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Personal Identification Based on Prescription Eyewear*

ABSTRACT: This study presents a web-based tool that can be used to assist in identification of unknown individuals using spectacle prescriptions. Currently, when lens prescriptions are used in forensic identifications, investigators are constrained to a simple "match" or "no-match" judgment with an antemortem prescription. It is not possible to evaluate the strength of the conclusion, or rather, the potential or real error rates associated with the conclusion. Three databases totaling over 385,000 individual prescriptions are utilized in this study to allow forensic analysts to easily determine the strength of individuation of a spectacle match to antemortem records by calculating the frequency at which the observed prescription occurs in various U.S. populations. Optical refractive errors are explained, potential states and combinations of refractive errors are described, measuring lens corrections is discussed, and a detailed description of the databases is presented. The practical application of this system is demonstrated using two recent forensic identifications. This research provides a valuable personal identification tool that can be used in cases where eyeglass portions are recovered in forensic contexts.

KEYWORDS: forensic science, personal identification, optical lenses, optical prescription strength, spectacle prescriptions, statistics, reliability

Forensic specialists customarily use medicolegal examination, odontology, anthropology, and DNA analysis to identify unknown individuals. Corroborating evidence, such as identification media, clothing, and personal effects, are also used to help secure identity. There are few published cases in which eyewear has contributed to the forensic identification of an unknown individual (1–4), and they are often located in obscure journals. Schwartz et al. (2) report an early 1990s homicide case in which multiple fragments of a left lens and a complete right lens found at several crime scenes related to a single case were examined for prescription data. The lens prescription was found to be consistent with a "match" to the decedent's most recent lens prescription. While the left eye glass fragment had a frequency of *c.* 0.3% in the general population, the frequency of the entire prescription was not determined. In this case, the identification of the victim was apparently based on other criteria and little value was placed on the lens data. Nevertheless, their ultimate conclusion was that optical glass can be "ideal specimens for trace evidence analysis with a potential towards personal identification" ((2), p. 308).

While the aforementioned example illustrates that eyewear potentially can contribute to identification, the actual effectiveness of this method remains largely undetermined. Identification methods using eyewear should be framed in terms of statistical frequencies, which allow the investigator to discuss the results in terms of scientific confidence rather than simple "match or no-match" conclusions. In a post-Daubert legal world, an evaluation of the surety of a conclusion is needed (5). This paper describes how to determine the refractive error of an unknown lens and presents a web-based tool that will allow the user to determine the frequency of a given prescription in a population. The strength of match can be used to evaluate how well a prescription fits an individual. Further, the application can determine the frequencies of overlapping prescriptions (a tolerance match), providing for clearer additional interpretation of the data. Two case studies provide examples in which this method was effectively utilized for personal identification.

Refractive Error

A refractive error is essentially a distortion of light waves as they pass through the eye, causing a blurry or out-of-focus image on the retina. Corrective lenses rectify these vision inadequacies. Refractive errors can be unique to an individual or relatively common in a population. Single-eye refractive errors can be common, rare, or unique. Dual-eye refractive errors are typically rare to unique, particularly in instances with astigmatism. A general rule is that as the severity of a correction increases, so does rarity. The most common and simple single-eye refractive error (for nearsightedness) occurs in $<3\%$ of the prescription population. The most common correction for astigmatism has a frequency of less than one-tenth of 1%.

