Genetic Discrimination in workplace, insurance industry and legal system: a review

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Introduction
There is not a unique definition of genetic information (GI), since the informativeness of a specific part of the genome strongly varies with the progresses of genetic research: every day, new genes that influence or cause the risk of developing a genetic or multifactorial disease are discovered and thus genes that previously were not "sensitive" from a social/clinical point of view become hot spots [1]. In the last decade, the fear of being discriminated because of genetic factors has been heavily discussed in scientific community [2]. A 2024 formal definition of genetic discrimination (GD) is: "Genetic discrimination involves an individual or a group being negatively treated, unfairly profiled or harmed, relative to the rest of the population, on the basis of actual or presumed genetic characteristics" [2]. In plain terms, GD is a differential treatment based on GI, and it has legal and ethical implications when it leads to undesired consequences, primarily resulting in stigmatization [3]. In reality, stigma is a broader concept than discrimination, since it is generally divided into "felt" stigma (perceived ostracization without actual discrimination) and "enacted" stigma (stigma with practical consequences) [4]. The fact that a stigma can be only perceived recalls the fact that GD remains a social construct and as such the acceptability of certain conducts varies according to the context and to the social perception of them [5]. The most perceived/feared source of GD is

represented by insurance companies (especially in countries without a public healthcare system, like the US), followed by employers and, lastly, by the society in general or by the family [3]. At the same time, fear of discrimination is usually directed not only to the occupational/insurance/legal consequences, but also to social/interpersonal difficulties [3]. Indeed, most research on this topic addresses severely impairing genetic diseases (Huntington's diseases and hemochromatosis), very frequent conditions with a genetic basis (hypercholesterolemia) and cancer (hereditary breast/ovarian cancer, colorectal cancer) [6, 7]. An associated concern is the belief that this form of discrimination cannot be completely prevented by current regulations [3]. Besides socio-legal and ethical aspects, GD represents a major threat also for individual and public health, since it is a strong barrier against early diagnosis and thus early/targeted treatment in many cases of genetic and multifactorial diseases [3, 8]. For instance, refusing the indication to genetic testing because of the fear of GD is particularly frequent when highly impairing syndromes - like Huntington's disease - are involved [3]. In the insurance industry and workplace, GI is often provided voluntarily. However, another potential form of GD occurs when individuals feel they cannot freely request the deletion of their data, even if they are considered its "owners" (the so-called "right to be forgotten") [9]. The introduction of advanced technologies in the field of genomics, such as epigenetics and polygenic risk scores, may also create new possibilities for genetic discrimination. Data on the acceptability and accuracy of these technologies are lacking and their potential to discriminate is also not well understood [10]. Concerns are raising regarding the national governments' use of 'OMICS' data for biometrics and other purposes in law enforcement, immigration, and national defense. Finally, a large amount of genetic data is collected on a regular basis (and frequently against the interests of the owner) in the criminal justice system, where the risk of GD may have specific and severe consequences for the violated person [11], raising significant ethical concerns and privacy issues. In this paper, we review the current knowledge of these four specific topics (GD concerning the right to be forgotten, insurance industry, employment, and justice system), with a narrative approach due to the broad scope of the research questions addressed.

Methods

Since the broadness of the research question (i.e., describing the GD in the four aforementioned topics), a narrative approach to the review was preferred. Two independent reviewers used PubMed, Google Scholar and GDO - Genetic Discrimination Observatory as search engines. The search was performed combining core terms "genetic information" and "genetic discrimination" with other terms like "regulation", "law", "insurance", "right to be forgotten", "right to erase", "employment", "workplace", "justice system", and "antisocial behavior". Only papers with full text in English were selected, with no date restriction. G7 Countries (US, UK, Italy, France, Germany, Canada, Japan) and European Union were selected as the main targets of interest.

Results

Eligible papers are presented in the following paragraphs.

