here]

Sidebar A: Electronic edition only

Two of the nonpaternity rates cited in the tables differ from those cited in Baker and Bellis (1995). In table 1, I cite the rate for Edwards (1957) as 3.7% while Baker and Bellis (1995) cite 5.9%. Edwards states (p. 85) that there are 17 blood group incompatibilities ("bastards"), out of 2578 matings. The exclusion rate is 18%. This calculation ((17/2578)/0.18) yields a nonpaternity rate of 3.66%, which is roughly equal to the "nearly 4 percent" (p. 85) inferred by Edwards. It is unclear how Baker and Bellis arrived at their figure of 5.9%.

In table 1 I cite nonpaternity in Salmon et al. (1980) as ranging from 6.9 to 9.4% (with a median of 8.15% used for analysis). Baker and Bellis (1995) cite the rate as being less than 14.6%. Salmon et al. (1980) state that they found 25 exclusions from 171 families, but they do not state how many children were tested (which is required for the denominator of the nonpaternity rate). Baker and Bellis divide 25 by 171 to reach an upper limit of 14.6%. However, Salmon et al. state that 76 if the families have one child, and 95 have between two to ten children. Thus, the sample cannot be smaller than 266 children. If the multiple-child families have three offspring on average, then N = 361 children in the sample. I use these numbers (25/361 and 25/266) to create lower and upper boundaries on nonpaternity in this sample.

The paternity exclusion rate for Böök (1950) in table 1 is 100% because paternity was deduced through a Mendelian inconsistency in a simple genetic disease. Among the older (pre-1985) samples, Ashton (1980) does not state the exclusion probability (table 1). However, he notes that his data have been corrected for exclusion and for laboratory error; thus, his stated nonpaternity rate is used as the actually nonpaternity. In table 3 I label the paternity exclusion rate for Baker and Bellis (1990) as not applicable rather than not stated because, alone among these estimates, Baker and Bellis do not deduce nonpaternity through DNA, blood type, HLA antigens, or other biological method. Rather, they estimate nonpaternity through information on the timing of women's sexual behavior, specifically how many women in their sample had extrapair partners around the time of conception (making assumptions about the probability of conception, etc.). Their sample was recruited from the readership of a British women's magazine; because the investigators had no data on men's assessment of paternity, and men were not involved in the sampling procedure (thereby biasing the sample towards high paternity confidence), I have put them in the unknown paternity confidence sample.

It could be argued that since the sample whose paternity confidence is unknown is unlikely to be composed of men actively disputing paternity, the cases in table 3 should be added to those of the men with high paternity confidence (table 1). This will also make my estimates of nonpaternity more comparable to previous studies (e.g., Baker and Bellis 1995). The analyses will first examine each group separately, and then combine the high and unknown paternity confidence groups into a single group.

The data presented in tables 1 - 3 allow us to examine whether there is worldwide variation in nonpaternity rates by men's paternity confidence level. The data were organized geographically into three groups: United States and Canada (N = 27), Europe (N = 26), and elsewhere (N = 14). The "elsewhere" category is extremely heterogeneous, as it encompasses samples from South and Central America, Africa, Israel and India; however, none of these regions have sufficient sample sizes to stand alone as separate categories. While it would be interesting to examine nonpaternity by ethnic group, the data do not allow this as most studies with multiethnic samples do not provide breakdowns by ethnic group.

Because the data are not normally distributed, comparisons between groups will be made using the nonparametric Wilcoxon rank-sum test. All analyses were done using STATA SE v. 8.2. The actual nonpaternity rates used for analysis are uncorrelated with the sample size, probability of exclusion, or year of publication associated with each study.