Refractive errors occur in three types: myopia, hyperopia, and astigmatism. A fourth correction type for reading can also be present. Myopia occurs when the optical power of the eye is greater than needed to focus light on the retina or when the length of the eye is longer than normal. In either case, the focal point for an image is in front of the retina, leaving the image at the retinal surface out of focus (Fig. 1). Hyperopia occurs when there is too little optical power in the eye or the axial length is shorter than normal. The focal point falls behind the retina, leaving the image blurry on the retinal surface (Fig. 2). Astigmatism occurs when the front surface of the eye (cornea) has more curvature in one meridian than another. In this situation, there is more optical power in one meridian than the other, subsequently generating two points of focus on the retina (Fig. 3). Each of these conditions can be

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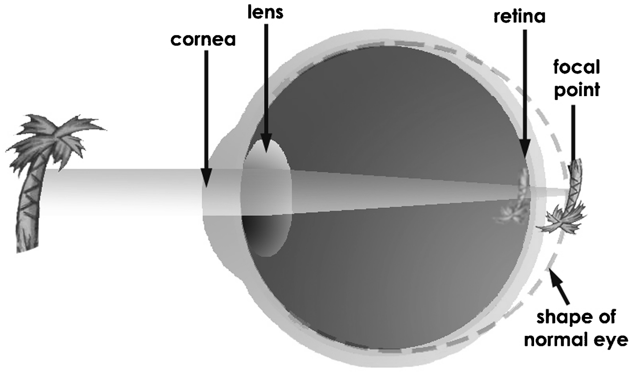

FIG. 1—*Example of a hyperopic eye.*

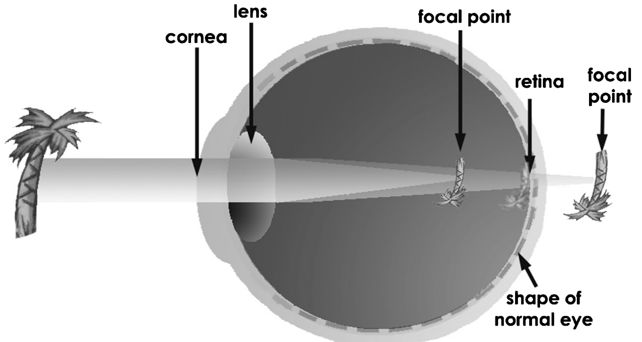

FIG. 3—*Example of a hyperopic eye with astigmatism.*

present alone in an individual. Single eyes can also have a combination of astigmatism with hyperopia or myopia.

Refractive errors are measured using three variables: sphere power (sphere), cylinder power (cylinder), and the axis of the cylinder power (axis). Sphere and cylinder powers are measured in quarter diopter increments. Although prescriptions can occur with very high numbers, the sphere correction rarely exceeds -15 diopters (myopic) to $+15$ diopters (hyperopic) in each eye. Cylinder corrections (for astigmatism) are measured from 0 to -10 in each eye. While the typical correction ranges are given for these variables, some corrections fall outside of these parameters. The axis is measured in single-degree increments from 0 to 180. This corresponds to the alignment needed to bring the optical powers into one meridian rather than two.

A fourth occurring characteristic of spectacles is a bifocal correction for close vision, such as reading. This is a separate magnification milled into a lens, located along its lower half. Bifocal corrections usually start at 1.0 diopter and may extend to 3.5 diopters. In severe cases, lesser or greater prescriptions can be produced. Bifocal corrections are often found in individuals older than 40 years, which, as will be seen below, can impact significantly the total number of variable states for middle to older age individuals.

In a clinical setting, prescriptions are annotated similarly in medical records. Myopic prescriptions are always a negative number and hyperopic prescriptions are always a positive number. Corrections for astigmatism contain a cylinder correction and an axis measurement. Bifocal corrections are written as an additional (add) power. For example, a prescription with all corrections would be annotated in the following format, where the first column is the sphere power, and the second column is the cylinder power by the axis degrees

$$\begin{array}{ll}\mathrm{OD(right\ eye)} & +4.00-2.00\times 180\\ \mathrm{OS(left\ eye)} & -0.50-2.25\times 90\\ & \qquad \mathrm{Add}+2.25\end{array}$$

