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Towards more relevance in forensic science research and development

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ABSTRACT

Many different issues have been identified in forensic science for more than 10 years. While quality management has often been suggested as a path forward, research is generally considered as an essential part of the solution. Through an overview of current forensic science research, this paper aims at evaluating if and how research answer the challenges forensic science is currently facing. While forensic related publications have massively increased over the years, approximately half of the publications were published in non-forensic sources, indicating that forensic science research tends to be led by other disciplines. Over the years, forensic science research has remained largely oriented towards methodological and technological development rather than relevance to the forensic science discipline and practice. Practical implementation of the techniques is rarely discussed from a forensic perspective, and thus research rarely move from the "proof-of-concept" stage to its utilisation in case investigation. The digital transformation also generated a massive increase of data, making it challenging to find the relevant pieces of information in the mass of "forensic" publications available on-line. Thus, we propose to refocus forensic science research on forensic fundamental and practical questions to strengthen the discipline and its impact on crime investigation and security issues. Our propositions represent an incentive to further discuss forensic science research and knowledge transmission through the definition of a common culture within the community, focusing on common fundamental knowledge such as a better understanding of the concept of trace and its case-based information content.

1. Introduction

Calls for more and better research in forensic science have regularly been raised among and outside the forensic science community [1–7]. While research has been uniformly identified as crucial to continuously improve and develop forensic science, there seem to be a disparity of opinion about the type of research considered as vital for forensic science [1,4–6,8,9]. There is also a gap between what research should be carried out and what is actually undertaken. For some, quality management and technical innovation need to be prioritised [2,3,10], while for others forensic science fundamental principles [1,4,11–14] or practice oriented research [7,8,15,16] should be addressed in priority.

Relatively early, Kirk noted that the body of knowledge which exists in criminalistics[1] was *"constantly being increased by a moderate research effort, largely technical rather than theoretical"* [1]. Kirk also suggested that *"Research, so essential to an active science, cannot remain undefined in its objectives, nor limited to technical progress alone"*. Later, Kind observed that scientists were driven by the need to publish for their own advancement, diverting them from the complex study of crime investigation [8] (rarely explicable by precise scientific rules as each case is known to be unique [14]). According to Kind, this explained the particularly high *"emphasis on laboratory studies of "forensic" problems which are of such little practical value, that one is forced to conclude that the "forensic" aspect of such research has been thought up to provide a justification for carrying it out"* [8]. He added that *"many of these studies (were doubtless) praiseworthy and desirable in a pure science or commercial context, but they (were) hardly productive in terms of crime investigation"*. Recently, an international group of forensic scientists confirmed that*"(…) a shared understanding and broad acceptance of the essence of forensic science, its purpose, and fundamental principles are still missing or mis-represented"* [11]. Margot and other forensic scientists also suggested that forensic science needed a sound scientific structure, before quality *"controls (often a poor replacement for competence* [4]*) and ethics"* are to be introduced [4,9,12].

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[1] In this paper, we do not make any distinction between the terms "criminalistics" and "forensic science". Please consult the Sydney Declaration for a detailed definition (Roux et al., [11,12].

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Table 1
Number of publications found with the keywords "forensic" for the year 2019 using different searching engines (July 2022). *A search made in 2020 resulted in slightly lower numbers for some searching engines, indicating a constant and retroactive feeding of the on-line databases. While the indicated numbers represent a snapshot in time, the orders of magnitude remained comparable.*

Searching engines	Number of "forensic" publications referenced for the year 2019
Scopus (2020) https://www.scopus.com	8289
Scopus (2022) https://www.scopus.com	9475
Web of science https://www.webofscience.com	7228
US national library of medicine https://pubmed.ncbi.nlm.nih.gov/	8603
Sciencedirect https://www.sciencedirect.com/	6137
Springer https://www.springer.com/	6017
Wiley https://onlinelibrary.wiley.com/	4002
Google scholar https://scholar.google.com/	127′000

This paper aims at evaluating if more research has been carried out in forensic science in the past years, before addressing what kind of research is currently undertaken. While acknowledging that the situation varies in different jurisdictions, this paper does not address these differences but rather seeks to use the.

findings to discuss the challenges forensic science research is currently facing, and suggest what research would sustain forensic science as a discipline with multiple purposes [11,12], not limited to the application of technology from other disciplines or the presentation of findings in Court.

2. Methodology

The search for forensic science publications has mainly been carried out through literature surveys using *Scopus*. The keyword "forensic" was searched for either in the title, abstract, keyword or source title (see Section 3). This gave an overview of publications covering forensic science published each year until 2021. The search was carried out in 2020 (up to 2019) and in 2022 (up to 2021). The type and numbers of categories constantly evolve in Scopus. Thus, the categories used to search for publications changed slightly between 2020 and 2022. In 2020, the selected source categories to search for "forensic" publications included *articles*, *conference proceedings*, *reviews, conference papers, communications,* and *editorials*, while in 2002 it included *articles, reviews, editorials, conference papers and reviews, book chapters, books, short surveys* and *data papers*. For example, conference proceedings and communications did not exist as categories anymore in Scopus in 2022. However, the obtained results remained close with 8289 vs. 9475 "forensic" publications indexed for the year 2019 for the two searches carried out in 2020 and 2022, respectively (see Table 1). The difference can also be explained by the fact that sources are retroactively added to Scopus thus constantly increasing the number of available publications even for past years. For example, the *Egyptian Journal of Forensic Sciences* has been launched in 2011 but was not indexed in Scopus in 2020 yet. This represented a total of 475 additional publications for the 2022 search (including 68 for the year 2019).

