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The "Starch Wars" and the Early History of DNA Profiling

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ABSTRACT: Just as the movie Star Wars had a prequel, so did the "DNA Wars"—the series of legal, scientific, and personal battles that took place over the admissibility of forensic DNA evidence from 1989 to 1994. Between the late 1970s and the mid-1980s, another forensic identification technique became mired in controversy: electrophoresis-based blood protein analysis. Although the debates over blood analysis were every bit as rancorous and frustrating to almost everybody involved—so much so that they became known as the "Starch Wars"—their importance has not been adequately appreciated in the recent history of forensic science. After reviewing the early history of blood typing, I will describe the development of the Multi-System approach to blood protein analysis that took place in California from 1977 to 1978. I will then elucidate the history of the Starch Wars, and demonstrate the ways that they shaped subsequent disputes over DNA evidence, especially in California. I will show that: (a) many of the forensic scientists, law enforcement officials, and lawyers who became prominent players in the DNA Wars were deeply involved in the court cases involving protein electrophoresis; and (b) many of the issues that became controversial in the disputes over DNA evidence first emerged in the Starch Wars. In the conclusion, I will suggest various ways to improve the quality of forensic science based on my analysis of the Starch Wars.

KEY WORDS: California, DNA, legal controversy, protein electrophoresis, Starch Wars.

INTRODUCTION

For many law enforcement agents and prosecutors, the introduction of forensic DNA analysis into the courtroom in 1987 was the most important advance in crime fighting since the advent of fingerprinting. The technique seemed not only to give definitive identifications (on the order of 1 in several million or more for multiple markers) but also required only a very small amount of biological material to get results. These qualities were in stark contrast to the limitations of other blood-typing methods, which required relatively large amounts of blood and delivered inclusion rates several orders of magnitude smaller than DNA profiling (e.g., 1 in 50 for individual markers or 1 in a few thousand for several markers combined). Defense attorneys, on the other hand, felt hopeless when faced with DNA evidence. Although juries could be convinced that their clients shared a serological profile with several other people, the same could not be said about DNA profiles. In early cases, the private companies that offered the technique presented probabilities of a false match as low as 1 in 30 billion [7]. As a result, defense attorneys either mounted feeble efforts to have the evidence thrown out or tried to convince their clients to seek a plea bargain. Judges, too, were in awe of the technique. Between late 1987 and early 1989, DNA evidence was admitted in more than 200 rape and murder cases around the country.

Beginning in mid-1989, however, this unquestioned acceptance changed dramatically. A small but dedicated group of defense lawyers (initially based in New York and California) began challenging the validity and reliability of DNA evidence in cases around the country. With the aid of highly respected geneticists and molecular biologists, they argued that the technique had not yet been subjected to adequate peer review; that the private companies offering the technique had failed to put the necessary quality control and quality assurance mechanisms into place; and that statistical methods used to evaluate the probability of a false match between two biological samples were scientifically flawed. Prosecutors and their experts fought back, criticizing both the testimony and the professional credentials of the defense witnesses. These legal, scientific, and personal battles lasted for more than five years, ending only at the beginning of the O.J. Simpson criminal trial in late 1994 [2,9,10,30].

While the sudden controversy over DNA evidence surprised many scientists and lawyers, not to mention the press and general public, it was not without precedent. Just as the movie Star Wars had a prequel, so too did the "DNA Wars." (To the best of my knowledge, William C. Thompson was the first to use the label "DNA Wars" to describe these debates [30]). From the late 1970s to the mid-1980s, another promising forensic identification technique became mired in legal and scientific controversy: an electrophoresis-based blood protein analysis technology called the "Multi-System approach." Although the debates over blood analysis were every bit as rancorous and frustrating to everybody involved—so much so that they became known as the "Starch Wars"—their importance

has not been adequately appreciated in the recent history of forensic science. This lack of attention may have arisen because subsequent debates over DNA evidence overshadowed them or because they did not attract the same eminent expert witnesses that eventually became enmeshed in the debates about DNA.

In this article, I will review the origins of the Starch Wars in the late 1970s, their development in the early 1980s, and their resolution in 1987. I will also demonstrate how the controversy over the Multi-System had a profound impact on the early history of DNA evidence in the courtroom, especially in California. At the most basic level, many of the forensic scientists, law enforcement officials, and lawyers who became prominent players in the DNA Wars were deeply involved in the court cases involving protein electrophoresis. Further, many of the issues that became controversial in the disputes over DNA evidence first emerged in the Starch Wars.

I. HISTORICAL BACKGROUND

A. Early Blood-Typing Methods

Around 1900, the Austrian doctor Karl Landsteiner realized that when he mixed the blood serum of one individual with the red blood cells of another individual, sometimes the cells clumped together, and sometimes they did not. Subsequent work revealed that this presence or absence of agglutination was caused by the reaction of antigens in the red blood cells and the antibodies in the blood serum. Landsteiner discovered this system had two major antigen/antibody types, which were later dubbed A and B. Red blood cells could have either the A antigen, B antigen, both, or neither, while the blood serum could have either the A antibodies, B antibodies, both, or neither. This meant that a person's blood could be typed simply by combining red blood cells with the various types of sera. Over the course of the next half century, many similar agglutination systems were elucidated, including the MN system and the Rhesus system.

The discovery that these systems persisted in dried blood stains meant that the blood-typing analysis could be performed on forensic samples [17]. Although many forensic scientists were excited by this finding and used agglutination-based blood-typing systems in their investigations, the technique had several shortcomings. Most importantly, it proved to be much more difficult than expected to analyze blood antigens in the small, dried biological samples typical in forensic casework. Another major reason was the fact that too many people fit into each blood type to make the results of these test discriminating enough.