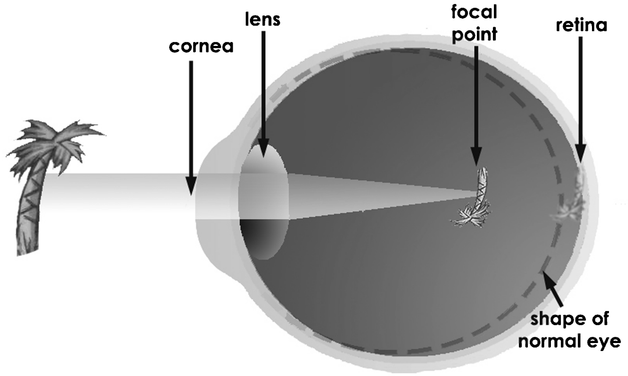

FIG. 2—*Example of a myopic eye.*

The only variation in refraction error notation is a negative or positive cylinder format; all refractive errors in this study are in the negative cylinder format. Positive cylinder prescriptions are usually written by ophthalmologists while optometrists typically annotate prescriptions in minus cylinder formats. The large majority of prescriptions fabricated in the United States are in the minus cylinder form.

Given the ranges of refractive errors for each variable state, a *conservative* estimate of the total number of variable states for a given eye or individual can be calculated. The estimate is conservative as some values can fall outside of the normal ranges (though infrequently). The number of possible biological conditions an eye can occupy is 1,152,000 states (160 [sphere] $\times$ 40 [cylinder] $\times$ 180 [axis]) and the number of possible combinations per pair is 1.33×10^{12} ($1{,}152{,}000^2$), or over one trillion combinations. This represents slightly over 220 times more combinations than there are individuals alive worldwide. If a bifocal correction is added to this equation, then the number of combinations increases to 1.33×10^{14}, or 100 trillion combinations.

Materials and Methods

The paper will discuss verification of lens prescriptions, followed by comparison databases and the presentation of the web-based tool for frequency calculations. The determination of a lens' refractive prescription (lensometry) is a simple process that can be conducted at any optical office. Prescription lensometry reveals the type and amount of refractive error present in a given lens, and subsequently, the refractive error of the individual for whom it was manufactured. A three-point laser lensometer, the Humphrey® 350 Lens Analyzer, was used in this study, although any manual lensometer can be used to determine refractive errors from optical materials. The Humphrey® 350 Lens Analyzer is calibrated within its designated manufacturing standards every year.

The Humphrey® lensometer can reliably read the refractive error from a fragment of optical glass smaller than 1 cm^2. While the axis variable cannot be obtained from loose fragments that do not have a mountable edge portion, sphere and cylinder variables are unaffected by this constraint. Heavily scarred or pitted glass fragments may not produce results, although the laser lensometer often can mitigate these problems. The measuring procedure is quick and reliable. The refraction strength is determined by placing the lens into the lensometer and observing its digitally measured strength. Three trials are performed, ensuring an accurate determination.

Databases

This study presents three databases containing large sample sizes from diverse populations for comparison purposes. Two databases have associated biological information about the patients, although none of the information is patient-identifying.

The largest database utilized in this study is prescription data from the Naval Ophthalmic Support and Training Activity (NOSTRA) located in Yorktown, VA. This database represents *c*. 40% of all Department of Defense ordered eyeglasses from across the United States. The database includes approximately a decade of refractive error information, from ~1992 to 2002. It contains over 375,000 individual prescriptions representing 750,000 individual eyes. While the database contains no biological information regarding sex, age, or ethnicity, it does contain information pertaining to an individual's military or civilian rank, branch of service, and lens style.

