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*Article*

# Implementation of Portable Digital Chest X-Ray Machine for Tuberculosis Contact Tracing in Oyo and Osun States, Nigeria: A Formative Assessment

**Aderonke Agbaje [1], Patrick Dakum [1], Olugbenga Daniel [1], Anyaike Chukwuma [2], Obioma Chijoke-Akaniro [2], Evaezi Okpokoro [1], Samuel Akingbesote [1], Christian Anyomi [3], Adekola Adekunle [1], Abiola Alege [4], Moroof Gbadamosi [5], Olutunde Babalola [6], Charles Mensah [1], Rupert Eneogu [7], Austin Ihesie [7], Debby Nongo [7] and Ademola Adelekan [1,*]**

[1] Institute of Human Virology Nigeria, Abuja, Nigeria
[2] Centre for Integrated Health Programs, Osogbo, Nigeria
[3] National Tuberculosis, Leprosy and Buruli Ulcer Control Programme, Federal Ministry of Health, Abuja, Nigeria
[4] Society for Family Health, Abuja, Nigeria
[5] Osun State Ministry of Health, Osogbo, Nigeria
[6] Oyo State Ministry of Health, Ibadan, Nigeria
[7] United States Agency for International Development, Nigeria
* Correspondence: ademola.adelekan@gmail.com

**Abstract:** This paper presents the formative assessment to implement mobile portable chest X-ray (PDX) machines for Tuberculosis (TB) contact tracing in Oyo and Osun States, Nigeria. This descriptive qualitative study was carried out in 8 Local Government Areas, and 24 FGDs and 33 KIIs were conducted using a 4-stage sampling technique to select participants. Validated transcribed notes were entered and analysed using Nvivo. The respondents' ages ranged from 17-85 years, with a mean age of 42.08±14.9 years, and 4.0% had a postgraduate degree. The majority of the government officials stated that deploying the PDX machine intervention at the community level is the best means as it offers a level of convenience to the community members in the sense that there will be limited disruption to their daily activities as well as zero concerns about the cost of transportation to the health facility. The portable X-ray machine intervention should be implemented at the community level for contact tracing to allow more TB contacts living with the index patient to be screened. However, the PDX machine can also be set up in a special location, and the TB contacts can be invited for the screening.

**Keywords** tuberculosis; contact investigations; portable X-ray machine

## 1. Introduction

Nigeria is one of the nations with a high burden of tuberculosis, TB/HIV, and drug-resistant tuberculosis [1,2]. Nigeria is one of the eight countries that bear two-thirds of the world's TB burden [3,4]. The risk of the disease spreading to other community members is considerably high because about 40% of the estimated 2.46 million cases in Africa go undetected [3]. The data that is currently available shows that more than 80% of TB patients are still undiagnosed and untreated [5–7]. As part of her National Strategy Roadmap for locating unidentified TB patients, Nigeria has accepted the End TB strategy, the Sustainable Development Goals (SDGs), and more recently, the resolutions of the United Nations High-Level Meeting (UNHLM) on Tuberculosis [8,9]. Throughout the last 20 years, the WHO has categorised Nigeria as having a high burden of TB to promote targeted interventions and push for resources and legislation to improve TB control. Enhancing the yearly reduction in TB incidence rates from 2% in 2015 to 10% in 2025 is the TB Strategy's ultimate target [10]. To ensure

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early TB diagnosis and close case detection gaps through regular contact screening and high-risk population screening, the first pillar of the End TB Strategy emphasises the need for patient-centred, integrated care and prevention [11]. To end the tuberculosis epidemic in a generation, the countries with a high tuberculosis burden countries should give priority investments to populations at the highest risk of tuberculosis, including households and close contacts. Economic evaluations have demonstrated the cost-effectiveness of contact investigation for preventing tuberculosis and its economic benefits to society [12–14]. Contact persons should have access to quality and rapid tuberculosis diagnosis, treatment, and prevention services [15]. Hence, contact investigation is imperative to facilitate the global End TB Strategy. Previous studies found that the proportion of positive cases among household contacts was 20% to 40% [16]. Contact investigation also potentially contributes to finding TB cases among children [17]. However, a previous study in Indonesia revealed that only 20% of household contacts followed screening. Furthermore, less than 10% wholly followed the evaluation for TB. The low participation of household contacts following TB screening and evaluation can lead to a loss of opportunity for case findings [16].

