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Review Article

# Improving Cytogenetic Surveillance in Radiology Workers Exposed to Low-Dose Radiation in Africa: A Call to Action

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## Abstract

Radiation exposure is an occupational hazard for diagnostic and interventional radiology workers, potentially leading to chromosomal damage and increased cancer risk. This review explores the status of cytogenetic monitoring of radiation exposure among radiology workers in Africa. Monitoring of Radiation Exposure in Diagnostic and Interventional Radiology Workers in Ghana and Africa provides a crucial examination of radiation safety practices within the Ghanaian and Africa healthcare sector. We recovered existing literature on the cytogenetic surveillance conducted on radiology workers in Ghana and Africa stressing on the impact and/or significance of cytogenetic monitoring programmes. In these studies, mostly mathematical modeling and physical methods were used to estimate and extrapolate risks of exposure to ionizing radiation. Additionally, we discuss the challenges and opportunities for implementing cytogenetic monitoring programmes in Africa particularly Ghana and provide recommendations for future research and occupational health policies.

This review attempts to bridge the gap between physical and biological dosimetry in surveillance studies. It addresses the significant gap in cytogenetic monitoring among diagnostic and interventional radiology workers in Africa. It highlights the importance of cytogenetic surveillance for early detection of radiation-induced genetic damage, assesses the current practices, and provides a recommendation and a roadmap for establishing robust monitoring programmes. This work would contribute significantly to the understanding of occupational radiation safety issues in the healthcare sector of Africa. It also offers a comprehensive examination of the challenges and opportunities in implementing cytogenetic monitoring programmes.

## Introduction

Diagnostic and interventional radiology procedures are essential in modern healthcare, and their use has increased dramatically worldwide. For instance, in 2012, it was estimated that the over 600% increase in medical radiation exposure to the US population since 2008. Despite the implementation of adequate radiation control measures to protect patients and healthcare providers, ionizing radiation exposure still poses inherent risks to the health of radiology workers. Concerns remain about the potential for adverse health effects, including increased cancer risk, chromosomal damage, and carcinogenesis in exposed populations [1-3].

There is growing evidence of an increased cancer risk in various populations exposed to chronic doses below several tens of millisieverts (mSv) or doses received over an extended period. Additionally, evidence indicates that relative risks are generally higher following radiation exposure in utero or during childhood [4]. Epidemiological studies dating back to 1956 have linked diagnostic X-rays during pregnancy to an increased risk of cancer in offspring. These studies have also associated higher



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breast cancer risks in women with tuberculosis who were monitored using fluoroscopy and in women with scoliosis who underwent repeated X-rays. Additionally, there is evidence of a modest excess in pediatric leukemia among patients exposed to these diagnostic procedures [5].

In Ghana and much of Africa, physical methods are primarily used to determine radiation dose and biological effects of ionizing radiation in healthcare, forming the basis for risk assessments and avoiding biological methods. It is worthy to note that the use of biotic index to evaluate radiation dose after personal exposure has become popular in radiation biology and radiation protection research [6]. Cytogenetic surveillance (analysis) conducted on peripheral blood lymphocytes of radiation-exposed populations provides a unique opportunity to detect radiation-induced genotoxic changes in individuals [7]. This allows for the assessment of both short- and long-term health risks, including carcinogenic and mutagenic effects, and bridges the biological gap needed to explain results derived from physical measurements and mathematical modeling.

Radiation has been described as a double-edged sword in healthcare delivery, offering both crucial diagnostic and therapeutic benefits and potential health risks. Given the significant impact of the increasing use of radiation procedures on health, cytogenetic surveillance is warranted in all countries that utilize radiation. This review aims to evaluate the current landscape of cytogenetic monitoring of radiation exposure among diagnostic and interventional radiology workers in Africa.

There is a critical lack of cytogenetic surveillance programmes for radiology workers in the whole of Africa, contrasting with established practices in developed countries like USA, Italy, Croatia, Brazil, China, Turkey, France, Belgium, Indonesia, Poland, Korea, Japan, India, and Iran. In our review we cited only two African countries namely Tunisia and Egypt who have stimulated cytogenetic surveillance studies. In the context of cytogenetic monitoring in Africa, this review highlights the scathing need for such programmes but also offers tailored recommendations for overcoming the specific challenges faced in this region. The integration of cytogenetic surveillance with existing radiation protection measures can significantly enhance the safety and health of radiology workers, thereby contributing to the broader field of occupational health.