Beginning in 1949, scientists studying the composition of blood discovered the existence of substances not related to antigens and antibodies that varied from person to person. Many of these proteins were enzymes, substances that catalyze metabolic reactions. While variants of these blood proteins performed the same function (even if they did it at slightly different rates or under slightly different conditions), minute differences in their chemical structure, electrical charge, and size meant that they could be separated using protein electrophoresis. Just as in electrophoresis of DNA, protein electrophoresis involved the separation of molecules with different surface charges in a porous gel-like substance subjected to constant current.

Although the separation of these polymorphic protein enzymes was relatively easy when fresh blood was used, the same could not be said for dried bloodstains. This situation arose primarily because proteins begin to deteriorate almost the moment after they leave the body. The environmental conditions under which the majority of forensically relevant bloodstains are found (i.e., high heat and humidity) speed this degradation process up considerably. Thus, it was more challenging to recover a significant quantity of usable protein in these samples. Partly as a result of these difficulties, there was a more than decade-long delay between the time that many blood proteins were discovered in fresh blood and their identification in dried blood stains. For starters, forensic samples had to be prepared differently from fresh samples. Additionally, more sensitive methods of detection had to be developed to reveal the presence of markers in forensic blood stains. Once these improvements were implemented, a large number of proteins were identified in dried blood samples, including: adenylate kinase (AK) in 1966, phosphoglucomatase (PGM) in 1969, adenosine deaminase (ADA) in 1971, esterase D (esD) in 1973, and erythrocyte acid phosphatase (EAP) in 1976 [5,11,12,15, 28].

B. A New Era in Forensic Serology

The discovery of these polymorphic proteins, as well as several others in the late 1970s, led many forensic scientists to believe that they were entering into a new era of forensic science in which individual identification would be based on forensic protein analysis. The power of protein electrophoresis lay in the existence of several different polymorphic systems that could be subject to electrophoretic analysis and in the presence of many variants within each system. This made the technique much more discriminating than the older agglutination system, which offered a very limited range of possible results.

This potential set off a flurry of research in the field designed to develop systems that could be used to detect these polymorphic enzymes as easily as possible. Much of this work was carried out in the United Kingdom under the direction of Brian Culliford at the Metropolitan Police Laboratory, who, in collaboration with his colleague, Brian Wraxall, developed a system using a very thin starch gel as the electrophoresis medium [33]. The primary impetus for this work was the need to create a system that used as little of the biological sample as possible.

Although these thin gel systems worked fairly well, they had several shortcomings. According to one forensic scientist, they required "a bit of artistry" to get the starch gel to have the proper consistency. He explained that each lot of potato starch had slightly different chemical properties, which meant that the forensic scientist had to use craft knowledge to get the gel to set up correctly [27]. Additionally, because protein systems initially had to be analyzed separately (due to the fact that different pH conditions and buffers were required for each), the process was slow, costly, and difficult to master for the average forensic scientist. Early attempts to simplify and speed up the process were generally unsuccessful for one reason or another. In one of the earliest attempts to combine systems, a large blood sample was run out on a thick gel, then the gel was cut into slices and each one was subjected to analysis for a specific system. This technique did not meet with much success, because it was hard to slice the gel into sections and the initial electrophoresis conditions could not be optimized for a particular system.

II. THE MULTI-SYSTEM APPROACH

A. The LEAA, Grunbaum, and Wraxall

Despite the lack of success in developing a quick, easy, multi-system approach to blood protein analysis, the thin starch gel-based electrophoresis tests created by Culliford, Wraxall, and colleagues generated a great deal of excitement when they were brought to the United States in the 1970s with financial help from the federal Law Enforcement Assistance Administration. (LEAA was formed in 1965 under the auspices of the U.S. Department of Justice in order to provide funding for research and development projects that would improve methods of law enforcement and court administration at the state and local levels. The agency was closed in 1982 after Congress did not renew appropriation in the federal budget, but many of its activities were transferred to the National Institute of Justice and Office of Justice Programs—both within the U.S. Department of Justice [20].)

Believing that protein electrophoresis had the potential to revolutionize forensic science if it could be standardized, simplified, and made cheaper, LEAA decided it would support research efforts to consolidate the tests of various enzymes in some way to make the analysis more efficient and cost-effective. Ultimately, LEAA decided to contract the project out to the Aerospace Corporation, a private, not-for-profit corporation established in 1960 to manage large research and development projects for the government during the Cold War [1]. Aerospace intended to subcontract this project out and began taking proposals. Benjamin Grunbaum, a research professor at the University of California-Berkeley with a Ph.D. in biochemistry, was one of the few scientists to submit a proposal to LEAA. (Grunbaum passed away while I was carrying out research for this article, so I was unfortunately unable to interview him.) According to many people I spoke to, this limited response stemmed primarily from the widely held belief that such a goal was unattainable given the current state of the art and the strict time limits imposed by the terms of the LEAA contract [33]. Nonetheless, short on alternatives, LEAA decided to give Grunbaum the chance to carry out his project.

Grunbaum's proposed technique was based on a technology that he had developed with Beckman Instruments, an established commercial scientific instrumentation firm based in Anaheim, CA. Aerospace ultimately subcontracted the project to Beckman, which, in turn, subcontracted the project to the University of California, where Grunbaum's laboratory was [33]. Shortly after the project began, Aerospace brought forensic serologist Bob Shaler in to oversee the entire project and to ensure that the terms of the contract were being met.

Instead of trying to optimize a single system, Grunbaum decided that he would use several of the Beckman electrophoresis tanks, which were small and used cellulose acetate as the gel medium (rather than starch), and run a bit of blood in each one. The resulting gels would then each be analyzed for a particular protein system. This process would not only require less sample on each gel membrane, it would also speed things up significantly since the small cellulose acetate membranes could be run much quicker than the larger starch gels.