Chest X-rays were seen as a breakthrough for quick identification of contacts for follow-up, TB active case finding, and ultimately, TB eradication because of their high sensitivity, better portability, and usability [18]. With the discovery of X-Ray for TB prevention and, subsequently, TB treatment, there were drawbacks to its use due to its immobility, high operating costs, and shortage of radiologists. Hence, because smear microscopy was affordable and easy to use, it became the alternative for diagnosing TB patients. However, the WHO formed the DOTS strategy for active case finding in hard-to-reach communities. Still, there were limitations to the DOTS strategy in screening children, people living with HIV, and people with smear-negative, which led to missed cases for screening and TB treatment [19,20]. To achieve the goal of Nigeria's National Tuberculosis, Leprosy, and Buruli ulcer control programme, the use of chest X-ray machines to conduct TB screening became an effective tool, and the United States Agency for International Development (USAID) assisted by funding TB-LON region projects targeted towards high burden areas [21]. The portable chest X-ray allows many persons to be screened daily and determine who should be further evaluated using Xpert MTB/RIF during community-based active case finding [22]. Also, there could be an increase in the diagnosis capacities of the portable chest X-ray machine when combined with a compatible Artificial intelligence-powered computer-aided detection (CAD) software solution. This could lead to higher efficiency and efficacy [23]. The use of portable digital chest X-ray machines supports the plan of WHO to end the TB epidemic globally by 2035 by assisting in finding millions of missing people with TB, even among those living in remote areas [24]. Also, according to [25], this will decrease the number of missed cases and the number of people who need to be screened. Therefore, the paper presents the formative assessment to implement mobile Portable Digital X-ray **(**PDX) machines for contact tracing in Oyo and Osun States, Nigeria.

## 2. Materials and Methods

### *2.1. Study Design*

This descriptive qualitative study was used to identify strategies to implement portable X-ray machine intervention for contact tracing in Oyo and Osun States, Nigeria. This formative assessment was used to plan and implement portable X-ray machine intervention for contact tracing.

### *2.2. Study Area*

This project was carried out in 8 (Osun=4; Oyo=4) Local Government Areas (LGAs) in hard-to-reach communities and TB's high burden in Oyo and Osun States, Nigeria. In Oyo State, the study LGAs were Ibadan North, Oyo East, Ogbomoso South, and Iseyin, while in Osun State, Iwo, Oshogbo, Ife Central, and Ede South were used for the study.

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*2.3. Target Population*

The target population for this study included bacteriologically diagnosed TB patients, household contacts, community volunteers, community gatekeepers, and government-employed TB personnel.

*2.4. Sample Size*

The saturation technique drove this study. However, we conducted 8 FGDs in each State among TB patients, household contacts, and community volunteers, while 13 and 15 KIIs were respectively conducted in Osun and Oyo States with government officials (DOT officers, LGA supervisors, and State TB officer), and community gatekeepers (Table 1). In each selected LGA, one FGD was done for TB Patients, TB Contacts, and Community Volunteers. The number of participants for each FGD varied; however, it ranged from 5 to 11.

**Table 1.** Sample Size.

| Osun State | | | | |
|---|---|---|---|---|
| S/N | **LGA** | **FACILITY** | **FGD (TBP; TBC, CVs)** | **KII (DOTS officers, TBLS, STBLM, WDC)** |
| | **Osun State** | | | |
| 1 | Iwo | Fees PHC | 3 | 3 |
| 2 | Ede South | State Hospital Ede | 3 | 3 |
| 3 | Ife Central | Enunwa PHC | 3 | 2 |
| 4 | Osogbo | State Hospital, Subiaco | 3 | 3 |
| | | IHVN Staff | | 1 |
| | | **Total** | **12** | **12+ 1 (STBLPM)** |
| **Oyo State** | | | | |
| 1. | Ibadan North | PHC Sabo | 3 | 3 |
| 2. | Oyo East | State Hospital, Oyo | 3 | 3 |
| 3. | Ogbomosho South | PHC Igboyi | 3 | 3 |
| 4 | Iseyin | General Hospital Iseyin | 3 | 3 |
| | | IHVN Staff | | 2 |
| | | **Total** | **12** | **13 + 1 (STBLPM)** |

*2.5. Sampling Techniques*

The participants for this research were chosen using a 4-stage sampling method.

**Stage 1:** Using the IHVN (Institute of Human Virology Nigeria) program sites, a purposeful sampling method was used to select two States (Oyo and Osun) in the Southwest of Nigeria.

**State 2:** Four LGAs were randomly selected from Oyo and Osun States.

**Stage 3:** One facility was chosen from each LGA using random numbers generated from www.randomizer.org from the IHVN-supported DOTS facilities list.

**Stage 4:** In the catchment areas of the chosen DOTS facilities, a purposeful sampling method was used to select all the stakeholders required for the study.

*2.6. Methods of Data Collection*

A qualitative method of data collection was adopted for this study.

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*2.7. Instruments for Data Collection*

Validated instruments (key informant interview (KII) and Focus Group Discussion (FGDs) guides) were developed and used for this study. The tools were used to identify perceived strategies for implementing the portable X-ray machine intervention for contact tracing. The instruments were developed by the research team based on the literature review and inputs of the TB and public health specialists.

