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Application of DNA Techniques in Identifying Human Remains: A South African Civil Aviation Perspective

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Abstract

The South African Civil Aviation Authority (SACAA) often employs Deoxyribonucleic Acid (DNA) techniques to identify human remains in aircraft accidents where traditional methods such as biometric are insufficient. DNA analysis aids accurate identification supporting families' closure and legal process. This article examines the application of DNA techniques in identifying human remains from the SACAA perspective. The researchers applied a qualitative approach to explore the application of DNA techniques in identifying human remains from SACAA perspective. The purpose of article is to examine the importance of DNA identification, challenges faced and benefits of DNA analysis in aviation accident investigations. The study's findings revealed a multiple of factors that impact the application of DNA techniques in identifying human remains in South African Civil Aviation accidents. Challenges such as contamination, degradation of DNA samples and limited resources were noted as significant obstacles to effective DNA analysis. The article recommendations to strengthening collaboration between SACAA and forensic labs to improve DNA analysis turnaround times. Stay updated with latest DNA tech to improve identification in challenging cases. Furthermore, train staff on DNA sampling and ensure equipment in available for quick collection. Additionally, ensure families get accurate information quickly to help with grief and closure. Again, collaboration with international organisations and forensic experts is essential to share best practices and stay updated on the latest developments in DNA analysis.

Keywords: Aircraft, Accidents, Civil Aviation, DNA, Identification.

Introduction

The identification of human remains in fatal aircraft accidents is a complex process, often complicated by the severity of injuries, degraded of tissues and environmental factors (Thompson, 2014:123). In South Africa, the Civil Aviation Authority (SACAA) is responsible for investigating aviation accidents and Deoxyribonucleic Acid (DNA) analysis has become an essential tool in this process (SACAA, 2018:15). As Butler (2012:457) notes, DNA techniques offer a reliable means of identifying victims, even when traditional methods such as biometrics or dental record are not possible. In South Africa (SA), the SACAA often collaborates with forensic experts to apply DNA techniques in identifying victims (Levin, 2015:10-15). Despite the

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effectiveness of DNA techniques, there are challenges and limitations in applying these methods in SA, such as DNA degradation due to environmental factors (Thompson, 2014:125).

Butler (2012:125-130) highlights that DNA techniques in identifying human remains include autosomal Short Tandem Repeat (STR) profiling and mitochondrial DNA analysis. Furthermore, in SA, the Forensic Science Laboratory utilises these methods to process DNA samples from fragmented remains, often comparing them against an ante-mortem DNA profile or family references (Le Roux, 2014:1-8). According to Snyman & Louw (2016:21-28), applying DNA techniques in SA faces challenges like degraded DNA samples due to environmental conditions, such as heat and humidity. And limited DNA databases for comparison. Despite these advances, advances in DNA technology have improved the identification success rate in complex cases like aviation disasters.

Methodology

This article applied qualitative methodology to explore the application of DNA techniques in identifying human remains from the SACAA's perspective. Leedy and Ormrod (2018:31) note that qualitative research involves selecting a few well-suited participants to illuminate the phenomenon under study. The methodology included analysing various sources such as academic articles, industry reports and regulatory documents. Face-to-face semi-structured interviews were conducted, allowing researchers to engage with participants' thoughts and experiences more freely than questionnaires (Yin, 2018:133). A semi-structured interview schedule guide with open-ended questions was used to gather data from South African Civil Aviation Authority (SACAA) investigators and Air Traffic Controllers, aiming to understand their perspectives as stated by Zahle (2017:146). The semi-structured interview guide included the following open-ended questions:

1. Elaborate briefly on your understanding of what is the meaning of DNA is.
2. What comes to mind when you think of DNA identification?
3. Could you explain how often DNA identification techniques are employed in the investigation of aircraft accidents?
4. How do you ensure the integrity and reliability of DNA samples collected from the crash sites?
5. How long does it take for the South African Forensic Science Laboratory to process and release DNA results for the identification of aircraft accident victims?