For comparison purpose, other searching tools were also tested in 2022 using the keyword "forensic" in all categories for the year 2019 (see Table 1). 7228 "forensic" publications were found in the *web of science*, while 8603 were indexed in the *US national library of medicine*. Other tools being too specific to a publisher, generally led to lower number of publications being indexed (for example, 6137 for *Sciencedirect*, 6017 for *Springer*, 4002 for *Wiley*). Only *google scholar* led to a much higher number of "forensic" publications as 127′000 manuscripts were indexed for 2019. This is probably due to searching options, as the google searching tool looked for the word "forensic" anywhere in the text and in all languages.

The present survey did not aim at being exhaustive and is not entirely specific either. Some papers indexed in Scopus as "forensic" are not forensic (i.e., false positive results), while some are "forensic" but will be indexed more specifically as "legal medicine" or "criminalistics" (i.e., false negative results). However, the order of magnitude gives an idea of the yearly number of publications in forensic science and provides a comparison basis with other disciplines (see Section 4).

Further, a detailed study was made for gunshot residue and questioned documents using review papers from the *Interpol International Forensic Science Managers Symposium*[2] (see Section 5).

3. Forensic science research in numbers

The number of forensic science-related publications has massively increased in the last 60 years (Fig. 1). This increasing trend was particularly marked over the last 20 years with more than 9000 publications released in 2019 compared to the approximately 2000 published in 1999. The number of sources in which scientific articles have been published has more than tripled in the same period (see Table 2). It is however difficult, given the numbers, to ascertain that all articles containing the term "forensic" in the title, keywords, abstract or source name were significantly related to forensic science. More than half of the sources, including the word "forensic" in their title were of a medical nature (including very specialized journals focused on *Forensic Nursing* or *Forensic Odonto-stomatology*). Excluding medical sources, only general forensic journals (e.g., *Forensic Science International*, *Science & Justice* and *Journal of Forensic Sciences*) were available in 1999, while an increasing number of specialized journals appeared in following years such as *Environmental Forensics*, *Forensic Chemistry*, *Forensic Engineering* or *Forensic Architecture*. Forensic journals with a digital focus started to appear in 2009 (e.g., *Digital Investigation* and *International Journal of Digital Crime and Forensics*). Some sources and publications were written in other languages than English (e.g., "Fa yi xue za zhi", "Z Zagadnien Nauk Sadowych" and "Revue Internationale de Criminologie et de Police Technique et Scientifique" [3]).

Only a small percentage (3–4%) of sources in which "forensic" articles were published include the term "forensic" in their title (e.g., *Forensic Science International*, *Journal of Forensic Sciences*) (see Table 2). However, approximately half of the "forensic" articles were published in those "forensic" journals. When other sources linked to forensic science were included (e.g., *Science & Justice*, *International Journal of Legal Medicine*, *Journal of Medical Entomology* or *Digital investigation*[4]), the percentage of "forensic" articles published in forensic related journal reached approximately 60%. However, a significant number of "forensic" articles are still published in largely

[2] https://www.interpol.int/How-we-work/Forensics/Forensic-Symposium (last access: August 2022)

[3] "Fa yi xue za zhi" is a Chinese Forensic Medical Journal, "Z Zagadnien Nauk Sadowychwhile" is a polish journal addressing problems in judicial sciences and "Revue Internationale de Criminologie et de Police Technique et Scientifique" is an international French-speaking journal of criminology and forensic science.

[4] Journals such as "Medicine, Science and the Law", "Policing", "Law, probability and risks" or "Law and Human Behaviour" were not considered as strictly forensic related.

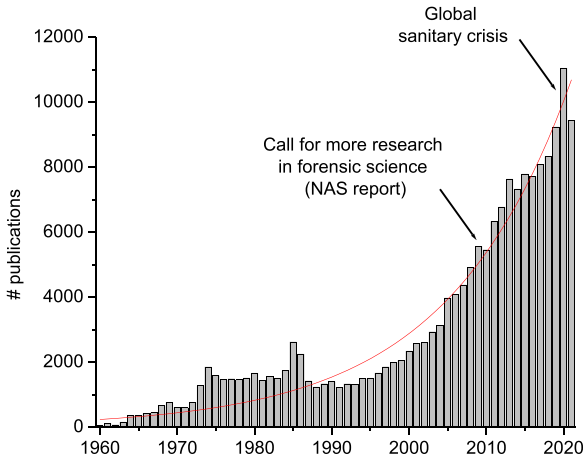

Fig. 1. A total of 183′116 publications were referenced in Scopus between 1960 and 2021 with the word "forensic" in the title, keywords, abstract or journal name. While an exponentially increasing number of "forensic" papers have been published over the years (see red line), there is no evidence that the NAS report [2] made a significant impact after 2009 compared to other main drivers (e.g. publish and perish paradigm). In 2020, there was a massive increase compared to 2019 and 2021. This may be a side effect of the shutdown during the acute phase of the COVID-19 pandemic; many researchers had more time to publish data that had been collected in previous years. (Source: Scopus 2022).