*2.8. Data Collection Procedures*

Digital recorders and field notes were utilised for the KIIs and FGDs to enable the interviewers to capture all the information during the interviews for accuracy in the data analysis process. The study recruited eight data collectors, comprising three males and five females (Osun=4; Oyo=4) with at least a First Degree in health and/or health-related to assist with data collection for the study. One of the data collectors with more than 5 years of experience in data collection and a Master of Public Health degree was selected as a supervisor to coordinate the process. The project team and data collectors participated in a 2-day intensive residential training, and they were involved in the pilot testing of the instruments on the third day of their training to create an opportunity for them to acquire practical interviewing skills. The pilot of tools took place at Oniyanrin PHC, Ibadan Northwest Local Government, and the main data collection took place in November 2022.

*2.9. Data Management and Analysis*

Several procedures were employed in the data management and analysis. Data processing started with the verbatim transcription of tape recordings by note-takers. This was done on the same day the data was collected to avoid losing or omitting important details. The data collectors were required to transcribe their interviews immediately after the interviews were conducted and were expected to work with their supervisors to audit and validate their transcribed notes. Field notes were used to beef up audio-taped recordings developed into transcribed notes. Data collectors transcribed their audio-taped recordings using the same local language(s) as the interviews. All the transcribed notes of interviews in local languages were given to linguistic experts alongside their respective audio-taped recordings for quality forward translation. The translated notes were also given to another set of two linguistic experts who performed the back translation of the English translation into the original languages to ensure the quality of the data. The transcribed notes were further subjected to validation, and data collectors, the consultant, supervisors, and data clerks participated in the audit and validation of the translated notes. Validated transcribed notes were entered into the computer using NVIVO version 12 Pro. An inductive-dominant coding approach was used to drive the coding process [26]. Thematic content analysis procedures guided the data analysis.

## 3. Results

*3.1. Respondents/Participants Socio-Demographic Characteristics*

The respondents' ages ranged from 17 to 85 years, with a mean age of 42.08±14.9 years; among these, 46.7% were between the ages of 35 and 54. Few (4.0%) had a postgraduate degree, were married (65.3%), and 31.3% were TB patients (Table 2). Table 3 shows the disaggregated socio-demographics of Osun and Oyo States. The mean age of respondents in Osun State was 46.07 ±15.8 years; 57.3% were male, 42.7% were female, 32.9% had secondary school education, 64.5% were married, and 27.6% were civil servants. More than half (65.8%) practice Islam and 96.0% were Yorubas. Oyo State's mean age of respondents was 38.15±12.8years; 45.9% had secondary school education, 66.2% were married, and 10.8% were civil servants. Over half (52.7%) practice Christianity, and 97.3% are Yorubas.

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**Table 2.** Socio-demographic characteristics (N=150).

| Socio-demographic variables | No | % |
|---|---|---|
| **Age*** | | |
| 15-34 | 49 | 32.7 |
| 35-54 | 70 | 46.7 |
| 55-74 | 27 | 18.0 |
| 75 and above | 4 | 2.7 |
| **Sex** | | |
| Male | 86 | 57.3 |
| Female | 64 | 42.7 |
| **Marital status** | | |
| Single | 43 | 28.7 |
| Married | 98 | 65.3 |
| Separated | 3 | 2.0 |
| Divorced | 2 | 1.3 |
| Widow/widower | 4 | 2.7 |
| **Religion** | | |
| Islam | 85 | 56.7 |
| Christianity | 62 | 41.3 |
| Traditional | 3 | 2.0 |
| **Ethnicity** | | |
| Yoruba | 145 | 96.7 |
| Igbo | 3 | 2.0 |
| Others | 2 | 1.3 |
| **Level of education** | | |
| None | 12 | 8.0 |
| Primary | 34 | 22.7 |
| Secondary | 59 | 39.3 |
| OND/NCE | 13 | 8.7 |
| HND/First Degree | 26 | 17.3 |
| Postgraduate degree | 6 | 4.0 |
| **Occupation** | | |
| Civil or public servant | 29 | 19.3 |
| Trader | 37 | 24.7 |
| Farmer or fisherman | 8 | 5.3 |
| Artisan | 26 | 17.3 |
| Unemployed | 12 | 8.0 |
| Others | 38 | 25.3 |
| **Respondent classification** | | |
| TB patients | 47 | 31.3 |
| Government Staff | 18 | 12.0 |
| TB contacts | 39 | 26.0 |
| Community volunteers | 34 | 22.7 |

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| | | |
|---|---|---|
| IHVN Staff | 3 | 2.0 |

*Mean age=42.08±14.9 years.