A cautionary note on the use of the NOSTRA database: this information source was compiled from orders placed to NOSTRA from various military optometrists and ophthalmologists around the world. Each prescription was given a unique order number, regardless of the patient. Thus, if a patient ordered regular glasses and sunglasses, two unique orders were filled at NOSTRA, thereby creating duplicate information in their system. We have chosen to minimize duplicate data conservatively by removing one or more consecutive orders if all categories of information were exactly matching. By undertaking this process, *c*. 400,000 prescriptions of the original 1.2 million were removed from the database. Duplicate prescriptions still occur in the database primarily due to a delay in ordering another set of glasses (e.g., the original order was followed by another order 3 weeks or 3 years later). As we cannot realistically remove all duplicate data, some remain present. Thus, when frequencies are calculated using the NOSTRA database, a degree of interpretation must accompany the results. The frequency of a common prescription in the NOSTRA database may actually be slightly less common than the results indicate due to duplicate data. For rare prescriptions, it is highly likely that the calculated frequencies are accurate. Any unique prescriptions are, obviously, unique.

The second largest database is derived from a recent multiyear study conducted by the National Center for Health Statistics on a U.S. population sample. The National Health and Nutrition Examination Survey (NHANES) compiled biological information on *c*. 20,000 study participants (6). The survey included a refractive error evaluation and *c*. 8000 of those participants are included in our study; the remainder of the study participants had no detectable refraction error or were excluded on other grounds. Those individuals who did not have at least one variable state (sphere or cylinder) >0.50 diopters in value were eliminated, as most individuals with corrections below this level do not seek medical attention. Further, due to lack of coding information in the original study, all individuals below 12 years and above 84 years were not included. All NHANES data were collected originally in a plus cylinder format that is now converted to a negative cylinder format. The refined NHANES database includes males and females from 12 to 84 years of age, all with self-reported ethnicity. Forty-seven percent of the database is male and 53% is female. Figure 4 depicts the age demographic for the entire database. The self-reported ethnicity is 41.3% White, 21.5% Black, 28.6% Mexican-American, 5.1% other Hispanic, and 3.5% other ethnicity.

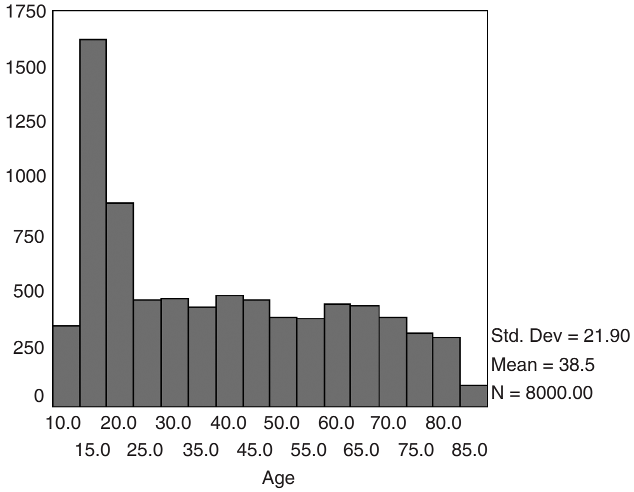

FIG. 4—*Demographic profile of the NHANES database by 5-year increments.*

The Central Identification Laboratory Eyeglass Prescription Information (CILEPI) database is a continuously open survey being conducted at Lackland AFB Optometry clinic in Texas and the 15th Airwing Optometry clinic in Hawaii. The survey participants are predominantly active-duty military personnel, but their dependants and other individuals eligible for treatment are also included. Currently, the database contains *c*. 4500 individuals and all entries contain information on sex, age, and self-reported ethnicity. Study participants range in age from 4 to 95 years. The majority are males (64.7%). Figure 5 depicts the demographic variation for this database. The CILEPI database contains 62% White, 17% Black, 13% Hispanic, 5% Asian, 2% of Native American, 1% Pacific Islander, as well as a small number of mixed-ancestry individuals.