Four accessible participants were interviewed through non-probability purposive sampling. A quantitative approach was avoided because it would not capture the complexity of participants' experiences, which cannot be quantified (Frechette, Bitzas, Aubry, Kilpatrick & Lavoie-Tremblay, 2020:1-2). Creswell and Creswell (2018:30) state that quantitative methods are typically used to test research questions in empirical studies. Ethical clearance Ref No: #5883 was obtained from the University of South Africa, and permission was granted by Wonderboom Civil, Airport South Africa for interviews. An approved interview schedule and informed consent were used to ensure

participants' rights and privacy were respected. The researchers applied bracketing to minimise bias, refraining from sharing their own views during interviews, which involves recognising and setting aside personal beliefs for a more objective understanding (Creswell & Poth, 2018:109; Baxter & Jack, 2018:32).

The meaning of Deoxyribonucleic Acid

The term "Deoxyribonucleic Acid" is a molecule that contains the genetic instructions used in the development and function of all living organisms. Literature defines DNA as a complex molecule that contains the genetic instructions used in the development and function of all living organisms (Alberts, Johnson, Lewis, Raff, Robert & Walter, 2002:195). Houck, Crispino and McAdam (2018:103) describe DNA as a polymer molecule comprised of smaller repeating units called monomers, which can be found in all living cells except in red blood cells and nerve cells. Similarly, Albert (2015: 195-200) define DNA as a molecule that carries genetic instructions used in the growth, development, functioning and reproduction of all known living organisms.

However, DNA contains the information required for the growth, development, and reproduction of all known living organisms as well as many viruses. The structural unit of DNA is nucleotides, which are arranged in four (4) different methods to create a double helix. Alberts, Heald, Johnson, Morgan, Raff, Roberts and Walter (2022:113) aver that these nucleotides are adenine (A), guanine (G), cytosine (C), and thymine (T). The genetic instructions are made up of the sequence of these nucleotides.

The most significant characteristic of DNA is its replication capacity, which allows genetic information to be transferred from one cell to another from generation to generation. Building on the research of Franklin and Wilkins, Watson and Crick's 1953 discovery of the DNA double helix was a turning point in our knowledge of the molecular basis of heredity (Watson & Crick, 1953:38). The base sequence might be duplicated using a pattern found on each strand of DNA in the double helix. This is the foundation of heredity at the molecular level and is essential for DNA replication and cellular division.

The biological sciences have been transformed by our growing understanding of the structure and functions of DNA, especially in the area of forensic science. With the exception of identical twins, each person's DNA sequence is unique, making DNA a vital tool for forensic investigations ranging from identifying criminals to clearing innocent parties. By mapping the whole human genome, creating a database for forensic comparison, and discovering disease genes, the Human Genome Project, which was finished in 2003, improved this knowledge even further (Green, Gunter, Biesecker, Francesco & Manolio, 2020:18).

The Meaning of Identification

Identification refers to the action or systematic process of selecting or recognising someone or something on account of the known or codified characteristics and distinctive traits (Becker & Dutelle, 2017:16). In this study, the process of identification is made possible through DNA investigative

analysis of the human remains of aircraft accidents. Interpol (2014:10) define identification as the process of recognising and confirming the identity of an individual, often in the context of forensic science or disaster victim identification. In aviation accidents, identification is crucial for providing closure to families (SACAA, 2018:15).

The Importance of Victim Identification in aircraft crash

The quick identification of victims in the aftermath of a major tragedy is critical for both legal and humanitarian reasons. Legally, identifying dead persons is critical for obtaining death certificates, resolving legal claims, and settling estates (Schuliar & Knudsen, 2012:105). Without correct identification, there might be legal problems, further complicating things for grieving families. Victim identification in mass disaster is crucial for several reasons:

1. Closure for families and loved ones: Accurate identification allows families to confirm the fate of their loved ones, facilitating emotional closure and the grieving process;
2. Dignity and respect of the deceased: proper identification ensures that victims are treated with dignity and respect;
3. Legal administrative: Official documentation, such as death certificate, and for solving legal and financial matters; and
4. Investigating and accountability: Accurate identification can aid in investigations, helping to determine the cause of the disaster and identifying responsible parties.