**Table 3.** Socio-demographic characteristics (disaggregated).

| State | Mean age | Marital status | Religion | Ethnicity | Highest educational level | Occupation |
|---|---|---|---|---|---|---|
| Osun (N=76) | 46.07 ±15.8 years | Single 22 (28.9%)<br>Married 49 (64.5%)<br>Separated 2 (2.6%)<br>Divorced 1 (1.3%)<br>Widow/ Widower 2(2.6%) | Islam 50 (65.8%),<br>Christianity 23(30.3%)<br>Traditional 3(3.9%) | Yoruba 73(96.1%)<br>Igbo 1(1.3%)<br>Others 2(2.6%) | None 11 (14.5%)<br>Primary 20(26.3%)<br>Secondary 25(32.9%)<br>OND/NCE 7(9.2%)<br>HND/ First degree 12(15.8%)<br>Postgraduate degree 1 (1.3%) | Civil/public servant 21 (27.6%)<br>Trader: 18 (23.7%),<br>Farmer/ Fisherman 5 (6.6%)<br>Artisan 14 (18.4%)<br>Unemployed 5(6.6%)<br>Other 13(17.1%) |
| Oyo (N=74) | 38.15±12.8years | Single 21(28.4%)<br>Married 49(66.2%)<br>Separated 1(1.4%)<br>Divorced 1(1.4%)<br>Widow/ Widower 2(2.7%) | Islam 35(47.3%)<br>Christianity 39(52.7%) | Yoruba 72(97.3%)<br>Igbo 2(2.7%) | None 1(1.4%)<br>Primary 14(18.9%)<br>Secondary 34(45.9%)<br>OND/NCE 6(8.1%)<br>HND/First degree 14(18.9%)<br>Postgraduate 5(6.8%) | Civil/public servant 8(10.8%)<br>Trader 19(25.7%)<br>Farmer/fisherman 3(4.1%)<br>Artisan 12(16.2%)<br>Unemployed 7(9.5%)<br>Other 25(33.8%) |

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*3.2. Recruitment of TB contacts*

3.2.1. Index TB Cases Identification for Contact Tracing

About half of the government officials said that index TB cases are identified via their phone numbers and house addresses previously documented in the treatment card or on the recording and reporting (R&R) tools, which are in the purview of the DOTS officers. With this information, the TB worker or community volunteer can contact and visit the index cases in their respective communities.

3.2.2. Procedures for Reaching and Recruiting Their Contacts

Most government officials reported that the "snow-balling" approach is being adopted in the process of TB contact investigation; the approach is to request a confirmed TB case to list out the number of persons living with them, and with necessary follow-up arrangements, the persons will be visited and screened for TB. One of the STBLM Officials specifically said,

> *"…Once you identify somebody who is a TB case, that is somebody that has been diagnosed to have TB, and you have even placed that person on treatment. So, you will now ask that person who the people living with him in the house are and how many they are, and then you follow that person to the house to go and screen those people. That is how we go about contact investigation."*

Some government officials did mention that contact investigation is the responsibility of the DOTS officers, and the contact investigation process follows a standard protocol. Few government officials reported that TB contacts are mostly reached via community volunteers.

On the part of the TB patients, the majority said that reaching the contacts will be mainly via the TB patients and that it is the patients' responsibility to bring their contacts for screening. The TB patients may also provide the phone numbers of their contacts to the DOTS officer so that they can be further contacted by the health facility and invited over to the facility. Still, they should not be informed that they are coming for TB screening. A few participants mentioned that the TB contacts could also be screened within the community and that they did not need to visit the health facility to be screened for TB.

Most of the TB contacts mentioned the adoption of a house-to-house screening approach and engagement of various mass media sources to advertise TB screening, emphasising the fact that it is at no cost to the populace as their perceived strategies that can be utilised in recruiting and reaching contacts of TB patients. Some participants also mentioned that once an index case is made, they could be counselled on the need to screen their relatives and contacts for TB, as well as get the phone number of the TB contacts from the TB patient. A few TB contacts further mentioned that it was the responsibility of the health workers to visit the communities and screen people for TB.

The majority of the community volunteers said that the TB contacts are mostly reached via their phone number, and the confirmed TB cases mostly provide it. Calls are being placed to the TB contacts regarding their need to visit the health facility for TB screening. A participant from Osun State said;

> *"It is through contact tracing, except maybe they drop the phone number. We trace them to where they are living and explain the benefit so that they can come for the test for those that have someone with cough."*

3.2.3. Challenges Involved in the Recruitment of TB Contacts for Investigation

The majority of the government officials highlighted that difficulties do occur when trying to reach the family members of a TB index case, including denial of TB symptoms by some of the contacts, which affects the screening process. In addition, resistance to providing sputum samples for further confirmatory tests by the TB contacts due to some cultural beliefs, such as ritual use, and provision of the wrong phone number and house address by some contacts were also listed as part of the challenges faced. Furthermore, some of the government officials mentioned limited logistics support in carrying out the contact investigation from the National TB, the refusal of TB contacts to

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enrol in the TB preventive therapy, as well as contract tracers not getting adequate remuneration for their services as part of the challenges encountered in contact investigation.