The novelty of this study resides in the fact that it proffers a comprehensive assessment of cytogenetic monitoring practices among radiology workers in Africa including Ghana. By marrying results of physical dosimetry with cytogenetic monitoring, a holistic picture of absorbed radiation dose and associated risks to victims obtained. The review proposes a roadmap for implementing cytogenetic surveillance programmes, addresses key challenges and offers practical solutions, which when heeded to might significantly contribute to developing comprehensive occupational health policies for all stakeholders in the region.

## Methods

A comprehensive literature search was conducted using electronic databases such as PubMed, Google Scholar, local Ghanaian and African medical journals. Keywords including "radiation exposure," "cytogenetic monitoring," "radiology workers" Africa" and "Ghana" were used to identify relevant studies.

### Selection criteria

The Population, Exposure, Comparator, and Outcome (PECO) framework tool was adapted to define the eligibility criteria. For eligibility and inclusion in this study, the following criteria were used. The review papers used involved only health workers, who routinely use ionizing radiation from diagnostic and interventional radiology procedures as a working tool. The comparator group included a cohort of healthcare workers in similar settings but who are not routinely exposed to ionizing radiation. The biological endpoints were a quantitative measure of incidence of radiation-induced health effects including changes in chromosome aberration, frequency of micronuclei or allied biomarker levels. Articles written in English and published between January 1, 2000, and 2024 were included in the review. This time frame was selected due to the significant advancements in diagnostic and interventional radiology during this period. Studies with 10 or fewer participants in either the exposed or unexposed groups were excluded. It also focused only on studies providing comprehensive and consistent quantitative data (such as frequencies, lengths, or scores) for both IR-exposed and unexposed worker groups, and only those using an exposed/unexposed design were included.

### Details of articles found and excluded

- **Initial number of articles found:** The search yielded 70 articles.
- **Excluded articles:** 30 articles were excluded due to reasons such as irrelevance to the study focus, insufficient quantitative data, or having less than 10 participants in the exposed or unexposed groups.
- **Included articles:** 40 articles were included in the review.
- **Types of literature and evidence levels:** Included studies comprised observational, cohort, and case-control studies. Evidence levels ranged from high-quality cohort studies to lower evidence case-control studies, providing a comprehensive view of the cytogenetic monitoring landscape.

The selected articles were analyzed using qualitative synthesis and meta-analysis where applicable. Data extraction was performed by two independent researchers to reduce bias. Discrepancies were resolved through discussion. The Cochrane risk of bias tool was employed to assess the quality of the studies. Furthermore, sensitivity analyses were conducted to ensure robustness of the findings.



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## Cytogenetic monitoring in Africa and Ghana

Physical dosimetry methods are more commonly used across the continent for monitoring radiation exposure, while cytogenetic methods, which can provide insights into biological effects, are underutilized.

Studies on cytogenetic monitoring in Africa, particularly for workers exposed to ionizing radiation, remain scant. While there have been some significant studies, the coverage across the continent is not comprehensive. Studies have shown that Tunisian hospital workers exposed to ionizing radiation exhibit higher frequencies of micronuclei and chromosomal aberrations compared to non-exposed controls [8,9]. These findings highlight the potential genetic damage due to occupational exposure. Research in Egypt focused on monitoring genetic damage among healthcare workers, revealing similar trends of increased chromosomal abnormalities and micronuclei frequencies among those exposed to ionizing radiation [1]. These studies are recorded in two North African countries; like Tunisia and Egypt, however it is instructive to note that, over the years Ghana, a sub-Saharan African country has built some capacity in cytogenetics studies using the tools of biodosimetry. However, there is an acute lack of extensive research covering sub-Saharan Africa.

In general records regarding cytogenetic surveillance studies conducted in Africa for either of the purposes enumerated above remain scant. A recent survey by Baudin, et al. 2021 cited Cytogenetic studies in only Tunisia and Egypt in Africa where it was used to monitor radiation exposure in medical workers [1]. A study was conducted Bouraoui, et al. in 2013 to assess chromosomal damage in Tunisian hospital workers occupationally exposed to low levels of ionizing radiation using the micronuclei assay in peripheral blood lymphocytes of exposed workers. The study revealed a MN frequency distribution of $13.6 \pm 4.9$ among the exposed workers and while the unexposed cohort had a MN frequency of $6.5 \pm 4.2$ [8].