Table 2
Some numbers about forensic publications, articles and sources referenced in Scopus ten years before and after the release of the NAS report in 2009 (Source: Scopus 2020). Articles are research papers, while publications also include review or conference papers (see methodology section for details).

	1999	2009	2019
# of "forensic" publications	3862	5557	8289
# of "forensic" articles	1624	2042	6823
# open access "forensic" articles	57	455	2245
% open access "forensic" articles	4%	22%	33%
# sources in which "forensic" articles were published	1449	861	448
# sources with "forensic" in title	40	28	16
% sources with "forensic" in title	3%	3%	4%

unrelated journals (e.g., *PLoS ONE*, *Scientific reports* or *Analytical Chemistry*). This may partly be explained by the fact that forensic journals generally have lower impact factors than journals from other disciplines.[5] For the year 2019, 89 "forensic" articles were detected in 32 sources containing the word "chemistry" in their title (*Forensic chemistry* excluded). The fact that unrelated journals contain up to 60% of articles published on fingermark research was also mentioned in the review papers of the *19th INTERPOL International Forensic Science Managers Symposium* [17].

The number of open-access articles has also significantly increased during the last few years, and this increasing trend will undoubtedly continue given the new open-access policy of many universities and funding agencies. However, only articles that are freely accessible directly from the publishers were accounted for in Table 2. Many authors enable green open access to pre-print or post-print versions of their manuscripts through non-commercial repositories (respecting embargo periods). Thus, the mentioned 33% ratio of open-access articles in 2019 is probably largely underestimated. The number of open-access "forensic" articles reached 40% for the year 2021.

4. Big data

While forensic science might be expected to rejoice in the general increase of published research, experienced academics will probably agree that a "publish or perish" science paradigm may have led to an increased number of irrelevant or less impactful publications (as already mentioned by Kind [8]). Excluding the 2020 peak probably due to the COVID-19 lockdown (see Fig. 1), the observed exponentially increasing trend is not specific to forensic science research (see Fig. 2) and reveal a big data issue all scientists (and our society at large) are facing nowadays.[6]

How is it possible to keep track of the relevant literature with such numbers? Indeed, how can a scientist gain an overview of the forensic science field, when several thousands of articles are published each year through recognised publishers (see Table 1)? Reading one article per day is largely insufficient – and most researchers will concentrate on reading the articles they co-author first [18]. Thus, we largely rely on searching engines (i.e., algorithms) to find relevant papers in our sub-discipline(s), knowing that looking too broadly will yield too many articles (i.e., false positives), while looking too specifically will not allow us to find all relevant articles (i.e., false negative). The number of sources in which forensic papers are published also complicate the matter as new (often open source) journals are proliferating, adding to the general background noise. Thus, many articles are brought to our knowledge through established networks and, increasingly, social media, thus redefining our "searching" strategies in an increasingly digital work environment. In this new searching paradigm, the question of biased search strategies should also be considered.[7] Once we have gathered the relevant articles from all available sources, we still need to find time to further triage and read them (often using fast reading techniques and potentially losing some of the sense meant by the authors).

Review papers aim at helping scientists gain an overview of their field. According to Scopus, 625 reviews containing the word "forensic" in their title, keywords or abstracts were published in the year 2021 (see Fig. 3). More than 60% of these reviews were related to (forensic) medicine, and only 35% were published in forensic related sources. Given the number of reviews published each year in forensic science, it is essentially impossible to keep up with forensic science research at large since the 90 s.[8]

5. Research topics

This "big data environment" is furthering the isolation of scientists in specialised silos [12,19] (as also shown by the multiplication of ultra-specialised forensic sources such as *Forensic Chemistry* or *Forensic Science International: Animals and Environments*. Thus, each scientist remains only (and barely) aware of the research carried out in their research field, which is not anymore "forensic science" but rather a specialist domain with potential applications to forensic science questions (e.g., forensic geology or soils). However, even

[5] Impact factors of scientific journals are calculated from the number of times the average article has been cited over a year. For example in 2020, *Analytical Chemistry* had an impact factor of 6.986, while the highest impact factor among forensic science journals was 2.395 for *Forensic Science International* (source: https://academic-accelerator.com/Impact-of-Journal/Analytical-Chemistry and https://academic-accelerator.com/Impact-of-Journal/Forensic-Science-International, last access: June 2022).

[6] The lack of relevance of research was also observed by experts in other disciplines, for example on COVID-19 For example, the German expert on coronavirus Christian Drosten stated in April 2020 that you could "*read through 50* (articles) *before you find something that's actually solid and interesting. A lot of research resources are being wasted.*" (https://www.theguardian.com/world/2020/apr/26/virologist-christian-drosten-germany-coronavirus-expert-interview, last access: August 2022).