Furthermore, from a humanitarian point of view, quick and precise identification of fatalities allows impacted families to grieve and perform appropriate religious or cultural ceremonies (Saukko & Knight, 2018:11). The process of identification also assists communities recover by offering closure and easing the return to routine. However, the difficulties experienced throughout the procedure often highlight the need of victim identification. According to Blau and Ubelaker (2019:21), degraded remains are common in mass catastrophe situations owing to the nature of the occurrence, environmental variables, or time passed after the disaster.

This may provide substantial challenges for standard identifying procedures, requiring the use of sophisticated techniques such as DNA identification. In this context, DNA-based identification has emerged as a critical tool, particularly in situations when conventional identification approaches, such as dental records or fingerprints, have proven useless or inconclusive (Prajapati, Sarode, Sarode, Shelke, Awan & Patil, 2018:111). The distinctive genetic blueprint provided by DNA has proven helpful in assuring correct identification, even when remains are extensively fragmented or damaged. This emphasises the critical importance of DNA-based techniques in the setting of mass catastrophes, emphasising the necessity for ongoing improvements and research in this field.

The principles of DNA analysis in forensic

DNA analysis in forensic science, including aviation accident investigations, relies on several key principles. One of the fundamental principles in the

uniqueness of DNA, which states that no two individuals (except identical twins) have the same DNA profile (Butler, 2012:15). DNA analysis in forensics relies on identifying individuals based on the unique genetic material found at crime scenes (Butler, 2012:1-5). According to Gill (2006:145-150) forensic DNA analysis typically involves comparing DNA profiles from evidence, such as saliva, blood and hair against known DNA profiles from suspect or database. Sample collection is often the first step in the procedure, and meticulous and contamination-free collection is critical for proper analysis (Dash, Shrivastava & Das, 2020:65). Common DNA profiling techniques including Polymerase Chain Reaction (PCR) and Short Tandem Repeat (STR) analysis to analyse DNA samples that may be degraded or contaminated (Goodwin, Linacre & Hadi, 2011:120). Another essential principle is the stability of DNA, which refers to the ability of DNA to withstand environmental stressors such as heat, humidity and degradation (Thompson, 2014:125). In aviation accidents investigations, DNA analysis is used to identify human remains and reconstruct the events surrounding the accident. The process involves collecting DNA samples from the remains, personal items or family members and comparing them to known DNA profiles (SACAA, 2018:15). DNA analysis is used to identify the victims and provide closure for families.

Technological advancements in DNA analysis

Recent technological advancements in DNA analysis have revolutionised the field of aviation accident investigation. Over time, the domain of DNA analysis noted technical progressions that have substantially improved its precision and efficacy. One significant development is the use of Next-Generation Sequencing (NGS) technology, which allows for the rapid analysis of large amounts of DNA data (Biesecker, 2012:123).

DNA analysis has been made even easier with the advent of multiplex STR methods, which analyse many STR locations at once. This development is important for aircraft accidents as it often calls for the quick identification of several victims. The development of mitochondrial DNA (mtDNA) analysis is another noteworthy breakthrough. Since nuclear DNA cannot be recovered from damaged materials, mtDNA, which is more prevalent in cells than nuclear DNA, might be removed (Riley & Tait, 2020:99). This approach has proven especially helpful in historical research and situations involving large-scale disasters. Despite these developments, forensic DNA analysis still encounters some obstacles. Analysing DNA samples that have been combined by multiple people can be challenging and call for sophisticated statistical methods (Gill, Brenner, Brinkmann, Budowle, Carracedo, Jobling, de Knijff, Kayser, Krawczak, Mayr, Morling, Olaisen, Pascali, Prinz, Roewer, Schneider, Sajantila, & Tyler-Smith, 2020:17). There is a significant possibility of DNA contamination and transfer, hence stringent processes for collecting and processing samples are necessary (Shang, Wang, Yu, Zhang, & Zhang, 2024:229).

