Chapter 1
Introduction

Cervical cancer is a form of cancer that impacts the cervix, the lower portion of the uterus that connects to the vagina. The abnormal cell growth in the cervix, resulting in the formation of cancer, characterizes this condition. If not treated, it has the potential to metastasize to other region of the body, posing a significant threat to life. According to "*World Health Organization*" (WHO), in 2020, cervical cancer was identified as the fourth most common cancer among women worldwide [1] [2]. The primary cause of this cancer is the Human Papilloma Virus (HPV), which impacts the lower portion of the uterus linked to the vagina. Fortunately, there are ways to prevent cervical cancer by taking the preventive measures like Human papillomavirus immunization and routine screening initiatives [3]. The early detection of cervical cancer allows for effective treatment and cure. However, various factors like anxiety, tension, and economic circumstances, absences of awareness, hesitation, and cultural norms have played a role to its steady rise, especially in developing countries [4].

Stages of Cervical Cancer

It is typically classified into stages based on the severity of the disease. It is categorized into four stages: Stage 0, Stage I, Stage II, and Stage III, each with subcategories to enhance precision [5]. Here's a brief overview of each stage:

Stage 0

- The cervical cancer appears in the lower part of the uterus.
- The cancer is typically small and has not metastasized to nearby tissues or organs.
- It is the primitive stage of cancer and often has the best prognosis when it is detected at this point.

Stage I

- The cancer has progressed beyond the cervix and uterus but has not reached the pelvic wall, which is the tissue lining the area between your hips or the vagina.
- The cancer may have spread to nearby region but has not yet reached distant organs.
- Although more advanced than Stage 0, cancer at this stage is still potentially curable with appropriate treatment.

Stage II

- In this stage II, indicates that cervical cancer has advanced further. It might have extended to the lower portion of the vagina and possibly to the pelvic wall.
- Moreover, it might encompass the ureters, which are the conduits responsible for transporting urine from the kidneys to the bladder.
- Lymph nodes in the vicinity of the cervix may also be affected.
- Treatment at this stage may be more extensive and complex.

Stage III

- The cervical cancer has reached an advanced stage. It may have spread to adjacent organs such as the rectum and bladder.
- In some cases, the cancer may have metastasized (spread) to distant body parts, including the bones or lungs.
- Treatment options for Stage III cervical cancer are often focused on managing symptoms and slowing the progression of the disease, as it may not be curable.

Cause and Risk Factors

It is mainly caused by the certain types of HPV, which is typically contracted through sexual contact. However, only a few of them are considered high-risk and can develop cervical cancer. HPV-16 and HPV 18 are the two most frequently encountered high risk type of HPV [6] [7]. The transition from HPV infection to cervical cancer typically spans several years. Most of the majority of HPV infections does not progress to cancer; the body's immune system usually clears the infection. However, in some cases, the virus can linger and alter cervical cells, which could lead to cancer in the end. Several variables increase the likelihood of acquiring cervical cancer:

- M**ultiple Sexual Partners:** A person who engages in multiple sexual partners is more likely to develop cervical cancer.
- **Sexual Activity:** Early initiation of sexual activity may increase the likelihood of HPV infection and, consequently, the risk of cervical cancer.
- **Sexually Transmitted Infections (STIs):** The risk of acquiring HPV increases when one has other sexually transmitted infections (STIs), such as gonorrhoea, syphilis, HIV/AIDS, or chlamydia. This increases the risk of cervical cancer.

- **Weakened Immune System:** If another medical problem weakens the immune system. It might make one more vulnerable to contracting HPV and raising the risk of cervical cancer.
- **Smoking:** It raises the chance of one of the more prevalent forms of cervical cancer, squamous cell carcinoma.

