Xournals

Academic Journal of Forensic Sciences

ISSN: 2581-4273 | Volume 07 | Issue 01 | April-2024

Beyond the Scalpel: Exploring Virtual Autopsy for Forensic Analysis – A comprehensive Review

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Available online at: www.xournals.com

Received 30th March 2024 | Revised 5th April 2024 | Accepted 17th April 2024

Abstract:

The term VIRTOPSY was coined from the words virtual and autopsy: Virtual is derived from the Latin word 'virtus', which means 'useful, effective, and good'. Autopsy is derived from the ancient Greek words 'autos' (self) and 'opsomei' (I will see). Thus, autopsy means 'to see with one's own eyes'. Because we wanted to erase the subjectivity of "autos," we combined the terms virtual and autopsy, removing the "autos" to form VIRTOPSY. Today, the name VIRTOPSY, which unifies study issues under a single scientific umbrella, is distinguished by a transdisciplinary research methodology that connects forensic domains to an international scientific network. Virtual autopsy, also known as digital or non-invasive autopsy, is a cutting-edge technique that has emerged as a promising adjunct to traditional post-mortem examinations. This process employs advanced imaging technologies and computerized analysis to render the 3D images of the scanned data of the body and explore the human body in a virtual environment. By combining high-resolution imaging techniques such as computed tomography (CT) and magnetic resonance imaging (MRI) with sophisticated visualization and analysis software, virtual autopsies offer numerous advantages over conventional autopsies while providing invaluable insights into the cause and circumstances of death. In cases like thanatological investigations, carbonised and putrefied body identifications, mass disaster cases, age estimation, anthropological studies, and skin lesion assessments, virtual autopsy uses high-tech medical imaging approaches to provide more effective and more accurate visualisation. Despite its potential, virtual autopsy also faces challenges. The availability of specialized imaging equipment and the need for trained personnel limit its widespread adoption. Additionally, virtual autopsies may have limitations in detecting certain types of injuries or subtle pathological changes that can be better assessed through traditional autopsies. However, the accuracy of virtual autopsy is 98% and advancements in technology are likely to lead to improved imaging techniques, including higher resolution scans and faster data processing, resulting in more detailed and accurate virtual reconstructions of the body. Integration with artificial intelligence and machine learning algorithms may enable automated analysis of digital data, aiding in the identification of patterns, anomalies, and potential causes of death.

Keywords: *Post Mortem Examination, Virtual Autopsy, Forensic Investigations*

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Introduction

Forensic analysis is a key tool in detection the truth behind incidents like crimes, accidents, and natural disasters. It involves thorough examination and interpretation of physical evidence to reconstruct events and ascertain causes of death or injury. Traditional autopsy methods have been central to forensic investigations, providing critical insights into the circumstances of a person's demise. However, they have limitations, particularly in cases involving advanced decomposition, severe trauma, or religious concerns. To address these challenges, virtual autopsy, also known as post-mortem imaging or digital autopsy, has emerged as a promising alternative. This non-invasive approach utilizes advanced imaging technologies such as computed tomography (CT) and magnetic resonance imaging (MRI) to create detailed three-dimensional representations of the body. Virtual autopsies offer numerous benefits over traditional methods, including the ability to examine internal structures without invasive procedures, preservation of evidence for future analysis, and compatibility with cultural and religious practices **(Lorkiewicz-Muszyńska, *et al.*, 2012; Joseph, *et al.*, 2018).**

The abrupt death of a young person frequently prompts suspicions of foul play, and criminal investigators have no choice but to seek help from forensic pathologists. In India, inquests in these matters are conducted under Section 174 of the CrPC **(Lorkiewicz-Muszyńska, *et al.*, 2012).** However, during the COVID-19 pandemic, the government **(Lee, *et al.*, 2002; Joseph, *et al.*, 2018)**, as well as various international scientific groups **(Buck, et al., 2007; Charlie *et al.*, *2012*; Michaud *et al.*, 2022)** issued numerous guidelines against doing autopsies in COVID patients, making this extremely difficult. In this scenario, whole-body PMCT examination, which is commonly used in many countries in virtual autopsy, can be used in conjunction with other non-invasive/minimally-invasive **procedures (Fais *et al.*, 2016; Jeffery *et al.*, 2008)**. In circumstances when the deceased has already been medically treated, the forensic pathologist can examine all antemortem medical data. However, this luxury may not be available in the event of a sudden death. The postmortem CT findings were suitably interpreted in light of both the clinical history and the postmortem examination results. After reviewing the medical records, external examination findings, and whole-body PMCT findings, it was determined that "Cerebral edoema with bilateral tonsillar herniation consequent to hypertensive intracerebral bleed" was the cause of death in this COVID-19 case, and the mode of death was classified as natural. Both the IO and the relatives were told on the techniques used in the investigation, and any concerns they had were addressed.

