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**922 P.2d 294**  
**186 Ariz. 329**  
**STATE of Arizona, Appellee,**  
**v.**  
**Robert Wayne JOHNSON, Appellant.**  
**No. CR-95-0393-PR.**  
**Supreme Court of Arizona, In Banc.**  
**July 16, 1996.**

Grant Woods, Arizona Attorney General by Paul J. McMurdie, Galen H. Wilkes, Phoenix, for State of Arizona.  
Robert F. Arentz, Phoenix, for Robert Wayne Johnson.

**OPINION**

FELDMAN, Chief Justice.

We granted review in this case to re-examine questions involving the admissibility of DNA profile probability statistics. The questions addressed are those left open by *State v. Bible*, 175 Ariz. 549, 858 P.2d 1152 (1993), our previous opinion on this subject.

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**FACTS AND PROCEDURAL BACKGROUND**

On the morning of July 9, 1991, in Sierra Vista, Arizona, a storekeeper was surprised by an intruder as she opened her business. The intruder overpowered the woman and raped her. The woman was taken to the emergency room where Sierra Vista police interviewed her and gathered her clothing. They then returned to the crime scene and retrieved paper towels the victim had used to clean herself.

Terry Hogan, a criminalist at the Arizona Department of Public Safety (DPS) crime laboratory, found that DNA extracted from blood and semen stains on the clothes and paper towels matched the DNA of a suspect, Robert Wayne Johnson. At Johnson's jury trial on sexual assault charges, the state presented evidence of the DNA match, and Hogan testified, over objection, that the probability of such a match occurring randomly was one in 312 million. The jury evidently believed that odds of one to 312 million established guilt beyond a reasonable doubt and found Johnson guilty of one count of sexual assault, a class two felony. The trial judge imposed an aggravated term of fourteen years' imprisonment and Johnson appealed, raising several issues. The court of appeals affirmed Johnson's conviction and sentence. *State v. Johnson*, 183 Ariz. 623, 636, 905 P.2d 1002, 1015 (App.1995).

Johnson then petitioned this court for review, claiming that the trial judge erred in admitting Hogan's testimony about the odds of a random match between Johnson's DNA and DNA extracted from the semen stains. In light of the importance of the issue and the uncertainty of the law on the point, we granted review of Johnson's claim regarding admission of the DNA evidence. See Ariz.R.Crim.P. 31.19.

**DISCUSSION**

**A. DNA analysis**

DNA analysis involves three basic steps: 1) creating the DNA profiles of evidence samples; 2) determining whether profiles of different samples match; and 3) if samples match, articulating the significance of the match, preferably by computing the probability of a random match. *State v. Bible*, 175 Ariz. 549, 577, 858 P.2d 1152, 1180 (1993), cert. denied, --- U.S. ---, 114 S.Ct. 1578, 128 L.Ed.2d 221 (1994).

Hogan used restricted fragment length polymorphism (RFLP) to create the DNA profiles and determine that they matched. The scientific principles underlying RFLP, its validity, and the process for declaring a match are well-documented and unchallenged here. Accordingly, we will not add to the literature by describing the complex technology and science underlying RFLP. 1

RFLP produces a picture or DNA profile of the suspect's blood, semen, or other specimen, which is compared to the DNA profile produced from the evidence sample. These profiles are referred to as autorads. An autorad resembles an x-ray and depicts with dark stripes or bands the presence of certain gene pairs. The particular genes represented on the autorad are called alleles.

If the two DNA profiles do not match then the suspect is positively excluded. If they do match, the evidence sample came either from the suspect or an identical twin, or the match was a complete coincidence. If there is no identical twin, as in the present case, the significance of a match can be expressed in terms of the probability that the suspect's DNA profile would occur randomly. See generally M. KRAWCZAK & J. SCHMIDTKE, *DNA FINGERPRINTING* 61-77 (Bios Scientific Publishers 1994). The probability can be expressed either qualitatively--

"probable," "highly probable"--or mathematically, as Hogan did in this case: one in 312 million. The issue under review concerns only this third step of DNA analysis: are DNA probability statistics produced by the modified ceiling method and expressed mathematically admissible under the standard for new scientific evidence? We held in Bible that admission of such evidence calculated by the product

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[186 Ariz. 331] rule was error. Bible, 175 Ariz. at 577, 858 P.2d at 1180.