1.1. Growth of Cervical cancer

According to the WHO report, cervical cancer persists as a substantial global health concern, with approximately 604,000 new cases reported annually. Most of these cases, accounting for around 90%, occur in low- and middle-income countries, where accessibility to essential precautionary actions is often limited. This disease takes a particularly devastating toll in these regions, leading to an estimated 342,000 cervical cancer-related deaths each year [8]. A concerning trend is that women with Human Immunodeficiency Virus (HIV) are six times more likely to get cervical cancer compared to those without HIV. HIV affects younger women disproportionately worldwide and accounts for about 5% of incidences of cervical cancer [9]. The high-income countries have established comprehensive programs that include HPV vaccination for girls and regular screenings for women. These efforts have led to initial identification and effective medical care of precancerous growths, reducing the impact of cancer. In contrast; developing countries encounter numerous challenges. The limited access to preventive measures, leading to cancer which is undetected until it reaches advanced stages, with noticeable symptoms. Additionally, these countries may struggle to provide adequate treatment options such as surgery, radiotherapy, and chemotherapy, resulting in higher mortality rates. In 2020, cervical cancer had the highest death rate worldwide, with 13.3 deaths per 100,000 women. Addressing this alarming statistic requires effective interventions at different stages of life [10]. It is particularly crucial in developing countries in regions like Sub-Saharan Africa and Asia, where cervical cancer incidence has significantly increased from 1990 to 2019, as shown in Figure 1.1.

In contrast, developed countries like Europe, America, and Australasia have seen a notable decrease in the numerical difference in cancer incidence during this period. Around 604,237 women worldwide had a cervical cancer diagnosis in 2020, accounting for 6.5% of all women. [11][12]. The main drivers behind the rise of cervical cancer in developing countries include insufficient healthcare infrastructure, poverty, and a shortage of healthcare professionals. Researchers are actively working on improving the initial diagnosis of

squamous cell carcinomas in low and middle-income countries to combat this concerning trend.

