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851 P.2d 884
Jeffrey FISHBACK, Petitioner,
v.
The PEOPLE of the State of Colorado, Respondent.
No. 92SC68.
Supreme Court of Colorado,
En Banc.
April 26, 1993.
Rehearing Denied May 17, 1993.

Richard F. Thurston, Solomon L. Leftin, Denver, for petitioner.

Gale A. Norton, Atty. Gen., Raymond T. Slaughter, Chief Deputy Atty. Gen., Timothy M. Tymkovich, Sol. Gen., John Daniel

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Dailey, Deputy Atty. Gen., Robert Mark Russel, First Asst. Atty. Gen., Deborah Isenberg Pratt, Asst. Atty. Gen., Denver, for respondent.

Chief Justice ROVIRA delivered the Opinion of the Court.

We granted certiorari to review the decision of the Colorado Court of Appeals in People v. Fishback, 829 P.2d 489 (Colo.App.1991), affirming the trial court's admission of identification testimony based on a comparison of deoxyribonucleic acid (DNA) obtained from the defendant's blood with the DNA from a semen sample recovered from the victim. The admissibility of DNA identification evidence is a question of first impression for this court.

I. FACTUAL AND PROCEDURAL BACKGROUND

The defendant was convicted of first degree sexual assault, second degree burglary, and mandatory sentence violent crime.

The evidence connecting the defendant to these crimes included the victim's identification of defendant, fingerprint evidence, and expert testimony that a DNA profile from seminal fluid obtained by a medical examination of the victim after the assault matched a DNA profile from a blood sample taken from defendant.

The trial court conducted an evidentiary hearing on defendant's motion to suppress the DNA typing evidence. At the hearing two witnesses testified: Dr. William Setzer, the director of the University of Colorado Health Sciences Center DNA Diagnostic Laboratory 1 who was qualified as an expert in the area of molecular biology, genetics, and "DNA testing"; and Dr. Lisa Forman, an employee of Cellmark Diagnostics, 2 who was qualified as an expert in population genetics. At the conclusion of the hearing, the trial court ruled that DNA typing evidence was admissible under both CRE 702 and the test articulated in Frye v. United States, 293 F. 1013 (D.C.Cir.1923).

The court of appeals affirmed, holding DNA typing evidence to be generally accepted within the relevant scientific communities and thus, admissible under the standard set forth in Frye. We affirm.

II. SCIENTIFIC BACKGROUND

A basic understanding of the scientific principles and techniques underlying DNA typing is essential in order to understand the legal issues relating to its admissibility. DNA typing for forensic purposes utilizes a technique in which the characteristics of a suspect's genetic structure are profiled and compared to the genetic structure found in material such as blood, hair, or semen recovered from a crime scene. The two profiles are then compared to see if they match. If the two profiles match, the statistical significance of such a match is calculated to determine the likelihood of a match occurring between the profile derived from the crime scene sample and a third person who is not the suspect. The process by which this is accomplished can be divided into three parts: (A) The theory underlying DNA typing; (B) the techniques which apply that theory; and (C) the method of calculating the statistical significance of a declared match.

A. DNA theory.

DNA is the material that determines the genetic characteristics of all living things. The significant feature of DNA for forensic purposes is that, with the exception of identical twins, 3 no two individuals have identical DNA. Furthermore, because DNA does not vary within a particular individual, a DNA molecule found in one cell will be identical to the DNA found in every other cell of that person.

In human beings, every cell that has a nucleus contains DNA which is distributed

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across forty-six sections of the nucleus of the cell. These sections are referred to as chromosomes, and they form twenty-three pairs: half of each pair are inherited from the mother, the other half from the father. These twenty-three chromosomes contain thousands of genes which comprise the total genetic makeup of an individual. "Alleles" are polymorphisms of a given gene, i.e., they vary from one individual to the next, and since each gene is represented by two copies (one from each parent) two alleles are inherited for each gene. When alleles that constitute a pair (or "genotype") differ, the person is said to be "heterozygous" for that allele. When a person inherits the same allele from both parents, that person is said to be "homozygous" for that allele.

A DNA molecule is a double helix, resembling a ladder that has been twisted which, if unraveled, would be approximately six feet in length. The "sides" of the ladder are composed of a chain of deoxyribose sugars and phosphates, while the "rungs" are composed of one pair of the following nucleotide bases: Adenine (A), Cytosine (C), Guanine (G), and Thymine (T). According to the "base pair rule," A can only bond with T and G can only bond with C. Thus, the order of the bases on one side of the rung will determine the order on the other side.

Each DNA molecule contains approximately 3 billion base pairs, or rungs, the vast majority of which (99%) do not differ from one human being to the next. It is this similarity in rungs which accounts for the human characteristics of human beings. Certain sections of the DNA molecule differ (i.e., they are allelic) from individual to individual, race to race, and ethnic group to ethnic group. These areas of variation are called "polymorphic sites." At some polymorphic sites short sequences of base pairs repeat in tandem, over and over again. The core sequence comprising a given allele is called a Variable Number Tandem Repeat (VNTR) and may contain just a few or as many as several dozen nucleotide bases. Because the number of times the core sequence of base pairs repeats may vary among individuals, the length of a given allele, measured in numbers of base pairs, may also vary. For instance, one person may have a particular allele in which a given core sequence repeats only ten times, whereas that same allele in another person may contain the same VNTR that repeats 100 times.

There are approximately three million alleles on each human DNA ladder. While all of these alleles are polymorphic, some are much more polymorphic than others. Forensic DNA typing utilizes a small number of highly polymorphic or "hypervariable" sites.

A DNA profile arrived at through the isolation and comparison of the lengths of several highly polymorphic alleles is known as restriction fragment length polymorphism (RFLP) analysis. 4 A DNA profile constructed by means of RFLP analysis is accomplished through the following techniques.

B. Techniques of RFLP analysis.

1. Extraction of DNA. The biological material that contains DNA must ordinarily be separated from the material in which it is found. Once separated, the DNA is extracted from the samples by a chemical treatment which releases the DNA. An enzyme is then added to digest cellular material other than DNA, rendering a purer DNA sample. 5

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2. Restriction or Digestion. The DNA is then mixed with restriction enzymes which "cut" the DNA molecules into fragments at specific base sequences. These enzymes recognize particular sequences of base pairs and sever the DNA molecule at all sites along the three billion base pair length of the molecule where the targeted base pair sequence occurs. This results in numerous DNA fragments which can vary in length from a few base pairs to several thousand. 6

3. Gel Electrophoresis. Next, the DNA fragments are sorted by length through a process known as "agarose gel electrophoresis." The solutions of DNA fragments from the various sources are placed in an electrically polarized gel near the negative electrode. Because DNA is negatively charged, the fragments will migrate towards the positive end of the gel. They will do so, however, to varying degrees based on the length of the fragment: the shorter fragments, being lighter and less bulky, will travel faster and farther in the gel. Several samples are run on the same gel but in different tracks or lanes which run parallel to one another. In addition to the sample fragments, other fragments of known length are placed in separate lanes of the gel in order to facilitate measurement of the sample fragments. At the completion of electrophoresis, the DNA fragments are arrayed across the gel according to length. 7

4. Southern Transfer and Denaturing. Due to the difficulty of working with agarose gel, the fragments are transferred to a more functional surface through the "Southern Transfer" method. A nylon membrane is placed over the gel and, through capillary action, the DNA fragments permanently attach themselves to the membrane while occupying the same position relative to one another as they had in the gel. At the same time, the fragments are treated with a chemical which splits each base from its complement by "sawing" through the middle of each rung so that the base pairs are separated into two strands. 8

5. Hybridization. A technique is then employed in order to locate the highly polymorphic alleles contained in the fragments which are useful for forensic DNA typing. This is done by dipping the nylon membrane in a solution of various "genetic probes" which are single-stranded DNA fragments of known length and sequence designed to complement the single-stranded base sequence of polymorphic fragments from the defendant and the crime scene samples. The probes hybridize only to those DNA fragments which contain base pair sequences that are complementary to the base sequence of the probe. Usually three to five different probes are used to isolate multiple alleles. The genetic probes are "tagged" with a radioactive marker so that, after linkage with the half of the core sequence that was split in two, the position of those alleles can eventually be observed. The nylon membrane is then washed to remove excess, unbound probes.