[Sidebar B: electronic edition only]

The probability of exclusion is highly correlated with the year of publication (Spearman's rho = 0.7180, N = 43, p < 0.0001), but is uncorrelated with the sample size of the study (Spearman's rho = -0.1291, N = 43, p = 0.4095). The observed nonpaternity rate (e.g., unadjusted for the probability of exclusion) is significantly correlated with the probability of exclusion (Spearman's rho = 0.5143, N = 18, p = 0.0290) and with actual nonpaternity (Spearman's rho = 0.8952, N = 18, p < 0.0001), but is uncorrelated with both year of publication (Spearman's rho = -0.2054, N = 18, p = 0.4136) and sample size (Spearman's rho = -0.3626, N = 18, p = 0.1392). In contrast, actual nonpaternity is uncorrelated with year of publication (Spearman's rho = -0.1994, N = 67, p = 0.1058), the probability of exclusion (Spearman's rho = 0.1506, N = 43, p = 0.3352), or sample size (Spearman's rho = -0.0671, N = 58, p = 0.6168). Because actual nonpaternity is uncorrelated with the other variables available in the dataset, there is no need to perform multivariate analysis to control for their effects.

Results

The median nonpaternity rate for the high paternity confidence sample is 1.7% (range: 0.4 - 11.8), while median nonpaternity for the low paternity confidence sample is 29.8% (range: 14.3 - 55.6). The median nonpaternity rates for these two groups are significantly different (Wilcoxon sign-rank test, z = -6.156, $p < 0.0001$). The median nonpaternity of men whose paternity confidence is unknown is 16.7% (range: 2.0 - 32.0). This is significantly greater than that of the high paternity confidence sample (Wilcoxon sign-rank test, z = -4.382, $p < 0.0001$), and significantly lower than that of the low paternity confidence sample (Wilcoxon sign-rank test, z = 3.531, $p = 0.0004$). When the high and unknown paternity confidence samples are combined, the median nonpaternity is 3.3% (range: 0.4 - 32.0). This is significantly less than median nonpaternity for men with low paternity confidence (Wilcoxon sign-rank test, z = -6.099, $p < 0.0001$).

Figure 1 shows median nonpaternity by geographic location for the high paternity confidence, combined high and unknown paternity confidence, and low paternity confidence samples. Within each paternity confidence group, there is no significant geographic variation in the median values of nonpaternity (Wilcoxon sign-rank tests, results not shown, $p > 0.51$ for every comparison). In other words, men with high paternity confidence have similar levels of actual paternity in the United States and Canada, Europe, and the rest of the world; the same is true for the other two paternity confidence groups. However, for all three geographic locations nonpaternity is significantly greater in the low paternity confidence sample than in the high paternity confidence sample (Wilcoxon sign-rank tests: United States and Canada z = -3.873, p = 0.0001; Europe z = -3.761, p = 0.0002; elsewhere z = -2.611, p = 0.0090) and in the combined high/unknown paternity confidence sample (Wilcoxon sign-rank tests: United States and Canada z = -4.392, $p < 0.0001$; Europe z = -3.763, p = 0.0002; elsewhere z = -2.333, p = 0.0196).

[Figure 1 about here]

Conclusion

This survey of published estimates of nonpaternity suggests that for men with high paternity confidence, nonpaternity rates are typically 1.7% (if we exclude studies of unknown methodology) to 3.3% (if we include such studies). These figures are substantially lower than the "typical" nonpaternity rate of 10% or higher cited by many researchers, often without substantiation (e.g., Alfred 2002; Cervino and Hill 2000; Stewart 1989), or the median worldwide nonpaternity rate of 9% reported by Baker and Bellis (1995).

Men who have low paternity confidence and have chosen to challenge their paternity through laboratory testing are much less likely than men with high paternity confidence to be the fathers of their putative children. Although these men presumably have lower paternity confidence than men who do not seek paternity tests, this group is heterogeneous; some men may be virtually certain that the putative child is not theirs, while others may simply have sufficient doubts to warrant testing. Most of these men are in fact the fathers of their putative genetic children; only 29.8% could be excluded as biological fathers of the children in question.