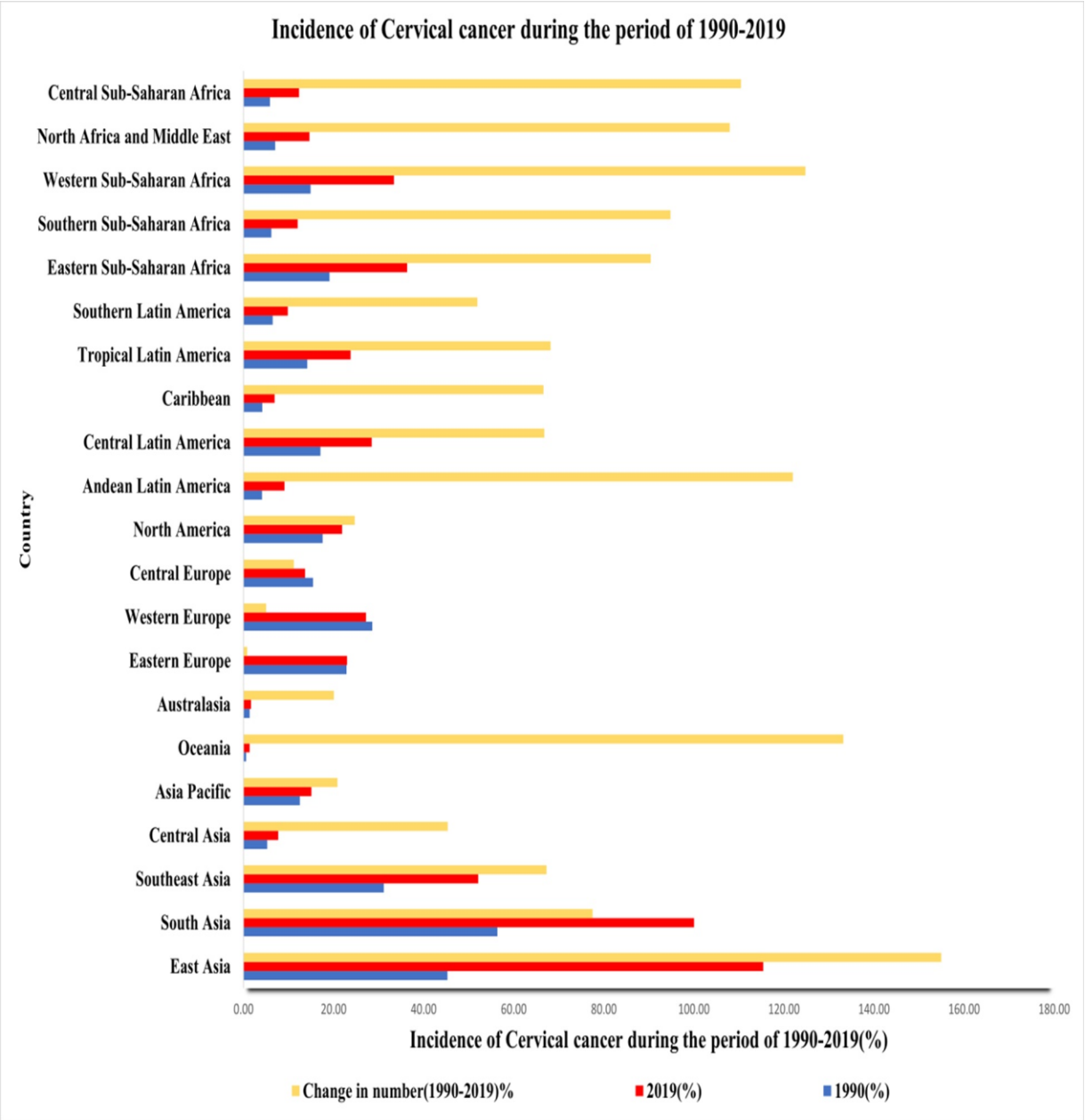


Figure. 1.1 Incidence of Cervical Cancer During the Period of 1990-2019

Based on the statistical studies, the countries belonging to East Asia (154.94%), South Asia (77.48%), Central Asia (45.34%), Eastern Sub-Saharan Africa (90.43%), Southern Sub-Saharan Africa (94.08%), Western Sub-Saharan Africa (124.75%) and North Africa and Middle East (107.98%) increased from 1990 to 2019 when compared to other developed countries. In countries like North America (24.65%), Central Europe (11.14%),

Eastern Europe (0.77%), and Western Europe (4.99%), the incidence of cervical cancer decreased from 1990-2019. It indicates a need to create awareness programs, conduct more cervical cancer screening camps, and formulate health care strategies in Sub-Saharan Africa and Asia. The tribal women who are residing in developing countries are highly affected by cervical cancer. Poverty, illiteracy, improper cleanliness, and poor health-seeking behavior are mainly known for the prevalence of cervical cancer in tribal women [4][13][14]. The primary reasons for the increase in cervical cancer among tribal women are early marriage, consanguinity, and other behavioral factors. Collecting demographic data, Papanicolaou test, and cervical samples of HPV Deoxyribonucleic acid (DNA) from American tribal women over ten years was conducted in Brazil. The women, who were 10-73 years old, participated in these screening camps, with an average age of 25. Of the 92 women, 78 were allowed to participate in Pap smear screening, and 49 were for the sample collection [15]. However, 13 tribal women from the age group of 13-28 did not take part in screening camps because two women were unwilling to participate, and eleven women did not participate because of the unknown location of the camp. Based on the screened results, six women were confirmed with HPV infection and one woman with HPV 16[16].

The United States established the "*National Breast and Cervical Cancer Early Detection Program (NBCCEDP)*" over 20 years ago to provide support in low-income countries. They sponsored 67 programs for the 50 states in the district of Columbia and 5 United States territories, as well as 11 tribal women [11]. In Lagos, Nigeria, HIV treatment centre conducted a pilot study on HIV-positive women. Organizing questionnaire section for 1517 women reveals that 853 women, i.e., 56.20%, were conscious of cervical cancer. Of the 1210 women, 79.80% accepted to take up clinical trials, 35.20% refused due to medical expense, and the rest, 14.00%, refused due to religious denial. This study proves that HIV-positive women are ready to be examine for cervical cancer, and this helps to reduce the prevalence of cervical cancer among women [17]. Tanzania conducted a new education program on cervical cancer, examination programs, and nursing for Maasai women. The education program consists of written content on cervical cancer in the Maa language and offers a 3D dimensional model presentation to help them understand the concept of cancer. It is helpful for the attendees to gain more knowledge and awareness about the cancer. It will motivate them to clearly understand and efficiently help them detect the prevalence of cervical cancer at the precancerous stage [18]. The tribal population in Sub-Saharan Africa and Asia is thickly populated [11], and very few tribal areas have been

covered for organizing awareness programs and screening. Conducting clinical trials for those unwilling to join the camp is tedious. It is also challenging to set up healthcare infrastructure facilities in tribal areas. In the next session, let's discuss the screening and diagnosis method engaged in the precancerous detection of cervical cancer.

1.2. Screening and Diagnosis Methods Involved in the Precancerous Detection

Examining cervical cancer entails the use of various methods to detect premalignant or malignant alterations in the cervix region. The initial detection of cancer is crucial for effective medical attention and improving outcomes of cancer care. The two methods involved in the examination of cancer are the clinical methods and the digitized method as represented in the Figure 1.2.