The probe will usually bind to DNA fragments at one or two locations in each lane, depending on whether the individual from whom the DNA was taken is heterozygous or homozygous for that allele.

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6. Autoradiography. This process enables the position of the probes, and their complementary and now linked polymorphic fragments, to be recorded. This is done by placing the nylon membrane on an x-ray film which is exposed by the energy of the radioactively tagged probes. This results in a pattern of bands called an autoradiograph, also known as a "DNA print" or "autorad," and is said to resemble a bar code such as those found on many grocery store products. Each band represents a different polymorphic allele and its position indicates the length of the fragment in which that allele occurs. Because the length of alleles may differ among individuals, the position of the bands on the autorad will tend to differ from person to person.

7. Interpretation. Next, the locations of the alleles on the autorad are examined to determine whether or not both DNA samples came from the same person. This comparison can be done through either a visual inspection or with a machine that measures the bands through a process of computer imaging, or both. In order to declare a match, however, the bands need not line up exactly. Rather, a match will be declared if the bands fall within a certain distance of one another. The Federal Bureau of Investigations, for example, will declare a match if the length of two fragments fall within plus or minus 2.5% of one another in base pairs. Cellmark will declare a match if the length of two fragments fall within 1 millimeter of one another. The smaller the allowable measure of deviation or "match window," the less chance there is that a match can be declared. 9

C. Statistical Analysis.

Once a match has been declared, its statistical significance must be determined. This is usually expressed in terms of the likelihood that the crime scene samples came from a third person who has the same DNA profile as the suspect.

In order to calculate the statistical significance of a match, Cellmark calculates how frequently each band produced by one probe is found in the target population. That population is determined by the race of the defendant. This is done by taking each band and categorizing it according to a specific range of base pair lengths--called a bin--and determining how often bands within that bin appear in the target population. The frequency with which a band appears in the African-American population was determined by Cellmark by profiling blood samples obtained from the Detroit Red Cross and were based on analysis of between 120 and 296 samples, depending on the particular genetic probe used.

First, the frequency of each allele is calculated, and then the frequency for each genotype is calculated. This is done by multiplying the frequency of each of the two alleles which comprise the genotype by one another. 10 This assumes that there is no statistical correlation between those two alleles. The absence of such a correlation is referred to as "Hardy-Weinberg equilibrium." Next, the frequency for the complete multilocus genotype is calculated by multiplying the genotype frequency at all the loci by one another. Again, this assumes that there is no correlation between genotypes at the individual loci. The absence of such a correlation is referred to as "linkage equilibrium."

III. STANDARD OF ADMISSIBILITY

In Frye v. United States, 293 F. 1013 (D.C.Cir.1923), the court declined to admit the results of a systolic blood pressure deception test, an early predecessor to the contemporary "lie-detector" test, designed

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to show if the defendant was telling the truth. The Frye court stated:

Just when a scientific principle or discovery crosses the line between the experimental and demonstrable stages is difficult to define. Somewhere in this twilight zone the evidential force of the principle must be recognized, and while courts will go a long way in admitting expert testimony deduced from a well-recognized scientific principle or

discovery, the thing from which the deduction is made must be sufficiently established to have gained general acceptance in the particular field in which it belongs.

Id. at 1014. By requiring the general acceptance of novel scientific evidence within the relevant scientific community, the Frye court sought to ensure that only reliable evidence was admitted. See United States v. Jakobetz, 955 F.2d 786, 794 (2d Cir.), cert. denied, 506 U.S. 834, 113 S.Ct. 104, 121 L.Ed.2d 63 (1992). Although the Frye test has been criticized, see generally, Paul C. Giannelli, The Admissibility of Novel Scientific Evidence: Frye v. United States, a Half-Century Later, 80 Colum.L.Rev. 1197 (1980) (hereinafter, "Frye a Half-Century Later "), it has a number of strengths, and remains the majority rule for determining the admissibility of novel scientific evidence. See Jakobetz, 955 F.2d at 794 (describing Frye as the majority rule); State v. Vandebogart, 136 N.H. 365, 616 A.2d 483, 488-89 (1992) ("Most courts that have considered the admissibility of novel scientific evidence have adopted the Frye test."). As one court has observed, the Frye test

(1) permits disputes concerning scientific validity to be resolved by the relevant scientific community ...; (2) ensures that "a minimal reserve of experts exist who can critically examine the validity of a scientific determination in a particular case," ...; (3) spares courts from the time-consuming and difficult task of repeatedly assessing the validity of innovative scientific techniques, ...; and (4) "promote[s] a degree of uniformity of decisions."

Vandebogart, 616 A.2d at 489 (citations omitted).

We adopted Frye as the applicable standard for determining the admissibility of novel scientific evidence in People v. Anderson, 637 P.2d 354 (Colo.1981). We reiterated our adherence to Frye in People v. Hampton, 746 P.2d 947 (Colo.1987), and again in Campbell v. People, 814 P.2d 1 (Colo.1991). Though Campbell and Hampton reaffirmed the applicability of the Frye test to novel scientific evidence, Frye was not applied in either of those cases because the evidence sought to be admitted did not fall within the traditional application of Frye. Consequently, the evidence in both Campbell and Hampton was analyzed under CRE 702. 11

In Hampton, we held CRE 702 was the proper standard for determining the admissibility of rape trauma syndrome evidence 12 noting that the evidence concerned only "the reactions of rape victims generally; none of [the expert's] testimony concerned this particular victim. [The expert] did not interview or contact the victim...." Hampton, 746 P.2d at 951. Therefore, we concluded that CRE 702, rather than Frye, was the proper standard for governing the admissibility of this evidence. 13

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Similarly, in Campbell we declined to apply the Frye standard in assessing the admissibility of evidence concerning the reliability of eyewitness identification and, instead, applied CRE 702, again noting that the traditional application of Frye did not encompass this evidence. Campbell, 814 P.2d at 8 ("[T]he Frye standard of general acceptance within a particular scientific field has been employed as a special foundational requirement for novel scientific devices or processes involving the evaluation of physical evidence.... Here, however, we deal with no such scientific device or process.").

DNA typing evidence, in contrast, is precisely the sort of scientific evidence which requires application of the Frye test. 14 See United States v. Porter, 618 A.2d 629, 633 (D.C.App.1992) (admissibility of DNA evidence "presents the very kind of issue which the language from Frye was designed to address"). For example, in Hampton we noted that

[g]enerally, the Frye test is applied to novel scientific devices and processes involving the manipulation of physical evidence including lie detector tests, experimental systems of blood typing, voice prints, identification of human bite marks, and microscopic analysis of gun shot residue.