Web Tool and Frequency Calculation

A new computer program has been developed to determine the rarity of an optical prescription within a given population. Optosearch is a web-based search tool that allows the user to calculate

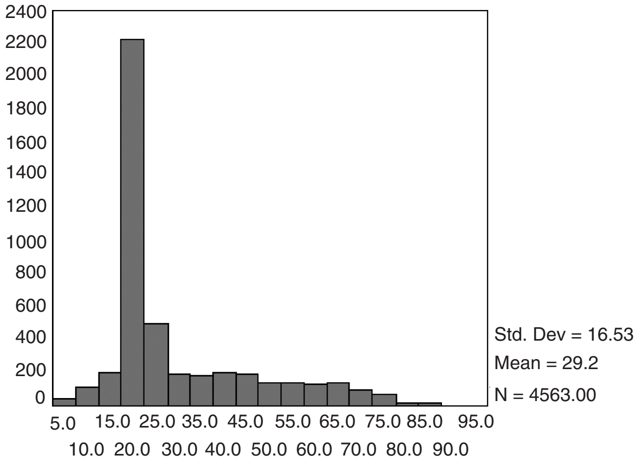

FIG. 5—*Demographic profile of the CILEPI database by 5-year increments.*

quickly the frequency of occurrence for specific or generalized eye or eyeglass prescriptions. By tabulating the number of occurrences of a known refraction error within a population, objective statistics can be generated to evaluate the strength of match between that refraction error and an individual's antemortem medical record. This search tool can be found at the JPAC website (internet address: http://www.jpac.pacom.mil/CIL/OptoSearch.htm). A detailed list of instructions is included at the web site, as well as information concerning each database and subset thereof.

The program allows the investigator to select an appropriate database per the desired query output. All three databases can be used for the comparison, singly, or as a composite comparison. Populations (e.g., biological or employment) within each database can be singled out for hypothesis testing. For example, a subsample comprised of only young males can be derived and queried. For prescription data, several levels of specificity are used; frequencies can be calculated using all or only part of a given prescription. If a recovered lens cannot be analyzed for the axis variable due to fragment size, then the sphere and cylinder corrections can be searched. Or, if the fragment cannot be determined to be a right or left eye piece, then a search can be performed for both eyes simultaneously. If a whole set of glasses is analyzed, then both eyes and all three variables can be searched for an exact match frequency. Finally, if a bifocal prescription is present, the lens can be searched as a complete prescription or as a stand-alone bifocal prescription. The resulting frequency of match can be then incorporated into the identification process or be used as a means to create a "short-list" of possible individuals based on the strength of match with already indicated antemortem records.

Based on the parameters of the search, the frequency of match is simply the number of occurrences of the target prescription based on the number of prescriptions in a given population. All frequencies are calculated as the number of prescription matches divided by the number of individuals/prescriptions in a specified search multiplied by 100 or

$$(X+1)/(N+1) \times 100$$

Unique prescriptions are simply calculated as $1/(N+1) \times 100$. As the parameters of the search can be by individual, eye, both eyes, and population group, the sample size will fluctuate accordingly.

Within eyeglass manufacturing, errors in the milling process can occur. The American National Standards Institute has implemented a series of guidelines for lens manufacturing processes that are enumerated in ANSI Z80.1-2005 (7). Essentially, these standards dictate that an eyeglass is milled properly if both the sphere and cylinder components are within 0.25 diopters, and the axis is within 3.0° of the prescription. Given these standards, a match between an antemortem record and a lens can be determined if any of the components are within these parameters. This is termed a "tolerance" match for the purposes of this study. While an exact match can be calculated using Optosearch, tolerance matches can likewise be searched and the frequencies can be determined. Tolerance matches are a more conservative estimate of the frequency in a given population, and those frequencies are likely more common than an exact match. Tolerance matches can be calculated for any case, but analyst discretion is advised. The size of a tolerance match frequency is based on the rarity of the original prescription; the effect can be from substantial on common type prescriptions (many similar prescriptions) to little or no effect on rare or unique prescriptions (no similar prescriptions).