The majority of the TB contacts mentioned financial constraints on the part of the TB contacts to visit the health facility to get screened for TB and that the distance to the health facility is a likely challenge. A few of the TB contacts were also of the opinion that the TB contacts can be in a state of denial and refuse to visit the health facility for TB screening.

More than half of the community volunteers mentioned that the TB contacts often give the wrong address and phone number so that they will not be contacted, making contact tracing difficult for them. Also, some TB contacts outrightly refused to be screened for TB because of fear and display of hostile attitude towards the community volunteers during TB screening. A community volunteer from Osun State said;

> *"If we get to those that have tuberculosis, a lot of them do hide; they won't say what is wrong or affecting them. Although it might not be tuberculosis, it might be another thing. They will be afraid that they may test positive, so they will hide. Those are part of the challenges."*

Another participant from Oyo State said;

> *"They would even insult you while asking them questions like the example you can ask them, ma, you've been coughing for the past two weeks. Do you think you can have tuberculosis? They will be like Are you okay? I'm coughing. Does that mean I'm having tuberculosis? So, with the insults, is it okay if someone has done it? Okay, if I went for community mobilisation and someone insulted me, if I'm not if I have low self-esteem or I'm not that brilliant, I won't be able to go to another person and talk to the person. So with the insults, it will be difficult for me to go to another person."*

Some community volunteers also mentioned that some TB cases who are on treatment do travel and discontinue therapy at the health facility. According to the IHVN staff, the challenges faced during project implementation are attrition, the resistance of patients to be tested in the community due to stigmatisation, rigorous logistics needed in the conduct of contact tracing in terms of being available to create interpersonal relationships with the TB patients, and a limited number of available contact tracers to trace TB contacts in the community optimally.

### *3.3. PDX Implementation for Contact Tracing*

#### 3.3.1. The Perceived Approach for Using PDX for Contact Tracing

A majority of the government officials stated that deploying the PDX machine intervention at the community level is the best means as it offers a level of convenience to the community members in the sense that there will be limited disruption to their daily activities as well as zero concerns about the cost of transportation to the health facility. However, some government officials mentioned that deploying the PDX machine at the household level would be the best means for contact tracing because it will encourage the TB contacts to show up for the TB screening. Also, community outreach is the best approach because it provides the opportunity to screen many persons quickly and eradicate the social stigma associated with TB disease since TB contacts are screened among a large group of people. One of the TBLS officials specifically said;

> *"We have to move to their doorstep because, you know, when we ask people to come to some point area because of the social stigma, some people will not move out, but when we reach to their doorstep, you know they will just you know so you will not tell anybody oo that I am coughing o we would say no problem we will not tell anybody we just go to them one by one tell them whatever any result it is within us and the people we contact"*

A few government officials also mentioned the sufficient availability of the PDX machines and the trained personnel who will operate the machines, which is crucial as plans are being made to implement this program. In addition, it was reported that the TB community screening is mainly carried out in conjunction with screening for other health conditions such as high blood pressure and diabetes. They further said free drugs are also provided and distributed during the outreach to encourage high turnout among the TB contacts. Regarding the reasons for not deploying the PDX

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machine at the facility level, few government officials mentioned the need for consent from the government.

Also, some of the TB patients stated that the house-to-house approach would be the best in the implementation of the PDX machine for the screening of TB contacts because of its discreet nature and the fact that it also offers a level of privacy and confidentiality to the TB contacts during the process of TB screening. A TB patient from Oyo State said;

*"The best method to make the work smooth is going from house to house because many people don't want to come out; they hide at home. So, when you get to their houses and explain, they will want to use the opportunity to be screened. So, when they take it to their houses and tell them they want to be screened for free, not money involved, to be screened for the disease will not be difficult."*

According to the majority of the community volunteers, deploying the PDX machine intervention for contact tracing at the health facilities is the best approach because it will allow for many contacts to be screened, the location of the health facility will be easily accessible to them, and this approach will guarantee the safety of the machine since it is not being moved around, from one place to another. A community volunteer from Osun State said specifically,

*"The best one is that we should use it in the health centre because there will be a place to place this machine in the facility. If we say we should be carrying it up and down through that, it can get damaged quickly; it might be that when we are doing it for them in the house, water or anything can pour on it. But nothing like that can happen if space is provided for the machine."*

Another community volunteer from Osun State also said;

*"It is the health facilities that are at least okay because if we place them in the health centre, we would say that it is in the hospital; those who need to do a test will know that it's in the health centre when they come. But if we are moving it all about, maybe we visit one community today, and some people just came and heard about it, they may end up going to the former point used for screening, and we might have visited another. It will be better if we put it in the health centre."*

However, some community volunteers believed that community screening should be the best approach to implementing the PDX machine intervention for contact tracing. This approach will allow for many community members and contacts to be screened since there is no distance barrier.

