Investigative Genetic Genealogy in India: Opportunities, Constraints and the Road Ahead

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ABSTRACT

Investigative Genetic Genealogy (IGG) extends forensic DNA analysis beyond conventional short tandem repeat (STR) profiling by using genome-wide single nucleotide polymorphism (SNP) data to identify distant biological relatives when direct database matches are unavailable. Although IGG has proven effective in resolving cold cases in several countries, its application in India remains limited. This article evaluates the scientific feasibility, infrastructural demands, and ethical considerations of implementing IGG within the Indian forensic system, with particular attention to population diversity, endogamy, and limited representation in genealogical databases. The discussion highlights the need for population-specific genomic datasets, legal clarity, and interdisciplinary capacity building. With appropriate safeguards and validation, IGG has the potential to serve as a complementary tool in advancing forensic genomics in India.

INTRODUCTION

India represents one of the most genetically diverse populations in the world, shaped by complex patterns of migration, endogamy, caste structure, and regional isolation. At the same time, the country faces a growing forensic challenge: high volume of

violent crimes and unidentified human remains, combined with the limited success rate when conventional forensic DNA profiling fails to produce database matches. While short tandem repeat (STR) profiling remains the backbone of forensic genetics in India, its effectiveness is inherently constrained by the absence of comprehensive national DNA databases and limited reference samples.

In this contact, Investigative Genetic Genealogy (IGG) offers a promising but largely unexplored extension of forensic genomics. By leveraging genome- wide SNP data and distant familial relationships, IGG has the potential to transform unsolved cases in India. However, unlike Western countries where IGG has already influenced investigative practice, its application in India faces unique scientific, legal, ethical, and infrastructural challenges(Dash & Al-Snan, 2025).

The Indian Forensic DNA Landscape: Current Status

Forensic DNA analysis in India is primarily conducted through government forensic science laboratories (FSLs) under state and central jurisdictions. STR-based profiling is routinely used for criminal identification, kinship analysis, sexual assault cases, and disaster victim identification. Oversight and data management roles are distributed across agencies such as the **Central Bureau of Investigation**, **National Crime Records Bureau**, and state forensic directorates.

Despite technical competence in STR analysis, India lacks:

- A fully operational nationwide forensic DNA database
- Population-representative genetic reference datasets
- Legal clarity for extended genomic applications beyond identity matching

As a result, DNA evidence frequently confirms biological involvement without enabling suspect identification. IGG, in theory, addresses this gap by moving beyond exact matching toward lineage-based inference(Watson *et al*., 2024).

Scientific Feasibility of IGG in the Indian Population

From a purely genetic standpoint, India presents both an opportunity and a complication for IGG. The country's population structure is characterized by high levels of endogamy, resulting in long shared haplotypes within communities. This can enhance the detection of distant genetic relatives, even at third- or fourth- cousin levels.

However, the same structure complicates genealogical reconstruction. Large family sizes, limited digitalized records, surname variability, migration from rural to urban centers reduce the completeness of family trees. Additionally, most global genealogical databases currently under- represent Indian populations, limiting the availability of informative SNP matches(Kumar Tiwari & Kumar Pandey, 2025).

To make IGG viable in India, population-specific SNP reference panels and community-representative datasets are essential. Without these, predictions of genetic relatedness risk reduced accuracy and interpretive ambiguity(Pemmasani *et al*., 2020).

Laboratory and Bioinformatics Requirements

Starting with IGG in India means moving away from STR-focused methods toward more detailed SNP analysis. Such a change brings along adjustments in how samples are

processed. One key aspect is upgrading lab equipment to handle larger data volumes. Training staff on new interpretation techniques becomes necessary at some point. Data storage systems must adapt to manage increased output. Each step affects the next in subtle but meaningful ways:

- Using newer gene analysis tools like NGS or SNP arrays
- Development of bioinformatics pipelines for identity-by-descent analysis
- Training forensic scientists in genomic data interpretation and genealogical logic

Though some Indian research centers have access to NGS technology, regular application in forensics is rare because of high expenses, the need for verification processes, and missing uniform methods(Vajpayee *et al*., 2025). Notably, implementing IGG effectively would require stronger ties among labs, genetics experts, data analysts, and law enforcement - a joint effort that is slowly taking shape across the country.

Legal and Regulatory Challenges

What stands in the way of IGG adoption across India? A clear legal foundation permitting genealogical methods in criminal probes does not exist. Current laws allow DNA use only for identifying individuals or confirming close biological relationships. Searching distant relatives via public genetic data lacks recognition under these rules(Clayton *et al*., 2019).

Not every nation handles police access to genetic databases the same way. In some places, tight rules control how officers can use such tools. India, however, remains without clear boundaries on the matter. Rules that exist elsewhere have not been mirrored here. What happens instead depends more on circumstance than structure

- Consent boundaries for indirect genetic involvement
- Limits of familial inference in criminal investigations
- Oversight mechanisms for genomic data usage

When laws lack clarity, personal genetic information can easily face abuse or privacy breaches. A system for IGG in India should grow out of open legal structures, court supervision, because accountability matters. Ethical checks need to shape its foundation, since trust depends on visible safeguards.

Ethical Dimensions in the Indian Socio-Cultural Context

Ethical considerations surrounding IGG are amplified in India due to social sensitivities related to caste, tribe, ancestry, and community identity. Genetic inference, if misunderstood or misrepresented, could reinforce social stigma or discrimination.

Furthermore, many individuals may be unaware of how their genetic data could implicate relatives in criminal investigations. This raises questions about informed consent and collective privacy- issues particularly relevant in collectivist societies like India.

Therefore, ethical safeguards must prioritize:

- Restriction of IGG to serious crimes only
- Clear separation between ancestry inference and social identity
- Public engagement to build trust in forensic genomics

Potential Applications in the Indian Context

Despite challenges, IGG holds immense potential in specific Indian forensic scenarios:

1. Cold violent crime cases, where STR profiling has failed for years.
2. Unidentified human remains, especially migrant laborers and disaster victims
3. Serial offences involving offenders without prior criminal records.

In such cases, even partial genealogical leads could significantly narrow investigative focus, saving time and resources while increasing resolution rates(Dowdeswell, 2022).

Capacity Building and Research Needs

For IGG to become viable in India, sustained investment in research and training is essential. Priority areas include:

- Creation of Indian population SNP datasets
- Validation studies on endogamous populations
- Development of ethical guidelines tailored to Indian society
- Integration of forensic genomics into postgraduate curricular

Academic-forensic collaboration will be key. Universities offering forensic science and molecular biology programs can serve as testing grounds for pilot IGG research under controlled ethical conditions.

Future Outlook: Toward Responsible Forensic Genomics

Investigative Genetic Genealogy should not be viewed as a replacement for conventional forensic DNA profiling in India, but as a **complementary, high-impact tool** for exceptional cases(Castro & De Ungria, 2022). Its success will depend not only on technology, but on governance, transparency, and societal trust.

With careful planning, India has the opportunity to develop a uniquely responsible IGG framework- one that respects genetic diversity, protects civil liberties, and enhances the pursuit of justice through science.

CONCLUSION

India stands at a crossroads in forensic genomics. While traditional DNA profiling continues to play a vital role, its limitations in database-negative cases are increasingly evident. Investigative Genetic Genealogy offers a powerful extension, capable of transforming stagnant DNA evidence into actionable leads.

However, successful adoption in India demands population-specific research, legal clarity, ethical sensitivity, and infrastructural readiness. If these challenges are addressed thoughtfully, IGG could become a landmark advancement in Indian forensic science- bridging molecular genetics, investigation, and social responsibility.

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