[7] The better advertised research will gather much more attention with all the risks associated with cronyism and flashy trends over scientific relevance and quality.

[8] Books and book chapters (such as Encyclopedia) were not considered, while some can also be considered as reviews of forensic science knowledge. 1128 "forensic" books (42 published in 2021) and 4780 book chapters (176 published in 2021) were indexed in Scopus.

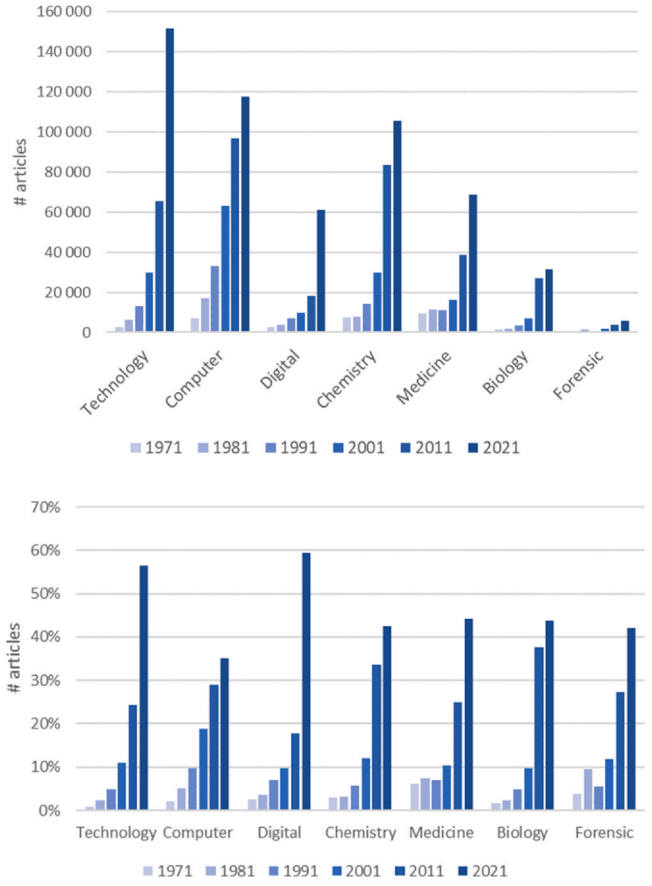

Fig. 2. Absolute numbers (above) and percentages (below) of articles as a function of the search words used in the title, keywords or abstract. A significant increase can be observed transversally in the last 50 years. The growth was particularly marked for "technology" and "digital" related articles.
Source: Scopus 2022).

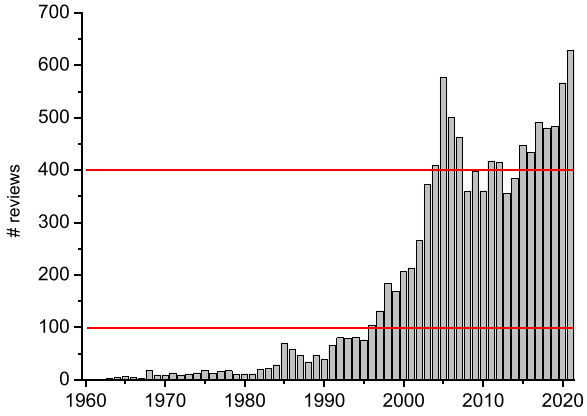

Fig. 3. Forensic related reviews published each year between 1965 and 2021. More than 100 "forensic" reviews were published each year after 1995, and over 400 a year since 2015.
Source: Scopus 2022).

when considering specific forensic traces, the numbers of published articles and reviews have considerably increased, especially in recent years (see Fig. 4). For the year 2021, the following forensic "specialised" publications were referenced in Scopus[9]:

[9] When two keywords are used in Scopus, publications including both terms in the title, abstract or keywords are searched for.

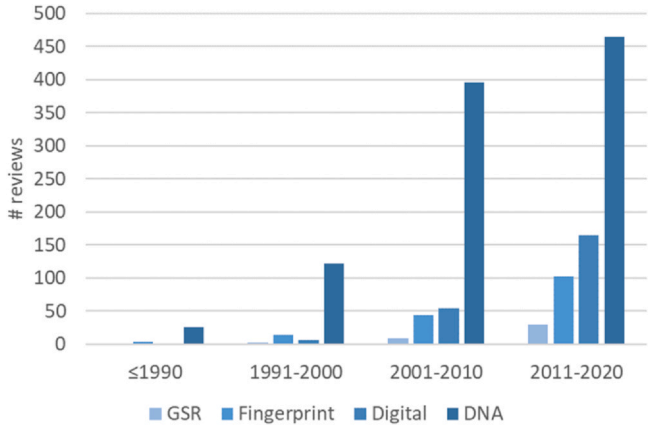

Fig. 4. Number of reviews including the words "gunshot residue" (GSR), "forensic fingerprint", "digital forensics" or "forensic DNA" in the title, abstract or keywords in Scopus over 10 years period.