Challenges and limitations in DNA analysis

Although DNA forensics has been increasingly important in identifying victims of disasters and assisting with criminal investigations, it is not immune

to problems and restrictions. One of the biggest worries about DNA analysis is contamination. Cases involving high stakes, such criminal prosecutions or catastrophic disasters, are more likely to produce inaccurate conclusions if DNA samples are contaminated (Alotaibi, Alsolami & Mehmood, 2021:78). Consequently, proper protocols for DNA sample collection, storage, and processing are crucial for ensuring the samples' integrity. DNA analysis in aviation accident investigations is a complex process that faces several challenges and limitations. One of the primary challenges according to Thompson (2014:125) is degradation, which occurs when DNA is exposed to environmental stressors such as heat, humidity and ultraviolet light. This can lead to poor quality DNA samples.

Another significant challenges is contamination, which can occur during the collection, handling and analysis of DNA samples (Butler, 2012:457). According to Hollad (2013:143) the complexity of identifying fragmented remains is also a significant challenges in aviation accident investigation. Additionally, the lack of DNA databases and resources in South Africa limit the effectiveness of DNA analysis in accident investigations (Interpol, 2014:10). It becomes difficult to determine which profile belongs to who, if they are not properly marked. Another challenge would be DNA degrading in the forensic laboratory. Lee (2019:10) avers that over time, DNA can break down, making it difficult or impossible to obtain a usable profile.

Application of DNA in Aviation Disaster

Photography is broadly defined as the scientific and artistic process of creating permanent visual images through the recording of light or other electromagnetic radiation typically using a camera (Hirsch, 2017:4). According to Bate (2016:18) photography serves both as a technological tool and a communicative medium enabling the documentation, interpretation and preservation of visual information. It is further described by London and Upton (2011:6) as a controlled process in which the photographer manipulates variables such as lighting, exposure, composition and angle to convey meaning, tell a story or accurately record a scene.

South African Civil Aviation Authority application of DNA in Identifying Victims

The SACAA investigates aviation accidents, sometimes using DNA analysis for identification (SACAA, 2020). In complex crashes with severe damage or fragmentation of remains where traditional identification methods are not possible, DNA analysis provides a reliable means of identification (SACAA, 2018:15). In the 2017 helicopter crash in Duma Valley, SA, DNA analysis was used to identify the victims. The crash resulted in the deaths of all on board and DNA samples were collected from family members to confirm identities (SACAA, 2018:20). This highlights the importance of DNA analysis in providing closure for families and aiding in accident investigations. The SACAA works closely with forensic laboratories and international agencies to ensure that DNA analysis is conducted to the highest standards, facilitating accurate identification of victims and contributing to aviation safety investigations (Interpol, 2014:10)

Table 1: Differences Between DNA identification and Traditional Identification

Identification Method	DNA Identification	Traditional Identification
Method	Analyses genetic material (DNA) from biological samples	Uses visual recognition, fingerprints or personal effects
Accuracy	High accuracy, even with degraded samples (Butler, 2012:15)	Can be less accurate, especially with severe damage (Thompson, 2014:125)
Sample required	Biological samples (e.g blood, tissues, etc.)	Visual evidence or personal items
Use in aviation accidents	Effective for identifying remains in severe crashes (SACAA, 2018:15)	Limited use in cases of severe damage or fragmentation (Interpol, 2014:10)

The comparison of DNA identification and traditional identification methods shows that DNA is a powerful tool for identifying victims, especially in aviation accidents. DNA identification is more accurate than traditional methods, even with damaged samples, and DNA analysis is effective in severe crashes. According to Thompson (2014:125), traditional methods such as fingerprints can be less accurate, especially with severe damage.

Empirical Discussion

The empirical discussion of the article focused on the SACAA's experiences with DNA identification in aviation accidents. The findings revealed one main theme and five sub-themes: 1) briefly describe your understanding of what DNA is, 2), briefly describe your understanding of what Identification is, 3) can you explain how often are DNA techniques used in aircraft accidents investigations, 4) how do you ensure the integrity and reliable of DNA samples collected from crash site?, 5 and) how long does DNA results takes?. The main theme, sub-themes, and direct quotes from participants will be discussed in detail below.