This review aims to explore the background and significance of forensic analysis, highlight the limitations of traditional autopsy methods, introduce virtual autopsy as a viable alternative, and outline the objectives of further investigation into its potential benefits.

Virtual Autopsy Techniques:

The potential of imaging techniques in forensic investigations became apparent shortly following Roentgen's discovery of X-rays in 1895. Even that year, X-rays were employed to document projectiles remained within the body, and in 1896, these imaging methods appeared in courtrooms in the United States and the United Kingdom as evidence for inquiries into gunshot wounds. Furthermore, in 1986, this imaging approach was used to estimate age, and in 1920, for identifying purposes based on paranasal sinus morphology.

However, the true development towards a more broad and effective use of imaging techniques in forensic medicine was inspired by the discovery of computed tomography (CT) in 1971, and particularly with the advent of spiral CT technology in 1989.

Lauterbur and Mansfield discovered magnetic resonance (MR) technology in 1973, but clinical applications did not begin until the early 1980s.

Computed Tomography (CT) imaging is a key component of virtual autopsies, using X-ray technology to provide comprehensive cross-sectional images of anatomical components. X-rays are produced from various angles during a rotating scan, collected by detectors, and processed by a computer to produce high-resolution images of bones, soft tissues, and organs.

CT imaging provides particular advantages in virtual autopsies. It has remarkable spatial resolution, allowing for the visualisation of complex anatomical details and minor damage. Furthermore, its non-invasive nature eliminates the need for invasive procedures, protecting evidence integrity while respecting cultural sensitivity. Nevertheless, CT imaging has limits. While adept in delineating bones and thick tissues, it may face difficulty in distinguishing some soft tissues or detecting subtle injuries, especially in cases of moderate trauma.

The Institute of Forensic Medicine conducted forensic autopsies on 40 deceased individuals. The sample included 18 cases of blunt trauma (11 from motor vehicle accidents, 4 from falls, 3 from blunt injuries), 8 from gunshot wounds, 6 from sudden cardiac deaths, 2 from drownings, 2 from knife wounds, 2 from strangulation, 1 from an electrical accident, and 1 from sudden infant death syndrome (SIDS). The sex ratio was f =7, m =33, and the average age at death was 46 years, ranging from 6 months to 83 years. We investigated one possible example of misconduct after dens fixation. One of the cadavers was burned, while another was decomposing. In six cases, the cause of death was natural, but in 34 cases, it was not. The latter included 3 homicides, 18 accidents, 12 suicides, and 1 incidence of abrupt infant death. The ethics commission sought anonymity for the deceased, therefore the remains were wrapped in artifact-free body bags. MSCT and MRI were typically conducted 32 hours after death, with the exception of a decomposing cadaver detected after around three weeks. This feasibility research suggested performing MSCT first, followed by a quick full-body screening to identify forensically significant locations. MRI is employed here; appropriate—where greater tissue contrast enables thorough documenting of significant organ and tissue discoveries. MSCT and MRI create images with exceptional spatial resolution, often exceeding clinical practice standards because to the absence of motion artefacts and the lack of radiation dose limitations. Micro-CT, MR microscopy, and postmortem angiography (33) could serve certain forensic needs. MR spectroscopy (MRS) paired with MRI can detect changes in metabolite concentrations in tissues, both before and after death.