- 743 articles and 76 reviews (9%) on "forensic DNA",
- 589 articles and 36 reviews (6%) on "digital forensics",
- 194 articles and 28 reviews (13%) on "forensic fingerprint",
- 37 articles and 11 reviews (23%) on "gunshot residue".

Thus, compared to research articles, a relatively high percentage of reviews were published in forensic sub-disciplines, either as an attempt to keep track of new knowledge, or to pursue the "publish or perish" injunction as reviews generally gather more attention (and thus, citations) than research articles.

The addressed subjects and content of the reviews are very disparate, rarely assessing reported research from a critical or practical point of view (see for example the GSR reviews published in 2021 in Table 3). Readers are thus often left to do the "triage" of relevance and quality assessment by themselves. While this may not be an issue for most experienced researchers (except for lack of time), it is challenging for students and inexperienced post-graduate researchers. Interestingly, we often observe that students use recent low-quality or irrelevant articles and reviews as starting point for their research, thus sometimes furthering poor quality, undefined objectives and low information science, while key research become lost in the background noise. These issues will be further discussed in the next section, through specific examples taken from gunshot residue and questioned document research.

5.1. Gunshot residue (GSR)

637 articles were indexed in Scopus for "gunshot residue" between 1981 and 2021. An automatic search for GSR "transfer", "persistence", "prevalence" and "interpretation" articles over the same 40 years period provided 54, 26, 19 and 51 articles, respectively. Thus, approximately **22%** of the published papers addressed what is often considered as fundamental forensic science topics [20–22]. This tendency was confirmed by the last detailed review of gunshot residue papers carried out for *19th Interpol International Forensic Science Managers Symposium* [23] (see Fig. 5 – left). A total of 90 publications were listed between 2016 and 2018 (ca. 30 per year). Among those, 48% focused on the method, while 22% addressed trace characteristics, prevalence and persistence; 14% discussed interpretation, and 30% addressed other topics (mainly the design of luminescent or doped ammunition and the estimation of the time since discharge). A detailed study of the 37 "gunshot residue" articles referenced in Scopus for 2021 was also conducted [24–60]. 18 (i.e., approximately 50%) of these articles were published in forensic science sources. A close look to the article contents revealed that more than half of those papers focused on method development,

Table 3
Title of the reviews published on "gunshot residue" in 2021 (Source: Scopus 2022).

1	Spectroscopic (analytical) approach to gunshot residue analysis for shooting distance estimation
2	Vibrational spectroscopy and chemometrics in GSR: review and current trend
3	Gunshot residue detection technologies—a review
4	Trends in Gunshot Residue Detection by Electrochemical Methods for Forensic Purpose
5	Advances and limitations in the determination and assessment of gunshot residue in the environment
6	Persistence & Detection of Organic Gunshot Residue in a Forensic Investigation: A Review
7	First lessons regarding the data analysis of gunshot residue traces at activity level in TTADB
8	Paper-based microfluidic devices: On-site tools for crime scene investigation
9	Environmental and health hazards of military metal pollution
10	Research Progress on Touch DNA on Cartridge Cases in Forensic Field
11	Forensic applications of DART-MS: A review of recent literature

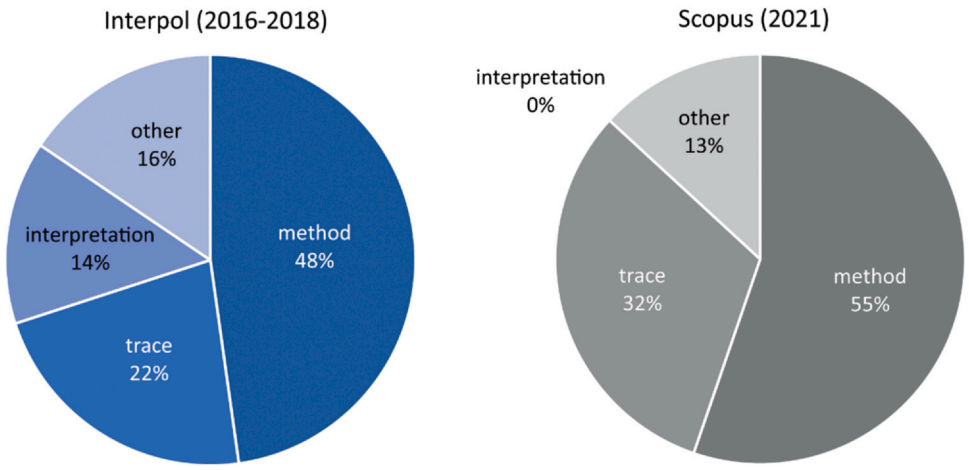

Fig. 5. Research articles on "gunshot residue" indexed in the Interpol review papers (2016–2018) (left – blue, $n_{2016-2018} = 90$) and in Scopus for 2021 (right – blue, $n_{2021} = 37$).

optimisation or evaluation (see Fig. 5 – right). Approximately **30%** of the articles addressed the questions of trace characterisation, transfer or prevalence, while none addressed persistence in 2021. Four articles were related to environmental issues (contamination of soils or animals), while the last paper was a review rather than a research paper [54].