Hampton, 746 P.2d at 950-51. See also Campbell, 814 P.2d at 8 (recognizing the same traditional application of Frye). DNA typing requires a number of highly technical and sophisticated techniques in order to extract, isolate, and observe alleles contained in human DNA molecules. Moreover, because the potential of DNA typing technology for forensic purposes was first recognized in the mid-1980's, first applied in the late 1980's, and involves techniques which are continuously evolving, DNA typing is a "novel" scientific process. In short, DNA typing is, in the words of the Campbell and Hampton courts, a "novel scientific ... process[ ] involving the evaluation of physical evidence." Id.

That Frye is the appropriate standard for determining the admissibility of DNA typing evidence is not seriously disputed by the parties here. 15 They disagree, however,

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on what formulation of Frye is to be applied. This disagreement apparently arises from the fact that there is some dispute among courts whether it is the underlying theory or the techniques which produce novel scientific evidence, or both, that are relevant under Frye. See Frye a Half-Century Later, supra, at 1211-15; William C. Thompson &

Simon Ford, DNA Typing: Acceptance and Weight of the New Genetic Identification Tests, 75 Va.L.Rev. 45, 55 (1989) (hereinafter "DNA Typing: Acceptance and Weight of the New Genetic Identification Tests").

The prior opinions of this court clearly indicate both the theory and techniques underlying novel scientific evidence must be generally accepted under Frye. For example, in Anderson we concluded that "the scientific theory or technique of the polygraph is [not] sufficiently advanced to permit its use at trial as competent evidence of credibility." Anderson, 637 P.2d at 359. Similarly, in both Campbell and Hampton we observed that the Frye test has traditionally been applied to "novel scientific devices and processes...." Campbell, 814 P.2d at 8; Hampton, 746 P.2d at 950-51. Numerous other courts apply this same two-pronged requirement under Frye. See, e.g., State v. Vandebogart, 136 N.H. 365, 616 A.2d 483, 489-90 (1992) (holding Frye test applies both to the underlying theory and process of novel scientific evidence and observing that this is the general rule); State v. Ford, 301 S.C. 485, 392 S.E.2d 781, 783 (1990) (same). A standard requiring acceptance of only one or the other could lead to the illogical admission of evidence because the theory underlying that evidence is generally accepted even though the techniques for implementing it are highly suspect or controversial. To avoid such an incongruous result, and help insure that only reliable evidence be admitted, we hold that under Frye, the admissibility of novel scientific evidence requires a showing of (1) general acceptance in the relevant scientific community of the underlying theory or principle, and (2) general acceptance in the relevant scientific community of the techniques used to apply that theory or principle.

We now consider whether the underlying theory and techniques utilized in DNA typing were generally accepted at the time of trial. Our analysis focuses on the time at which this evidence was offered at trial because under Frye, a party need not prove the absolute validity of the techniques used in producing novel scientific evidence before it can be admitted. Such an exacting requirement would necessarily be based on conjecture and speculation for it would require witnesses to venture their opinions regarding events, theories or discoveries which may, or may not, arise in the future. Rather, Frye mandates that if scientific evidence is generally accepted at the time it is offered, then it is admissible. Frye requires nothing more. 16 Consequently, it is the task of an appellate court reviewing a Frye determination to assess whether novel scientific evidence was generally accepted in the relevant scientific communities at the time it was offered into evidence at trial. The evidentiary hearing in this case on the issue of DNA typing's admissibility was conducted in October of 1989, and therefore, our assessment of general acceptance is determined by reference to that time. 17

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IV. LEGAL ANALYSIS

There are a number of relevant scientific communities for purposes of DNA typing. The fields of molecular and human genetics are largely responsible for the theory underlying DNA typing. The fields of molecular biology, biochemistry and their related disciplines are largely responsible for RFLP analysis. The disciplines of population genetics, human genetics, and demographics are responsible for determining the statistical significance of a declared match.

A. Underlying Theory.

There is no question the theory underlying DNA typing was generally accepted among the relevant scientific communities. As one commentator has observed: "There is nothing controversial about the theory underlying DNA typing. Indeed, the theory is so well accepted that its accuracy is unlikely even to be raised as an issue in hearings on the admissibility of the new tests.... [A]mong informed scientists, dissenting points of view are almost totally absent." DNA Typing: Acceptance and Weight of the New Genetic Identification Tests, supra, at 60-61. No evidence was presented at the evidentiary hearing which casts any doubt on this conclusion, and we are aware of no authority which contradicts it. Thus, we hold that the theory underlying DNA typing was generally accepted in the relevant scientific communities at the time of trial.

B. Techniques of RFLP Analysis.

The techniques of RFLP analysis--DNA extraction, digestion, gel electrophoresis, Southern transfer and denaturing, hybridization, autoradiography, and the interpretation of the autorads--were generally accepted techniques. See, e.g., Caldwell v. State, 260 Ga. 278, 393 S.E.2d 436, 441 (1990) (observing that there is "no real dispute" concerning the acceptance of the techniques involved in RFLP analysis but rather, that "dispute centers on the techniques and procedures followed (or not followed) ... in this case"). The concerns expressed in the scientific and legal literature, as well as cases from other jurisdictions, center on essentially two issues: (1) whether the techniques employed in RFLP analysis can be transferred to the area of forensics; and (2) whether these techniques were properly performed in a particular case. DNA Typing: Acceptance and Weight of the New Genetic Identification Tests, supra, at 63-76 (noting that all the basic techniques that comprise RFLP analysis are generally accepted in the relevant scientific communities and that the only potential areas of dispute under Frye are (1) the application of those techniques in forensics and (2) the proper performance of those techniques in individual cases).

These concerns were exemplified in the present case. Here the defendant only challenged the implementation and execution of these techniques by Cellmark; the soundness of those techniques in the abstract and their general acceptance if properly performed were never questioned. This fact is consistent with the observation that no serious dispute exists as to whether the techniques involved in RFLP analysis are generally accepted. See Andrews v. State, 533 So.2d 841, 849 (Fla.1988) (observing that DNA sequencing and comparison testing has been scientifically accepted as reliable and has been used by laboratories worldwide in the study, diagnosis, and treatment of inherited diseases for well over a decade); State v. Schwartz, 447 N.W.2d 422, 425 (Minn.1989) ("It is undisputed that RFLP analysis is routinely performed and generally accepted for research

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and diagnostic purposes within many scientific disciplines.").

We are of the opinion that the areas of concern regarding RFLP analysis go to the weight, and not the admissibility, of DNA typing evidence under Frye. As noted above, the techniques employed in RFLP analysis are generally accepted in the relevant scientific communities. Those techniques do not vary when they are applied in the context of forensic science. Rather, identical techniques are employed which, when used with forensic samples, raise concerns that are generally nonexistent in the clinical laboratory. See supra notes 5-10. As one court has observed, RFLP "analysis has been utilized for a number of years in diagnostic settings. Because the focus is different than in the diagnostic setting, problems may exist that are unique to forensic DNA tests.... Such problems, however, concern the reliability of the particular tests performed in a particular case." State v. Ford, 301 S.C. 485, 392 S.E.2d 781, 783 (1990). See State v. Vandebogart, 136 N.H. 365, 616 A.2d 483, 493 (1992). As such, those concerns, and the weight to be accorded them, are properly left for jury determination.

Similarly, the concerns that may arise in the implementation of these otherwise generally accepted techniques are not relevant factors under a Frye analysis. Those concerns go only to the proper performance of RFLP analysis techniques, not whether those techniques themselves are generally accepted. As such, they go only to the weight to be accorded such evidence. United States v. Porter, 618 A.2d 629, 634 (D.C.App.1992); Vandebogart, 616 A.2d at 490 (whether generally accepted techniques were adhered to in a particular case is not a relevant factor under Frye); People v. Mohit, 153 Misc.2d 22, 579 N.Y.S.2d 990, 992 (Westchester County Ct.1992) (adherence to generally accepted technique goes to the weight, not admissibility, of evidence).