However, 2D photo documentation and, in particular, 3D surface documentation are time-consuming procedures requiring particularly educated individuals. In this work, a 3D imaging technology called VirtoScan-on-Rails was created to automate and simplify 3D surface documentation for photo documentation in autopsy suites. The imaging system was designed to quickly capture photogrammetric image sets of entire bodies at various phases of exterior and internal exams. VirtoScan-on-Rails was installed at the autopsy suite of the Zurich Institute of Forensic Medicine at the University of Zurich (Zurich, Switzerland). The imaging system is built around a moveable frame that houses a multi-camera array. Two test series were conducted to analyse and assess data quality and system applicability. Up to 200 overlapping photographic photos were captured at consecutive image-capturing sites separated by around 2000 mm. It took 1 minute and 23 seconds to capture 200 photos from one side of the body. During test series one and two, 53 photogrammetric image sets from 31 forensic cases were successfully recovered. VirtoScan-on-Rails is an automated, rapid, and simple 3D imaging system for autopsy suits. It makes it easier to document bodies at various phases of forensic examinations and standardises the photo documentation process **(Levy et al., 2007; De Bakker et al., 2018; Nishiyama et al., 2016).**

Virtual Dissection and visualization software:

Virtual dissection and visualization software are essential components of virtual autopsies, facilitating the manipulation and analysis of imaging data obtained from CT or MRI scans. These software tools enable forensic pathologists to interactively explore and dissect virtual representations of anatomical structures. Forensic cases are increasingly being documented using 3D imaging of both individuals (victims, offenders) and items (crime scenes, vehicles, weapons) via a range of scanning techniques **(Lorkiewicz-Muszyńska, *et al.*, 2012; Lee, et al., 2002; Joseph, et al., 2018; Buck, et al., 2007)**. Postmortem imaging uses x-rays, computed tomography (CT), CT angiography, magnetic resonance imaging (MRI), and different surface scanning modalities to analyse and document the circumstances of a deceased person's death **(Lorkiewicz-Muszyńska, et al., 2012;).** In such cases, postmortem CT (PMCT) is the ideal modality because it can examine the majority of forensically relevant abnormalities, including bone fractures, haemorrhage, parenchymal lacerations, free intracorporal gas buildup, and the presence of foreign bodies (**Michaud *et al.*, 2022; Fais *et al.*, 2016)**. The huge variety of methodologies, picture modalities, and software available might make visualising forensic medical data challenging at first. There is free or open-source software available for each of the visualisation tasks listed in this article. While commercial software programmes frequently have streamlined graphical user interfaces and cutting-edge visualisation features to boost their commercial success, they are often rather expensive (**Charlie *et al.*, *2012)***. In contrast, for individuals with a limited budget, free open-source software may be more economical and provide for vendor independence, as well as outstanding performance in some cases (**Fais *et al.*, 2016)**. A preliminary study on the forensic 3D visualisation of CT data using cinematic volume was rendered where seventy participants were shown VRT and CRT reconstructions from ten separate situations. They were instructed to note the findings on the photographs and grade them for realism and understandability. A total of 48 of the 70 questionnaires were returned and used for analysis. Based on the majority of the studies presented, CRT appears to be equal or superior to VRT in terms of visual realism and understandability.

Overall, there was a substantial difference in realism between the strategies ($p < 0.05$). Most participants thought the CRT findings were more intelligible than the VRT findings, although the difference was not statistically significant .CRT, like conventional VRT, is not meant for diagnostic radiologic image analysis, therefore it should be used primarily as a tool to give visual information in the form of radiological image reports.

OsiriX is a prominent open-source medical image processing software used for virtual autopsies. It allows for the visualisation, analysis, and manipulation of DICOM (Digital Imaging and Communications in Medicine) pictures, allowing forensic pathologists to study detailed anatomical structures from CT or MRI scans.3D Slicer is also a free, open-source software platform developed primarily for medical image computation and visualisation. It provides extensive tools for 3D reconstruction, segmentation, and volume rendering, allowing users to generate detailed 3D models from imaging data collected during virtual autopsies while Amira is a robust commercial software package designed specifically for biomedical image processing and analysis. It includes a comprehensive package of tools for visualisation, segmentation, and quantitative analysis of medical imaging data, which enables deep evaluation of anatomical structures **(Jian *et al.*, 2019; Baryah *et al.*, 2019; Koopmanschap *et al.*, 2016).**

Application of Virtopsy in Forensic Pathology:

- **Mechanical Asphyxia:**

Decker et al. investigated the role of CT in detecting suffocation in neck compression-related deaths, such as constriction, strangling, or throttling. In strangling instances, CT was comparable to conventional autopsy in detecting hyoid bone fractures and soft tissue haemorrhage, but was more sensitive for microfractures. In the case of lighter throttling forces, visible evidence of neck compression are rare. With the advancement of radiological technology, Fais *et al.* discovered that micro-CTs and thyroid cartilage ossification may be used to detect microfractures that traditional autopsy or CT could not detect.