A quick perusal of the 11 reviews published on "gunshot residue" in 2021 indicate that only seven reviews are specific to GSR (see titles 1–7 in Table 3), but this is still a considerable percentage [61–71]. Four out of the seven GSR reviews focus on (often very specific) methods. The remaining four have other main topics (i.e., crime scene investigation, military pollution, touch DNA and DART-MS application).

Scanning Electron Microscopy with Energy Dispersive X-Ray Analysis (SEM-EDX or EDS) was proposed in the 1970 s for the analysis of GSR [72–74] and has since then been implemented for the screening of GSR inorganic particles in many forensic laboratories [23,75–77]. In the past 40 years (1981–2021), a total of 142 articles on "gunshot residue" also mentioned "SEM-EDX" or "SEM-EDS" in their title, abstract or keywords.[10] This represents only 22% of the total number of articles published on GSR and referenced in Scopus. In 2021, 9 articles (24%) reported the use of SEM-EDX, sometimes in combination with other techniques such as Inductively Coupled Plasma Mass Spectrometry (ICP-MS) or Laser Induced Breakdown Spectroscopy (LIBS) [39,40]. Thus, over the years, many alternatives to SEM-EDX have been proposed and most research articles (over 70%) focused on the development or implementation of novel analytical approaches, either to propose alternatives (e.g., Laser Induced Breakdown Spectroscopy) or to expand the targeted trace characteristics and purposes (e.g., from inorganic to organic GSR, to estimate the shooting distance or time) [20,22,78–82]. If we exclude other currently applied approaches (e.g., the shooting distance estimation, routinely applied in practice, represented 9% of the articles published between 2016 and 2018 [23]), many research projects have relatively little to no impact on forensic science practice, as SEM-EDX is still the method of choice in most forensic laboratories for the analysis of GSR. Several hypotheses may explain this gap between research and practice and will be discussed below (in Section 5.3).

5.2. Questioned document

The review papers from the *17th, 18th and 19th Interpol International Forensic Science Managers Symposium* listed 743 articles in the field of questioned documents between 2010 and 2019 (about 80 per year) [78–80]. Approximately one-third of the papers published during that period focused on the study of handwriting (including digital signatures), while another third targeted inks, toners and papers. 12% and 10% of the publication focused on dating issues (including the determination of the writing sequence) and security documents, respectively (see Fig. 6). The remaining 19% represented smaller categories such as seals, latent writings, quality insurance or reviews. Only, 25% of the ink differentiation studies were published in forensic sources between 2016 and 2018 [83].

While ink analysis is carried out only in a small amount of questioned document cases (at least compared to handwriting comparison and security document examination), it still represents a significant amount of publications in the field [84,85] (see Fig. 5). In practice, ink analysis is mainly carried out using relatively simple optical methods such as filtered light examination or hyperspectral imaging [84]. However, a high percentage (at least 80%) of the

[10] The numbers are indicative, as some articles mention SEM-EDX as the method of reference for GSR analysis in the abstract but do not implement it in their research, while others do not mention SEM-EDX in the title, abstract or keywords, while they do implement the method.

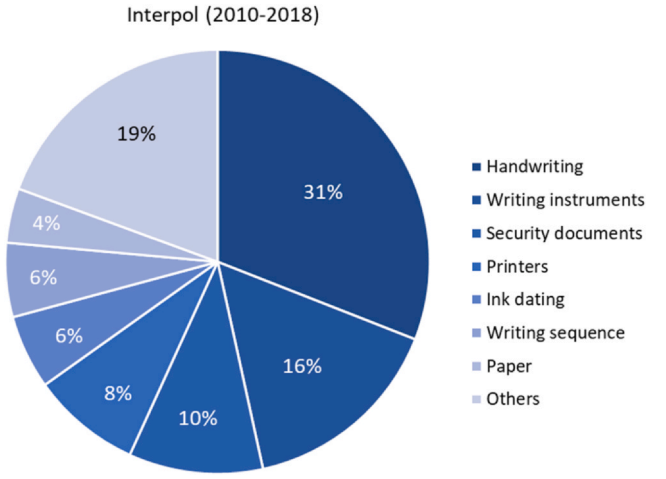

Fig. 6. 743 articles were referenced in the field of questioned documents between 2010 and 2019. Such a search cannot be quickly carried out using searching engines such as Scopus as the words "document" and "ink" are frequently used in all kinds of forensic publications unrelated to questioned documents.
Source: Interpol Review Papers [78–80].

reported papers on ink analysis focused on more advanced spectrometric or separation techniques (such as Raman spectroscopy, Fourier Transform Infra-Red spectroscopy, capillary electrophoresis, liquid chromatography, and diverse mass spectrometric approaches [83,85]). Similarly, to gunshot residue, it is interesting to investigate why there is such a large gap between practice and research.