Thus, we hold that both the underlying theory of DNA typing as well as the techniques employed in RFLP analysis were (and remain) generally accepted in the relevant scientific communities. Therefore, trial courts may, in the future, take judicial notice of their general acceptance and avoid the need for relitigation of these issues.

C. Statistical Analysis.

The final step in DNA typing for forensic purposes involves the method by which Cellmark and other laboratories calculate the probability of a random match between the DNA profile derived from the crime scene and the profile derived from the suspect. 18 We hold that the techniques employed in this case to calculate the statistical frequency of a declared match were, as of the date this evidence was admitted at trial, generally accepted in the relevant scientific communities.

In so holding we note first that the testimony of Dr. Forman was uncontradicted, and established that the method by which Cellmark calculated the statistical frequencies in this case were reliable and generally accepted in the relevant scientific communities. On cross-examination, defendant attempted to rebut this testimony with reference to a single article which questioned the validity of these statistical frequencies.

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See Eric S. Lander, DNA Fingerprinting on Trial, 339 Nature, June 15, 1989 at 501. Dr. Forman testified, however, that in her opinion, the concerns expressed by Lander had been adequately addressed and were, therefore, no longer valid.

In addition, the vast majority of published opinions which existed at the time of trial reveal that the statistical frequencies which accompany a declared match were considered generally accepted in the relevant scientific communities. Indeed, the only published opinions we are aware of that held DNA typing evidence inadmissible under Frye did not do so on the basis that the statistical frequencies which accompany a declared match were not generally accepted. See, e.g., United States v. Castro, 144 Misc.2d 956, 545 N.Y.S.2d 985 (Sup.Ct.1989) (DNA typing evidence inadmissible due to failure of laboratory to comply with generally accepted techniques); State v. Schwartz, 447 N.W.2d 422, 428 (Minn.1989) (same). Finally, we are aware of only the one scientific study referred to at trial that questioned the acceptability of these statistical frequencies in October of 1989. This single source is, of course, not an adequate basis by which to find a lack of general acceptance in the relevant scientific community. Consequently, we hold that, given the acceptance by other courts and the relative absence of dissenting points of

view, DNA typing evidence accompanied by statistical frequencies arrived at in the manner here was generally accepted in the relevant scientific community at the time it was offered at trial. Therefore, we conclude that this evidence was properly admitted under Frye.

In so holding, we are mindful that considerable debate has emerged in the three years since the trial in this case concerning the acceptability of the statistical frequencies which accompany a declared match of DNA profiles. See DNA Technology in Forensic Science 9-15, 74-96 ("[s]ubstantial controversy" exists regarding the current method of estimating allele frequency) (hereinafter "NRC Report "); Richard C. Lewontin & Daniel L. Hartl, Population Genetics in Forensic DNA Typing, Science, Dec. 20, 1991, at 1745; Ranajit Chakraborty & Kenneth K. Kidd, The Utility of DNA Typing in Forensic Work, Science, Dec. 20, 1991 at 1735. This debate has manifested itself in a number of forums. 19 In addition, numerous courts which have recently considered the question have found these statistical frequencies to lack general acceptance in the relevant scientific communities. See People v. Barney, 8 Cal.App.4th 798, 10 Cal.Rptr.2d 731 (1992); United States v. Porter, 618 A.2d 629 (D.C.App.1992); People v. Atoigue, DCA No. CR 91-95A, S.C. No. CF0023-91, 1992 WL 245628 (D.Guam App.Div. Sept. 11, 1992); Commonwealth v. Lanigan, 413

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Mass. 154, 596 N.E.2d 311 (1992); State v. Vandebogart, 136 N.H. 365, 616 A.2d 483 (1992); State v. Anderson, 175 N.M. 433, 853 P.2d 135 (N.M.App.1992); State v. Cauthron, 120 Wash.2d 879, 846 P.2d 502, 516 (1993). Cf. Commonwealth v. Curnin, 409 Mass. 218, 565 N.E.2d 440 (1991) (DNA evidence inadmissible as there is no general acceptance of statistical probabilities); People v. Wardell, 230 Ill.App.3d 1093, 172 Ill.Dec. 478, 595 N.E.2d 1148 (Ill.App.1992) (affirming trial court's finding of no general acceptance of DNA typing on abuse of discretion review). Still other courts have allowed the admission of DNA typing evidence while prohibiting or limiting the admission of evidence regarding the statistical significance of a declared match. See State v. Pennell, 584 A.2d 513 (Del.Super.Ct.1989); Caldwell v. State, 260 Ga. 278, 393 S.E.2d 436 (1990); State v. Schwartz, 447 N.W.2d 422 (Minn.1989); Rivera v. State, 840 P.2d 933 (Wyo.1992). Cf. Harris v. Commonwealth, 846 S.W.2d 678, 681 (Ky.1992) (trial court's admission of DNA evidence not an abuse of discretion, but refusing to "embrace conclusively" DNA typing evidence). 20

We leave to the trial courts the initial determination of whether, in light of events which have occurred subsequent to the trial in this case, the method for calculating the statistical frequency of a declared match remains generally accepted.

The judgment of the court of appeals is affirmed.

MULLARKEY, J., concurs in the result.

Justice MULLARKEY concurring in the result:

In this case, the majority affirms the decision of the court of appeals allowing identification testimony based on DNA testing. The majority determines that, at the time of trial, the DNA test results and statistical analysis of such results were generally accepted by the scientific community and thereby admissible under the test of Frye v. United States, 293 F. 1013 (D.C.Cir.1923). Because I would affirm under CRE 702 and reject Frye, I concur in the result only.

The defendant, Jeffrey Fishback, was convicted in 1989 of first degree sexual assault, second degree burglary, and mandatory sentence violent crime. Part of the evidence used in the trial against Fishback consisted of the testing and statistical analysis of his blood DNA compared with DNA derived from semen samples which were taken from the victim. 1 These tests indicated that the alleles found in the defendant's DNA matched those found in the samples. The statistical significance of that match was expressed in terms of the

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probability that the match occurred by chance, that is, the likelihood that someone other than the defendant would match the DNA found in the samples. According to the testimony, that probability or likelihood was 1 in 830,000,000. The defendant moved to suppress this evidence, and the trial court conducted an evidentiary hearing as to its admissibility.

At the hearing, two expert witnesses were offered by the prosecution. One was Dr. William Setzer, the director of the University of Colorado Health Sciences Center DNA Diagnostic Laboratory, who was qualified as an expert in molecular biology, DNA testing and the field of genetics. He testified as to the laboratory procedures used to match the defendant's blood DNA to that of the semen samples. The other was Dr. Lisa Forman of Cellmark Laboratories, the facility which conducted the tests, who was qualified as an expert in population genetics and population biology. Her testimony related primarily to the data base used for the statistical analysis. The testimony of both witnesses was essentially undisputed by the defendant, who did not put on any witnesses of his own. The

court found these witnesses to be credible, and allowed the prosecution to enter the DNA test results and statistical analysis into evidence under both the Frye test and CRE 702.

The trial court's reliance on both tests was due to confusion as to which test should apply to DNA evidence. It is apparent that the time has come for this court to set forth clearly the standard by which novel scientific evidence should be assessed. In the interests of logic and practicality, I believe CRE 702 is the more viable and persuasive test. In order to explain why I reach this conclusion, it is necessary to first examine Frye and its ramifications in the present case.