The results of this study raise many questions. What is the true level of nonpaternity in any particular human population? Since most if not all samples are biased toward men with either high or low paternity confidence, this question cannot yet be answered. Presumably the true level of nonpaternity is a weighted average of men from these two groups, raising the question of how many men have low versus high paternity confidence. For example, in order for the population nonpaternity rate to be 10%, 75% of men in the population would have to have high paternity confidence (nonpaternity = 3.3%) and 25% have low paternity confidence (nonpaternity = 29.8%). Anderson et al. (2006a) report that men living in Albuquerque, New Mexico do not believe that they are the father of 1.46% of pregnancies attributed to them, implying a total nonpaternity rate for that sample of 3.7%. I know of no other study that has estimated the frequency of low and high paternity confidence within a particular sample, though this clearly has important implications for child wellbeing and family dynamics. Further cross-cultural investigation of the relationship between paternity and paternity confidence is warranted.

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Footnote

1. The unpublished !Kung nonpaternity rate reported in Trivers (1972) has subsequently been suggested to be due almost entirely to laboratory error, since the rate of nonmaternity in the sample was approximately the same (Howell 2000; Smith 1984).

References

ALEXANDER, RICHARD D. 1974. The evolution of social behavior. *Annual Review of Ecology and Systematics* 5: 325-383.

ALFORD, R.L., H.A. HAMMOND, I. COTO, AND C.T. CASKEY. 1994. Rapid and efficient resolution of parentage by amplification of short tandem repeats. *American Journal of Human Genetics* 55: 190-195.

ALFRED, JANE. 2002. Flagging non-paternity. *Nature Reviews Genetics* 3: 161.

ALLISON, D.B. 1996. The use of discordant sibling pairs for finding genetic loci linked to obesity: Practical considerations. *International Journal of Obesity* 20: 553-560.

ANDERSON, KERMYT G., HILLARD KAPLAN, AND JANE B. LANCASTER. 2005a. Demographic correlates of paternity confidence and pregnancy outcomes among Albuquerque men. Unpublished manuscript. Department of Anthropology, University of Oklahoma.

ANDERSON, KERMYT G., HILLARD KAPLAN, AND JANE B. LANCASTER. 2005b. Confidence of paternity, divorce, and investment in children by Albuquerque men. Unpublished manuscript. Department of Anthropology, University of Oklahoma.

ASHTON, GEOFFREY C. 1980. Mismatches in genetic markers in a large family study. *American Journal of Human Genetics* 32: 601-613.

BAIRD, M., I. BALAZS, A. GIUSTI, L. MIYAZAKI, L. NICHOLAS, K. WEXLER, E. KANTER, J. GLASSBERG, F. ALLEN, P. RUBINSTEIN, AND L. SUSSMAN. 1986. Allele frequency distribution in two highly polymorphic DNA sequences in three ethnic groups and its application to the determination of paternity. *American Journal of Human Genetics* 39: 489-501.

BAKER, R. ROBIN, AND MARK A. BELLIS. 1990. Do females promote sperm competition? Data for humans. *Animal Behavior* 40: 997-999.

BAKER, R. ROBIN, AND MARK A. BELLIS. 1995. *Human Sperm Competition: Copulation, Masturbation and Infidelity.* London: Chapman and Hall.

BECKERMAN S, LIZZARRALDE R, BALLEW C, SCHROEDER S, FINGELTON C, GARRISON A, AND SMITH H. 1998. The Barí partible paternity project: Preliminary results. *Current Anthropology* 39: 164-167.

BÖÖK, J.A. 1950. Clinical and genetical studies on hypodontia. *American Journal of Human Genetics* 2: 240-263.

BOSTER, JAMES S., RICHARD R. HUDSON, AND STEVEN J.C. GAULIN. 1999. High paternity certainty of Jewish priests. *American Anthropologist* 100: 967-971.

BROCK, D.J.H., AND A.E. SHRIMPTON. 1991. Non-paternity and prenatal genetic screening. *Lancet* 338: 1151.

BROMAN, KARL W. 1999. Cleaning genotype data. *Genetic Epidemiology* 17 (Suppl. 1): S79-S83.

CERDA-FLORES, RICARDO M., S.A. BARTON, L.F. MARTY-GONZALEZ, F. RIVAS, AND R. CHAKRABORTY. 1999. Estimation of nonpaternity in the Mexican population of Nuevo Leon: A validation study with blood group markers. *American Journal of Physical Anthropology* 109: 281-293.