B. The standard for admitting new scientific evidence

The state urges us to jettison the Frye 2 test for determining when new scientific evidence is ready for the courtroom and to adopt in its place the standard articulated in *Daubert v. Merrell Dow Pharmaceuticals, Inc.*, 509 U.S. 579, 113 S.Ct. 2786, 125 L.Ed.2d 469 (1993).

Under Frye, scientific evidence based on a newly postulated theory is admissible when that theory has been generally accepted in the relevant scientific community. See Bible, 175 Ariz. at 578, 858 P.2d at 1181. In contrast, *Daubert* says the trial judge in each case must make a "preliminary assessment of whether the reasoning or methodology underlying the testimony is scientifically valid and of whether that reasoning or methodology properly can be applied to the facts in issue." *Daubert*, 509 U.S. at 592-93, 113 S.Ct. at 2796.

The Frye rule has long been followed in Arizona, both before and after adoption of the Arizona Rules of Evidence. See, e.g., *State v. Velasco*, 165 Ariz. 480, 486, 799 P.2d 821, 827 (1990); *State ex rel. Collins v. Superior Court*, 132 Ariz. 180, 195-202, 644 P.2d 1266, 1281-99 (1982); *State v. Valdez*, 91 Ariz. 274, 277-80, 371 P.2d 894, 896-98 (1962).

In Bible we noted that *Daubert* "leaves many questions unanswered" and concluded that we would continue to follow Frye, at least for the present. In doing so we stated that notwithstanding legitimate criticism of Frye, and our desire to preserve uniformity when possible [that] ... even were we to use *Daubert*'s reliability/scientific validity analysis, we would still be left with the problem posed by Frye: precisely when "in [the] twilight zone the evidential force of the [scientific] principle must be recognized."

175 Ariz. at 580, 858 P.2d at 1183. We have seen nothing since and, as in Bible, find nothing in the arguments or briefs to persuade us that this case presents us with a reason to abandon Frye and follow *Daubert*. The federal courts have not yet had a fair opportunity to apply *Daubert*; thus, it is too early to properly evaluate it. We therefore conclude that for the present, and for the reasons stated in Bible, the Frye rule, which has been followed without causing significant problems since it was first adopted in 1962, remains the rule in Arizona. We turn then to apply that rule to the problem presented in this case.

C. Admissibility of probability evidence

1. *State v. Bible*

In Bible, we reviewed the admissibility of DNA probability evidence calculated with the product rule 3 and held that the DNA probability calculations based on Cellmark Laboratory's application of the product rule were inadmissible because,

[f]or purposes of Frye, these probability calculations are flawed in three ways: (1) they are impermissibly based on the disputed assumption of linkage equilibrium; (2) the database relied on is of disputed statistical validity; and (3) the database relied on is [concededly] not in Hardy-Weinberg equilibrium.

*Id.* at 585-86, 858 P.2d at 1188-89. The modified ceiling method, which was used to calculate the probabilities introduced at Johnson's trial, is inextricably linked to the product rule. Therefore, as a threshold requirement, the modified ceiling method must produce results untainted by the shortcomings articulated for the product rule in Bible.

