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The role of isotope ratio mass spectrometry as a tool for the comparison of physical evidence

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ABSTRACT

This paper considers how likelihood ratios can be derived for a combination of physical, chemical and isotopic measurements. Likelihood ratios were formulated based on the characteristics of a small convenience sample of 20 duct tapes. The propositions considered were:

H_p two samples are from the same batch
H_d two samples are from different batches.

The physical and isotopic characteristics of ten rolls of duct tape were shown to be consistent throughout each roll. The width and thickness of the tapes and the density of the scrim fibres provided equivalent information and the combined physical characteristics provided a basis upon which to discriminate between many of the samples.
Scatter-plots and confidence ellipses provided a convenient method to group the isotopic composition of the tape backing material and provided a basis to discriminate between samples which were physically indistinguishable. Considering both the physical and isotopic characteristics it was possible, at best, to ascertain that the evidence provided moderately strong support for the proposition that two samples of tape were derived from the same batch (LR = 400).
Kernel density estimates were used to model the distribution of isotopic compositions of the backing material. Using this technique it was possible to estimate objectively the probability that a sample with given characteristics could be drawn, at random, from the background population and to calculate a likelihood ratio based on the propositions above.
The strength of evidence which could be presented by either model was ultimately limited by the size of the background sample.

1. Introduction

In this paper the authors consider methods for the interpretation of isotope ratio mass spectrometry (IRMS) data in a forensic context and its presentation within a system exercising criminal justice. When we were aware of contradictory opinions regarding the assumptions and methods presented, we have attempted to highlight the alternative approach and welcome discussion on the subject.

Forensic scientists are frequently required to compare items or fragments of physical evidence such as; fibres, paint and glass, recovered from crime scenes with similar items associated with potential suspects. Comparisons are often initially based on physical characteristics [1,2] such as colour and size but many forms of physical evidence, such as white paints or un-dyed fibres lack distinguishing features [3,4]. For these evidence types chemical analysis becomes necessary, to elucidate further characteristics of the samples. A range of analytical techniques, appropriate to the analyte and matrix [5–9], may be applied and these results will then be interpreted in combination with any physical characteristics.

Many materials of forensic interest are now ubiquitous in modern societies and are manufactured on vast scales with little variation in physical or chemical properties. To overcome this apparent homogeneity forensic science is looking beyond conventional chemical analysis and, increasingly, considering stable isotopic composition as a means to associate or to discriminate samples obtained at different times and locations [10–14].

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In this paper we consider how best to interpret stable isotopic data derived from physical evidence in the form of duct tape and consider the strength of the associative evidence which can be determined using models derived from a sample of the background population. We base our interpretations on a small convenience sample, typical of those used in real criminal investigations [15] and derive likelihood ratios from physical, chemical and isotopic data to determine the strength of evidence that can be asserted from an exhibit with many features.

Duct tape was chosen as the basis for this study because it is made up of many components each of which may have different physical, chemical and isotopic characteristics. In this study we have focused on isotopic analysis of the backing material and the scrim although other components such as the adhesive and filler may also be examined [8].

From the outset, it must be stated that IRMS evidence must be based upon data that are fit-for-purpose, meaning that these data are both reproducible and traceable to the international δ scales; VSMOW,[1] VPDB,[2] N_2Air and VCDT[3] [16].

1.1. What questions need to be answered?

Before any analytical work is undertaken on forensic exhibits it is important to consider what might be contended in Court if two items have closely similar physical, chemical and isotopic characteristics. A reasonable contention might be that the two items had originated from the same batch; in which case the term "batch" must be defined.

The practical definition of "batch" will usually be based on the requirements of a particular case and may refer to a grouping at the level of a small package of similar items e.g. a box of candles or an entire factory production batch. It must be noted that it is often difficult, if not impossible to estimate the size of a batch.

It is not scientifically valid to assume that items from the same batch have the same isotopic composition, nor vice versa [13]. The first action when approaching a forensic case must be to establish the extent of homogeneity or degree of variation for each parameter of interest within a single batch (within-batch variation). The second action must be to establish the variability within the general population of similar items or within a specified sub-population of these items (between-batch variation). If a degree of variation can be demonstrated for a number of batches it is reasonable to extend this assumption to the wider population, until there is evidence to the contrary. The conventional approach to determine variation is to analyse a small convenience sample [15]. The "database" obtained from such a survey can then be relied upon to estimate the likelihood of drawing a sample with certain characteristics from the general population. The weight that can be attributed to IRMS evidence typically relies on the existence of comparative samples or background information and, for this reason, few cases have been presented as evidence in the Courts of Law; despite the potential value of IRMS data [17].