CERVINO, A.C.L., AND A.V.S. HILL. 2000. Comparison of tests for association and linkage in incomplete families. *American Journal of Human Genetics* 67: 120-132.

CHATAWAY, JEREMY, STEPHEN SAWCER, ROBERT FEAKES, FRANCESCA CORADDU, SIMON BROADLEY, HYWEL B. JONES, DAVID CLAYTON, JULIA GRAY, PETER N. GOODFELLOW, AND ALASTAIR COMPSTON. 1999. A screen of candidates from peaks of linkage: evidence for the involvement of myeloperoxidase in multiple sclerosis. *Journal of Neuroimmunology* 98 (2): 208-213.

COHEN, J. 1977. *Reproduction*. Butterworths: London.

DU TOIT, E.D., R.M. MAY, I.L. HALLIDAY, T. SCHLAPHOFF, AND D.F. TALJAARD. 1989. Paternity exclusion using 18 genetic systems in 2124 cases in four South African population groups. *South African Medical Journal* 75: 103-105.

EDWARDS, J.H. 1957. A critical examination of the reputed primary influence of ABO phenotype on fertility and sex ratio. *British Journal of Preventative and Social Medicine* 11: 79-89.

FLINN, MARK. 1981. Uterine vs. agnatic kinship variability and associated cousin marriage preferences: An evolutionary biological analysis. In *Natural Selection and Social Behavior*, R.D. Alexander and D.W. Tinkle (eds.), pp. 439-475. Chiron Press: New York.

GASPARINI, P., P. MANDICH, G. NOVELLI, E. BELLONE, F. SANIUOLO, F. DE STEFANO, L. POTENZA, E. TRABETTI, M. MARIGO, P.F. PIGNATTI, B.

DALLAPICCOLA, AND F. AJMAR. 1991. Forensic applications of molecular genetic analysis: An Italian collaborative study on paternity testing by the determinations of variable number of tandem repeat DNA polymorphisms. *Human Heredity* 41: 174-181.

GAULIN, STEVEN J.C., AND ALICE SCHLEGEL. 1980. Paternal confidence and paternal investment: A cross cultural test of a sociobiological hypothesis. *Ethology and Sociobiology* 1: 301-309.

GEADA, HELENA, RUI M. BRITO, TERESA RIBEIRO, AND ROSA ESPINHEIRA. 2000. Portuguese population and paternity investigation studies with a multiplex PCR—the AmpFISTR Profiler Plus. *Forensic Science International* 108: 31-37.

GREENE, PENELOPE J. 1978. Promiscuity, paternity, and culture. *American Ethnologist* 5: 151-159.

GRÜNFELD, JEAN-PIERRE. 1985. The clinical spectrum of hereditary nephritis. *Kidney International* 27: 83-92.

HARTUNG, JOHN. 1985. Matrilineal inheritance: New theory and analysis. *Behavioral and Brain Sciences* 8: 661-688.

HELGASON, AGNAR, BIRGIR HRAFNKELSSON, JEFFREY R. GULCHER, RYK WARD, AND KÁRI STEFÁNSSON. 2003. A population coalescent analysis of Icelandic matrilineal and patrilineal genealogies: Evidence for a faster evolutionary rate of mtDNA lineages than Y chromosomes. *American Journal of Human Genetics* 72: 1370-1388.

HELMINEN, PÄIVI, CHRISTIAN EHNHOLM, MARJA-LIISA LOKKI, ALEC JEFFREYS, AND LEENA PELTONEN. 1988. Application of DNA “fingerprints” to paternity determinations. *Lancet* 1 (Mar 12): 574-576.

HELMINEN, P., A. SAJANTILA, V. JOHNSSON, M. LUKKA, C. EHNHOLM, AND L. PELTONEN. 1992. Amplification of three hypervariable DNA regions by polymerase chain reaction for paternity determinations: Comparison with conventional methods and DNA fingerprinting. *Molecular and Cellular Probes* 6: 21-26.