Grunbaum's decision to use cellulose acetate struck many other forensic scientists as a bad choice in the forensic context. They claimed that although Grunbaum's system worked well in the clinical context, where blood samples were fresh and the possible range of results were well characterized, the amount of protein loaded into the unit in forensic work would often not be sufficient to give a clear result [27]. So, in addition to studying the Beckman technology, Grunbaum also agreed to bring in a few other

forensic scientists to examine the efficacy of using the starch gel approach in developing a multi-system. As a result, Brian Wraxall, a colleague of Culliford's at the Met Lab in London, was brought on board. Shortly thereafter, another forensic serologist, Mark Stolorow from the Illinois Department of Law Enforcement's Bureau of Scientific Services, was hired to assist Wraxall.

According to Wraxall, the moment that he and Stolorow came to Berkeley, it was apparent to both of them that Grunbaum was fixated on his own technology. He had no plan of action to evaluate the various other approaches that LEAA wanted them to study, and expressed little interest in developing one. In response to this situation, Wraxall and Stolorow sat down and put together a blueprint for evaluating the potential of the four major gel media (starch, cellulose acetate, agarose, and acrylamide) and their effectiveness with eight protein systems that had been the subject of previous forensic research. According to numerous people familiar with the project, Grunbaum concentrated solely on the cellulose acetate system, while Wraxall and Stolorow evaluated the other three media.

B. The Emergence of Controversy

The narratives and counternarratives about what happened during the intervening year are complicated and convoluted enough to fill an article on their own. Perhaps the only fact that everybody involved in the project agrees on is that the project began in earnest in early 1977. Soon after the project started, a personal, professional, and scientific rift began to develop between Grunbaum, the project's leader, and Stolorow and Wraxall, the project's technicians. Wraxall said that at the monthly meetings with project managers, Grunbaum would report that that he was making great progress using the Beckman system that he had developed, while Stolorow and Wraxall's research was not going as well [33]. Soon, according to numerous sources, it became obvious that Grunbaum's actual results were not nearly as good as his stated results. Essentially, he did not have any data to back up his claims about the efficacy of the cellulose acetate method. Stolorow and Wraxall, on the other hand, had produced a considerable amount of data that showed that the starch method was by far the most accurate and reliable of the four systems being tested. Indeed, they kept meticulous notebooks that systematically recorded their successes and failures. Grunbaum on the other hand, seemed only to have recorded positive results, and failed to produce new data as the trial period progressed.

According to interviews with Wraxall and Shaler, as the end of the initial 10-month period funded by the LEAA grant approached, Beckman and Aerospace grew increasingly aware that Grunbaum's claims could not be backed up with solid evidence. Wraxall and Stolorow, on the other hand, had amassed considerable data to show that the starch system was the way to go. At about this time, Stolorow returned to his job in Illinois. In an October 2002 interview, Wraxall stated that, at this point, his contract was about to expire and Grunbaum believed he would be able to take over the project and steer it in the direction of cellulose acetate. However, Beckman and Aerospace decided to renew his contract because they realized that he was the person most likely to generate a desirable outcome. As a result of this decision, Grunbaum quit the project. Beckman, however, wanted it completed, and brought Wraxall to their laboratories in Anaheim to perfect the system that he and Stolorow had begun to develop. (This account is a summary of the events as described by Bashinski, Shaler, and Wraxall, in interviews with the author [4,29,33]. Grunbaum's account is taken from the summaries of various court cases, including Kansas v. Washington [16]). In Grunbaum's version of the story, the University of California pulled out, and he resigned from the project after the initial 10-month period because they had not developed a single workable test. Further, he came to believe that such a goal was impossible due to the vagaries of forensic samples [16].

C. Wraxall Takes Over

Wraxall removed all of the project materials from Berkeley and moved down to Beckman's facility in Anaheim, where he finished the project within the deadline (with the help of one of Grunbaum's former technicians, Gary Harmor) and came out with the final version of the Multi-System. According to Sensabaugh, Wraxall's major innovation was to develop a system in which the samples could be run on a thinner starch gel and then analyzed for multiple proteins at the same time. In order accomplish this task, Wraxall first chose enzymes that would separate out well under similar electrophoresis conditions. He then developed three different dye systems (two visible and one fluorescent) that could be used simultaneously on the same gel. Sensabaugh says that their work was not so much an invention as it was pushing existing technology to its limit, taking some of the artistry out of the process.

Wraxall's system was perceived as a major improvement in the existing tests, and was well received in the forensic community [27]. This acceptance, however, was catalyzed in great measure by LEAA's excitement about the Multi-System, as well as their decision to give Wraxall an additional grant to bring forensic scientists to Beckman from across the country to train them in the new technique.

The grant also provided for these early labs to receive free materials from Beckman to get the system up and running back in their laboratories [33].

D. The Final Report

The final report of the project was never formally published. It was written up and circulated as a booklet in September 1978. Because Grunbaum was part of the project, he had to be included in this process in some way. Wraxall said this was the start of Grunbaum's discontent. When he received a draft of the report, he began to charge that results had been manipulated and falsified [16]. Based on these allegations, LEAA set up a three-person committee to examine Grunbaum's charges. (The committee included among its members Dennis J. Reeder, from the National Bureau of Standards [now NIST], who would come to play a crucial role in the development of DNA typing). This committee found that Grunbaum's allegations were unfounded. As a result of this controversy, though, LEAA decided not to publish the report. The agency instead made the booklet available to any forensic lab or forensic scientist who requested a copy.

Because the booklet was never officially published, it was not subjected to kind of peer review that is associated with widely circulated scientific claims. Perhaps if it was peer reviewed, some of the issues that concerned Grunbaum would have been analyzed by more objective readers. These problems could have then either been rejected as scientifically irrelevant or resolved before Grunabum began testifying against the Multi-System in court.