High-income countries laws against GD (Table 1)

All the G7 countries but UK and Japan have legally binding protection measures against GD [12]. Specifically, France, Germany, Italy are part of the European Union, that has its own sovra-national regulations. In the European Union, confidentiality and privacy of GI were originally protected by the Directive 95/46/EC of the European Parliament [13]. However, the current regulation that addresses personal data (in general) is the 2016 General Data Protection Regulation - GDPR [14]. According to the GDPR, GI is considered a possible identifier of the natural person and thus it should be considered as personal data protected by the regulation [13]. Genetic data are considered sensitive

and as such their processing can be justified if a substantial public interest (e.g., scientific research) is pursued and suitable safeguards are adopted [13]. When a public interest can be considered substantial and when a safeguard can be considered suitable are defined by Member States, that then are free to regulate in a broad or restrictive way [13]. Additionally, France and Germany promoted a general prohibition of GD - similarly to Canada, while Italy adopted a dynamic approach, based on the Personal Data Protection Code and General Authorization for the Processing of Genetic Data, that is yearly reviewed by a dedicated public authority [12].

US adopted a specific law against GD: the 2008 Genetic Information Nondiscrimination Act – GINA, which targets GD perpetrated by the cornerstones of the US healthcare system: health insurers and employers (with more than 15 employees; military and federal employees are not covered by this law) [15]. GINA covers GI obtained through both anamnesis and individual/familiar genetic testing and does not apply to those who have already clinically manifested a genetic disease [15, 16]. This limitation is partially applied as other federal laws (ADA to protect workers with disability and HIPAA/ACA to avoid exclusion from health insurance for people with pre-existing health conditions) and local laws address the persons who have already manifested signs of a genetic disease [15]. In Canada, the GNA (Genetic Non-Discrimination Act) prohibits insurers, employers, educational institutions, landlords, adoption agencies, and other service providers from using GI when establishing contractual relationships with individuals [17]. The UK lacks specific legislation addressing GD. Nevertheless, the Data Protection Act (2018) and the General Data Protection Regulation (GDPR) of the UK provide safeguards for genetic data which are classified as a special category of personal data. The processing of such data, along with other special categories, is generally presumed to be prohibited unless certain specific conditions are met [18]. Genetic discrimination (GD) has not been discussed in East Asia as extensively as in Europe and North America [19]. In Japan, Genetic Data are regarded as a special category of personal data under Japan's Personal Data Protection Law. Furthermore, the Genome Medicine Promotion Act of 2023 establishes the need to advance genomic medicine while protecting individuals from GD [20].

Country / Area	**Legislative protections against genetic discrimination**
United States of America	*Specific law: GINA (from 2008) against GD perpetrated by health insurers and employers (with more than 15 employees), excluding who have already clinically manifested a genetic disease (these ones are protected by other federal/local laws like ADA/HIPAA/ACA).*
European Union	*Sovra-national regulation by European Union (GDPR, from 2016) GI is considered sensitive personal data and its processing is allowed only for substantial public interest under state-defined safeguards.*

Italy	*Dynamic approach based on the Personal Data Protection Code and General Authorization for the Processing of Genetic Data, annually reviewed by public authority.*
France	*General prohibition of GD*
Germany	*General prohibition of GD*
Canada	*Specific law: GNDA Genetic Non-Discrimination Act (from 2017) [17]. General prohibition of GD.*
United Kingdom	*No specific law: Genetic Data is indirectly addressed under DPA (from 2018) and considered as a special category of personal data [18] in accord with UK GDPA [28].*
Japan	*Japan's Personal Data protection Law included genetic information as "special-care-required personal information", affording it enhanced privacy protections. Specific law: The Genome Medicine Promotion Act (from 2023): general prohibition of GD. [20]*

Table 1 *– international regulations against GD (only G7 countries)*

Right to be forgotten (Table 2)