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[186 Ariz. 332] 2. Assumption of linkage equilibrium

Cellmark's application of the product rule was rejected in Bible, in part because of "the disputed assumption of linkage equilibrium." *Id.* Linkage equilibrium refers to the principle of independent assortment, which states that the frequency of occurrence of alleles expressing different genetic traits will be determined independently of the frequency of the occurrence of other alleles in the sample. See MONROE W. STRICKBERGER, *GENETICS* 104-05 (3d ed., Macmillan Publishing Co., 1985). The National Research Council (NRC), in its 1992 report, *DNA Technology in Forensic Science* (NRC report), 4 illustrates the principle thusly:

From a statistical standpoint, the situation is analogous to estimating the proportion of blond, blue-eyed, fair-skinned people in Europe by separately counting the frequencies of people with blond hair, people with blue eyes, and people with fair skin and calculating their proportions [by application of the product rule].

NRC report at 76.

Thus, by way of illustration only, linkage equilibrium assumes that whether a person inherits the allele for blue eyes is unrelated to whether that person inherits the allele for blond hair or fair skin. Of course, as the NRC report points out, these three traits tend to co-occur in Nordics. Therefore the actual frequency of these three traits occurring together (assuming each trait occurs one time in ten) is not simply a straight calculation under the product rule of  $.10 \times .10 \times .10$  equals 1 in 1000. Instead, because of the co-occurrence of such observable, physical traits in certain sub-populations, the actual frequency in the total population of all three traits appearing in any one individual is probably considerably higher than 1 in 1000. Id.

This does not, however, necessarily invalidate the assumption of linkage equilibrium because the alleles chosen to create the DNA profile with the RFLP protocol are non-coding, that is, they are not responsible for producing any observable characteristic. See NRC report at 77; KRAWCZAK & SCHMIDTKE, *supra*, at 74; MAJ. DOUGLAS A. DRIBBEN, DNA Statistical Evidence and the "Ceiling Principle": Science or Science Fiction?, 146 MILITARY L.REV. 94, 105 (1994). Furthermore, these alleles are known to be extremely variable from person to person, and scientific studies have not shown any statistical correlation between them. NRC report at 77; KRAWCZAK & SCHMIDTKE, *supra*, at 74. Thus, as the NRC report makes clear, the assumption of linkage equilibrium inherent in protocols such as RFLP is well-grounded and has been proved accurate for purposes of DNA profiles. NRC report at 77. Accordingly, the assumption of linkage equilibrium for purposes of RFLP analysis and use in applying the product rule has been demonstrated to be generally accepted in the relevant scientific community. NRC report at 77; KRAWCZAK & SCHMIDTKE, *supra*, at 74.

### 3. Hardy-Weinberg equilibrium

The statistical validity of the product rule also assumes that mates are chosen randomly within any population, resulting in an equally random occurrence of any particular allele. Populations that are in random-mating proportions are said to be in Hardy-Weinberg equilibrium. See THE EVALUATION OF FORENSIC DNA EVIDENCE 4-2 (National Academy Press 1996) (prepublication copy) (1996 NRC report).

Of course people who live in close geographic proximity to each other are more likely to choose each other as mates, and people often select mates on the basis of certain physical, racial, cultural, and behavioral characteristics. However, the alleles used in DNA profiling do not represent physical, racial, cultural, and behavioral characteristics and are therefore not the basis for the choice of mates. Accordingly, the alleles

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[186 Ariz. 333] used for profiling remain in Hardy-Weinberg equilibrium. Id.

Our concern with Hardy-Weinberg equilibrium in Bible was not with the general acceptance of the scientific principle but instead was limited to Cellmark's admittedly defective database. Bible, 175 Ariz. at 585-86, 858 P.2d at 1160-61. Unlike the situation with Cellmark's database, Hogan testified to testing for and finding the DPS database in Hardy-Weinberg equilibrium. Nothing in the record refutes this testimony.

### 4. Statistical validity of the database--size, randomness and representativeness

To estimate the probability that a defendant's DNA is the same as that taken from a crime scene, the expert relies on a previously constructed database. LORNE T. KIRBY, DNA FINGERPRINTING: AN INTRODUCTION 171 (1990). This database allows the expert to calculate the frequency of the alleles with which such a match could be expected in the general population. See *State v. Cauthron*, 120 Wash.2d 879, 846 P.2d 502, 513 (1993).