Major theme: Extent of Application of DNA Techniques

Sub-theme 1: Conceptualising the meaning of DNA

Participants were asked to provide a descriptive definition of the term" DNA", as it pertains to the study's focus on conceptualisation of DNA. This was an open-ended question, and the participants were not provided with alternative response options.

The following **Table 1** capture the participants' responses to the above question:

Participant number	Responses
PARTICIPANT 1	*DNA plays a crucial role in fatal aircraft accidents, particularly in identifying human remains and determining the cause of the death … DNA can help identifying victims of an aircraft accident. In aircraft accident investigation they use Mitochondrial DNA (mtDNA) which is used to identify human remains to identify male individuals and determine paternal relationships.*
PARTICIPANT 2	*DNA is a molecule that carries the genetic instructions used in the growth, development and reproduction functions of all living organisms.*
PARTICIPANT 3	*I don't know.*
PARTICIPANT 4	*Molecule that contain the genetics.*

The above responses demonstrate that the participants have a general understanding of DNA. Although Participant 3 does not know the meaning of DNA, participants 1, 2 and 4 gave clear understanding of DNA. Numerous studies and publications confirm that DNA is indeed a molecule that contains the genetic instructions used in the functioning of all living organisms. In the context of this study, DNA testing is crucial because it helps identify victims, even when traditional methods are not possible and the testing can identify victims from fragmented remains, in aircraft accidents.

Sub-theme 2: Understanding "DNA Identification

In this section, the article sought to investigates participants' understanding of DNA identification. **Table 2** participants' responses.

Participant number	Responses
PARTICIPANT 1	*It is the process of analysing and identifying individual unique characteristics.*

PARTICIPANT 2	*… to determine whether a man in the biological father of a child.*
PARTICIPANT 3	*That is done by actually the pathologist.*
PARTICIPANT 4	*DNA in identifying victims is not only for identifying victims, although it's important to bring closure to those survivors. But it's also important for us to identify the sitting arrangements, who was sitting where and what was the body mass?*

When comparing the responses of participants 1, 3 and 4, it is clear that the response by Participant 2 lacked clarity and accuracy. Instead of defining "DNA identification", Participant 2 addressed paternity test, indicating a knowledge gap about DNA identification and its applications in forensic science.

In the literature, DNA identification is explained as a direct identification method that involves analysing an individual's DNA to establish their identity (Alvi, 2019:22; van Graan, van Niekerk & Budhram 2024:259). In the context of this study, DNA identification is critical for identifying victims in a mass aircraft accident or disaster, exhumation, genetic genealogy, forensic analysis of crime scenes, unidentified human remains, paternity and criminal investigation. Therefore, it is evident that DNA identification is frequently employed in the aftermath of a mass disaster or accident.

Sub-theme 3: How often are DNA techniques used in aircraft accidents investigations?

In this section, the researcher sought to explore the participants' view on how often DNA techniques are utilised in aircraft accident investigations. The participant responses are discussed in the **Table 3** below.

Participant number	**Responses**
PARTICIPANT 1	*Most of the time to identify human remains and for family to have closure.*
PARTICIPANT 2	*I am not sure*
PARTICIPANT 3	*The investigators and forensic pathologists work hand-in-hand to match body parts and verify victim identities through family DNA comparison". Pathologist to collect*

	human remains after photographic documentation in complete"
PARTICIPANT 4	*DNA in identifying victims is not only for identifying victims, although it's important to bring closure to those survivors. Okay. Right. But it's also important for us to identify the sitting arrangements, Who was sitting where and what was the body mass?"*

DNA plays important role in identifying the deceased of aircraft mascara. The researcher is of the opinion that DNA sample should be taken from all members on board as a preventative measure of wrongful identification after aircraft accident. These should be requirements of all the individuals who are boarding any plane. Participants 1, 3 and 4 agrees that DNA assist them in identifying the victims after the accidents, they also emphasis the role of pathologists in identifying the victims and collect evidence.