In Frye, a federal district court contemplating the new procedure of a systolic blood pressure deception test (i.e., a lie detector test) set forth certain precepts of analysis. These precepts since have become established as the primary standard by which to assess the admissibility of novel scientific principles. The court stated:

Just when a scientific principle or discovery crosses the line between the experimental and demonstrable stages is difficult to define. Somewhere in this twilight zone the evidential force of the principle must be recognized, and while courts will go a long way in admitting expert testimony deduced from a well-recognized scientific principle or discovery, the thing from which the deduction is made must be sufficiently established to have gained general acceptance in the particular field in which it belongs.

Frye, 293 F. at 1014. Thus a novel scientific principle is held to be inadmissible unless it enjoys general acceptance among the scientific community. This view has been followed in the past by a majority of the jurisdictions, which notes that Frye addresses certain concerns such as the reliability of the proffered scientific data, the availability of experts, and the uniformity of decision concerning the admissibility of certain types of evidence. See, e.g., United States v. Addison, 498 F.2d 741 (D.C.Cir.1974); People v. Kelly, 17 Cal.3d 24, 130 Cal.Rptr. 144, 549 P.2d 1240 (1976).

Now seventy years later, however, we should acknowledge that Frye, although it may have served this area of inquiry arguably well in the past, does not deal adequately with the issue of the admissibility of novel scientific principles as such evidence comes before trial courts today. Frye is premised on the assumption that once a scientific principle or discovery becomes "generally accepted" in the relevant scientific field, it forever remains accepted. Hence, once a particular form of evidence has passed the Frye test, it need not be tested again. This case shows that the Frye premise is not necessarily true and application of Frye does not achieve the stability of decision-making that it is meant to accomplish. According to the majority, "considerable debate has emerged in the three years since the trial in this case concerning the acceptability of the statistical frequencies which accompany a declared match of DNA profiles." Maj. op. at 894. The opinion leaves to future cases the determination

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of whether DNA statistical evidence "remains generally accepted." Maj. op. at 895. Frye no longer provides certainty or ease of decision-making.

There are other serious problems involved in the application of Frye such as courts' inconsistencies in characterizing evidence as "scientific," difficulty in identifying the relevant scientific field, and ambiguity as to what constitutes "general acceptance." See Edward J. Imwinkelried, A New Era in the Evolution of Scientific Evidence--A Primer on Evaluating the Weight of Scientific Evidence, 23 Wm. & Mary L.Rev. 261, 264-265 (1981); Paul C. Giannelli, The Admissibility of Novel Scientific Evidence: Frye v. United States, a Half-Century Later, 80 Colum.L.Rev. 1197 (1980). My primary dissatisfaction with Frye, however, is its unduly restrictive treatment of novel scientific evidence, excluding testimony that may have strong support within the community but not be "generally accepted," as in the situation here. And as Justice Potter Stewart stated, "any rule that impedes the discovery of truth in a court of law impedes as well the doing of justice." Hawkins v. United States, 358 U.S. 74, 81, 79 S.Ct. 136, 140, 3 L.Ed.2d 125 (1958) (concurring).

To my mind, the treatment of novel scientific principles is not only better addressed but pre-empted by the relevancy determination mandated by CRE 702, which is identical to the analogous federal rule of evidence. Enacted in Colorado in 1979, this rule reads as follows:

If scientific, technical, or other specialized knowledge will assist the trier of fact to understand the evidence or to determine a fact in issue, a witness qualified as an expert by knowledge, skill, experience, training, or education, may testify thereto in the form of an opinion or otherwise.

As stated by Professors Weinstein and Berger in reference to the federal rule, "Rule 702's failure to incorporate a general scientific acceptance standard, and the Advisory Committee Note's failure to even mention the Frye case must be considered significant." 3 Jack B. Weinstein & Margaret A. Berger, Weinstein's Evidence p 702 (1992). It has also been stated that the Frye standard "seems at odds with Rule 702" since "[e]vidence which is not yet accepted in the scientific community may still be helpful, and continued refusal to accept the testimony of a qualified expert for this reason alone cannot be supported by any other provision in the Rules." 3 David W. Louisell

& Christopher B. Mueller, Federal Evidence § 382 at 644 (1979). Although there are some voices to the contrary, I likewise believe that Frye has lost its viability since the implementation of CRE 702, which directly refers to scientific evidence and thus pre-empts any previous standards by which scientific testimony was weighed. 2

Furthermore, I do not believe that the Frye rule has become established in our state to the extent that all scientific testimony must be examined under its standard. It is true that we applied the Frye test in People v. Anderson, 637 P.2d 354 (Colo.1981). This case is distinguishable, however, on the grounds that the issue it addressed was the admissibility of polygraph test results into evidence--the identical issue that was addressed in Frye. It has been noted that the Frye standard "was applied consistently only in cases in which the admissibility of polygraph results was at issue." Mark McCormick, Scientific Evidence: Defining a New Approach to Admissibility, 67 Iowa L.Rev. 879, 884 (1982) (cited in 1 John W. Strong, ed., McCormick on Evidence § 203 at 869 n. 6 (1992)). In our decision, we discussed Frye solely in the context of polygraph

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evidence, and we never referred to it in terms of scientific evidence as a whole. At least one other jurisdiction has adopted Frye only as to polygraph evidence, but has chosen to utilize the Rules of Evidence as to all other scientific evidence. State v. Walstad, 119 Wis.2d 483, 351 N.W.2d 469 (1984).

Critics of the Frye test, of whom there are many and who are increasing in number, have found a relevancy determination to be far more appropriate and efficient, addressing the concerns of Frye without its problems in application. Professor Charles McCormick has said of the Frye standard that:

"General scientific acceptance" is a proper condition for taking judicial notice of scientific facts, but not a criterion for the admissibility of scientific evidence. Any relevant conclusions which are supported by a qualified expert witness should be received unless there are other reasons for exclusion ... If the courts used this approach, instead of repeating a supposed requirement of "general acceptance" not elsewhere imposed, they would arrive at a practical way of utilizing the results of scientific advances.

1 Strong, ed., McCormick on Evidence § 203 at 874-75. Other commentators have agreed with this position. See, e.g., 1 David W. Louisell & Christopher B. Mueller, Federal Evidence § 105 at 818 (1977); see also M. McCormick, Scientific Evidence: Defining a New Approach to Admissibility, 67 Iowa L.Rev. at 916 ("Procedures that operate within the framework of general relevancy and expert testimony rules offer a more meaningful and effective alternative [to Frye]."); E.J. Imwinkelried, A New Era in the Evolution of Scientific Evidence--A Primer on Evaluating the Weight of Scientific Evidence, 23 Wm. & Mary L.Rev. at 263-64 ("[W]e are now entering a new stage in the evolution of scientific evidence--a stage that will be dominated by questions of the weight of scientific evidence rather than admissibility."); John W. Strong, Questions Affecting the Admissibility of Scientific Evidence, 1970 U.Ill.L.Forum 1, 22 (1970) ("[I]t is suggested that the decision ultimately to admit scientific evidence, like other evidence, requires the striking of a balance between the probative worth of the evidence and its capacity to confuse or prejudice the jury.").