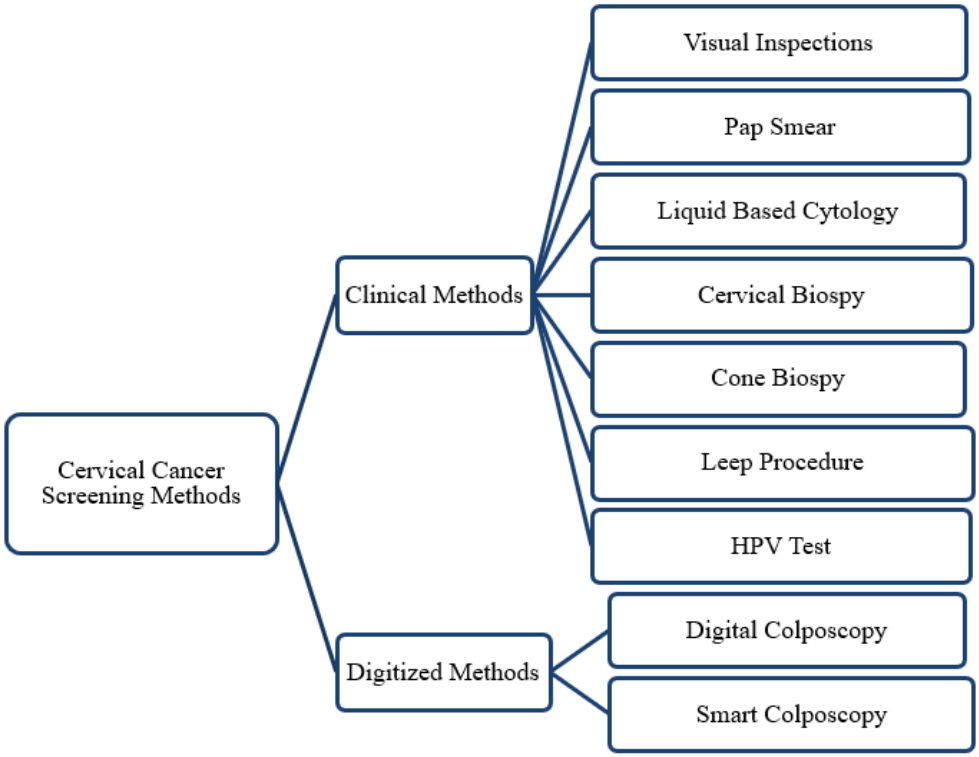


Figure. 1.2 Screening and Diagnosis method used for Cervical Cancer

1. Visual inspection

Visual inspection is a medical screening method for the precaution and timely detection of cervical cancer. It involves visually examining the cervix and surrounding tissues for abnormalities, including precancerous or cancerous changes. Trained healthcare providers typically conduct visual inspection methods and may include different techniques. It is done in two ways, as shown in Figure 1.3.

1. **Visual Inspection with Acetic Acid (VIA):** Using a cotton swab, the medical professional applies the diluted acetic acid solution to the cervix [19]. This causes changes in the appearance of cervical tissue, making it easier to identify abnormal areas. After applying acetic acid, the healthcare provider visually examines the cervix for any visible white regions, known as acetowhite lesions, which may indicate abnormal tissue. Further assessment of abnormal areas involves the possibility of a biopsy for confirmation.
2. **Visual Inspection with Lugol's Iodine (VILI):** VILI involves the use of Lugol's iodine solution to the cervix [20]. Healthy cervical tissue absorbs the iodine and appears brown, while abnormal areas that do not absorb the iodine remain unstained and appear yellow. The healthcare provider visually inspects the cervix to identify unpainted regions, which may indicate cervical abnormalities. Like VIA, further evaluation is conducted on any suspicious areas, and a biopsy is performed if necessary.

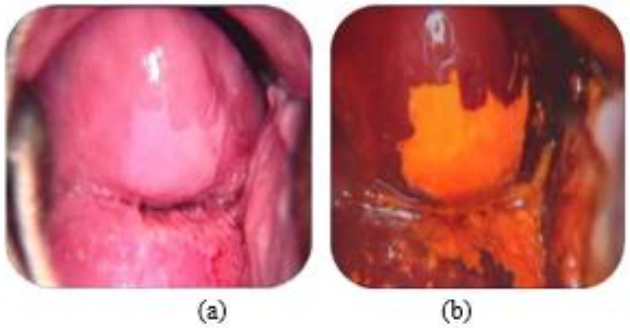


Figure1.3 Visual Inspection on Cervical Images. (a) Visual Inspection with Acetic Acid. (b) Visual Inspection with Lugol's Iodine.