The right to be forgotten is a relatively new concept, and in the limited number of countries where it is recognized, there are no specific laws dedicated to it. Furthermore, GI remains largely unaddressed within existing regulations [9]. Specific regulations, like GDPR, recognize the individual right to obtain the deletion of personal data if the purpose for which it was processed ceases or if the consent is revoked, but it is not an "absolute" right, depending on whether the erasure threatens other more relevant rights [9]. Indeed, this right cannot be invoked for any type of health information (for

instance, not when the information is of relevant public interest), and - for instance - in UK it is substantially restricted to confidential treatment requests and information no longer required by local public healthcare system [9]. Moreover, in the United Kingdom, the right to erasure, as extended to genetic data, does not apply when such data are processed for research purposes [18]. In Japan, the right to be forgotten is not formally codified but only partially safeguarded through APPI (Act on the Protection of Personal Information). Individuals can demand the deletion of their personal data when it is handled in violation of legal provisions or when retaining the data is no longer necessary for the stated utilization purpose. While court decisions have begun recognizing the right to be forgotten in specific contexts, and the APPI provides some mechanisms for data erasure, genetic discrimination lacks comprehensive legal protection despite principles opposing it [21].

Country / Area	**Legal framework**
United States of America	*Not explicitly provided for by GINA or other laws such as HIPAA.*
European Union	*In accord with GDPR of European Union, the right to request deletion of personal data is guaranteed when:* *-the consent is revoked or* *-the processing purpose no longer applies.* *The right is not guaranteed if more relevant rights prevail*
Italy	*GDPR of European Union*
France	*GDPR of European Union*
Germany	*GDPR of European Union*
Canada	*Not formally provided for by GNDA or other laws.*
United Kingdom	*In accord with UK GDPR, the right to request erasure of personal data is extended to genetic data but it does not apply when data are processed for research purposes [18].*

Japan	*This right is not formally codified but partially safeguarded through APPI (Act on the Protection of personal information) and case law, allowing data deletion in specific cases.*

***Table 2** – international regulations regarding right to be forgotten (only G7 countries)*

***GD in the insurance industry (*Table 3)**

A frequently claimed risk is that of insurance discrimination. The insurance sector is heavily regulated in high-income countries, but regulations are strictly country-specific: for instance, in the US, GINA bars mandatory disclosure of GI for health insurance underwriting (but not for other kinds of insurance coverages, like for life or disability) [22]. As said, in European Union, the use of GI for private interests without owner's consent is prohibited and some Member States (France in particular) prohibited GI use for insurance purposes even if with owner's consent [7]. In some countries, like United Kingdom and Australia, agreements between public authorities and associations of insurers tend to restrict access to GI, limiting it to specific circumstances, depending on set financial limits [7]. Finally, other countries - like Japan - have no law against GD [7]. In the UK, for example, the Association of British Insurers (ABI) prohibits insurers from requiring or considering predictive genetic test results, except when life insurance coverage exceeds £500,000 and relates to Huntington's disease; additionally, results from scientific research cannot be taken into account [23]. In Canada, the Genetic Non-Discrimination Act (from 2017) forbids the use, request, or disclosure of GI in every kind of contract stipulated with individuals, including insurance one [17]. Finally, other countries - like Japan - have no law specific law against GD in the insurance industry but after "The Genome Medicine Promotion Act" of 2023 the Ministry of Health, Labour and Welfare ("MHLW") is currently preparing a Q&A for the insurance sector [20].

Country / Area	**Legal framework**
United States of America	*GI disclosure is not mandatory, in accordance with GINA, for health insurance (excluding other types of insurance coverages).*
Italy	*Use of GI for private interests without owner's consent is prohibited.*
France	*Use of GI for insurance is banned even with owner's consent.*
Germany	*Use of GI for private interests* without owner's consent is prohibited.

Canada	*GNDA (from 2017) forbids the use, request, or disclosure of GI in contractual and service contexts [17].*
United Kingdom	*GI access is limited by agreements between authorities and ABI (Association of British Insurers), usually based on specific conditions and financial limits [18].*
Japan	*No specific law against GD in insurance industry but after "The Genome medicine Promotion Act" of 2023, the government is currently preparing a Q&A for the insurance sector against GD. [20]*

Table 3: *international regulations regarding GD in insurance industry (only G7 countries)*