Although some scientists might find this situation troubling because of the centrality of peer review as a hallmark of good scientific practice, Wraxall did not think it was significant at the time. In his view, a forensic technology like the Multi-System "either works or it doesn't" [33]. Besides, the procedure was adopted in many laboratories across the country, and was used for many years. For him, this was proof of the validity of the technique. The only paper they published in a formal peer-reviewed manner was a characterization of the first "group" of three enzymes (the enzymes tested were divided into three major groups according to their physicochemical properties) [35]. In an October 2002 interview, Wraxall reported that the FBI was upset that it took them such a long time to publish in such a journal, but he said that they had better things to do, like teach the technique to labs across the country. He said that they gave the paper at about six meetings before it was published, so it was not as if his colleagues were unaware of his activities [33,36].

III. THE STARCH WARS

The decision of the LEAA panel that investigated Grunbaum's assertions did not satisfy him. Depending on whom you believe, this either made him bitter, or caused him to worry that the results of the Multi-System test were not reliable and should not be admitted into court. Whatever the case, as the Multi-System test began to be introduced into court, Grunbaum traveled around the country to serve as a defense witness in numerous admissibility hearings. Grunbaum's challenges, along with countertestimony by Wraxall, Stolorow, and others involved in the project, came to be known as the "Starch Wars." (As most readers of this article will remember, the similarly titled movie about the intergalactic battle between good and evil was in theaters at the same time the Multi-System was developed. The term "Starch Wars" was coined before the end of the development project. The joke took off when Wraxall had a T-shirt made up with a caricature of Grunbaum as Darth Vader and the phrase "Starch Wars" [33]. According to several people I spoke to, Grunbaum was highly offended by the shirt and took it intensely personally.)

A. Early Trials

The first case in which Grunbaum was called as an expert witness was the 1979 trial of Kansas v. Washington [16]. On the stand, Grunbaum testified that he did not believe that the Multi-System test was reliable or generally accepted within the scientific community. Until the Merrell Dow v. Daubert decision in 1993, the precedent-setting case on the admissibility of scientific evidence in almost all jurisdictions was Frye v. United States [13]. In this 1923 case, the defendant appealed the trial court's decision to exclude results from a lie-detector test that was favorable to him. The Court of Appeals for the District of Columbia Circuit upheld the trial court's decision based on the following logic:

> 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 [13].

The requirement set forth in this statement—that the principles underlying an evidence-generating technique be generally accepted within a relevant scientific

community—has come to be known as the "Frye rule," or "Frye standard." In practice, the Frye rule meant that a judge was charged with the responsibility of taking the pulse of a particular scientific community (or set of scientific communities) to determine whether or not an idea or technique was accepted by enough scientists to be considered valid and reliable in a court of law.

In addition to making the claim that the Multi-System was inadmissible under the Frye rule, Grunbaum also argued that blood proteins always degrade once they leave the body, so test results must be carefully interpreted (especially the EAP system, in which the A type degrades quickly, causing blood that is AB to appear B after a short while). In Washington, the prosecution called Stolorow, who rebutted Grunbaum's testimony about the EAP system (he said that it was stable up to 13 weeks after leaving the body) and told the court that the test was indeed generally accepted because it was used in numerous crime labs across the country. Both the trial court and appeals court in Washington affirmed the admissibility of the Multi-System test, and justified this conclusion by pointing to the more than 100 crime labs in the United States and Canada (including the FBI) that use the technique. The appeals court explicitly rejected the claim that the only acceptance of the Multi-System technique was within the law enforcement community. It pointed out that many of the experts who testified in the case were members of various scientific communities, most notably chemistry and biochemistry, in addition to being forensic scientists.

The next case that Grunbaum testified in was Michigan v. Young [18]. In Young, his challenge to protein electrophoresis was expanded to include all types of genetic marker typing. In addition to Grunbaum, a genetic counselor named Diane Juricek also testified. During the trial, Juricek admitted that she had no actual experience performing bloodstain analysis, and all of her knowledge was based on a literature review. Their basic argument echoed and expanded on Grunbaum's testimony in Washington. They argued that it was extraordinarily difficult to accurately type forensic samples because of degradation of biological materials and contamination from the substrate on which the crime scene sample is recovered. In this case, the blood was taken from a sidewalk that was potentially contaminated by gasoline, insecticides sprayed on nearby grass, and any bacteria that would be found in the area. It was also subjected to variations in temperature, sunshine, and moisture that could seriously damage its electrophoretic behavior. Grunbaum also argued that all forms of protein electrophoresis were unreliable in the forensic context, including his own. In order to counter this testimony, the prosecution called seven witnesses, including Stolorow and Sensabaugh, to rebut the defense experts' testimony. In his testimony, Stolorow stated that he directed a research project involving 1,000 people in the Detroit area for the purpose of determining the frequency of blood factors in the general population, and was, therefore, intimately involved with the use of the technique. He further pointed out that protein electrophoresis, although it had only recently been applied to forensic bloodstains, was a well-established technique that was widely used "in Red Cross clinics, in hospitals, at universities, in medical schools, and wherever studies in genetics are performed, as well as in crime laboratories" and that he knew at least six other people in Michigan outside of forensic science who used electrophoresis on a regular basis [18].

Based largely on this testimony, the Appeals Court affirmed the trial court's decision to admit protein electrophoretic evidence. After the initial trial, though, the judge sent the record to the Michigan Supreme Court for them to decide on the issue of the admissibility of forensic protein electrophoresis. Ultimately, in a 3-2 ruling, the Michigan Supreme Court ruled that electrophoretic bloodstain evidence was not admissible in court [19]. This decision was reached primarily because Michigan employed an additional requirement for admissibility: that general acceptance be established by "disinterested and impartial experts in the particular field to which it belongs" whose "livelihood [is] not intimately connected with the new technique" [19]. The Court also concluded that the trial court was in error for not conducting an official Frye hearing on this issue. Simply accepting the testimony of Stolorow, the co-developer of the technique and an employee of the police department, was not enough. Further, they cited "an apparent growing controversy" between Stolorow and Grunbaum as evidence that such a hearing needs to be held [19].