### 3.3.2. Foreseen Challenges

When asked about the challenges of implementing PDX for contact tracing, a few government officials raised concerns that there may be negative feedback in the community that using the PDX machine will only expose people to unnecessary radiation, especially pregnant women. The low acceptability rate of TB screening via the PDX machine at the initial stages of implementation was also mentioned.

More than half of the TB patients mentioned that the community members may be hostile to the field personnel because of the belief that they do not have TB, and financial constraints in visiting the health facility for the TB screening were also mentioned. A few participants mentioned issues around logistics coordination, such as creating a conducive environment for the people to sit during the screening exercise as a challenge. Refusal to be screened by some TB contacts, abusive responses from some community members, low turnout rates for TB screening, the PDX machine becoming faulty while in use, and denial of test results if positive were also mentioned by TB contacts as likely challenges.

Most community volunteers mentioned refusal to be screened by TB contacts due to the stigmatisation attached to having TB disease in society. On the difficulties expected if the facility screening is adopted, more than half of the community volunteers said the negativity commonly attached to being at the health facility might scare people off and further enhance their unwillingness and refusal to utilise the health facility for TB screening. A community volunteer from Osun State specifically said;

*"It won't allow people to come for the test because once they hear about the health centre, they attribute something negative to it. But if we take it to the community and we explain to them softly*

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*and with a good disposition and with those we've informed before who have seen the outcomes of what has been done before, that may draw their attention to wanting to do the test: they will want to their health status so that they will know maybe they are not infected."*

With regards to implementing the PDX machine intervention at the community level via the free medical outreach approach, some community volunteers mentioned fear of the test outcome, TB contacts getting tired because of the long waiting time before screening, security threats, and non-approval to conduct the health outreach in some communities as the likely challenges.

Some IHVN staff mentioned the refusal of TB contacts to be screened for TB, irrespective of the location of the screening – community-based or facility-based. Another IHVN mentioned that deploying the PDX machine at the community level will be challenging because of the considerations and measures that must be put in place to ensure safety and security throughout the screening process within the community. Measures such as ensuring radiation and machine safety during community outreach sessions are also needed.

3.3.3. Prevention or Mitigation of the Challenges

According to the government officials, routine community awareness on the project, proper communication during community awareness activities, effective health education on the various TB components – screening, contact tracing, employing trained personnel that can operate the PDX machine and interpret its results accurately, the majority of the government officials listed provision of a radiation-free PDX machine as strategies that can help mitigate the predicted challenges during program implementation. Few of the respondents believed the outreach sessions have to be deployed in addition to the screening of another health condition or the provision of other health services. They further mentioned that this information should be stated over and again during community awareness and that nothing about TB should be mentioned, or else it will scare the people from showing up for the TB screening. A DOTS officer in Osun State reported that;

*"Any personnel that is going to handle the machine has to be well trained, then the issue of radiation has to be put in place if this machine can be developed in such a way that the radiation aspect of it will not be there that it will be free of radiation. Yes, it will be better. Everybody will like to take part; it doesn't have any aftermath effect on me; everybody will like to do that, and I will have access to my result immediately."*

Another DOTS Officer also said,

*"People must not be told that they want to be screened for tuberculosis because if you tell them, they won't respond. We will tell them this machine works for the general body, to check how your body is functioning, and they will turn up. Still, if you tell them it's for tuberculosis diagnosis, they won't answer, be it household or community level. But for the facility, what you can use to hold such a person is the fact they walked by him/herself, he/she will have no choice."*

Most of the TB patients mentioned the need for the project workers to have endurance, exercise patience, and composure during field activities. Also, more than half of TB contacts mentioned the need for the field personnel to execute their job responsibilities with lots of patience because of the perceived resistance they will face from some members of the community as a strategy that can be employed to help prevent the challenge of sheer unwillingness that some TB contacts will exhibit when it comes to screening for TB. A TB contact from Oyo State said;

*"Patience is very important because most TB patients are not happy with their condition; thus, they need consolation. Recruitment of an adequate number of staff, provision of incentives to the people, making the services accessible, and continuous awareness creation were also mentioned as a means of preventing the likely challenges.*

All the WDCs mentioned that proper advocacy visits must be conducted to community gatekeepers – community leaders, market leaders, and religious leaders to elicit their buy-in into the program; in addition to that, they also stated that the cost of screening must be low or free to increase the turnout of the people in the utilisation of the intervention. Some WDCs also mentioned that there is a need to elicit the presence of community leaders during the implementation process to ensure