GD in the workplace

As said, in Europe GDPR addresses GD in general, prohibiting the use of GI for non-public (relevant) interests. Instead, in the US, GINA specifically bars use of GI by the employer to make decisions like hiring/firing or length of the contract and, in general terms, to collect GI except for monitoring workers exposed to specific toxic risks and fully voluntary wellness programs [24]. Some employers offer voluntary genetic testing as a benefit, with relatively high engagement by the employees (who tend to prefer genetic testing offered by employers over testing performed in health institutions or as direct to customer) and with major concerns represented by the erasure of GI upon owner's request and by the risk to sell data to third parties [24, 25]. This phenomenon is particularly frequent in the US, where most of the health insurances are paid by the employers [24]. In Canada, both GNDA and the Federally regulated employees specifically bar the use of or access to GI without the employee's written consent; at the same time, they prevent third parties from disclosing the results of genetic tests to the employer without the employee's written consent [26]. In Japan, following the enactment of "The Genome Medicine Promotion Act" on August 20, 2023, the Ministry of Health, Labour and Welfare (MHLW) issued a Q&A on Ensuring Appropriate Measures Against Unjust Discrimination Based on Genomic Information in the Labor Sector. This document offers guidelines to prevent discriminatory practices in employment and to promote fairness within the workplace. While the Q&A does not introduce new regulations, it provides clarity by interpreting and applying existing labor laws [20].

Country / Area	**Legal framework**

United States of America	*Specific law: GINA (from 2008) bans employers from using GI, except for toxic risk monitoring and voluntary wellness programs.*
European Union	*GDPR (from 2016) bans the use of GI for non-public (relevant) interest in the countries of the European Union.*
Italy	*GDPR of European Union*
France	*GDPR of European Union*
Germany	*GDPR of European Union*
Canada	*Employers cannot collect, use, or access genetic information without the employee's written consent in accordance with GNDA [17] and the Federally regulated employees [26].*
United Kingdom	*The Data Protection Act does not explicitly prohibit GD in workplace*
Japan	*According with "The Genome Medicine Promotion Act", the government issued the Q&A on Ensuring Appropriate Measures Against Unjust Discrimination, etc., Based on Genomic Information (Labor Sector) to provides guidelines to prevent GD in workplace [20].*

Table 4: *international regulations regarding GD in workplace (only G7 countries)*

GD in criminal justice

All the G7 countries have DNA databases controlled by the respective governments, containing from few hundreds of thousands DNA profiles (Italy) to many millions of individual profiles (US) [12]. The main source of information for these databases is represented by traces found on crime scenes and DNA collected from suspected/convicted/arrested persons [12]. GI has been successfully used as primary identifier in criminal justice for the last decades: for instance, in the US genetic data of arrested/convicted persons is stored in the CODIS - Combined DNA Index System (and thus personal

identification is possible also for traces belonging to relatives of the owners of this information) [27]. Moreover, public authority can have access to other sources of GI, like that obtained through direct-to-consumer testing, that can combine with CODIS data to enhance the possibility of a match [27]. A specific form of GD in the legal system has been reported due to the use of GI to investigate the capacity of the defendant, relatively frequent as line of defense in criminal trials with the risk of severe penalties (like trials for murder or multiple rapes) [11].

Country / Area	**Government DNA databases**
United State of America	*Combined DNA Index System (CODIS)* *National DNA Index System (NIDS)*
Italy	*Banca dati Nazionale del DNA*
France	*Fichier national automatisé des empreintes génétiques*
Germany	*Bundeskriminalamt (BKA) DNA Database*
Canada	*National DNA data Bank (NDDB)*
United Kingdom	*National DNA Database (NDNAD)*
Japan	*National Police Agency DNA database*

Table 5: *international regulations regarding GD in criminal justice (only G7 countries)*

Discussion

High-income countries laws against GD

Privacy, in relation to genetic information (GI), is increasingly interpreted in the context of data ownership. However, unlike traditional patent law, this framework doesn't fully apply because GI often serves broader public or collective interests—such as advancing scientific research or identifying hereditary diseases within families. As a result, managing privacy in this area requires a careful balance between respecting individual autonomy and addressing societal needs [29]. The current review showed that in the European Union the risk of GD is mitigated by the use of GI except for activities of substantial public interest, leaving the definition of when the public interest is sufficient and what safeguards should be adopted to the Member States. On the other end, US GINA limits its effects on employment and health insurances (failing to cover all the other kinds of insurances) and does not apply to people with signs of genetic disease. These patients should be protected primarily by HIPAA at federal level and by statal laws. An example of the application of a US regulation in a case of alleged wrongful collection of information about the congenital