It is particularly valuable in resource-limited settings where more advanced screening tools are not readily available. It can help identify precancerous or cancerous cervical lesions early, allowing for timely intervention and treatment. It is often a cost-effective cervical cancer screening method, making it suitable for areas with limited healthcare resources. It provides immediate results, enabling healthcare providers to offer on-the-spot treatment or referral for further evaluation when necessary. These methods may be used alongside other cervical cancer screening methods, such as Pap smears or HPV testing, to enhance the overall effectiveness of screening programs. Even though visual inspection is a valuable screening method, it may have limitations regarding sensitivity and specificity

compared to more advanced techniques like colposcopy or HPV testing. Therefore, its use may vary depending on local healthcare infrastructure and guidelines [21][22]. Patients should consult with their healthcare providers to determine the most appropriate cervical cancer screening method for their circumstances. These methods rely on the examiner's interpretation, which can introduce subjectivity into the screening process. Different healthcare providers may have varying levels of expertise and may interpret findings differently [23][24]. The major disadvantage of these methods is false positive and false negative results. These methods may result in false positives (indicating abnormality when none exists) or false negatives (missing abnormalities). It can lead to unnecessary anxiety for patients or missed opportunities for early intervention. Combined with other screening methods or as part of a comprehensive cancer examination program, which can help increase the chances of early detection and intervention. However, addressing their limitations through proper training, quality control, and follow-up procedures is essential to minimize the risk of missed cases or unnecessary interventions.

2. Pap smear

It is a medical examination procedure utilized to identify early indication of cervical cancer and other abnormalities in cervix [25]. It is an essential tool for women's health and is typically recommended for routine gynecological care [26]. Here's how the Pap smear procedure works:

1. **Preparation:** Before the Pap smear, the patient should avoid sexual intercourse, using tampons, or using vaginal creams or medications for at least 48 hours because these activities can interfere with the accuracy of the test.
2. **Positioning:** The patient lies down on an examination table and places her feet in stirrups to allow the healthcare provider easy access to the vaginal area.
3. **Speculum Insertion:** The healthcare provider gently inserts a speculum into the vagina. A speculum is a metal instrument that holds the vaginal walls apart, allowing for a clear view of the cervix.
4. **Sample Collection:** The healthcare provider scrapes a small piece of cervix's tissue using a small spatula or brush. They may also take a piece from the cervical canal (endocervical sample) with a separate brush or swab. These collected samples are then positioned on a glass slide or in a liquid medium for laboratory analysis.

5. **Speculum Removal:** The speculum is removed carefully from the vagina.
6. **Laboratory Analysis:** The laboratory analyses the cervical cancer cell samples for the analysis. The sample tissues collected are examined under the microscope to identify the cancer. In the lab, a cytotechnologist or pathologist examines the cells under a microscope to look for abnormalities, such as precancerous or cancerous changes.

The primary goal of a pap smear is to identify abnormal cervical cells early before they develop into cervical cancer. It allows for timely intervention and treatment to prevent disease progression. It also detects other cervical conditions, such as infections or inflammation, which may require treatment [27]. Additional diagnostic procedures, like a colposcopy or a biopsy, could be suggested if abnormal cells are detected during the pap screening in order to confirm the existence of cervical abnormalities or cancer. The frequency of this method depends on a woman's age, medical history, and risk factors. In recent years, guidelines for cervical cancer screening have evolved, and in some cases, healthcare providers may recommend co-testing with HPV testing. Individuals need to discuss their specific screening schedule with their healthcare provider to ensure they receive appropriate and timely cervical cancer screening.

3. Liquid-Based Cytology (LBC)

It is a similar method to a pap smear, which collects the cervix tissues and utilize the alcoholic fixative fluid to detect the abnormalities in the cervix that lead to cervical cancer [28].