In 2017, Doukali, et al. conducted another cytogenetic study in Tunisia to assess micronucleus (MN) yields and Sister Chromatid Exchanges (SCE) in hospital staff occupationally exposed to ionizing radiation (IR). The study also evaluated the association of these biomarkers with XRCC1 399 Arg/Gln and XRCC3 241 Thr/Met polymorphisms in this group. The results demonstrated that the MN frequency among the exposed group was $1.16 \pm 0.65$, while the unexposed group had a yield of $0.46 \pm 0.21$, indicating a significant effect of radiation on MN yield. The SCE was $8.47 \pm 0.45$ for the exposed group compared to $7.22 \pm 0.82$ for the unexposed group. Despite these findings, the study did not find an association between the XRCC1 399 Arg/Gln and XRCC3 241 Thr/Met polymorphisms and the severity of DNA damage in the population studied [9].

Additionally, Sakly, et al. conducted two independent studies in 2012 and 2013 on cytogenetic surveillance in hospital workers exposed to IR in Tunisia. These studies aimed to assess occupationally induced chromosomal damage in a large population of hospital workers exposed to low doses of IR using the MN, chromosomal aberration, and comet assays. Both studies established that IR influenced DNA damage, as evidenced by higher MN yields, the presence of chromosomal aberrations, and pronounced comet tail lengths [7,10,11].

In 2016, El-Benhawy and co-workers conducted cytogenetic surveillance on individuals occupationally exposed to Ionizing Radiation (IR) in Egypt aimed at assessing the significance of chromosomal aberrations and the oxidative adduct 8-hydroxy-2-deoxyguanosine (8-OHdG) as biomarkers of radiation injury in the study [12].

Despite the well-known risks of radiation exposure in radiology practice, cytogenetic monitoring programmes for radiology workers on the African continent is lacking. The literature extensively covers physical measurements and the risks of radiation damage to these workers but falls short when it comes to cytogenetic surveillance. Challenges such as limited resources, insufficient trained personnel for cytogenetic analysis, lack of awareness about the diagnostic and clinical benefits of cytogenetic studies, and inadequate training might be some of the reasons that hinder the establishment of comprehensive monitoring programmes.

## Physical and cytogenetic monitoring methods

Physical monitoring methods of measuring radiation exposures such as dosimetry, are most widely used in Africa. However, these methods only measure external radiation doses received by victims and fall short of providing information on the biological consequences of the absorbed radiation. In contrast, cytogenetic monitoring methods, such as chromosomal aberration analysis and micronucleus assays, offer insights into the biological impact of radiation exposure on workers [13,14]. Moreover, in the presence of in-house dose response (validated) curves, these methods can also provide information on absorbed doses to recipients. Physical monitoring involves measuring radiation doses using devices like badge dosimeters while cytogenetic monitoring, assesses biological effects of radiation exposure by examining biomarkers such as CA, MN, and Sister Chromatid Exchanges (SCE). From the forgoing it is obvious that cytogenetic methods provide insights into the biological impact of radiation, which physical methods cannot [15-17].

## Cytogenetic monitoring methods

Different cytogenetic monitoring methods abound and vary in sensitivity and specificity. For instance, the micronucleus assay is less specific but more sensitive compared to chromosomal aberration analysis, which is more specific but less sensitive [18-20]. The most common radiation induced cytogenetic biomarkers include the Chromosome Aberrations (CA) which includes stable (e.g., translocations) and unstable (e.g., dicentrics) aberrations, the Micronuclei (MN) an indicator of chromosomal instability, Sister Chromatid Exchanges (SCE) which reflect DNA repair processes and the Comet Assay which measures DNA strand breaks [16,19,21].



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## Limitation

The Dicentric chromosome aberration is specific to radiation [19,22] but the other cytogenetic biomarkers could be caused by other factors other than radiation including antioxidant stress [23,24]. A limitation of this study is that chromosomal damage observed in radiology workers may be influenced by various environmental and genetic factors, not solely by radiation exposure. Factors such as family history, spontaneous abortions, stillbirths, neonatal mortalities, birth defects, and malignancy have been implicated in chromosomal abnormalities [25-28]. Moreover, family history of genetic disorders and environmental factors are also known to increase susceptibility to chromosomal damage and could play confounding role in this study [29-32].