Many federal courts have agreed with this position, rejecting the Frye rule in favor of a relevancy test balancing probativeness against prejudice in cases involving scientific tests and principles other than those concerning DNA. See, e.g., United States v. Williams, 583 F.2d 1194 (2d Cir.1978), cert. denied, 439 U.S. 1117, 99 S.Ct. 1025, 59 L.Ed.2d 77 (1979) (court applied balancing test); United States v. Kelly, 420 F.2d 26 (2d Cir.1969) (probity of government's expert evidence as attacked by defense is typical question for jury); United States v. Downing, 753 F.2d 1224 (3rd Cir.1985) (Frye standard neither a necessary nor sufficient question for admissibility; general acceptance is single factor in broader reliability inquiry); United States v. Baller, 519 F.2d 463 (4th Cir.1975), cert. denied, 423 U.S. 1019, 96 S.Ct. 456, 46 L.Ed.2d 391 (1975) (court found, in light of balancing test, dangers of new scientific evidence adequately guarded against); United States v. Stifel, 433 F.2d 431 (6th Cir.1970), cert. denied, 401 U.S. 994, 91 S.Ct. 1232, 28 L.Ed.2d 531 (1971) (it is better to admit relevant scientific evidence and allow its weight to be attacked by cross-examination and refutation); United States v. Piccinonna, 885 F.2d 1529 (11th Cir.1989) (new technology required flexibility within legal system); United States v. Sample, 378 F.Supp. 44 (E.D.Pa.1974) (Frye test precluded too much relevant evidence).

State courts also have demonstrated disenchantment with Frye. See, e.g., Whalen v. State, 434 A.2d 1346 (Del.1980), cert. denied, 455 U.S. 910, 102 S.Ct. 1258, 71 L.Ed.2d 449 (1982) (general acceptance not indispensible criterion for admissibility); Coppolino v. State, 223 So.2d 68 (Fla.App.1969), appeal dismissed, 234 So.2d 120 (Fla.1969), cert. denied, 399 U.S. 927, 90 S.Ct. 2242, 26 L.Ed.2d 794 (1970) (appellate court deferred to trial court's wide discretion in admissibility determination); State

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v. Hall, 297 N.W.2d 80 (Iowa 1980), cert. denied, 450 U.S. 927, 101 S.Ct. 1384, 67 L.Ed.2d 359 (1981) (court rejected Frye); State v. Washington, 229 Kan. 47, 622 P.2d 986 (1981) (despite lack of general acceptance, court found testimony sufficiently reliable for admission); State v. Catanese, 368 So.2d 975 (La.1979) (the criteria used for determining admissibility of scientific evidence should not rise to level necessary for judicial notice); State v. Williams, 388 A.2d 500 (Me.1978) (Frye should be limited to its original context--lie detector tests); State v. Williams, 4 Ohio St.3d 53, 446 N.E.2d 444 (1983) (court rejected Frye and used "a more flexible standard derived from this state's Rules of Evidence"); State v. Brown, 297 Or. 404, 687 P.2d 751 (1984) (court adopted relevancy test); Phillips ex rel. Utah St. Dept. of Social Serv. v. Jackson, 615 P.2d 1228 (Utah 1980) (trier of fact should not be deprived of scientific data simply because of controversy); Walstad, 351 N.W.2d 469 (court found Frye adopted only as to polygraph evidence; all other evidence held to relevancy test of Rules of Evidence).

In addition, it should be noted that we conducted a balancing test of sorts in Anderson, the case in which we applied Frye strictly to polygraph evidence. We determined that, in addition to the inadmissibility of the polygraph evidence under Frye, such evidence is also inadmissible "because of the serious interference with and potential prejudice to a jury's evaluation of the demeanor and credibility of witnesses and their testimony." Anderson, 637 P.2d at 361. This is a balancing test weighing CRE 401 relevancy against CRE 403 prejudice--the same test I believe to be viable under CRE 702 and to be applicable to the present situation.

A balancing test under the rules of evidence was also applied in People v. Hampton, 746 P.2d 947 (Colo.1987), a case that the majority cites as support for its discussion of the Frye test. Maj. op. at 889-891. Frye was not applied in Hampton and a plain reading of that case reveals a strong criticism of the Frye test. In that case, the prosecution sought to introduce evidence of rape trauma syndrome. We acknowledged the use of Frye by other jurisdictions with regard to such evidence, but then declined to apply Frye and held that the evidence should be assessed under CRE 702. Although we noted that "the Frye test is applied to novel scientific devices and processes involving the manipulation of physical evidence ..." Hampton, 746 P.2d at 950, we also remarked upon the fact that Frye had been applied only in one case--Anderson --and that we had declined to apply it to another involving post-hypnotic testimony. People v. Romero, 745 P.2d 1003 (Colo.1987), cert. denied, 485 U.S. 990, 108 S.Ct. 1296, 99 L.Ed.2d 506 (1988).

Subsequent to our decision in Hampton, we also declined to apply Frye in another case concerning the reliability of eyewitness identification, since it did not involve scientific testimony per se. Campbell v. People, 814 P.2d 1 (Colo.1991). As before, we did not state whether Frye was the law of our state or not. In light of these cases and contrary to the majority's position, it is my belief that we have not adopted Frye as being applicable to any scientific testimony other than the lie detector test. Thus, we are free to adopt other tests which would prove to be more efficient in assisting our search for the truth--namely CRE 702.

Other courts share my view as to the applicability of the Rules of Evidence to DNA evidence in determining that such evidence is admissible. See, e.g., United States v. Yee, 129 F.R.D. 629 (S.D.Ohio 1990); United States v. Jakobetz, 747 F.Supp. 250 (D.Vt.1990), judgment aff'd, 955 F.2d 786 (2d Cir.1992); Andrews v. State, 533 So.2d 841 (Fla.App. 5 Dist.1988); Spencer v. Commonwealth, 238 Va. 295, 384 S.E.2d 785 (1989).

In applying CRE 702, the presiding judge must weigh the helpfulness of the evidence against the possibility that the jury may be misled or prejudiced by the admission of such evidence. One such factor to be utilized in the assessment would be the acceptance of the new technique within the scientific community, but it would not be the determinative factor as under Frye. As long as the proffered evidence is reliable and has support, although there may be controversy in the scientific field, such evidence would be admissible.

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As did the trial court, I find, on the facts in the record before this court, that the scientific testimony as to both the testing procedures and statistical analysis is helpful and non-prejudicial. The trial court stated the following reasons for its admission of the DNA testimony into evidence. First, it determined that the same procedures are used in diagnosis of genetic diseases as well as paternity determinations, rendering the techniques not novel. In addition, there is a great deal of literature concerning the topic. The procedures are subject to peer review. Furthermore, the expert witnesses were well-qualified and shared the views of other witnesses around the country.

I find the testimony of the expert witnesses to be particularly persuasive. Dr. Setzer, from his perspective as a member of a national committee in the process of implementing standards as to testing procedures, testified that he thought such standards were met in this situation. Dr. Forman defended the validity of the data base used to determine the probabilities at issue in this case. The data base to which the defendant's DNA was compared was compiled of members of the African-American community in Detroit. The defendant attacked the data base as not being a truly random population. Dr. Forman stated that Detroit was chosen for the very reason that its African-American population was in a constant state of flux, as stated by other population geneticists, sociologists and data

base experts. Furthermore, she testified that the laboratory used a conservative approach to declaring matches as to the tested alleles, rendering the frequencies of matching much higher than the actualities.

Given Dr. Forman's expert testimony as to the statistical significance of the DNA match, I find the 1 in 830,000,000 probability to be a reliable number. 3 The methods used to calculate that number have support within the scientific field. See, e.g., Ranajit Chakraborty & Kenneth K. Kidd, The Utility of DNA Typing in Forensic Work, 254 Science 1735 (Dec. 20, 1991); B. Devlin, Neil Risch & Kathryn Roeder, No Excess of Homozygosity at Loci Used for DNA Fingerprinting, 249 Science 1416 (Sept. 21, 1990). Because Dr. Forman's calculation was reliable and relevant, it was properly admitted into evidence under CRE 702 and 401.

