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Review Article

Isotope ratio mass spectrometry as a tool for source inference in forensic science: A critical review

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ABSTRACT

Isotope ratio mass spectrometry (IRMS) has been used in numerous fields of forensic science in a source inference perspective. This review compiles the studies published on the application of isotope ratio mass spectrometry (IRMS) to the traditional fields of forensic science so far. It completes the review of Benson et al. [1] and synthesises the extent of knowledge already gathered in the following fields: illicit drugs, flammable liquids, human provenancing, microtraces, explosives and other specific materials (packaging tapes, safety matches, plastics, etc.). For each field, a discussion assesses the state of science and highlights the relevance of the information in a forensic context.

Through the different discussions which mark out the review, the potential and limitations of IRMS, as well as the needs and challenges of future studies are emphasized. The paper elicits the various dimensions of the source which can be obtained from the isotope information and demonstrates the transversal nature of IRMS as a tool for source inference.

Contents

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1. Introduction

The applications of IRMS in forensic science were reviewed for the first time by Benson et al. in a concise paper presenting the theory, instrumentation and forensic applications up to 2006 [1]. Few years later, Meier-Augenstein published an overview of the theory and principles underlying stable isotopes in addition to details on technical aspects and general considerations for the forensic application of IRMS. He also surveyed different forensic applications illustrated by the main ongoing research in the fields and some case studies [2–4]. Some of the main applications were presented by Chesson et al., from the point of view of isotope geochemists [5].

The applications of IRMS in forensic science are numerous and varied. The flourishing contributions of the researchers have led to a huge quantity of information. This paper provides a global overview on the potential and limits of IRMS through a systematic and thorough review of the studies undertaken in the traditional fields of forensic science (the term 'traditional' is to be understood here as 'generally dealt with by the police'). Publications on illicit drugs, flammable liquids, human provenancing, explosives and miscellaneous applications (such as paints, soils, fibers, packaging tapes, safety matches, plastic and paper, etc.) are reviewed and the essential detail is extracted from the study to assess the state of application of IRMS. For each field, the main findings are summarised in a discussion, where the relevance of the results is brought to light in a forensic context. The discussions point at the needs and challenges of future research.

The notion of source inference is first introduced. The first part reports applications of IRMS to fields which are not directly related to police services. In the second part, studies undertaken in the traditional fields of forensic science are reviewed. The ability of IRMS to answer the different questions related to the notion of source is revealed throughout the review.

1.1. The notion of source inference

The applications of IRMS in forensic science all have a common approach: the exploitation of stable isotopes in order to infer the source of a trace. This aspect is often at the heart of the questions to be answered in forensic science. The notion of source in itself is vast and goes far beyond the scope of this article. Interested readers are referred to the work of Kwan for further considerations [6].

The variety of information obtained in the applications of IRMS demonstrates the ability of this technology to treat the questions of source under different aspects. Indeed, the notion of source does not cover only one single question but a variety of questions, which reflect its numerous dimensions and are dependant on the trace and its context. Its applications in several fields which are not directly related to police services – although directly in connection with law – highlight the transversality and potential of IRMS to answer the many questions of the source.

2. Application of IRMS to fields not directly related to police services

2.1. Authentication

A major application of IRMS is authentication, as employed in food, pharmaceuticals and fields concerned with forgery (luxury product, watches, etc.). This technology allows inferring the authenticity, forgery or adulteration of a material. More precisely, the authenticity of a material – and thus its source – may be defined by its geographical provenance (regional or continental) or its specific signature derived from features of production (manufacturer, batch, raw materials, production method, etc.).

Several authors reviewed the numerous studies undertaken in food authentication [7–12]. Most of the studies concern the assignment of the geographical origin of food and the detection of adulterated products. The distribution of stable isotopes in both organic and inorganic materials are characteristic of geographical or regional locations. Isotopic analyses of light elements, mostly hydrogen and oxygen, indicators of climatic characteristics, are often supplemented by heavier trace element isotope analysis, the most common being strontium [9,11]. Authentication of animal derived products is based on knowledge of food chain. Their geographical provenance may be inferred, as animal tissues and products necessarily inherit their isotopic signature from the isotopic composition of their diet (food and water intake) [7,13,14]. Beside the geographical source, stable isotope analysis has also helped in answering the question of the production method of food (organically grown food vs. grown with synthetic fertilisers, specific animal diets, etc.) [10,12]. Although less popular than food authentication, authentication of pharmaceuticals with stable isotopes has also been evaluated. Individual batches of active pharmaceutical ingredients analysed by IRMS are characterised by specific isotopic signatures [15]. The combination of stable isotope ratios allows differentiating genuine from counterfeit pharmaceutical tablets [16].

2.2. Environmental issues

The application of IRMS in environmental issues, such as wildlife forensic science or contamination studies, shows the potential of isotope information to answer different questions of the source. In wildlife forensic science, the food and water intake reflected in animal tissues is used to gain information on the movements of animals [17–25]. The turnover rate of the tissue (feather, hair, muscle, etc.) provides a time frame, ranging from weeks to months or years, for the interpretation of isotope ratios.