## Significance of monitoring radiation-induced chromosomal damage

Among its various important uses, cytogenetic surveillance plays a critical role in the early detection of genetic damage caused by ionizing radiation, helping to prevent the progression of radiation-induced diseases (IAEA 2021). It is also essential for monitoring radiation exposure, offering opportunities to assess and ensure that exposure levels in individuals remain within safe limits. Moreover, cytogenetic surveillance is important for risk assessment and management, aiding in evaluating the risks associated with radiation exposure and implementing appropriate risk management strategies (IAEA 2021). It plays a crucial role in the ongoing health surveillance of radiation workers, protecting their health and safety by identifying early signs of radiation damage. Additionally, information obtained from cytogenetic surveillance can guide medical treatment and interventions for individuals exposed to high levels of radiation. Lastly, cytogenetic surveillance helps organizations comply with regulatory requirements by providing data on radiation exposure and its biological effects.

## Recommendations and future directions

Important as cytogenetic programmes seem to be, activities in this area are woefully inadequate in Africa and Ghana and it is important to establish competence in these skills in Africa and its sub-regions in especially as the use of IR is on the ascendancy. Ultimately, an efficient effective cytogenetic surveillance programme will contribute to effective assessment of health risk associated with identified workplace hazards; Assess exposure (dose) –response relationships, ultimately this will ensure that worker exposure does not reach levels capable of eliciting adverse effects (effective control measures).

The following key roadmaps ought to be adopted to encourage Ghana join the league of countries with cytogenetic monitoring programmes to enhance radiation safety, protect public health, and contribute to broader efforts in occupational health and safety.

i. **Public engagement and advocacy**: It behooves on the country to engage stakeholders, including government officials, healthcare providers, academia, and civil society organizations, in advocacy efforts to prioritize and support the establishment of cytogenetic surveillance programmes.

ii. **Policy development and implementation**: It is worthy to mention the development of national policies and guidelines that will mandate or incentivize the integration of cytogenetic surveillance into occupational health programmes, particularly in high-risk sectors like healthcare, nuclear industries, agriculture workers exposed to weedicides, herbicides and fertilizers, scrap and electronic waste dealers. and research facilities.

iii. **Education and awareness** In studies of this nature, biological samples are employed, it is therefore important to initiate educational initiatives to raise awareness among healthcare professionals, policymakers, and the public regarding the significance and advantages of cytogenetic surveillance in monitoring health risks induced by radiation. This way we can obtain the approval from the responsible authorities.

iv. **Capacity building**: it is important to create a critical pool of skilled labor to handle such technical activities. Thus, it is mandatory to implement training programmes and workshops aimed at developing a substantial number of skilled personnel in cytogenetic analysis. This effort encompasses offering specialized training in cytogenetics, molecular biology techniques, and bioinformatics to bolster local expertise

v. **Infrastructure development**: for a successful cytogenetic surveillance programme, adequate resources allocation to develop infrastructure and laboratory facilities equipped with state-of-the-art cytogenetic technologies and equipment is fundamental. Moreover, it is important to ensure sufficient funding for sample collection, processing, and capabilities for analysis.

vi. **Collaboration and partnerships**: It is also essential to foster collaborations between local institutions, international organizations, and research centers with expertise in cytogenetic surveillance. This may include partnerships for knowledge exchange, technical support, and collaborative research projects.

vii. **Quality assurance and accreditation**: it is important to ensure the implementation of quality assurance measures and accreditation standards for cytogenetic laboratories to ensure accurate and reliable testing results. This includes adherence to international standards and regular proficiency testing.

viii. **Research and evidence generation**: Local research initiatives to generate evidence on the prevalence of radiation-induced chromosomal damage, associated health risks, and the effectiveness of cytogenetic surveillance in mitigating these risks should be identified and supported.

ix. **Monitoring and evaluation**: A successful cytogenetic biomonitoring programme should establish mechanisms



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for monitoring and evaluating the implementation and impact of cytogenetic surveillance programmes. This includes tracking programme outcomes, assessing the effectiveness of interventions, and making necessary adjustments based on findings.

## Concluding remark

Cytogenetic monitoring could serve as a valuable tool for assessing radiation-induced chromosomal damage among diagnostic and interventional radiology workers in Ghana and Africa as a whole. It is also an invaluable tool for human biomonitoring studies for persons exposed to various genotoxic chemicals and/or physical agents. Despite the current limitations, there is potential for the establishment of robust monitoring programmes through concerted efforts and investment in infrastructure and training. An improved understanding of the cytogenetic effects of radiation exposure, will sure lead to a better protection of the health and safety of radiology personnel and inform evidence-based occupational health policies in Africa.

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