The evidentiary hearing was held under the auspices of the Supreme Court [19]. In addition to the witnesses who had testified in previous hearings, the prosecution asked James Kearney, the chief of the FBI's serology laboratory, to testify that the Multi-System approach was reliable and generally accepted within the serological community. Although he had not examined the actual evidence in the case, Kearney testified that the Bureau used the technique on a regular basis since it was developed in 1979, and that it produced sound results. Specifically, he noted that the FBI had undertaken numerous studies of the stability of protein markers in bloodstains. He also told the court that Juricek's testimony about the unreliability of blood typing should be ignored because she had no experience with forensic casework or the analysis of bloodstains [12,19].

The court, however, concluded that Kearney could not be considered an impartial witness because his laboratory used the Multi-System on a regular basis and would be harmed if it were ruled inadmissible. As a result, his testimony did not meet the requirements of Frye, and the Multi-System could not be considered generally accepted by impartial and disinterested experts. In reaching this decision, the court lamented that:

> Evaluating the scientific community's acceptance of the reliability of electrophoresis of dried evidentiary bloodstains presents some unusual problems. The number of scientists not working for a police agency who are familiar with electrophoresis of evidentiary bloodstains is small. If these scientists alone were considered, the community would be too small for a fair sampling of scientific opinion (p. 271 in Ref. [19]).

The lack of independent experts who could vouch for the general acceptance of the technique was not the only reason that the Supreme Court determined that the Multi-System was inadmissible. They accepted the defense's argument that the technique had never been adequately validated or subjected to independent peer review. Although Wraxall and Stolorow did conduct trials of the technique, including the one large population study in Detroit, as well as some studies on the effects of environmental contaminants, such experiments had never been carried out by scientists with no stake in the outcome of the trial. As the court noted:

> Although electrophoresis has been generally accepted as reliable in the scientific community for many years, Wraxall's multisystem test is a new technique. No independently conducted verification studies have been undertaken. Scientists evaluating the technique necessarily base their conclusions on the unpublished reliability study conducted by the multisystem's developer. General agreement in the scientific community cannot be achieved on the basis of this type of testing alone (p. 283 in Ref. [19]).

This controversy continued to grow and become more apparent throughout the early 1980s. There were numerous cases across the country in which the defense challenged the validity and reliability of the technique, usually unsuccessfully. In most of the cases, Grunbaum either served as a witness or offered advice to the defense attorneys. By 1985, both sides of the Starch Wars were well entrenched in their positions, launching verbal and written attacks at one another. The situation became so bad that the FBI started sending members of its serological research unit around the country, including Randy Murch and Bruce Budowle, to testify that the Multi-System approach was fundamentally reliable and scientifically sound. This battle would reach its crescendo in the mid-1980s in a pair of California cases that would take many years to resolve, and would remain a bitter memory in the minds of California's forensic science community.

In the case of People of California v. Brown [23], Grunbaum filed an amicus brief in the California Supreme Court on behalf of the defendant. He stated that the blood analysis evidence was admitted in error in the original trial (the rape/murder in question occurred in 1980) because the prosecution failed to satisfy the Kelly/Frye rule. (In the 1976 case of People v. Kelly, the California Supreme Court unanimously adopted Frye as the state's admissibility standard, adding the additional requirement that the technique in question must have been properly applied in the instant case.) By this time, Grunbaum and the defense attorneys he worked with had adopted the strategy perfected in Young. Instead of disputing the validity and reliability of protein electrophoresis itself, which no longer seemed to captivate the minds of juries and judges, they argued that drying, aging, temperature, contamination, and the substrate—i.e., the general conditions of forensic samples—could have potentially devastating effects on the results of such testing. They even raised the possibility that such factors could lead to false-positive or false-negative results. Further, the defense argued that there was no standard and proven methodology to avoid these dangers [23]. The prosecution countered that such factors are important, but the enzymes chosen for forensic study are the most resistant to adverse conditions. Further, they argued that although false negatives (i.e., errors benefiting the defendant) were possible, false positives were not. Finally, they pointed out that forensic scientists are trained to evaluate the condition of a particular sample, and always factor such information into the interpretation of a given test result.

In its ruling, the Supreme Court briefly reviewed similar cases from other jurisdictions, including Washington and Young. The Court wrote, "Our review thus makes clear that the acceptance of tests for typing stale body-fluid stains is a matter of substantial legal controversy. Where that issue remains open, the party offering the evidence has the burden of proving in the trial court that a consensus of scientific opinion has been achieved" [23, p. 532]. The court further concluded that the trial record was inadequate in establishing the scientific acceptance of the technique under Kelly/Frye. The Court stated that it occasionally undertakes a consensus-seeking review of scientific literature in order to resolve a case-by-case controversy over the acceptance of a particular technique. However, both the prosecutor and the California District Attorneys' Association urged that the court not do this with respect to protein electrophoresis because of

the complexity of the matter. In their view, this work should be done in the trial courts [23].

Ultimately, the Court concluded that it was impossible to state definitively whether there was a consensus about the validity and reliability of protein electrophoresis in the forensic context because prosecutors had not yet put on an adequate Frye hearing. They wrote: "We do not foreclose future attempts to admit stain-typing evidence based on a foundation such as we have described. In this case, such a record, not having been made, the evidence should not have been admitted" [23, p. 535]. However, the error was harmless in light of overwhelming additional evidence against the defendant and the conviction was upheld.