1.2. Evaluative opinions

The role of the forensic scientist as an expert witness is to assist the Court by providing objective, unbiased opinions on matters within his or her expertise [18]. One means of ensuring that the forensic scientist fulfils this role is to employ a likelihood ratio (LR) approach to interpret evidence. An evaluative opinion, derived from the calculation or estimation of a LR, is based on case specific hypotheses and clear conditioning information or a framework of circumstances relating to the matter at hand. In doing so, the forensic scientist ensures that the evidence is of greatest value to the Court.

In this context, the following example is presented: assuming that fragments of duct tape were used to bind the victim of a physical assault, recovered from an illegal drug packaging or from an improvised explosive device, and that visually similar material was recovered from a suspect.

At trial the prosecution contention might be that the two items are from the same batch and part of the evidence might be that the items have closely similar physical, chemical and isotopic characteristics. The defence contention might be that the items are from different batches and part of the evidence might be that between-batch variation is limited and that the physical, chemical and isotopic characteristics are similar purely by random chance. Ideally the hypotheses will be mutually exclusive.

The prosecution contention or hypothesis (H_p)	The items are from the same batch
The defence contention or hypothesis (H_d)	The items are from different batches

A LR can be calculated or estimated according to Eq. (1) in which Pr(E|H) is the probability of the evidence given the hypothesis. The numeric value obtained is an indication of the extent to which observations, findings or results support one of the contentions as opposed to the other; values greater than unity favouring H_p and those less than unity favouring H_d. The likelihood ratio approach can also help to identify irrelevant evidence: the closer the likelihood ratio is to 1 the less relevant the evidence as it favours neither the prosecution nor the defence. In addition, this approach ensures that fallacies in logical reasoning such as transposition of the conditional (considering the probability of the hypothesis given the evidence) are avoided [19].

Because most people understand the probabilities of outcomes, more so than the probabilities for evidence given the hypotheses, verbal scales have been proposed to represent the strength of the evidence in support of a hypothesis or proposition. The scale shown in Table 1 has been recommended by the UK Association of Forensic Science Providers for the presentation of evidence [20]. By convention H_p is the numerator and, therefore, the scale is presented from a prosecution perspective.

Where it is not possible to offer an evaluative opinion for example, in circumstances where there is insufficient information to calculate or estimate a likelihood ratio, then an investigative opinion may be offered, explaining the results obtained within the case context [21].

2. Materials and methods

2.1. Duct tape samples

In this limited study of duct tapes (available in the UK, 2010) we attempted to obtain as varied a sample as possible, typical of a convenience sample obtained in a forensic investigation [15]. Samples were obtained from local retailers (Bristol, UK) (tapes #1–4), from UK wholesale suppliers (tapes #5–17) and from work colleagues (tapes #18–20). In total, twenty samples of duct tape were obtained and analysed. Without evidence to the contrary we assumed, from the outset, that each tape belonged to a different batch.

All tapes were physically examined and the width, thickness and scrim count were recorded. Width was measured using a ruler with a resolution of 1 mm and thickness was measured using a micrometre with a resolution of 0.001 mm. A microscope slide with a one inch^2 window was used to count the warp and weft fibres of the scrim.

To establish within-sample variation, the physical characteristics of tapes #1–10 were examined at 1 m intervals along the entire length of each roll. Samples for isotopic analysis were collected at the same sampling points.

Each tape was prepared for isotopic analysis by dissolving the adhesive to allow the backing and scrim to separate. A sample of tape, approximately 2 cm^2, was floated adhesive side down on chloroform (reagent grade) in a Petri dish. Once the adhesive dissolved, the backing and scrim separated and were removed from the Petri dish. Each component was then rinsed with two further portions of clean chloroform and allowed to dry in ambient air. The scrim was separated into warp

[1] Vienna standard mean ocean water.
[2] Vienna PeeDee belemnite.
[3] Vienna canyon Diablo troilite.

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