HEYER, E., J. PUYMIRAT, P. DIELTJES, E. BAKKER, AND P. DE KNIJFF. 1997. Estimating Y chromosome specific microsatellite mutation frequencies using deep rooting pedigrees. *Human Molecular Genetics* 6: 799-803.

HIRSCH, JERRY, AND ATAM VETTA.1978. Gli errori concettuali dell’analisi genetico-comportamentale. *Richerche di Psicologia* 78: 47-67.

HIRSCHFELD, JAN, AND AAGE HEIKEN. 1963. Application of the Ge system in paternity cases. *American Journal of Human Genetics* 15: 19-23.

HOUTZ, TERRY D., ROBERT E. WENK, MARGARET A. BROOKS, AND R. BEN DAWSON. 1982. Laboratory evidence of unsuspected parental consanguinity among cases of disputed paternity. *Forensic Science International* 20: 207-215.

HOWELL, NANCY. 2000. *Demography of the Dobe !Kung*, Second Edition. Aldine de Gruyter: New York.

HRDY Sarah B. 2000. The optimal number of fathers: Evolution, demography, and history in the shaping of female mate preferences. *Annals of the New York Academy of Science* 907: 75-96.

JAMES, W.H. 1993. The incidence of superfecundation and of double paternity in the general population. *Acta Geneticae Medicae et Gemellologiae* 42: 257-262.

JEFFREYS, ALEC J., MICHELLE TURNER, AND PAUL DEBENHAM. 1991. The efficiency of multilocus DNA fingerprint probes for individualization and establishment of family relationships, determined from extensive casework. *American Journal of Human Genetics* 48: 824-840.

KRAWCZAK, MICHAEL, INGOLF BÖHM, PETER NÜRNBERG, JOCHEN HAMPE, JOACHIM HUNDREISER, HUBERT PÖCHE, CHRISTIAN PETERS, RYSZARD SLOMSKI, JOLANTA KWIATKOWSKA, MARION NAGY, ANITA PÖPPER, JÖRG T. EPPLEN, & JÖRG SCHMIDTKE. 1993. Paternity testing with oligonucleotide multilocus probe (CAC)5/(GTG)5: A multicenter study. *Forensic Science International* 59: 101-117.

LE ROUX, MARIE-GAELLE, OLIVER PASCAL, MARIE-THERESE ANDRE, ODILE HERBERT, ALBERT DAVID, AND JEAN-PAUL MOISAN. 1992. Non-paternity and genetic counseling. *Lancet* 340: 607.

LEVINE, Nancy E. 1987. Fathers and sons: Kinship value and validation in Tibetan polyandry. *Man (N.S.)* 22: 267-286.

LUCASSEN, ANNEKE, AND MICHAEL PARKER. 2001. Revealing false paternity: Some ethical considerations. *Lancet* 357: 1033-1035.

MACINTYRE, SALLY, AND ANNE SOOMAN. 1991. Non-paternity and prenatal genetic screening. *Lancet* 338: 869-871.

MARSTERS, ROGER W. 1957. Determination of nonpaternity by blood groups: A series of two hundred cases. *Journal of Forensic Sciences* 2: 15-37.

MICKEY, M.R., D.W. GJERTSON, AND P.I. TERASAKI. 1986. Empirical validation of the Essen-Möller probability of paternity. *American Journal of Human Genetics* 39: 123-132.

MOLYAKA, Y.K., I.V. OVCHINNIKOV, A.B. SHLENSKII, G.I. KOROVAITSEVA, AND E.I. ROGAEV. 1997. DNA Genotypescopy in paternity testing: Use of hybridization probes. *Genetika* 33 (6): 831-835.

NEEL, JAMES V., AND KENNETH M. WEISS. 1975. The genetic structure of a tribal population, the Yanomama Indians. XII: Biodemographic studies. *American Journal of Physical Anthropology* 42: 25-52.

PENA, SERGIO D.J., AND RANAJIT CHAKRABORTY. 1994. Paternity testing in the DNA era. *Trends in Genetics* 10: 204-209.