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the smooth organisation of the process and to design a proper plan for crowd management. Increased awareness and sensitisation about the intervention via media outlets and community sensitisation to encourage positive behaviour towards TB screening were also stated by some WDCs. More so, the whole process must be authenticated, which could only be done through the involvement of community leaders. A WDC in Osun State reported that;

> *" One of the WDCs in Osun state further emphasised that if we get to a mosque, we can talk to the imam and explain our purpose of coming so he can tell his members our reason for coming, in church too, we can see the pastor in charge and also explain. If it is the market, we can talk to maybe the market leader to create awareness in the market. For those in the villages, we talk to the 'Baale' (village leader) to inform his co-villagers that the chest people are coming, making it easy. "*

Most of the community volunteers mentioned the need for enough machines in the community during project implementation, continuous outreach activities at the community level, provision of IEC materials targeted at improving behavioural change towards TB screening, collaborating with security agents to offer protection during project implementation in various communities as some of the strategies that can help prevent or mitigate the challenges. According to the IHVN Staff, the use of a unified model, proper counselling on the importance of screening TB contacts, and the need for them to be available on the day marked for screening either at the community or facility level were mentioned as part of the strategies that can help prevent the envisioned implementation challenges.

## 4. Discussion

This study was used to explore perceived strategies for implementing portable digital chest X-ray machines for contact tracing in Oyo and Osun States, Nigeria, and to identify likely challenges and possible solutions it presents. Implementing PDX machines for TB contact tracing has been identified as a crucial step in controlling the spread of the disease. However, deploying this technology in real-world settings presents several challenges that must be carefully considered and addressed. The Political Declaration adopted by the United Nations General Assembly in September 2018 commits to diagnose and treat 40 million people with TB by 2022; therefore, there is an urgent need to deploy strategies to improve diagnosis and care for people with TB who are currently being missed [27]. This study identified some foreseen challenges in implementing the PDX machine for contact investigation. Acceptability was a proposed concern as negative misconceptions and feedback, especially with the radiation involved, can lead to low intervention acceptability. A previous study on this theme similarly identified the need for widespread technology adoption. For the PDX machine to be effective in contact tracing, it must be used consistently by a large portion of the population [28]. This requires overcoming potential barriers to adoption, such as concerns about privacy, lack of awareness about the technology, or lack of trust in the system [29]. According to a study by Adebayo et al. [28], the accuracy and reliability of data collected using PDX machines is a key concern in contact tracing efforts. Inaccurate data can misidentify individuals exposed to a disease, impacting the ability to contain and mitigate its spread. Ensuring the availability of adequately trained human resources to operate the machine and interpret its results is, therefore, essential to the success of the PDX intervention.

The majority of the TB contacts in this study mentioned financial constraints on the part of the TB contacts who visit the health facility to get screened for TB, and the fact that they are far from the health facility is the likely challenge. A few of the TB contacts were also of the opinion that the TB contacts can be in a state of denial and refuse to visit the health facility for TB screening. A study by [30] also reported that despite the incentives offered, some contacts could not access tuberculosis screening due to challenges such as poverty, stigma, and health-system responses. Refusal to be screened by TB contacts due to the stigmatisation attached to having TB disease in society was mentioned in this study as part of the foreseen challenges that may be associated with PDX implementation. Other studies have also reported that stigma against tuberculosis threatens contact investigation and the effort to end tuberculosis because index patients keep their illness confidential and conceal information about their contacts. As a result, contacts at high risk of tuberculosis, such as children younger than 5 years of age, do not benefit from tuberculosis prevention and care [30,31].

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The stigma alone remains a major barrier to healthcare access and has impacts on the physical, social, and mental health and the overall quality of life of individuals with TB [32]. Stigma may lead the patient often to hide the fact of their disease from others and isolate themselves to escape from negative public perceptions [33–35]. TB-related stigma has a significant impact on the diagnosis, patient adherence to treatment, and recovery from the disease, and it can also affect the care given by the family and healthcare provider-patient relationship [36,37].

Routine community awareness of the project, proper communication during community awareness activities, and effective health education on the various TB components – screening contact tracing were listed as strategies to help mitigate the predicted challenges during program implementation. It has also been reported that good health education to improve knowledge, awareness, and belief and minimise barriers to health-seeking behaviour is essential to optimise early detection of TB [38,39]. To improve household contact participation in the early detection of TB, a change in health-seeking care behaviour is required. Therefore, health education intervention should be developed using relevant health behaviour theories and evidence-based planning [40]. Proper advocacy visits to community gatekeepers and engagement of community members were also identified as ways to mitigate proposed challenges. Previous research similarly identified partnerships with relevant stakeholders, such as healthcare providers and community organisations, that can help promote the adoption of the technology and build trust in the system [29]. Routine community and media awareness for effective health education was also identified as an effective way to mitigate the proposed challenges in this study. [28]similarly highlighted the need for awareness and education campaigns about the benefits of PDX machines and TB contact tracing to help overcome barriers to adoption and encourage widespread use. To implement the PDX machine intervention, it may be possible to partner with government agencies through strengthened collaboration, such as leveraging existing structures to carry out awareness campaigns and screen for TB contacts in communities, schools, and other community groups. [29)] recommend robust data protection measures and education about the safeguards in place to protect personal information to solve privacy concerns.