Drowning is another sort of mechanical asphyxia and a typical method of suicide, although there are homicides that involve drowning or postmortem dumping. The examination of drowned bodies may be required in criminal cases, thus it is critical to be able to determine the cause of death. In 2007, Levy *et al.* discovered that CT scans of drowned corpses showed a distinct imaging expression of frothy airway fluid or high-attenuation debris in the airways compared to abrupt death (**Fais *et al.*, 2016)** conducted a controlled investigation in China, using a drowned rabbit model and comparing it to animal models of hemorrhagic shock and mechanical asphyxia.

Comparative Analysis of virtual autopsy and traditional autopsy:

Table No. 1: shows a comparative analysis of traditional and virtual autopsy

Aspect	**Traditional Autopsy**	**Virtual Autopsy**
Procedure	Traditional autopsies are performed by a pathologist who manually examines the body by making incisions and dissecting organs.	Virtual autopsies involve using advanced imaging technologies such as CT scans, MRI, and 3D scanners to visualize the body without invasive procedures.
Equipment	Traditional autopsies require surgical instruments like scalpels, forceps, and other tools for dissection.	Virtual autopsies use specialized imaging equipment such as CT scanners, MRI machines, and 3D scanners to create detailed images of the body.
Invasiveness	Traditional autopsies are invasive and involve cutting open the body to examine internal organs.	Virtual autopsies are non-invasive, as they do not require any incisions or physical dissection of the body.
Time	Traditional autopsies typically take several hours to complete due to the manual	Virtual autopsies can be completed relatively quickly, depending on the quality of

	examination process.	imaging technology used.
Cost	Traditional autopsies can be expensive due to the need for specialized equipment and trained personnel.	Virtual autopsies may have high initial costs due to the purchase and maintenance of imaging equipment, but can be cost-effective in the long run.
Preservation of Body	Traditional autopsies involve dissecting organs, which are then preserved in formalin for further examination.	Virtual autopsies leave the body intact, making it suitable for funeral or religious customs.
Accuracy	Traditional autopsies offer high accuracy in identifying physical abnormalities and injuries through direct examination of tissues.	Virtual autopsies' accuracy depends on the quality of imaging technology and the interpretation skills of the pathologist analyzing the images.
Availability of Data	Traditional autopsies provide limited data from physical examination and tissue samples.	Virtual autopsies offer detailed 3D images, providing more comprehensive data for analysis.
Post-mortem Analysis	Traditional autopsies allow for further analysis of tissue samples for histology and toxicology.	Virtual autopsies enable repeated analysis of images without altering the body, but lack the ability to analyze tissue samples directly.
Accessibility	Traditional autopsies require access to specialized facilities and trained personnel.	Virtual autopsies can be performed in hospitals with appropriate imaging equipment and trained staff.
Limitations	Traditional autopsies are limited by the accessibility of the body and the quality of tissue preservation.	Virtual autopsies are limited by the availability and quality of imaging technology.
Legal Considerations	Traditional autopsies are often required by law in cases of suspicious deaths for legal and forensic purposes.	Virtual autopsies are not universally accepted as a legal substitute for traditional autopsies and may not fulfill legal requirements in all jurisdictions.

Ethical Considerations and Evidentiary Value:

Virtual autopsies, while providing obvious benefits, have ethical concerns that require careful thought. First, the problem of consent emerges, emphasising the significance of gaining clear permission from the deceased's next of kin or legal agent. Informed consent guarantees that the deceased's or their family's preferences for post-mortem procedures are respected, which is consistent with the values of autonomy and self-determination. Furthermore, virtual autopsies must adhere to the concepts of privacy and decency, treating the deceased with the same honour and respect as traditional autopsies. To ensure trust and integrity, image data must be kept confidential and sensitive information must be handled securely **(Jeffery *et al*., 2008; Scholing *et al*., 2009; Jian *et al*., 2019; Baryah *et al*., 2019).**