Sub-theme 4: How do you ensure the integrity and reliability of DNA samples collected from the crash site?

This was an open-ended question, whose response was based on the participants' perception and experiences.

Below is **Table 4:** responses of the participant:

Participant number	Responses
PARTICIPANT 1	*It is done by pathologists*
PARTICIPANT 2	*Is work for pathologists.*
PARTICIPANT 3	*That that is done by actually the pathologist and get our reports from the police pathologist because they get involved during a fatal accident".*
PARTICIPANT 4	*DNA is needed to do that. But, that's what they do to match the two, body members together. And, also, if we can't, if we find maybe, let's say, like, on a high velocity impact accident like a fighter jet". "That that is done by actually the pathologist and get our reports from the police pathologist because they get involved during a fatal accident*

All participants state that DNA integrity and collection is the function of the South African Police Service and the pathologists. Alketbi (2022:7) states that investigators must use suitable sampling methods depending on the nature of the evidence, such as swabbing, cutting, scraping or tape-lifting, using sterile, single-use tools and gloves, again the author state that to maintain integrity DNA samples must be stored at optimal conditions to prevent degrading, and transport them securely to prevent contamination or loss.

Sub-theme 5: how long does DNA results takes?
This was an open-ended question, allowed participants' to share their experiences regarding the typical turnaround time for DNA results. Below is **Table 5** responses of the participant:

Participant number	**Responses**
PARTICIPANT 1	*It takes time*
PARTICIPANT 2	*It takes time*
PARTICIPANT 3	*So, usually, it takes it takes very long. Yeah. I can't recall I can't recall where we were looking for DNA test and whatever because we usually get to find who get to know who is who is who was flying and who was on board*
PARTICIPANT 4	*DNA is offering a revolutionised victim identification. There's one which I we investigated in the eighty two thousand, And the only thing that we found was a pelvic bone. And for is it doctor **S**? the head of pathology in South Africa. For him to be able to accurately say it was him, he needed then to get the family members to give them samples, and he then conducted or did their thing, and he did confirm that, yes, it was in there. So they come they will compare. If they find two Uh-huh. Pelvic bones, and we know that there were two people on board. Uh-huh. Like, they will then verify if this particular pelvic bone Uh-huh. Belongs is a pair Uh-huh. With this one, you know, to one person Uh-huh. Or is two separate people.*

All 4 participants agrees that DNA take very long time before they can access them. These made the identification of victims to take very long time.

Literature and Empirical Findings

The study's findings revealed a multitude of factors that impact the application of DNA techniques in identifying human remains. Challenges such as contamination, degradation of DNA samples and limited resources were noted as significant obstacles to effective DNA analysis. Lacks of SACAA own dedicated laboratory and forensic experts, relying heavily on government laboratories for DNA analysis and expertise.

Recommendations

Based on the findings, it is recommended that SACAA prioritise the establishment of a comprehensive DNA database for aviation personnel and passengers. Additionally, standard operating procedures for DNA sampling and analysis should be developed and implemented to minimise contamination and ensure efficient processing. Furthermore, collaboration with international organisations and forensic experts to share best practices and stay updated on the latest developments in DNA analysis.

Conclusion

The proper collection and sampling of all Onboard passengers will make it easy to collaborate with the deceased in a crashed incident. The identification of any deceased through DNA will simplify the work of the civil aviation investigators and also assist to verify with the relatives and families. *DNA* plays important role in identifying the deceased of aircraft mascara. The researcher is of the opinion that DNA sample should be taken from all members on board as a preventative measure of wrongful identification after aircraft accident. These should be requirements of all the individuals who are boarding any plane. Participants 1, 3 and 4 agrees that DNA assist them in identifying the victims after the accidents, they also emphasis the role of pathologists in identifying the victims and collect evidence. The above is confirmed by the participants in this research and very important for international organizations to apply this rule by compelling all passengers to deposit DNA before boarding.

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