PENA, S.D.J., P.C. SANTOS, M.C.B.N. CAMPOS, AND A.M. MACEDO. 1993. Paternity testing with the F10 multilocus DNA fingerprinting probe. In *DNA Fingerprinting: State of the Science*, S.D.J. Pena, R. Chakraborty, J.T. Epplen and A.J. Jeffreys (eds.), pp. 237-247. Birkhäuser Verlag: Basel, Switzerland.

PEÑALOZA, ROSENDA, CARLOTA NÚÑEZ, SILVIA ALATORRE, ROBERTO LAGUNES, BLANCA GARCÍA ESCOBAR, FABIO SALAMANCA, AND CARLOS ZAVALA. 1986. Frecuncia de paternidad extraconyugal en una muestra de la población mexicana. *La Revista de Investigación Clínica* 38: 287-291.

PERITZ, ERIC, AND PHILIP F. RUST. 1972. On the estimation of the nonpaternity rate using more than one blood-group system. *American Journal of Human Genetics* 24: 46-53.

PHILIPP, E.E. 1973. Comment in Discussion: Moral, social and ethical issues. In *Law and Ethics of A.I.D. and Embryo Transfer*, Ciba Foundation 17, G.E.W. Wolstenholme and D.W. Fitzsimmons (eds.), pp. 663-666. Associated Scientific: London.

POON, MAN-CHIU, SAMANTHA ANAND, BARBARA M. FRASER, DAVID I. HOAR, AND GARY D. SINCLAIR. 1993. Hemophilia B carrier determination based on family-specific mutation detection by DNA single-strand conformation analysis. *Journal of Laboratory and Clinical Medicine* 122: 55-63.

ROUGER P., AND V. VAN HUFFEL. 1996. Polymorphisme de l'AND et exclusions de paternité: Analyse de 543 cas de recherché de filiation. *Transfusion et Clinical Biologie* 5: 273-278.

SALMON, DENISE, JEANINE SEGER, AND CHARLES SALMON. 1980. Expected and observed proportion of subjects excluded from paternity by blood phenotypes of a child and its mother in a sample of 171 families. *American Journal of Human Genetics American Journal of Human Genetics* 32: 432-444.

SASSE, GEORG, HANSJAKOB MULLER, RANAJIT CHAKRABORTY, AND JURG OTT. 1994. Estimating the frequency of nonpaternity in Switzerland. *Human Heredity* 44: 337-343.

SCHACHT, L.E., AND H. GERSHOWITZ. 1963. Frequency of extra-marital children as determined by blood groups. In *Proceedings of the Second International Congress on Human Genetics*, L. Gedda (ed.), pp. 894-897. G. Mendel: Rome.

SCHARFETTER, C. 1978. Alleged vs. biologically possible paternity. *Behavior Genetics* 8: 383-384.

SMITH, ROBERT L. 1984. Human sperm competition. In *Sperm Competition and the Evolution of Animal Mating Systems*, R.L. Smith (ed.), pp. 601-659. Academic Press: New York.

STEWART, ALISTAIR D. 1989. Screening for cystic fibrosis. *Nature* 341: 696.

STROM, CHARLES M., SVETLANA RECHITSKY, NORMAN GINSBERG, OLEG VERLINSKY, AND YURY VERLINSKY. 1996. Prenatal paternity testing with deoxyribonucleic acid techniques. *American Journal of Obstetric Gynecology* 6: 1849-1854.

SUSSMAN, LEON N. 1954. Blood grouping tests in disputed paternity proceedings. *Journal of American Medical Association* 155 (13): 1143-1145.

SUSSMAN, LEON N. 1956. Blood grouping tests in disputed paternity proceedings and filial relationships. *Journal of Forensic Sciences* 1: 25-34.

SUSSMAN, LEON N., AND SIDNEY B. SCHATKIN. 1957. Blood-grouping tests in undisputed paternity proceedings. *Journal of the American Medical Society* 164: 249-250.

SYKES, BRYAN, AND CATHERINE IRVEN. 2000. Surnames and the Y Chromosome. *American Journal of Human Genetics* 66: 1417-1419.