Concerns about the accuracy and reliability of virtual autopsy results highlight the necessity for stringent standards in image gathering, interpretation, and analysis. While virtual autopsies provide non-invasive alternatives to traditional procedures, their efficacy is dependent on the quality of imaging equipment and the knowledge of the medical professionals involved. Transparency in approach and validation of results are critical for maintaining the integrity of forensic investigations and ensuring justice for the bereaved and their families. Furthermore, cultural and religious beliefs must be considered, as well as various perspectives on post-mortem exams and respect for the spiritual and emotional well-being of the deceased's family and community **(Thali *et al.*, 2009; Yen *et al.*, 2007).**

While post-mortem reports are important in murder cases, they do not constitute substantial evidence. It can only be used to support other evidence in the case. It can also be used to refute the evidence of the medical witness in the case. The post-mortem report will not be automatically admitted by the court of law. The prosecution and defence will question the doctor who did the post-mortem examination on the contents of the report. The Code of Criminal Procedure exempts some government scientific experts from examinations.

The Code of Criminal Procedure exempts some government scientific experts from examinations. Section 293, Cr.P.C. allows a Government Scientific Expert's report on a matter submitted for examination to be used as evidence in a proceeding, even if the expert is not examined. However, a doctor's post-mortem report will not be covered by Section 293 of the Criminal Procedure Code. Thus, in Sowam Kisku v. State of Bihar (2006 Cri.L.J. 2526), the Jarkhand High Court held that the contents of a postmortem report could not be shown if the doctor who performed the postmortem was not examined. The court ruled that in such situations, the defence had no opportunity to cross-examine the doctor concerning the nature of the injuries and whether they were sufficient in the ordinary course of nature to cause death.

Section 294 of Cr.P.C. allows for the admission of a post-mortem report without cross-examining the doctor who made it, as long as the defence does not contest its authenticity.

In Munshi Prasad v. State of Bihar (2002 (1) S.C.C. 351), the Supreme Court stated that the credibility of a post-mortem report lies on the doctor's statement in court, not the paper itself.

Typically, this should only be used to refresh a doctor's memory or to challenge their testimony in court. The inquest report, prepared by non-medical police staff at the early stage of the procedure, cannot be considered fundamental or substantive evidence.

Section 60 of the Evidence Act requires the best evidence to show a fact, including post-mortem reports, which must be proved by a doctor who performed the post-mortem and not by any other third party. In some cases, the court may allow a competent person to testify on the contents of the report under section 32 of the Evidence Act.

The second essential consideration is how much weight to assign to doctors' opinions.

A doctor's opinion is relevant in cases where it is beneficial to the court in reaching a specific decision while assessing a fact in issue in a case. In a homicide case, the court may depend on the doctor's post-mortem examination to determine the cause of death. The Supreme Court has ruled that a medical witness's opinion should not be considered final. The court will test such opinions. Courts are not obligated to follow opinions that lack logic or objectivity. After all, opinions are created in a person's head regarding a true situation. If two doctors form opposing opinions on the same data, the judge can choose the more objective or probable viewpoint. If a doctor's view contradicts likelihood, the court cannot rely on it solely based on the doctor's statement. State of Haryana v. Bhagirath (1999 A.I.R. (S.C.) 2005).

Challenges and Limitations:

Virtual autopsies, while promising advances in forensic medicine, face numerous obstacles and restrictions. The most significant of these is the reliance on imaging technologies, which may not always provide the same degree of information as traditional autopsy, especially in finding small injuries or diseases. Imaging data interpretation necessitates specialised knowledge, and misinterpretations might occur, leading to diagnostic errors. Furthermore, the high initial cost of purchasing and maintaining modern imaging equipment prevents widespread adoption, especially in resource-constrained environments. Furthermore, virtual autopsies may not be appropriate for cases requiring comprehensive histological or toxicological analyses because they do not allow direct access to tissue samples. Cultural and legal acceptance of virtual autopsy findings differs, which affects their admissibility in court proceedings. Image modalities used in virtual autopsies, such as CT scans, MRIs, and 3D scanners, have constraints that can affect the accuracy and comprehensiveness of the examination. CT scans, for example, are excellent at visualising bone structures and solid tissues but may fail to separate soft tissues or artefacts from diseased findings. MRI, on the other hand, provides better soft tissue contrast but is slower and may be less accessible in some cases. Both CT and MRI are prone to motion artefacts, which can reduce image quality, especially in cases involving post-mortem alterations or violent injuries. Furthermore, the resolution of these imaging techniques may not be sufficient to identify minor injuries or microscopic abnormalities.