Although the Young and Brown decisions frustrated prosecutors, forensic scientists, and law enforcement agents throughout the country, proponents of the Multi-System learned a great deal from these negative rulings. For starters, they realized that it was absolutely crucial to take the time to establish the validity and reliability of the technique in the admissibility hearing. They could not simply rely on the people who used and developed the technique to provide testimony, but had to go out into the wider community to find scientists whose livelihood did not depend on the admissibility of the technique in the courtroom. Most importantly, though, they realized that they had to convince the judge in the case that, far from being a voice of the mainstream scientific community, Grunbaum was an embittered outsider fighting a personal battle against Wraxall, Stolorow, and the project that he left with hard feelings.

B. *People v. Reilly*: Admissibility Achieved Nine Years After Introduction

At approximately the same time that the Brown decision was being handed down by the Supreme Court, the case of People v. Reilly [24] was wending its way through California's legal system. The murders in this case took place in January 1978. After the first trial in 1983, the court of appeals reversed the conviction (March 1985), stating that the bloodstain evidence (in this case, the Multi-System was not used) did not meet the requirements of Kelly-Frye. Frustrated by this decision, as well as the progress in Brown, the prosecution and forensic science community decided to put on a significantly more extensive Kelly-Frye hearing than they believed should be necessary [4].

At retrial, which finally took place in 1987, the admissibility hearing featured more than eight days of testimony. The prosecution called numerous witnesses, including Sensabaugh, forensic serologist Bashinski, Ed Blake, Wraxall, and two others. The defense once again called Grunbaum as the sole witness to contradict prosecution testimony with respect to blood protein electrophoresis. In his testimony, Grunbaum took yet another approach to attacking the state's blood analysis evidence. He stated that he would have "confidence" in crime lab work on bloodstains if minimal quality assurance guidelines were made mandatory for all labs. A set of proposed guidelines that he had previously written and published in the Spring 1985 issue of California Defender were entered into the record. They included: licensing of analysts, proficiency testing with publicly available results, use of established protocols, analysis of samples within a week of receipt, use of standards and controls as specified in written procedures, duplicate runs and independent (blind) retesting, with any differences of opinion noted and called "inconclusive," reporting only clear and unambiguous patterns, recording of all test procedures, and photographing all electrophoretograms. Grunbaum testified that if such guidelines were followed, test results would be "reliable in a scientific sense," and that, until such time, one must assume that all test results are unreliable. He testified that the analyst in this case, Jan Bashinski, had not followed these procedures. The prosecution witnesses repeated their earlier claims that Grunbaum was an outlier in the scientific community and did not represent mainstream views.

Based on this testimony, the appeals court held that the prosecution had met its burden under Kelly-Frye to show that electrophoretic testing of dried bloodstains was generally accepted within the scientific community, and that the technique had been properly used in this case. The court concluded that Grunbaum stood alone in his opposition to the use of protein electrophoresis in forensic casework. As such, his position was not a sign that the technique was not "generally accepted." It also pointed out that although all witnesses agreed that there was great potential for degradation and contamination of the crime scene sample, only Grunbaum argued that these problems could not be corrected for. Nearly nine years after its introduction, Reilly served as the precedent for the admissibility of protein electrophoresis results in California courts.

C. Reaction

According to several people interviewed, the California law enforcement community was relieved to finally have a definitive ruling that neutralized Grunbaum's claims. In addition to making the Multi-System admissible in California courts, it also quelled the debates taking place in other states. After Reilly, there were very few

challenges to the Multi-System around the country. That said, there was widespread frustration in the forensic community that it took almost a decade to get a definitive ruling on the admissibility of protein electrophoresis evidence in the California court system. In the eyes of forensic scientists, the court system had allowed a single vindictive individual to stall the implementation of a very useful forensic tool. One of the major problems they pointed to was the perceived personal nature of Grunbaum's attacks against specific forensic scientists. According to Bashinski, the Supreme Court took "so long, from my perspective, to agree with the obvious." She said that the whole process, although beneficial from the perspective of forcing forensic scientists to be careful in their work, was "a vast waste of everybody's time and money, in terms of litigating these things over and over while we [were] waiting for a definitive ruling" [4].

IV. THE STARCH WARS AND THE EMERGENCE OF DNA PROFILING

Just as the decision in Reilly was finally handed down, the law enforcement community was becoming increasingly excited about DNA profiling, which had recently been admitted in the Florida serial rape trial of Tommie Lee Andrews and was being introduced into courtrooms around the United States. Despite the enthusiasm of people around the country, and a strong marketing push by the two private companies offering the technique to law enforcement agencies, California forensic scientists and prosecution lawyers decided to be ultraconservative, both legally and scientifically, in their approach to bringing the technique into court. They did not want to wait a decade for a definitive ruling to be issued on the admissibility of DNA evidence (as had been the case with the Multi-System).

One measure of this caution was the massive effort undertaken by the California Association of Crime Laboratory Directors to educate the state's law enforcement community about the possibilities and pitfalls of this new technique and to perform blind proficiency testing of the two corporations (Lifecodes Inc. and Cellmark Diagnostics) that initially offered it to prosecutors and the police. In July 1987, shortly before the Andrews decision was reached in Florida, the CACLD formed an ad hoc committee on DNA. The mission of this three-member panel was to provide education on DNA technology to CACLD members, to coordinate the evaluation of private laboratories engaged in DNA typing, and to collect and disseminate information about forensic DNA analysis to CACLD members [6].