The testimony of the prosecution experts is convincing, and it was not called into serious question by the defendant. As with other types of expert testimony, the burden is on the defendant to disprove such testimony or to demonstrate substantial prejudice, whether through the use of cross-examination or rebuttal expert witnesses. That burden was not met by the defendant in this case, and exclusion under CRE 403 is not mandated.

I thus concur in the majority's holding that the DNA testimony in this case was properly admitted into evidence. I disagree, however, with the majority's use of the Frye test, and instead would apply a relevancy test as to novel scientific principles. Such a test in this situation would allow the jury to hear any debate as to the statistical principles involved in interpreting DNA test results and apply that debate to the weight the evidence should be given.

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1 Dr. Setzer is also an assistant professor of pediatrics, biochemistry, biophysics, and genetics.

2 Cellmark is the laboratory that performed the DNA analysis in this case.

3 Because identical twins originate from the union of a single sperm cell with a single egg, they will share identical DNA molecules.

4 Because Cellmark utilized only RFLP analysis in this case, we neither discuss nor consider the admissibility of DNA typing which is based on "polymerase chain reaction amplification" (PCR) analysis, otherwise known as "allele-specific probe" analysis.

5 Myriad problems can arise in extracting DNA in the forensic context. These are due, primarily, to the size and nature of samples the forensic scientist works with. For example, often the sample is not only too small to subject it to DNA analysis at all, it may also be too small to repeat the DNA typing process. Repeating the process in a clinical setting provides the opportunity to better insure that a declared match is in fact a match, because the clinical scientist can subject the biological material to multiple RFLP analysis. Frequently, such a procedure is not possible in the forensic context. In addition, forensic samples are often contaminated as a result of environmental exposure at the crime scene: semen or blood samples may have been exposed to aging, heat, drying, high humidity, or been contaminated by bacteria. The degradation or contamination of the DNA sample can result in misleading band size or location, and the appearance of nonhuman bands which obscure human ones.

6 Degraded DNA samples can also complicate this procedure. If a DNA fragment is contaminated, this may cause the restriction enzymes to cut the DNA in the wrong places, causing fragments to be different lengths than they ordinarily would be.

7 Variations in the thickness, consistency, temperature and voltage level running through the gel can all contribute to altering the speed and distance with which the fragments move.

8 Difficulties that may result from Southern Transfer concern the precision and visibility that may be lost as a result of transferring the probes from the agarose gel. Bubbles on the nylon membrane can block the transfer of DNA causing some bands to "disappear." Poor quality Southern Transfers can make interpreting the results very difficult. Finally, it is often difficult to distinguish "background noise" from an actual band.

9 Problems surrounding the interpretation of the autorads include the acceptable measure of deviation in band match that should be allowed before declaring a match, the level of subjective evaluation that inheres in this interpretation, and the level of skill and expertise of the analyst who does the interpreting.

10 Such a calculation is done by applying the "product rule"--a standard mathematical calculation used to determine the likelihood of finding a number of statistically independent variables present at the same time.

11 Colorado Rule of Evidence 702 is identical to Fed.R.Evid. 702 and provides:

If scientific, technical, or other specialized knowledge will assist the trier of fact to understand the evidence or to determine a fact in issue, a witness qualified as an expert by knowledge, skill, experience, training, or education, may testify thereto in the form of an opinion or otherwise.

12 Rape trauma syndrome involves a recurring pattern of emotional distress that is commonly found among rape victims and is a paradigmatic example of post-traumatic stress disorder. Hampton, 746 P.2d at 949-52.

13 Nothing in Hampton was meant to suggest that the Frye test is no longer applicable to novel scientific evidence and no opinions of this court so suggest. See generally Campbell, 814 P.2d 1; H. Patrick Furman, The Introduction

of Scientific Evidence in Criminal Cases, The Colorado Lawyer 273, February 1993, ("The rule in Colorado, set forth in People v. Hampton, is that the Frye test should be applied 'to novel scientific devices and processes involving the manipulation of physical evidence.' ").

14 Whether DNA typing evidence requires application of the Frye test is usually not in question. See, e.g., People v. Barney, 8 Cal.App.4th 798, 10 Cal.Rptr.2d 731 (1992); State v. Pennell, 584 A.2d 513 (Del.1989) (applying "relaxed" Frye standard); United States v. Porter, 618 A.2d 629 (D.C.App.1992); Andrews v. State, 533 So.2d 841 (Fla.App.1988); Commonwealth v. Curnin, 409 Mass. 218, 565 N.E.2d 440 (1991); State v. Schwartz, 447 N.W.2d 422 (Minn.1989); State v. Vandebogart, 136 N.H. 365, 616 A.2d 483 (1992); People v. Castro, 144 Misc.2d 956, 545 N.Y.S.2d 985 (Sup.Ct.1989); State v. Pennington, 327 N.C. 89, 393 S.E.2d 847 (1990); State v. Pierce, 64 Ohio St.3d 490, 597 N.E.2d 107 (1990); State v. Ford, 301 S.C. 485, 392 S.E.2d 781 (1990); State v. Wimberly, 467 N.W.2d 499 (S.D.1991); Glover v. State, 787 S.W.2d 544 (Tex.App.1990), aff'd, 825 S.W.2d 127 (Tex.Crim.App.1992); Spencer v. Commonwealth, 240 Va. 78, 393 S.E.2d 609 (1990) (applying both Frye and 702); State v. Woodall, 182 W.Va. 15, 385 S.E.2d 253 (1989). But see People v. Lindsey, No. 90CA0556 (Colo.App. Jan. 7, 1993), cert. pending (applying Frye but questioning its application to DNA typing evidence).

In fact, among those jurisdictions which have adopted the Frye test, we are aware of no reported cases in which the admissibility of DNA typing evidence was not analyzed under that test.

15 Though we acknowledge that some courts assess the admissibility of all novel scientific evidence only under their rules of evidence, we find that the bases for adopting such an analysis are simply not applicable in Colorado. First, most jurisdictions which do not adhere to Frye do so on the grounds that the adoption of analogous provisions to the Federal Rules of Evidence have superseded the Frye test. See generally David W. Louisell & Christopher B. Mueller, Federal Evidence § 105 (1977). Such an argument is devoid of any merit it might otherwise have in Colorado because CRE 702 became effective in January of 1980, whereas this court first adopted the Frye test in Anderson, decided in November 1981. Thus, it would strain reason to suggest that rule 702 could preempt Frye in Colorado, in light of the fact that 702 preceded adoption of the Frye test. Second, it is questionable whether the Federal Rules of Evidence were even intended to supersede Frye in those jurisdictions where it was in force prior to adoption of the Rules.

Those who argue that the Frye test survived the enactment of the Federal Rules have some support in the legislative history. Because the Federal Rules were not intended to be a comprehensive codification of the rules of evidence, a number of evidentiary rules are not covered, and many others, though mentioned, are treated only in a general fashion. Therefore, it can be argued that because Frye was the established rule and no statement repudiating Frye appears in the legislative history, the general acceptance standard remains intact.

Frye a Half-Century Later, supra, at 1229-30 (citations omitted).

Consequently, we decline to overrule the precedent of this court adopting Frye as the test for determining the admissibility of novel scientific evidence.