Case Examples

Two case examples are presented to detail the utility of this procedure in identifying unknown individuals. Both cases were selected from forensic identifications of missing U.S. service personnel killed during the Vietnam War. These examples are also used to examine the contribution of refractive error frequency in conjunction with dental frequencies of extraction and restoration and the resulting probabilities of identification based on the combined data. Case 1 utilized solely eyewear fragments that could be one of two individuals, while Case 2 focused on eyewear from a single individual, in conjunction with odontological analysis. Neither of these cases will address biological assessments, such as age or racial populations, as they are topics of a future study.

Case 1

In 1968, a small observer plane crashed into dense jungle terrain in central Vietnam. The two crew members were reported as Missing in Action as a result of this incident. No formal recovery excavation efforts were undertaken until 2000; a series of JPAC-CIL excavations over the next few years at the site yielded aircraft- and aircrew-related artifacts, personal effects, possible human remains, and three sunglass lens fragments.

Analysis of the recovered artifacts included an optical evaluation of the lens fragments. Each portion was examined with a Humphrey® 350 Lens Analyzer at the 15th Airwing Optometry Clinic, Hickam AFB, Hawaii. Two of the fragments yielded identical prescriptions, sphere $= -0.50$, with no correction for astigmatism. The third fragment was too small for analysis. The antemortem records of both missing individuals were examined for possible matches to the eyeglass fragments. One individual, the co-pilot, had no refractive error annotated in his medical charts. The second individual wore corrective lenses. The lens fragments were found to exactly match the refractive error of his left eye. His total prescription was: right eye -0.75, -0.25×100, left eye -0.50, no astigmatism. The total prescription is unique in both the CILEPI and NHANES databases (frequency $= 0/11{,}850$), but it does occur in the NOSTRA database twice, for a frequency of 5.33×10^{-6}. The left eye prescription is relatively common throughout all databases, occurring in frequencies of 2.0%, 0.2%, and 1.0% for the CILEPI, NHANES, and NOSTRA databases, respectively. Even though the refraction error in this case is relatively common, analysis of the lens still accomplished two important goals toward personal identification: (1) it eliminated the co-pilot from consideration for identification using the lens portions and, (2) it placed the pilot in the aircraft at the time of impact with a strong level of certainty (e.g., the pilot did not parachute to safety before the crash).

Case 2

In1967, a U.S. military F-105 pilot crashed while on an armed reconnaissance mission over Southeast Asia. In 1993 and 1997, JPAC-CIL teams traveled to Laos to investigate the loss of the pilot. Several witness claimed that the pilot's body was buried near the crash site. In 2002–2003, two JPAC-CIL teams excavated the purported burial site and recovered skeletonized remains, as well as portions of an antigravity flight suit, other pilot-related gear, and several fragments of a sunglass lens (Fig. 6).

The four fragments of sunglass lens were analyzed using the above-outlined method, and two yielded a readable prescription of sphere $= -0.50$, cylinder $= -0.25$, axis = unreadable. These fragments exactly matched the left eye prescription of the miss-

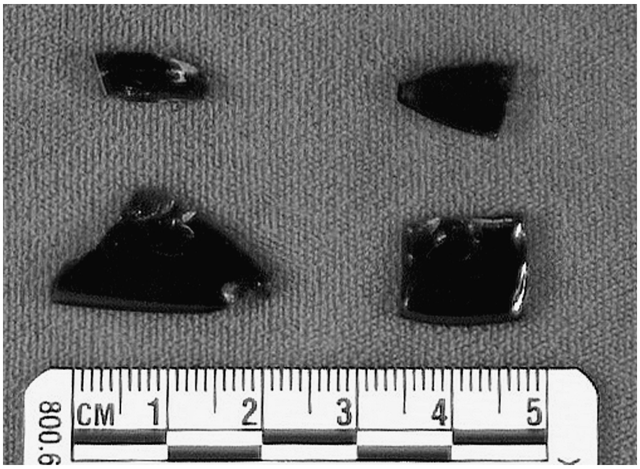

FIG. 6—*Sunglass fragments recovered from an F-105 aircraft crash site in Southeast Asia. The bottom two fragments yielded readable prescriptions.*