The CACLD's initial position statement on DNA typing (20 November 1987) drew a direct analogy between the introduction of this new technique into the criminal justice system and the early history of protein electrophoresis in the 1970s. Indeed, two of the three members of the CACLD's ad hoc committee on DNA, Jan Bashinski and Margaret Kuo, had a very strong forensic serology background. As detailed earlier, Bashinski had first-hand knowledge of the kinds of defense challenges that were leveled against protein electrophoresis in the late 1970s and early 1980s, and wanted to make sure that the same situation did not develop with DNA typing [4]. The position statement pointed out that in both cases a technology developed for genetic research, clinical diagnosis, and paternity studies had been transferred to the forensic laboratory. As a result, the potential effects of environmental influences (i.e., the damaged and degraded nature of forensic samples) had to be carefully studied with both. Clearly, this document was a reflection on the way that the forensic community handled the introduction of the Multi-System. It is important to note that CACLD members did not explicitly criticize the process by which the Multi-System was developed. However, they did seem to implicitly recognize that at least some of Starch Wars controversy could have been avoided had the technique been more thoroughly validated before it was disseminated to forensic laboratories.

In another sense, though, the CACLD saw DNA typing as a radically new situation—one that excited and concerned them at the same time. Although they noted quite early on in this document that "DNA typing promises to revolutionize forensic serology," they also lamented that they were not in control of the technique—private corporations were. In their view, the professional forensic community had the authority, expertise, and, indeed, the responsibility, to ensure that all of the appropriate scientific issues had been addressed.

Another measure of this caution was California Attorney General John Van De Kamp's decision in January 1988 to declare that prosecutors should avoid bringing DNA evidence into California courtrooms until prosecutors could be certain that it would pass the Kelly-Frye test with ease. "We better put our ducks in order before we go to court … If one person botches this up, they botch it up for everybody," he was quoted as saying [8, see also 32]. In his view, a considerable amount of validation work still had to be done to ensure that the technique would be deemed valid and reliable in California courts. Although courts in other states had already admitted DNA evidence into trial, he was not convinced that this would happen in his state. District attorneys across California heeded this call, which essentially created a moratorium

on DNA typing in the state for nearly a year. Again, while not explicitly criticizing the forensic community's handling of the Multi-System, there was an implicit sense that DNA profiling had to be handled differently. In numerous newspaper interviews, California prosecutors justified their actions. In one article, Frederick R. Millar, Jr., a supervising deputy attorney general in California, was quoted as saying: "DNA analysis is very new. Prosecutors have to look for the right case. That can create a situation that is hard for victims to understand. They are looking for justice. But for the prosecutors, there are other concerns in terms of validating this process." [32]

Although California bore the brunt of the Starch Wars, and felt their biggest impact on the development of DNA profiling, it is important to note that the effects of this controversy were felt throughout the country. At a disciplinary level, many people I spoke to told me that Grunbaum forced the forensic science community to come to grips with the issues of quality control and quality assurance for the first time in the field's history. Indeed, one of the anonymous reviewers for this journal commented that "before all the 'starch wars' controversies, most forensic labs didn't even know what the words meant. By the time DNA came along, people realized what they needed to do." Although more historical and sociological analysis needs to be done before this claim is accepted as fact, the paucity of proficiency tests available to the forensic community before the late 1970s lends some support to this view.

At the personal level, most of the people who participated in the Starch Wars went on to participate in the development and validation of DNA profiling. The first two commercial providers of forensic DNA testing in the United States each hired people who had participated in the development of and controversy surrounding the Multi-System (Stolorow went to Cellmark and Bob Shaler—who was brought in by Aerospace to manage the development of the Multi-System—went to Lifecodes). In both cases, they were hired partly because of their contacts within the law enforcement community and partly because of their experiences dealing with the admissibility of forensic evidence [3,14].

Additionally, the members of the FBI serology research unit who were sent around the country to testify on behalf of the Multi-System (Kearney, Murch, and Budowle) went on to form the core of the Bureau's team that developed their DNA profiling technologies. George Sensabaugh's laboratory went on to play a crucial role in the development and testing of various DNA profiling systems. He also helped organize the Banbury Conference on DNA Technology, held at Cold Spring Harbor Laboratory in November 1988. This conference represented the first time that representatives from all of the major stakeholders in the realm of forensic DNA analysis were brought together to debate the strengths and weaknesses of the new technique. Sensabaugh also served as a member of both National Research Committee panels (1992 and 1996) that were commissioned to examine the points of disagreement that had emerged in the courtroom debates over DNA evidence.

In a recent interview, defense attorney and psychologist William C. Thompson, who was one of the first lawyers to challenge DNA evidence in California courts, said that the Starch Wars influenced not just the actions of forensic scientists and prosecutors, but also their legal strategies and courtroom rhetoric. In his view, they hoped to avoid Grunbaum's trap by promoting DNA profiling as being "error-free" [31]. In other words, the test would give the right result or no result at all without the possibility of false positives or false negatives. The only potential problem was "human error," which most courts would see as affecting the weight of the evidence rather than its admissibility. Thus, they "were maneuvering as well as they could to try to create the proper atmospherics that would allow admissibility to be achieved easily, without opposition. They knew the dangers of the emergence of critics and the emergence of a controversy" [31].

Despite their best efforts, prosecutors and forensic scientists in California (and around the country) were unable to avoid legal controversy over the admissibility of DNA profiling. Although they learned many lessons about the importance of validating techniques for use in forensic casework, quality control, and peer review, so too did defense attorneys. As defense challenges to DNA evidence became increasingly common in early 1989, the arguments made by Grunbaum in the context of the Multi-System resurfaced. Defense attorneys in the earliest challenges to DNA profiling began their attack with the claim that although the technique was valid and reliable for laboratory and diagnostic work (in which biological samples were usually pristine and plentiful), it had not been adequately validated to use on aged and degraded forensic samples. As readers will recall, this is essentially the same argument made by Grunbaum. They also argued that the private companies offering the technique began doing forensic casework before their methodology was adequately scrutinized by disinterested and unbiased members of the general scientific community [26]. In doing so, the defense claimed, the companies thwarted the process of scientific peer review by restricting access to its probes, protocols, and databases to close collaborators and scientists who they felt would not testify against them in a court of law [26].