predisposition to health disorders for employment is given by the Civil Case No.: 13-CV-248-CVE-PJC of the U.S. District Court for the Northern District of Oklahoma: the employer was condemned also for the request of family medical history in a post-offer medical examination, that violated GINA. That being said, US regulations concerning GD differ widely in both scope and specificity. For instance, some laws target the insurance sector, others focus on employment, and some address both [1]. Moreover, entities not covered by HIPAA (so other than health care providers and health care institutions, for instance) can still share GI [16]. Another weakness of the US regulatory system is that the Privacy Rule of the HIPAA allows disclosure of anonymized GI [16].

The coverage granted by European Union regulation (GDPR) is generally considered broader and fairly elastic, since processing GI is valid only in very limited circumstances (e.g., it is necessary for substantial public interest or necessary for the establishment, exercise or defense of legal claims). For instance, in the European Court of Justice (CJEU) case C-205/21, the Bulgarian Specialized Criminal Court's practice of systematic data collection—including genetic data—was challenged and found to be in violation of EU data protection law. The Court ruled that competent authorities are under a legal obligation to demonstrate that the collection of genetic data adheres to the principle of proportionality. Specifically, such processing must be deemed strictly necessary to achieve legitimate judicial objectives, provided that no alternative, less intrusive means of protecting the individual's privacy are available. Although the GDPR generally permits the anonymization of genomic data, this approach often fails to fully protect privacy. Advances in forensic DNA phenotyping (FDP) now make possible to infer identifiable traits—such as eye color, hair color, and skin tone—from genetic markers [27, 30]. Moreover, despite the entity of the genetic information retained or leaked, more GI can be obtained through genotype imputation, especially when GI from blood relatives is known [27]. Therefore, it is complex to propose a solution to these issues. Hence, some authors advocated a dynamic definition of how a data must be de-identified to be able to promptly adjust to scientific and technological innovations [16]. As a result, a more genetic-specific broad legislation would be required, but currently GI are frequently shared between different countries for commercial and non-commercial (research) purposes, so an isolated national initiative is unlikely to successfully address the issue of GI [5, 12]. It is not surprising the several authors underline the need for internationally harmonized regulations able to reach across various sectors with the expression of the GD as the violation of a fundamental human right [5].

Finally, the common perception of the presence and the efficacy of a regulation should not be neglected. Both US and European surveys showed a diffuse lack of awareness about local legislations against GD and a common mistrust by the persons who were aware of them [3]. Educating patients, consumers, and citizens is one of the most effective ways to provide individuals with the knowledge and agency needed to address the challenges of genetic discrimination. Legislative efforts should not be limited to employment and insurance sectors, as genetic testing is also widely used in areas such as the legal system and direct-to-consumer services [12]. Furthermore, all portions of the population, including those with limited education and minority groups, have equal rights and deserve to be thoroughly informed about the risks and regulations related to this area [12]. Education should also help citizens to have a proper perception of the contexts where GD may be an actual threat as many genetic data are not collected for insurance or employment purposes but by commercial companies for the so-called direct to consumer genetic testing (e.g., genetic testing to trace ancestry) [31]. These fields are often not as regulated as the insurance industry and the workplaces, and this could lead to blind spots in the social perception of these risks.