5.3. From research to practice?

The previous sections highlighted a large gap between research and practice, indicating either that most research is not answering practical needs or/and that practice does not easily adapt to research outcomes [9]. There might indeed be some delay between proof-of-concept studies and their validation for practical implementation. However, 40 years of research in the GSR field has brought little change as the residue is still mainly analysed using SEM-EDX. Similarly, ink has been examined for years using simple filtered light options. While the instruments themselves evolved, the techniques remained based on the same physical and optical principles. Thus, the implementation state of research seems to point to other issues that will be investigated in the following paragraphs:

- **Proof-of-concept studies**: Research rarely move beyond the "proof-of-concept" stages and seem to follow a constant 'zapping' pattern. Indeed, most publication are preliminary (and in all appearance successful) "proof-of-concept" studies based on new techniques or data treatments. As many techniques can detect GSR particles [86] or differentiate a limited amount of ink specimens with a high level of confidence [84], research focusing on the methods guarantees a positive and publishable result, if not in a forensic journal, then at least in chemistry or technique-based sources such as *Microchemical Journal* or *Journal of Raman Spectroscopy*. In fact, articles refused by a forensic science journal (due to their lack of added value to the field) are regularly published in other fields.[11] This observation tends to confirm that many papers linked to a forensic application may not be as relevant to forensic practice as they should be. In this view, research does not answer practical needs, but implicit or explicit publication criteria from other disciplines such as the novelty of the technology, rather than the novelty of the data (i.e., information extracted from the trace [11]). These proof-of-concept studies also requires less time and effort and lead to higher numbers of publications (meeting the "publish or perish" implicit rule of academia [8]).
- **Specialisation and standards**: Forensic science practice is often guided by specialised skills and detailed guidelines and standards that took years to be developed and implemented [12,75–77]. This is well illustrated by the following citation by Charles et al. [23]: *"For instance, since organic GSR (OGSR) analysis is mainly related to bulk chemistry and since current GSR-experts are for most of them working in material analysis departments, in our opinion only a new technique offering substantial benefits in terms of analytical performances will gain the favour of these experts and change their analytical paradigm."* Once a highly sophisticated technique such as SEM-EDX has been implemented in practice, requiring specialists to operate the instrument as well as maintenance costs and standards, it is very difficult to change practice for technical, structural and financial reasons. Indeed, a specialist trained on SEM-EDX may not be able or motivated to operate another instrument such as LIBS or LC-MS/MS (technical issue). They also operate on a daily routine with little time for additional training and no easy access to other instruments (structural issue). Finally, buying a new costly instrument with associated training may not be financially viable (financial issue). From the manager point of view, it is also difficult to free time and resources for practitioners to carry out research. When they do, the research may not meet the criteria to be published outside established networks (e.g., European Network of Forensic Science Institutes,[12] The Chartered Society of Forensic Science in the UK, [13]The Organization of Scientific Area Committees for Forensic Science in the US[14] or The Australian and New Zealand Forensic Science Society).[15] Indeed, practice-oriented research is not always considered novel enough (at least in a technical point of view) and scientific publication requires specific formatting, language, [16]submission, revision and proofing that can hamper publication from scientists outside the academic field. This also further the gap between research and practice.
- **Lack of relevance:** A third explanation might be found in the fact that advanced techniques do not bring much more information compared to the added costs of implementing them in routine. This hypothesis is supported by the fact that ink differentiation using an advanced and often destructive technique (e.g., analytical chemistry technique) is not the most relevant examination in practice [84]. Indeed, a high number of inks can already be differentiated using straightforward optical techniques available in all forensic laboratories. In contrast, the added values of additional techniques will in most cases only bring confirmation that the ink entries cannot be differentiated. While the meaning of a reliable differentiation is straightforward (i.e., the ink entries are different in their composition), the result of a non-differentiation is not so easily interpreted as inks are mass products. Many different pens and brands share the same ink formulation (i.e., it is rarely possible to conclude that two ink entries were made by the same pen). Thus, the fact that ink analysis is carried out only in a small number of cases can be explained not by the

[11] This comment is based on the authors' roles in the edition and reviewing of papers submitted to forensic journals. While not limited to the gunshot residue and questioned document topics, this observation is not substantiated by a quantitative analysis.

[12] https://enfsi.eu/ (last access: August 2022)
[13] https://www.nist.gov/organization-scientific-area-committees-forensic-science (last access: August 2022)
[14] https://www.csofs.org/ (last access: August 2022)
[15] https://anzfss.org.au/ (last access: August 2022)
[16] Many recognised journals are published in English, while most researchers and practitioners around the world are not native English speaker.

lack of useful analytical approaches, but by the lack of relevant additional information brought by such analysis. Indeed, **no amount of new technology will allow increasing the initial relevance of the trace** [11,84,87,88].

This brings us to the relatively small percentage of articles addressing more fundamental forensic issues, such as a better understanding of the trace and its information content [11,87]. Thus, the issue may be more of an interpretative nature than a technical one. It should be noted that we do not restrict the term "interpretative" to the use of complex statistical approaches. We are rather advocating the necessity of case-based critical thinking to focus the research efforts where they will bring the most impact (in terms of relevance and reliability). Thus, 60 years after Kirk's call for better defined research [1], we have to acknowledge that the increase of technological research has been much larger (and has gathered more consensus) than the increase of research into fundamental forensic theory and principles [11]. In other words, the problem identified by Kirk may even have worsened over the last 60 years.