TERASAKI, PAUL I. 1978. Resolution by HLA testing of 1000 paternity cases not excluded by ABO testing. *Journal of Family Law* 16: 543-557.

TRIVERS, ROBERT L. 1972. Parental investment and sexual selection. In *Sexual Selection and the Descent of Man 1871-1971*, B. Campbell, ed., pp. 136-179. Chicago: Aldine.

UNGER, LESTER J. 1953. Blood grouping tests for exclusion of paternity: Results in one hundred eight cases. *Journal of American Medical Association* 152: 1006-1010.

VALENTIN, JACK. 1980. Exclusions and attributions of paternity: Practical experiences of forensic genetics and statistics. *American Journal of Human Genetics* 32: 420-431.

WIENER, ALEXANDER S. 1950. Heredity of the Rh blood types IX. Observations in a series of 526 cases of disputed parentage. *American Journal of Human Genetics* 2: 177-197.

WIENER, ALEXANDER S. 1966. Estimation of nonpaternity. *American Journal of Human Genetics* 18: 309-310.

WIENER, ALEXANDER S., EVE B. GORDON, AND LILLIAN HANDMAN. 1949. Heredity of the Rh blood types VII. Additional family studies, with special reference to factor Rh. *American Journal of Human Genetics* 1: 127-140.

WILSON, MARGO. 1987. Impact of the uncertainty of paternity on family law. *University of Toronto Faculty of Law Review* 45: 216-242.

Table 1. Nonpaternity Rates (%) when Paternity Confidence Is Relatively High

Population	**Actual nonpaternity (%)**	**Observed nonpaternity (%)**	**Probability of exclusion (%)**	**Sample size**	**Source**
Sephardic Kohanim (Jewish priests)	0.4	not stated	not stated	24	Boster et al. (1999)
United States	0.8	not stated	not stated	496	Broman (1999)
Switzerland	0.83	not stated	99	1,607	Sasse et al. (1994)
Ashkenazic Kohanim (Jewish priests)	1.2	not stated	not stated	44	Boster et al. (1999)
Canada (Quebec)	1.2	not stated	not stated	42	Heyer et al. (1997)
England	1.3	not stated	not stated	48	Sykes and Irven (2000)
England	1.35	not stated	not stated	521	Brock and Shrimpton (1991)
United States (Michigan), white	1.49	0.28	18.8	1,417	Schacht and Gershowitz (1963)
Iceland	1.49	not stated	not stated	not stated	Helgason et al. (2003)
United Kingdom	1.59	not stated	not stated	756	Chataway et al. (1999)
Sweden	1.6	not stated	100	63	Böök (1950)
Canada	1.75	not stated	not stated	57	Poon et al. (1993)
United States (California), white	2.1	0.8	38.1	6,960	Peritz and Rust (1972)
United States (Hawaii)	2.3	not stated	not stated	2,839	Ashton (1980)
United States	2.8	0.5	18	200	Wiener et al. (1949)
France	2.8	not stated	not stated	362	Le Roux et al. (1992)
Mexico	2.9	2.3	80.3	217	Peñaloza et al. (1986)
United Kingdom (West London)	3.7	0.7	18	2,596	Edwards (1957)
France	6.9 - 9.4	not stated	94.4	266 - 361	Salmon et al. (1980)
Brazil/Venezuela (Yanomamo)	9.1	6.1	64	132	Neel and Weiss (1975)
United States (Michigan), black	10.1	1.91	18.9	523	Schacht and Gershowitz (1963)
Mexico (Nuevo Leon)	11.8	8.1	64	396	Cerda-Flores et al. (1999)