Cellmark's concededly flawed database in Bible and the then-disputed assumption of linkage equilibrium made it unnecessary to consider other statistical qualities of Cellmark's database. Bible's other concerns have been addressed here, but Johnson also challenges the statistical validity of the DPS database used in this case. Thus, we must determine whether the DPS database, which is comprised of samples from blood banks, is generally accepted in the relevant scientific community. See Bible, 175 Ariz. at 583 n. 22, 858 P.2d at 1186 n. 22.

With respect to size, "the scientific community now generally agrees that a database consisting of as few as 150 individuals will suffice, so long as the individuals are unrelated." DRIBBEN, *supra*, at 104-05 (citing Ranajit Chakraborty, Sample Size Requirements for Addressing the Population Genetic Issues of Forensic Use of DNA Typing, 64 HUM. BIOLOGY 141, 157 (1992)). Additionally, the recommended sample size for the NRC's "non-modified" ceiling method, proposed in the same report, is 100 for a given racial group. The DPS database consisted of approximately 200 samples for each of four racial groups.

As for randomness, the NRC report concludes that to be sufficiently random, the database need only consist of samples drawn at random from designated populations. NRC report at 77, 83. Randomness is satisfied when there is linkage equilibrium and Hardy-Weinberg equilibrium. See *Cauthron*, 846 P.2d at 514; NRC report at 83. Finally, to ensure the database is sufficiently representative, the modified ceiling method calls for samples drawn from at least three racial populations. NRC report at 91. The DPS database was drawn from four different racial populations. Three of these populations were used by Hogan in his calculations, and the samples were identified only by race.

Hogan tested for and found the database to be in Hardy-Weinberg equilibrium. We have already determined that the assumption of linkage equilibrium has been sufficiently proven. Thus, we believe the size, randomness, and representativeness of the DPS database were such that the database was generally accepted in the relevant scientific community.

#### 5. The modified ceiling method

The modified ceiling method is an application of the product rule. This method, however, has the added dimension of addressing any effect subpopulations might have on product rule calculations. Subpopulations refer to stratifications within distinct racial groups. See NRC report at 11-15, 91-93. The modified ceiling method addresses the possible effects of subpopulations by making product rule calculations more conservative. See *id.* at 13, 91-93. It does this by utilizing databases containing frequency information on at least three principal racial populations. The occurrence frequency of alleles represented in the autorads are calculated for each racial population. If any allele's frequency in any of the populations is less than ten percent, that allele is assigned the frequency of ten percent. In other words, no allele will be assumed to occur less frequently than ten percent of the time in any of the several populations, regardless of how infrequently it

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[186 Ariz. 334] might actually have occurred. If an allele's frequency is greater than ten percent in any population, then the highest observed frequency is used to compute the ninety-five percent confidence interval 5 for that frequency. This results in moving the highest observed frequency, if it was over ten percent, higher still. NRC report at 14-15, 91-93. Employing these occurrence frequencies for the individual alleles, the product rule is then applied to determine the probability of a suspect's DNA profile occurring randomly. This probability is both race-neutral and conservative, thereby accounting for any effect of subpopulations. NRC report at 13, 91-92. Any error in the probability would be in the direction of increased probability of a random match, so that the final calculation favors defendants. *Id.*

NOTE: OPINION CONTAINS TABLE OR OTHER DATA THAT IS NOT VIEWABLE

#### 6. Admissibility of the modified ceiling method under Frye

Hogan testified at the Frye hearing and at trial about the modified ceiling method procedures he used to compute the DNA probability evidence. Johnson asserted at oral argument that admissibility of the modified ceiling method was not ruled on by the trial judge and is not properly an issue before this court. We have reviewed the transcript of the Frye hearing, the trial testimony, and the NRC report describing the modified ceiling method. We conclude that the issue of admissibility of the modified ceiling method was squarely ruled on by the trial judge and is properly before us. See Reporter's Transcript (R.T.), Sept. 23, 1992, at 126-36; R.T., Oct. 15, 1992, at 317-22; NRC report at 91-92.