16 Of course, "[e]ven if the technique was previously determined correctly to have been generally accepted, the converse may subsequently be shown by evidence 'reflecting a change in the attitude of the scientific community.' " Barney, 10 Cal.Rptr.2d at 737 (quoting People v. Kelly, 17 Cal.3d 24, 130 Cal.Rptr. 144, 549 P.2d 1240 (1976)).

17 A review of a vast body of cases from other jurisdictions reviewing Frye determinations on appeal reveals virtually no discussion of the point in time at which an appellate court is to determine the existence, or lack thereof, of general acceptance. The reason for this may be that in most cases, the scientific community's regard for particular evidence will not vary from the time of trial to the time of appellate review. This is not, however, the case with DNA typing evidence where significant changes in the regard for DNA typing evidence have occurred between the time this opinion was authored and the time this evidence was admitted at trial. See infra pp. 894-895.

Reviewing recent opinions addressing the admissibility of DNA typing evidence, however, also reveals no consideration of the temporal issue noted above. Moreover, none of those cases, while relying on up-to-date scientific and legal literature as well as current case law, mention the time at which the initial Frye determination was made. Therefore, we are unable to determine the time at which other appellate courts assess the question of general acceptance. Nevertheless, it is our conclusion that, for the reasons stated above, such a determination should be assessed from the time at which evidence is offered at trial.

18 The general acceptance of this final step is critical for the admissibility of DNA typing evidence because a declared match, unaccompanied by its statistical significance, is essentially meaningless. See Barney, 10 Cal.Rptr.2d at 742 ("The statistical calculation step is the pivotal element of DNA analysis, for the evidence means nothing without a determination of the statistical significance of a match of DNA patterns."); Commonwealth v. Lanigan, 413 Mass. 154, 596 N.E.2d 311, 316 (1992) ("Because the frequency estimates are inadmissible, evidence of a match between profiles is also inadmissible."); Commonwealth v. Curnin, 409 Mass. 218, 565 N.E.2d 440, 443 n. 7 ("we would not permit the admission of test results showing a DNA match (a positive result) without telling the jury

anything about the likelihood of that match occurring"); Vandebogart, 616 A.2d at 494 ("evidence of a match will not be admissible if it is not accompanied by a population frequency estimate that has been produced from a generally accepted method"); State v. Cauthron, 120 Wash.2d 879, 846 P.2d 502, 516 (1993) (DNA evidence unaccompanied by statistical significance not helpful to trier of fact and therefore, inadmissible).

19 The dispute centers around the issue of random mating within the broad racial categories which form the bases of the statistical analysis of DNA typing. The critics argue that such random mating does not exist and that the absence of random mating within these broad racial categories (which results in population substructure) renders the current multiplication method invalid because the requirements of statistical independence within a locus (Hardy-Weinberg equilibrium), and statistical independence across loci (linkage equilibrium) are not met. The conclusion is that using the current multiplication method, the probability of a random match may be in error by two or more orders of magnitude (i.e., 1 in 830,000,000 may actually be 1 in 8,300,000.) NRC Report at 10-12; Richard C. Lewontin & Daniel L. Hartl, Population Genetics in Forensic DNA Typing, Science, Dec. 20, 1991; Ranajit Chakraborty & Kenneth K. Kidd, The Utility of DNA Typing in Forensic Work, Science, Dec. 20, 1991.

We are also mindful, however, that this dispute may be rendered essentially moot if alternative methods for calculating allele frequency from the one used here are determined to be generally accepted. See NRC Report at 13, 82-85 (proposing a "ceiling principle" which would adequately account for the possibility of population substructuring while still providing extremely powerful evidence of a suspect's identity). See also People v. Barney, 8 Cal.App.4th 798, 10 Cal.Rptr.2d 731 (1992) (DNA typing evidence accompanied by statistical frequencies calculated according to ceiling principle likely admissible); United States v. Porter, 618 A.2d 629 (D.C.App.1992) (same); People v. Atoigue, DCA No. CR 91-95A, S.C. No. CF0023-91, 1992 WL 245628 (D.Guam App.Div. Sept. 11, 1992) (same); Commonwealth v. Lanigan, 413 Mass. 154, 596 N.E.2d 311 (1992) (same); State v. Vandebogart, 136 N.H. 365, 616 A.2d 483 (1992) (same); State v. Anderson, No. 12,899, --- N.M. ----, --- P.2d ---- (App.1992) (same); Cauthron, 846 P.2d at 517 (same).

20 Other courts, however, have held DNA typing evidence to be admissible under Frye since the recent events noted above. See State v. Jobe, 486 N.W.2d 407 (Minn.1992) (no challenge to the method of calculating the statistical significance of a declared match); State v. Myers, No. 03-C-019108CR00255, 1992 WL 297626 (Tenn.Crim.App. Oct. 22, 1992) (refusing to consider the NRC report or any other information not presented to the trial court and holding, based on the testimony of one prosecution witness, that the statistical probability of 1 in 50,000 was admissible). See also Perry v. State, 606 So.2d 224 (Ala.Crim.App.1992) (statistical frequencies admissible based on pre-1992 case law from other jurisdictions, without mention of more recent court decisions, the NRC report, or the Science articles); State v. Montalbo, 73 Haw. 130, 828 P.2d 1274, 1281 (1992) (finding "little basis for concern over the theory underlying the statistical evidence.... [and concluding that the] statistics and the underlying sampling theory are not novel or controversial").

1 Deoxyribonucleic acid (DNA) determines the genetic makeup of all living things. Every human has DNA, which is contained in the nucleus of his or her cells. The DNA is divided among forty-six chromosomes, half of which are inherited from each parent, constituting twenty-three pairs. Each chromosome is composed of thousands of genes, and each of a pair of chromosomes contains the same genes. Alleles are the polymorphisms, or variations, of a given gene, i.e. for the gene of haircolor, an allele may be for brown or black or blond coloring, determined by different DNA patterning. Thus each individual, having received a half of a pair of chromosomes from each parent, has two alleles for the same gene. Some of these alleles are more polymorphic in composition than others, and DNA testing targets these "hypervariable" alleles. See maj. op. at 885-886.

2 Further evidence of the conflict between the Frye test and the Rules of Evidence may be found in the fact that the United States Supreme Court recently heard oral argument as to the standard to be applied when determining the admissibility of scientific test results concerning birth defects allegedly caused by the drug Bendectin. Daubert v. Merrill Dow Pharmaceuticals, Inc., No. 92-102, argued Mar. 30, 1993. At trial, the district court utilized the Rules of Evidence in determining that the testimony was not sufficiently reliable for admission into evidence. 727 F.Supp. 570 (S.D.Cal.1989). The trial court ruling was affirmed under the Frye test. 951 F.2d 1128 (9th Cir.1991).

3 Because this number is reliable, I do not believe it is necessary for us to address the viability of the "ceiling principle," as the majority opinion does. Maj. op. at 894 n. 19. The application of this principle will not alter the legal effect of the statistical probability of a match. The majority uses the example that, under the "ceiling principle," the probability of 1 in 830,000,000 may actually be 1 in 8,300,000. Id. I would like to point out that while the difference between those two probabilities may be important for scientific purposes, either number still gives substantially more than a 99 percent certainty of no person other than the defendant matching the DNA sample for legal purposes. From an evidentiary standpoint, either statistic expresses a high degree of certainty. As long as both numbers are reliable, although one arguably may be "more reliable" than the other, the difference between the two (1 in 830,000,000 and 1 in 8,300,000) should go to the weight, not the admissibility of the DNA evidence.