Right to be forgotten

This aspect of GD is particularly complex, because not all the GI can be erased upon owner's request, because losing this information could have significant consequences. A highly debated application of this legal principle concerns the gender transition [9]. As previously mentioned, individuals generally have the right to request the deletion of their health data if the original purpose for processing ends or if they withdraw their consent. However, in the specific context of genetic information, additional factors must be considered. For example, Correia et al. highlighted that deleting genetic data can prevent patients from accessing important health information later, such as for personalized treatments. It also affects the ability of patients descendants to identify hereditary conditions and hinders research efforts aimed at advancing scientific knowledge and public health [9]. This latter point is not of lower importance than the other two: researchers can oppose the request if they claim that data were collected for research of public interest [29]. Finally, the right to be forgotten faces unparalleled challenges with generative Artificial Intelligence (AI) technologies [32, 33]. While traditional search engines index and retrieve information via links, large language models (LLMs), on the other hand, need to absorb data during training and embed it within complex neural networks. [34]. This essential difference raises significant concerns in terms of GD. Entire or partial genetic information can be stored forever in these neural networks, including in form of the so-called "digital health footprints" [14]. In detail, in pre-trained deep learning models, deleting specific individual sensitive data is inherently challenging due to the stochasticity of training: models do not operate deterministically but rather explore potential associations through a probabilistic approach (https://doi.org/10.1038/s41467-023-41703-x). Furthermore, these models often undergo incremental training—where the model evolves with each new data entry—leading to the risk that removing even a single piece of information could adversely affect the performance of the entire system (https://doi.org/10.1038/s41467-023-41703-x). Consequently, the process of data unlearning in such models is not merely a matter of deleting information. It necessitates a rigorous auditing process to determine whether the sensitive data was utilized during training and to ensure that the specific information can be purged without compromising the system's overall functionality (https://doi.org/10.1038/s41467-023-41703-x). Conversely, regarding the deletion of specific genetic data, certain deep learning methods leveraging linkage disequilibrium patterns can attempt to reconstruct missing genetic segments, such as genomic sequence regions containing potentially variants with a discriminatory potential (https://doi.org/10.1038/s10038-023-01213-6).

GD in the insurance industry

Economic sustainability of insurance companies' operations (and then premiums pricing) strictly relies on their understanding of the actual density of the risk, and in many situations genetic factors can influence the risk of death (e.g., SCN5A pathogenic variants increase the risk of sudden cardiac death) or severe disability [35]. Regarding this latter circumstance, a primary example is provided by carriers of pathogenic mutations in the BRCA1 and BRCA2 genes, who may face a significantly increased risk of high-grade malignancies—specifically breast and ovarian cancer—that predominantly manifest during their working life (https://doi.org/10.1136/ijgc-2023-005225). Equating the duty to disclose pre-existing multifactorial pathologies (wherein risk levels may have been exacerbated by an individual's lifestyle choices) with the duty to report congenital mutations in these genes places women at a high risk of being denied insurance coverage or being offered policies at higher costs and with restrictive terms.

In plain terms, GI is useful to assess the actual density of the risk (actuarial fairness) and without it private companies (that are owned by stakeholders who have the right to profit from a proper risk assessment) are forced to only rely on other sources of information, that are probabilistic as well (e.g., anamnestic factors) [15]. Additionally, when genetic information affects the approval and pricing of insurance coverage, individuals without genetic anomalies may have an advantage by choosing to

disclose this information [15]. However, when GI is disclosed, there is a risk of discrimination (in the strict sense) that could be perpetrated by employees of the insurance industry who could overestimate the actual impact of some GI [35]. It should be noted that a grey area could be represented by variants of unknown significance, a frequent occurrence in clinical genetic testing: insurance companies need to know the density of the risk in a specific person to evaluate the actuarial fairness, and these uncertain results can expose the carrier to highly variable (and possibly arbitrary) insurance decisions [36, 37, 38]. It has been highlighted that since both interests (of the data owners and of the insurance companies) are in general terms legitimate and - as said - with potential implications for the citizens/premiums payers, regulations able to adjust to the dynamic trade-off between these interests should be considered [7].

GD in the workplace

Some authors underlined the benefits of genetic testing offered to the (potential/actual) employees: this may help identifying traits relevant to assess the fitness for a job/promotion (and all the alternative ways to ponderate a decision, like interviews, are based on predictions, albeit subjective) [15]. However, in the countries where it is possible, as in the US for example, employers should be able to guarantee to the participants of voluntary programs not only that data will not be sold/shared to third parties but also the safety of GI, a very complex task that can likely imply more costs than savings [39, 40]. Moreover, it should be considered that anonymization is often insufficient in small entities: GI regarding extremely rare diseases obtained within a small sample (e.g., the workforce of a small enterprise) make reidentification extremely easy [16].