ing pilot, an exam that was dated *c.* 1 year before he crashed. The left eye prescription was compared against the NOSTRA database and returned an exact match frequency of 0.66 (95% confidence interval $= 0.68$–0.63), or $<1\%$ of all prescriptions for a left eye. The pilot's complete eye prescription is unique in the database, generating a frequency of 2.66×10^{-6}. The strength of match frequencies indicates that another individual having the exact same left eye prescription (not including axis) is *c.* 6/1000, and a minimum estimated frequency for an exact match to both eyes is *c.* 2/100,000. Being conservative, the estimate of only the left eye prescription is used for the remainder of the analysis.

The identification of the pilot was based primarily on odontological and anthropological analyses of the skeletal remains as well as circumstances of the loss. The sunglass fragments played a minor supporting role in the identification, but the method proposed here demonstrates that optical wear can definitively increase the confidence of the identification based on the strength of the match to the pilot's antemortem records.

If two different pieces of data are independent of each other, then their probability inferences (frequencies) can be combined via the product rule. Leney and Adams (8) have applied the product rule in cases with mitochondrial DNA and odontological patterns of extraction and restoration, making the assumption that these datasets are independent of each other. In cases where the product rule is applied, Leney and Adams (8) urge the use of similar populations (e.g., Whites, Black, Hispanics), rather than mixed groups, due to the *possibility* of dependent data (such as age). Optical frequencies are not unlike odontological patterns of extraction and restoration. Both have a genetic basis, although they are likely affected by environment, disease patterns, and trauma. Genetic coding for dental states, and the subsequent treatment of those states, should be independent of coding for biological eye conditions as well as the treatment of those refractive errors. The identification probabilities dramatically increase if both datasets are used together.

The dental charting for the pilot was input into the Odontosearch program per Adams (9). The calculated frequency of this dental pattern using a generic search in all possible databases yielded a frequency of 2.49×10^{-5}. The frequency indicates that the exact dental pattern is found in only 2/10,000 individuals. Ethnicity information is not currently available in the Odontosearch program and therefore cannot be factored into this portion of the analysis.

The optical data frequencies were calculated using a population-based model as well as a generic search model (the original frequency). The population-based model utilized the NHANES and CELEPI databases for Caucasian male individuals, above 20 years but below 50 years of age (the likely age range of a pilot during the Vietnam conflict). This yielded a frequency of 0.0135, or 17/1257. This frequency is less than the frequency calculated from the NOSTRA database, likely due to the age and sex demographic restrictions placed on the search. Using the product rule, the dental and optical frequencies are multiplied together to determine the chance that an individual selected from the population at random would have the exact same dental pattern and matching refractive error. Using the NOSTRA frequency, the combined total is 1.64×10^{-7}. The more conservative estimate based on age, sex, and ethnicity data produces a slightly higher estimate of 3.36×10^{-7}. Stated another way, approximately three per million persons are estimated to have the same dental and optical corrections by chance alone. This case depicts a significant increase (sixfold) in statistical surety of the probability of a correct identification when both optical and odontological evidence are used.

Conclusion

This research provides the needed statistical surety behind optical refraction errors when making identification judgments based on optical lenses. It moves the eye doctor or forensic specialist out of the realm of "match or no match" into a world of calculable realities. The presented web-based analytical tool enables refractive errors to be weighed against large databases that include subsets of the U.S. population and that include biological information such as sex, age, and ethnicity.

The provided case examples show the utility of this research in several areas. First, optical lenses can place individuals at recovery scenes (crime scenes) and eliminate other possible individuals. Second, the frequency of a given prescription indicates the rarity of the individual (probability of a random individual having the same refraction error by chance alone) and increases certainty of an accurate identification. Third, the frequency of a refraction error can be combined with other data, e.g., odontological, to produce probabilities of identification that are far greater than those produced by a single method alone.

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