6. Towards more relevance in research

In summary, research trends seem to be mainly focused on new instruments and technology (i.e., respecting the issue of originality) and easiness of producing positive results (i.e., high feasibility), thus following implicit requirements of apparent novelty and quantity. Indeed, the reward and research funding systems often promote trendy short-term projects with dubious impact on forensic science (thus fostering disruption and fragmentation rather than common longer-term and effort endeavours). Despite alternative propositions [89],[17] the academic world mainly strives on metrics such as the number of publications, citations, h-index[18] or even number of tweets. Such requirements, linked to the digital transformation of our society, led to a massive increase in scientific publications accentuating the current big data challenges, that are not restricted to forensic science [18,89]. At this stage, **the real challenge is not to increase the research novelty and quantity, but rather its relevance and quality.**

While many universities and funding agencies strive to promote open science as a mean to improve the diffusion and sharing of this massive amount of generated information (a very positive endeavour), the questions of triage and long-term storage are not sufficiently addressed, and mainly viewed as additional technological and economic issues, rather than as scientific and sustainability challenges. Thus, relevant information remains, too often, a needle lost in the haystack of publications.

Efforts to increase quality had little impact on the present state of (forensic) science research, as standards and metrics can relatively easily be diverted from their original purpose and may sometimes even hamper the imaginative minds of scientists to explore more relevant, but risky, pathways [9,90,91]. While it is our opinion that researchers should carry out more impactful (even if fundamental) research, they are often forced by the systems to follow the publishing trends and associated administrative workload (to “ensure” quality, ethics, copyright, credits, open access…). As highlighted in a previous publication [9]: *“There are many examples of research papers that may easily pass the integrity test while being of little value to forensic science, let alone of dubious quality”*.

Meanwhile most forensic science laboratories struggle with high workloads, making the adoption of new technology unattractive because of the activation energy to be overcome even for those which lessens workloads. The drive for efficiency and the fact that case numbers and turnabout time are the only metrics further restricts the practicality of carrying out research or adopting new approaches. While there are exceptions, most forensic science laboratories do not have sufficient resources to manage their workloads adequately. It is necessary to acknowledge that the different reward system operating in research and practice do not promote synergy or cooperation.

Thus, we argue that science, and hence forensic scientists, should dictate what research is needed rather than the systems, the politicians or other disciplines. Our propositions to move towards better and more impactful forensic science research are the following:

- We advocate for **more substance in forensic science publications**. A shift from less preliminary studies towards more forensic science content is needed, particularly in terms of more realistic specimens and tests. Preliminary studies carried out by students may still be published more locally or included in larger collaborative works (for the advancement of young researchers). However, the research effort should, at least partly, be refocused on the main object of study of forensic science: the trace (i.e., the remnants of past activities) in the case context [11] rather than the means [12].
- We also argue that less forensic science journals are needed. This will allow our relatively small community to concentrate on increasing the relevance and quality of the published articles. Every time a new forensic science source is created (often by the same publishers), a part of our community dedicates its efforts to the new source in terms of edition and peer-review, thus scattering the efforts on multiple smaller and disparate sources rather than **strengthening a selected number of main forensic science sources**. We should also avoid assisting the creation of too specialised “forensic” sources that are more attached to other disciplines than to forensic science (e.g., chemistry, computer sciences or statistics) [92]. A path toward open and relevant science may come from entirely forensic science-driven initiatives, rather than profit-driven options, through the development of Shared Open Access Publishing (SOAP) sources linked to recognised international forensic networks.
- That said, **the development of new techniques can be led in collaboration with other disciplines and published in other specialised sources**, thus ensuring a strong technological basis before moving from the proof-of-concept stage to its potential forensic application [93]. The later should be published in forensic sources and reviewed by forensic peers to ensure relevance.

Following these suggestions may be difficult in our present academic systems, but it seems essential to move towards more relevance and quality (i.e., to make more sense in our daily activities). Young promising researchers have a long way to go before reaching semi-permanent positions in academia and the constant need to obtain funding (generally evaluated by non-forensic peers) strongly biased research topics from the start of an academic career. Thus, we call to well established researchers and managers in universities, funding agencies, publishing houses and forensic laboratories, to slow the frantic chase towards metrics (i.e., quantity and apparent novelty) and start **increasing critical forensic thinking to address longer-term real life, as well as fundamental, challenges in collaborative enterprises** [9,89,91,92].

It is also important to remind all involved stakeholders that no amount of new technology will allow increasing the initial relevance and quality of traces resulting from uncontrolled criminal activities [11,16,87,94]. The only way to answer these challenges adequately may be through the development of a forensic science culture through adequate forensic science education [4,11–14].

[17] The San Francisco Declaration on Research Assessment (https://sfdora.org/, last access: August 2022).

[18] The H-index is calculated as the maximum value of h publications that have each been cited at least h times.

CRediT authorship contribution statement

Céline Weyermann: Conceptualization, Data curation, Writing – original draft. **Sheila Willias:** Conceptualization, Writing – review & editing. **Pierre Margot:** Conceptualization, Writing - review & editing. **Claude Roux:** Conceptualization, Writing – review & editing.

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Conflict of interests

none.

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