GD in criminal justice

Although genetic discrimination in insurance and employment is widely recognized and addressed, similar concerns receive much less attention in the context of criminal justice, even though large-scale genetic data is increasingly used. As previously mentioned, a central aspect is the use of GI for criminal defense, a concept that, if accepted by the legal system, would result in the high risk of GD for the non-criminal carriers of the contested variants (who could be discriminated by police/employers/insurers) [11]. Moreover, it should be noted that in this context GD could easily combine with other forms of discrimination in particularly vulnerable groups of the society, like the minorities [8, 16, 41, 42]. The conceptual basis of the use GI to investigate conducts of criminal interest belongs to behavioral genetics, a branch of genetics based on the theory that molecular products corresponding to some genes can influence the brain functioning and thus the human behavior [43, 44, 45] In particular, the relationship with sociality could be bidirectional, since molecules encoded by genes could alter social behavior as well as social stimuli may influence the expression of some genes [44]. A specific “class” of behavior - antisocial behavior - is the target of behavioral genetics studies of most importance from an ethical and legal perspective [47]. Many of these studies compare twins raised together and twins separated by adoption [46, 47]. Hereditability of personal traits is thought to be generally around 30-50%, depending on many genes of small effect [46]. These studies have some limitations [47]. For instance, actual evidence regarding genetic predisposition to criminal behavior remains fundamentally uncertain, as study methodologies and target populations vary significantly across the literature. Notable limitations arise from the very parameters used to define antisocial behavior: the concept of "crime" is inherently dependent on specific socio-legal contexts, and discrepancies frequently occur where antisocial individuals remain without a criminal record while, conversely, individuals lacking genuine antisocial traits may have prior convictions (doi:10.1016/j.ijlp.2016.09.005). Similarly, it is unlikely that pathogenic variants would predispose an individual to all types of crime—a selection bias that can distort findings. Such

variants might instead lead to aggressive behavioral alterations that carry no legal relevance, resulting in the misclassification of individuals as "asymptomatic carriers". Furthermore, even in studies supporting a correlation, the relationship is often observed only in conjunction with external factors, such as a history of childhood abuse, which independently predisposes individuals to antisocial behavior (doi:10.1016/j.ijlp.2016.09.005). Moreover, in many studies genetic influence tends to vary depending on the type of crime, with strongest evidence found in non-violent crimes [47]. However, scientific research that advocates genetic influence in antisocial behavior reports that the first signs become overt in the childhood before the age at highest risk of criminal behavior (15-25 years) [47]. Because of the ongoing debate without strong evidence, many authors advised against the use of GI in criminal justice to argue the lack of mental capacity, especially when the crime is not of impulsive nature [11]. However, despite this substantial scientific uncertainty, there is a profound social and media penetration of the "born criminal" narrative—the notion that crimes, particularly the most heinous ones, can only be committed by predisposed individuals (doi:10.1037/xge0001240). This phenomenon is referred to as genetic essentialism: a cultural bias that fosters deterministic logic. Under this view, the more severe the crime, the more likely it is attributed to a genetic predisposition. Consequently, this perspective devalues social prevention and rehabilitation, advocating instead for harsher punitive measures for carriers of pathogenic variants (doi:10.1037/xge0001240).

Conclusions

GD and all its connected risks (e.g., inability to regulate access to GI) should be target of significant international regulatory efforts. An international, comprehensive and dynamic regulation is essential because GI voluntary/mandatory sharing is extremely common and causes the intersection of interests of private citizens and public/private larger entities (e.g., employers, insurance underwriters, public prosecutors). An involuntary dual use of freely disclosed GI is particularly alarming in contexts like the workplace (where the employee may think of genetic testing as a free tool for health promotion while his/her GI may be used for economic purposes of third parties or against the interest of the employee, for instance to exclude him/her from a job selection). Another high-risk context is represented by legal system, where – besides the “traditional” use of GI for purposes of extreme public interest, like personal identification – GI is sometimes presented as line of behavioral defense in absence of sound evidence that would overcome the risks of discrimination for the carriers of the contested variants.

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