Whereas the Starch Wars had a tremendous impact on the way the law enforcement community went about introducing DNA evidence into California courts, the effect of the dispute on California courts was a bit more ambiguous. Although the courts did not express any outright desire to avoid a repeat of the Starch Wars, they did make it clear that there were ways to prevent the testimony of a single individual from holding up the admissibility of a novel scientific technique. Most importantly, the appellate court in People v. Axell (the first DNA case to be reviewed in the state) noted that any witness wishing to offer testimony on a specific technique or body of knowledge "must have sufficient academic and professional credentials to understand both the scientific principles involved and any difference of view concerning their reliability, and must be impartial" [21]. Under this standard, although a witness like Grunbaum might meet the first criterion, he or she almost certainly would fail the impartiality test. Following Reilly, the court also concluded that it could also look to decisions in other jurisdictions in cases when expert opinion was ambiguous. Surprisingly, though, the substance of the disputes over protein gel electrophoresis did not seem to enter into the decision-making process of the Axell court, or of subsequent published cases involving DNA evidence in the state [22,25].

CONCLUSION

Despite the similarities between disputes over the Multi-System and DNA profiling, it would be a mistake to assume a direct causal relationship between the Starch Wars and the debates over DNA evidence. To begin with, the adversarial nature of our legal system makes defense challenges to scientific evidence inevitable, even if they are not always of serious scientific merit. Further, as most forensic scientists whom I interviewed took pains to point out, Grunbaum was very much alone in expressing his reservations about the pitfalls of protein electrophoresis and the Multi-System. There are three potential explanations for this situation, none of them mutually exclusive. First, it is possible that Grunbaum's reservations were motivated more by personal hatred of Wraxall than a legitimate scientific point of view. Second, it is also possible that although Grunbaum's worries were justified on scientific grounds, the issue of protein electrophoresis never generated enough public interest (through a highly publicized trial or through other major media attention) to encourage scientists outside of law enforcement to seriously investigate his concerns. Third, it is possible that because the technique was developed within the forensic science community (rather than being transferred from the academic laboratory to the law enforcement community), few academic scientists felt comfortable taking the time to examine and critique it.

Whichever explanation is correct, the situation in the DNA profiling arena was dramatically different. Once a few academic scientists declared their unease about the technique, other members of the academic scientific community quickly became interested in the technical aspects of DNA profiling. Although one can question the personal, political, and professional motives of the scientists who entered the debate, it is clear that concerns about the validity and reliability of DNA profiling rapidly spread through the academic community.

Despite the difficulties in establishing causation, there are lessons to be learned by examining the legal controversies over starch gel electrophoresis and DNA profiling. To begin with, defense challenges (whatever their scientific merit) can sometimes encourage forensic scientists to undertake scientifically valuable efforts that ultimately improve the quality of scientific evidence being offered. It is clear that the Starch Wars taught the forensic community (but apparently not the employees of Lifecodes and Cellmark), that it needed to be careful when introducing new technologies into the courtroom. Indeed, the California Association of Crime Laboratory Directors' blind proficiency test, which showed that the private laboratories offering the test were capable of making mistakes, might not have taken place in the absence of the Starch Wars. Further, the influx of criticism from other branches of science (especially molecular genetics and population genetics) led to an improvement in the kinds of quality-control mechanisms used to ensure that test results were accurate. It also led to significant changes in the way that probabilities of a false match between two DNA profiles were calculated.

More importantly, an analysis of the controversies also suggests that forensic scientists and prosecutors should encourage the most challenging admissibility hearing possible for a new scientific technique immediately upon introduction into court. They should not seek to shield the technique from outside scrutiny because, by its very design, the adversarial Anglo-American legal system makes it inevitable. Unfortunately, in countless interviews that I have carried out, forensic scientists express significant anxiety about allowing outsiders to critique their work. They go to great lengths to point out that that forensic context is so unique that only other forensic scientists with similar experience are capable of evaluating their work. They note that forensic samples are so fundamentally different from those analyzed in academic and research contexts that the scientific protocols and procedures used by academic researchers would fail to

produce results. They also suggest that calls by academic scientists and legal scholars for the "blind" analysis of forensic samples (i.e., not allowing a forensic technician to know what sample he or she is testing until after it is processed), are impractical because the context in which the material was recovered influences how it is handled, analyzed, and interpreted. On a similar note, the forensic community has resisted blind proficiency testing because they believe it is expensive, impractical, and not an appropriate proxy for how forensic casework is actually carried out in the laboratory. Indeed, the CACLD endeavor described above remains one of the few examples of blind proficiency testing in the history of American forensic science.

Finally, my research suggests that forensic scientists should take a liberal view of who constitutes the peers in peer review, because they can be assured that defense lawyers will do so in court. Allowing their work to be scrutinized by nonforensic scientists will have multiple benefits. First, it will encourage forensic scientists to uphold the norms of science (e.g., objectivity, organized skepticism, and replication) in ways that they might not if they are only being policed by members of their close-knit community. Although all scientists share a commitment to "the scientific method," sociological and historical research shows that norms associated with proper behavior, appropriate laboratory practice, and adequate peer review vary considerably among the sciences. Sometimes, being forced to justify one's actions to members of a discipline with different norms can provide a useful moment of reflection on one's own research practices. Second, as we saw in the case of DNA profiling, nonforensic scientists recognized significant problems with the way that the forensic scientists carried out DNA profiling and interpreted their results. Although the process was less than smooth, and often lacked civility, the bottom line is that the technique improved significantly as a result of the intervention from outside the forensic DNA testing community. Finally, subjecting a new scientific technique to rigorous scrutiny up front makes it less likely that defense attorneys and their witnesses will be able to claim later that the technique has never been subjected to adequate peer review. Had the initial Multi-System study been published and widely read, it is possible that Grunbaum's testimony would have had less weight in court.

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