Table 2. Nonpaternity Rates (%) from Paternity Testing Laboratories

Population	Actual nonpaternity (%)	Observed nonpaternity (%)	Probability of exclusion (%)	Sample size	Source
Russia	14.3	not stated	99.75	21	Molyaka et al. (1997)
Finland [a]	15.2	14.3	94	35	Helminen et al. (1992)
United Kingdom	16.6	not stated	99.99	1,702	Jeffreys et al. (1991)
Germany	16.8	not stated	99.87	256	Krawckak et al. (1993)
Brazil (Belo Horizonte)	22.0	not stated	99.99	200	Pena et al. (1993)
South Africa, white	22.4	not stated	99.4	264	Du Toit et al. (1989)
United States (Cleveland, OH)	23.9	12	50	67	Marsters (1957)
United States (Los Angeles), white	24.9	not stated	97	1,393	Mickey et al. (1986)
United States	25.0	not stated	90 - 99	1,000	Terasaki (1978)
United States	25.2	not stated	97	2,500	Houtz et al. (1982)
United States	26.0	not stated	99.39	50	Alford et al. (1994)
Portugal	27.7	not stated	99.9	83	Geada et al. (2000)
United States (New York City)	28.7	14.3	50	300	Sussman (1956)
United States (Baltimore)	29.0	not stated	not stated	124	James (1993)
United States (New York City)	29.4	not stated	93	102	Baird et al. (1986)
Portugal	29.8	not stated	99.9	790	Geada et al. (2000)
South Africa, Cape Malay	30.5	not stated	98.0	59	Du Toit et al. (1989)
United States (New York City), black [a]	30.6	15.3	50	98	Wiener (1950)
United States (Cleveland, OH)	32.0	16	50	200	Marsters (1957)
United States (New York City), white [a]	34.4	17.2	50	425	Wiener (1950)
Finland	34.6	not stated	99	26	Helminen et al. (1988)
United States (Illinois)	37.0	not stated	99	753	Strom et al. (1996)
France (Paris)	38.1	not stated	99.99	543	Rouger and van Huffel (1996)
Sweden	38.7	33.5	86.5	5,018	Valentin (1980)
South Africa, Cape Coloured	40.1	not stated	99.8	1,156	Du Toit et al. (1989)
South Africa, black	41.1	not stated	99.5	645	Du Toit et al. (1989)
United States	42.0	21	50	100	Sussman (1954)
Italy	45.0	not stated	99.6	31	Gasparini et al. (1991)
United States (Illinois)	53.0	not stated	99.83	37	Strom et al. (1996)
Sweden [a]	55.0	8.4	15.4	142	Hirschfeld and Heiken (1963)
United States [a]	55.6	27.8	50	108	Unger (1953)

a. Actual nonpaternity not calculated in the original paper;

Table 3. Nonpaternity Rates (%) When Paternity Confidence Is Unknown

Population	**Nonpaternity (%)**	**Probability of exclusion (%)**	**Sample size**	**Source**
Southern Africa (!Kung)	2	not stated	not stated	Harpending (unpublished), cited in Trivers (1972)
United Kingdom	4.8	not stated	21	Shields (unpublished), cited in Scharfetter (1978)
England	6.9 - 13.8	not applicable	2,708	Baker and Bellis (1990)
United States (rural Michigan)	"ca. 10"	not stated	not stated	Chagnon (unpublished), cited in Smith (1984)
Munich and Copenhagen	"at least 10"	not stated	not stated	unpublished; cited by Ritz in Grünfeld (1985)
United States	10 - 30	not stated	not stated	Reed (unpublished), cited in Allison (1996)
Italy	13.2	not stated	38	Hirsch and Vetta (1978)
India	"~15.3"	not stated	not stated	Meisner 1999, cited in Cervino and Hill (2000)
United States	18.0	50	67	Sussman and Schatkin (1957)
England (Liverpool)	20 - 30	not stated	not stated	McLaren (unpublished), cited in Cohen (1977)
United States (Michigan), black	20.1	18.75	265	Wiener (1966)
England	30	not stated	200-300	unpublished, cited in Philipp (1973)
Africa	"~30"	not stated	not stated	Ruwende 1996, cited in Cervino and Hill (2000)
India (Vishakapatnam)	32	not stated	not stated	Meisner 1999, cited in Cervino and Hill (2000)

Figure 1. Median nonpaternity rates by paternity confidence and geographic location