The suggestion to set up the PDX machine in a special location whereby contacts are then invited for the screening aligns with a similar intervention by [41] in Balochistan, where it was reported that a mobile van equipped with a digital X-ray, CAD4TB, and printer was used in the screening camps. CAD4TB (Delft Imaging Systems, Hertogenbosch, The Netherlands [42] is designed to help (non-expert) readers detect TB patients more accurately and cost-effectively [22]. The X-ray image is sent automatically to a separate computer on which the CAD4TB software is installed, which identifies abnormalities consistent with TB and indicates Presumptive TB cases (PTCs). The programme performs a quality check and image analysis and gives a probability percentage in numerical scores (range 0–100). This allows for administering a follow-up TB test such as Xpert, which can be used only in presumptive TB cases [39]. However, the contact tracers should take caution and not mention it is TB screening but rather a general body check-up. The prevalence of stigma associated with TB has been shown to vary from 27% to as high as 82% in different settings across the world [43–46]. Eradicating the stigma surrounding TB is, therefore, a crucial component of efforts aimed at encouraging people to seek early diagnosis and treatment, to adhere to treatment guidelines and treatment completion, along with psychosocial support or social protection benefits after diagnosis [47–49].

It was found in this study that the fear of radiation exposure is one of the reasons the PDX machine is not adopted for contact investigation at the household and community level. Fortunately, it was established by [50] that the system operated within the manufacturer's reported emissions parameters and reported leakage doses that were well below the threshold doses for participants and health workers. With respect to the participants, the reported exposure and leakage doses were well below the average annual radiation dose from the environment (3 mSv) and the yearly accepted dose of ionising radiation for the general public (1 mSv) (7). Regarding the health workers and especially the radiographers, the leakage doses were similarly below international guidelines on the stochastic limits for occupational exposure of <20 mSv/year over five years [51].

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On the perceived approach for using PDX for contact tracing, it was suggested that deploying the PDX machine intervention at the community level is the best means as it offers a level of convenience to the community members as there will be limited disruption to their daily activities as well as zero concerns about the cost of transportation to the health-facility and all these benefits will, in turn, increase the testing yield and case identification rates of TB in the community. Study results confirm the importance of accessibility to healthcare facilities, as highlighted by a previous study, justifying the need for an effective community-based screening strategy in areas with high numbers of missed TB cases [52]. As pointed out by several previous studies, TB case-finding will only be successful if an effective screening algorithm is implemented using sensitive diagnostic tools according to the specific needs of the population [22].

## 5. Conclusions

The portable X-ray machine intervention should be implemented at the community level for contact tracing to allow more TB contacts living with the index patient to be screened. However, the PDX machine can be set up in a special location, and the TB contacts can be invited for the screening. Alternatively, contacts should be invited to the facility for the screening. By implementing effective solutions to foreseen challenges, such as privacy protection, awareness and education and community engagements, a radiation-free environment, and partnerships with stakeholders, the use of PDX machines in contact tracing efforts can be a valuable tool in the containment and mitigation of disease spread.

**Author Contributions:** Agbaje, Dakum, Mensah, and Daniel conceived the study and developed the protocol with Adelekan, Okpokoro, Akingbesote, and Adekunle. Anyaike, Alege, Gbadamosi, Chijoke-Akaniro, and Babalola implemented the protocol and supervised data collection for this study. Agbaje, Daniel, Dakum, Okpokoro, and Adelekan validated the transcripts and performed the analysis. Anyomi, Mensah, Adekunle, Alege, and Akingbesote developed the draft manuscript, while Eneogu, Ihesie, Alege, Nongo, and Anyaike reviewed and finalised it. All authors have read and agreed to the published version of the manuscript.

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**Informed Consent Statement:** Before being accepted into the research, participants were required to give written informed consent. The primary regional language spoken at the study locations was available alongside English on the informed consent forms. The nature of the research, the participants' roles, their vulnerability, and the risks and advantages of participating in the study were all covered in the informed consent form that was given to the participants. They were informed that they could leave the study at any moment. Confidentiality was also guaranteed to safeguard the participants' identification information and other sensitive data. Data from different sources were labelled with codes. Participants received incentives (sanitisers and face masks) to compensate for the time spent participating in the research.

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