Hybrid approaches: Combining elements of virtual and traditional autopsies

In a prospective cohort study, 9 ICUs in a single academic medical centre were studied. Consent for both medical and virtual autopsies was sought from the families of all consecutive patients who died in the ICU between 1 January and 30 June 2010. Clinical records were reviewed to determine whether unsuspected autopsy findings would have altered care if known (major diagnosis) or would not have altered care (minor diagnosis).

Of 285 patients, 47 underwent both virtual and medical autopsy. Of 196 clinical diagnoses made before death, 173 (88%) were identified by virtual autopsy and 183 (93%) by medical autopsy. Fourteen new major and 88 new minor diagnoses were detected by any autopsy method. The main diagnoses missed by virtual autopsy were cardiovascular events (9 of 72) and cancer (12 of 30). In contrast, medical autopsy missed 13 traumatic fractures and 2 pneumothoraces. Among 115 additional patients in whom only virtual autopsy was performed, 11 new major diagnoses were made. Only 57% of patients (n = 162) underwent virtual autopsy, and only one-third of them gave consent for traditional medical autopsy.

One such option is to perform needle biopsies or tissue collection techniques on specific locations identified by virtual imaging. Pathologists can collect tissue samples for subsequent investigation without requiring extensive dissection by specifically targeting regions of interest. These minimally invasive treatments not only lessen the overall invasiveness of the autopsy, but also save crucial tissues for future investigations, such as genetic or molecular analysis. In some cases, virtual imaging precedes standard autopsies, providing a complementary approach to post-mortem assessment. Following the study of virtual images, pathologists can conduct a standard autopsy with a better grasp of the anatomical components and prospective results. This combination of imaging and physical examination provides for a more efficient and targeted approach to autopsy operations. Pathologists can focus their efforts on regions of interest highlighted using virtual imaging, making better use of resources and reducing wasteful dissection. Furthermore, the combination of virtual imaging and traditional autopsies allows pathologists to connect findings from the two modalities, improving overall diagnosis accuracy. Pathologists can evaluate and strengthen their findings by comparing virtual observations to physical examination results, ensuring a thorough assessment of the deceased's medical state.

The potential ramifications of virtopsy, or virtual autopsy, are substantial and multifaceted, affecting many facets of forensic medicine, healthcare, and society in general. To begin, advances in imaging technology and computational approaches are projected to improve the accuracy and reliability of virtual autopsies, allowing for more exact identification and characterisation of injuries and disorders. This could lead to more accurate forensic investigations, a better understanding of disease processes, and more educated medicinal therapies. Furthermore, virtual autopsies have the potential to eliminate the need for invasive post-mortem procedures, relieving the emotional strain on mourning families while honouring cultural and religious beliefs about death and burial rituals. Furthermore, the non-invasive nature and accessibility of virtual autopsies may encourage wider implementation, particularly in areas with limited access to forensic pathology facilities. From a research standpoint, the abundance of imaging data created by virtual autopsies opens up possibilities for big data analytics and machine learning algorithms to uncover patterns, trends, and correlations that could benefit medical research and public health efforts. Furthermore, incorporating virtual autopsy results into court procedures may simplify forensic investigations, speed up case settlement, and improve access to justice. However, issues such as cost, data security, and regulatory considerations must be overcome before virtopsy can reach its full potential.

Conclusion

To summarise, virtopsy, or virtual autopsy, is a game-changing innovation in forensic medicine with far-reaching ramifications for healthcare, forensic investigations, and societal conventions surrounding death and grieving. As imaging technology advances, virtopsy has the potential to improve the accuracy, accessibility, and efficiency of postmortem examinations while reducing the emotional strain on mourning families and honouring cultural sensibilities. By combining advanced imaging techniques and computer analysis, virtopsy has the potential to transform forensic pathology by providing a non-invasive, all-encompassing approach to diagnosing injuries, illnesses, and other pathology. Furthermore, incorporating virtopsy discoveries into judicial proceedings may simplify investigations, speed up case resolution, and ensure access to justice.

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