Under Frye, this court conducts a *de novo* review to determine whether a scientific principle used as a basis for expert testimony is generally accepted in the relevant scientific community. *Bible*, 175 Ariz. at 578, 858 P.2d at 1181. At the Frye hearing, Hogan testified that the modified ceiling method is recommended by the NRC. See NRC report at 91-92. Other courts have recognized that the [NRC] is a distinguished cross section of the scientific community.... Thus, that committee's conclusion regarding the reliability of forensic DNA typing, specifically RFLP analysis, and the proffer of a conservative method for calculating probability estimates can easily be equated with general acceptance of those methodologies in the relevant scientific community.

*United States v. Porter*, 618 A.2d 629, 643 n. 26 (D.C.App.1992), quoting *United States v. Bridgett*, 120 Daily Wash.L.Rep. 1697 (D.C.Super.Ct.1992); see also *Cauthron*, 846 P.2d at 517 (NRC's adoption of ceiling method "indicates sufficient acceptance within the scientific community" for Frye purposes). We, too, believe that endorsement by the NRC of the modified ceiling method is strong evidence of general acceptance within the relevant scientific community. But we need not rely solely on the NRC's endorsement. Several other courts have addressed this issue and found the modified ceiling method to be generally accepted. See *Commonwealth v. Lanigan*, 419 Mass. 15, 641 N.E.2d 1342 (1994); *State v. Bloom*, 516 N.W.2d 159, 167 (Minn.1994); *State v. Anderson*, 118 N.M. 284, 881 P.2d 29, 47 (1994).

These judicial views are supported by the weight of scientific opinion. Eric S. Lander and Bruce Budowle were two of the principal antagonists involved in the initial debate over forensic DNA typing. See *DNA Fingerprinting Dispute Laid to Rest*, 371 NATURE 735 (Oct.1994). Both Lander and Budowle have concluded that following the NRC's report "there is no scientific reason to doubt the accuracy of forensic DNA typing results," such as the modified ceiling method. *Id.*

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[186 Ariz. 335] Most telling, perhaps, is that those forensic experts who take issue with the modified ceiling method do so because they believe it produces excessively conservative results that unduly favor the defendant. See, e.g., Eric E. Wright, DNA Evidence: Where We've Been, Where We Are, And Where We're Going, 10 MAINE BAR J. 206 (1995); David H. Kaye, DNA Evidence: Probability, Population Genetics, and the Courts, 7 HARV. J.L. & TECH. 101 (1993); DRIBBEN, supra, at 124-42; Peter Aldhous, Geneticists Attack NRC Report as Scientifically Flawed, 259 SCIENCE 755 (1993); B. Devlin, Neil Risch, Kathryn Roeder, Statistical Evaluation of DNA Fingerprinting: A Critique of the NRC's Report, 259 SCIENCE 748 (1993); Richard Lempert, DNA, Science and the Law; Two Cheers For The Ceiling Principle, 34 JURIMETRICS J. 41 (1993); Kenneth R. Kreiling, DNA Technology in Forensic Science, 33 JURIMETRICS J. 449 (1993).

The National Research Council's Committee on DNA Forensic Science and Commission on DNA Forensic Science have released a pre-publication version of THE EVALUATION OF FORENSIC DNA EVIDENCE updating the 1992 NRC report. This report concludes that sufficient data has been gathered to make the conservative approach of the ceiling principles no longer needed. *Id.* at 5-32. It further concludes that alternative methods, primarily the product rule, are now appropriate. *Id.* We fail to see any prejudice to a defendant in results produced by a method that, if biased, is biased in the defendant's favor.

Based on our review of the NRC reports, legal commentary, scientific literature, and consideration and acceptance of the modified ceiling method by other jurisdictions, we conclude that the method is generally accepted in the relevant scientific community and that DNA probability calculations computed with that method are admissible under Frye. Our holding extends only to the issue presented in this case--the modified ceiling method. Notwithstanding the 1996 NRC report's conclusions, we do not at this time address the admissibility of probability statistics calculated with the "pure" product rule.

#### D. DPS methodology

Johnson also argues that even if the modified ceiling method is generally accepted, the procedures Hogan used did not properly implement that method. Specifically, Johnson claims that the entire procedure used to calculate the probability of a match was invalid because Hogan did not search the DPS database for a match with his DNA profile. We disagree.

In its first report, the NRC recommends that the defendant's profile be checked against all the profiles in the database to see if it matches any of them. NRC report at 91. "Assuming that it does not, [the jury should be told] that the [profile] was compared to a database of N individuals from the population and no match was observed, indicating its rarity in the population." *Id.* The purpose of testing for such a match is to generate a separate and unrelated statistic to indicate the rarity of a suspect's profile in the database and "make[ ] clear the size of the database being examined." *Id.* Although such a statistic is arguably helpful, it is not part of the modified ceiling method and does not affect the probability calculation that is admissible under that method.

#### CONCLUSION

The Frye test remains the standard for admissibility of new scientific evidence. DNA probability evidence calculated by use of the RFLP protocol and with the modified ceiling method is generally accepted in the relevant scientific community and is therefore admissible under the Frye test, subject to proper foundational showing. See Bible, 175 Ariz. at 580, 858 P.2d at 1183. Upon such a showing, the significance of a DNA profile match may be explained with probability estimates based on the method's calculations. Accordingly, we approve the court of appeals' opinion finding that the trial judge did not err in permitting testimony on the mathematical probability of Johnson's

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[186 Ariz. 336] DNA profile occurring randomly and affirm Johnson's conviction and sentence.

ZLAKET, V.C.J., MOELLER and MARTONE, JJ., and JACOBSON, Judge (retired), concurring.

ROBERT J. CORCORAN, J., did not participate in the determination of this matter; pursuant to Ariz. Const. art. VI, § 3, the Honorable EINO M. JACOBSON, Judge (retired) of the Arizona Court of Appeals, Division One, was designated to sit in his stead.

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1 For a more detailed explanation of RFLP analysis, with cites to the scientific literature, see Bible, 175 Ariz. 549, 858 P.2d 1152; State v. Anderson, 118 N.M. 284, 881 P.2d 29 (1994); or State v. Cauthron, 120 Wash.2d 879, 846 P.2d 502 (1993).

2 Frye v. United States, 293 F. 1013 (D.C.Cir.1923) (use of lie detectors).

3 The product rule is described as follows:

Suppose, for example, that a pair of DNA [profiles] match on two bands, and that one band reflects an allele found in ten percent of the population and the other an allele found in fifty percent of the population. Applying the product

rule, an analyst would conclude that the probability of a coincidental match on both alleles is  $0.10 \times 0.50 = .05$ , or a five percent probability.

William C. Thompson & Simon Ford, DNA Typing, 75 VA.L.REV. 45, 81-82 (1989).

4 The National Research Council's members are drawn from the councils of the National Academy of Sciences, the National Academy of Engineering, and the Institute of Medicine. The members who prepared this report were chosen for their special competencies. The report was reviewed by a group other than the authors who prepared it, according to procedures approved by a Report Review Committee, consisting of members of the National Academy of Sciences, the National Academy of Engineering, and the Institute of Medicine. NRC report at ii.

5 According to the NRC, the upper 95% confidence limit is given by the formula:

Here,  $p$  is the observed frequency and  $N$  is the number of chromosomes studied, which should correspond to the number of loci multiplied by the size of the population studied. NRC report at 92.