1. **Preparation:** Before an LBC procedure, similar to a pap smear, patients should avoid sexual intercourse, tampons, or vaginal creams or medications for at least 48 hours to ensure accurate test results.
2. **Positioning:** The patient lies down on an examination table and positions her feet in stirrups, allowing the healthcare provider clear access to the vaginal area.
3. **Speculum Insertion:** A speculum is placed into the vagina by the healthcare provider. This instrument holds the vaginal walls apart, providing a clear view of the cervix.
4. **Sample Collection:** A brush or spatula is employed to gather cells from the cervix's surface, akin to the pap smear procedure. Instead of depositing these cells onto a glass slide, as done in a conventional method, they are put into a vial containing a liquid

preservative (liquid-based cytology solution or transport medium). This liquid helps preserve the cells and prevents them from drying out or deteriorating.

5. **Speculum Removal:** After cell collection, the speculum is carefully removed from the vagina.
6. **Laboratory Analysis:** The cervical cell sample is sent to a laboratory for processing and analysis. In the lab, the sample collected undergoes specialized processing techniques to concentrate and evenly distribute the cells. A thin, uniform layer of cells is then applied to a glass slide using automated or semi-automated equipment, ensuring that cells are evenly spread for better visualization and analysis.

It has been shown to decline the rate of false-negative results compared to conventional method, as it minimizes obscuring factors such as blood and inflammation [29]. It provides a cleaner and more uniform sample, reducing the likelihood of inadequate specimens that can lead to repeat tests. Its specimens can be used for HPV testing in cases where co-testing is recommended. The liquid preservative helps keep the sample stable longer, allowing for delayed processing if necessary. LBC slides often offer improved visualization of cells, making it easier for pathologists to identify abnormalities. The choice between LBC and conventional method may depend on local guidelines, cost considerations, and healthcare provider preference. LBC is a beneficial tool in cervical cancer examination, potentially improving the accuracy and reliability of outcome and contributing to the early detection of cervical abnormalities and cancers.

4. Cervical Biopsy

This procedure takes a small tissue region from the cervix region for analysis. This method is carried out if there are abnormalities in the cervix region.

1. **Indication:** Cervical biopsies are typically recommended in the following situations:
   - Abnormal Pap smear results, such as detecting precancerous or cancerous cells.
   - The abnormal findings during a colposcopy examination, which is a procedure that allows for a closer examination of the cervix using a magnifying instrument.
   - Persistent symptoms, such as abnormal vaginal bleeding, pain, or discomfort.
2. **Local Anesthesia:** Before the biopsy, a local anesthetic is applied to the cervix to minimize discomfort during the procedure. The use it may differ based on the type and extent of the biopsy.

3. **Biopsy Procedure:** The patient is typically positioned similarly to a pap smear, with feet in stirrups to access the cervix. The biopsy instrument (e.g., punch biopsy forceps) collects a small tissue sample from the cervix. The collected tissue sample is forwarded to a pathology laboratory for analysis.
4. **Laboratory Analysis:** In the pathology laboratory, a pathologist examines the tissue sample under a microscope. The analysis aims to determine the nature of cervical abnormalities, including whether they are precancerous or cancerous.
5. **Post-Biopsy Care:** After the biopsy, patients may experience mild cramping, spotting, or vaginal discharge. These indications are transient and can be managed with over-the-counter pain relievers.

Cervical biopsy results are crucial for guiding further management and treatment decisions [30][31]. Depending on the findings, additional procedures or treatments, such as excisional procedures, cryotherapy, or surgery, may be recommended to address any precancerous or cancerous lesions. It's essential for individuals undergoing a cervical biopsy to discuss the procedure, possible risks, and post-biopsy care with their healthcare provider to ensure a clear understanding and appropriate follow-up care. It plays a critical role in the diagnosis and early intervention of cervical abnormalities and cervical cancer.

6. Loop Electrosurgical Excision Procedure (LEEP)

The cervix is treated medically in order to eradicate aberrant cervical cells. It is often performed when cervical abnormalities, such as precancerous or dysplastic cells, are identified during cervical cancer screening tests like pap smears or colposcopy. Here's an overview of how the LEEP procedure works:

1. **Indication:** LEEP is recommended when abnormal cervical cells are detected through screening tests and further evaluation or treatment is necessary. It is used to prevent the progression of these abnormal cells into cervical cancer.
2. **Preparation:** Before the procedure, the patient may be advised to empty the bladder to make the cervix more accessible. Avoid sexual intercourse, tampons, or vaginal creams/medications for a specified period before the procedure.
3. **Positioning:** The patient reclines on an examination table with her feet in stirrups, allowing the healthcare provider clear access to the vaginal area and cervix.
4. **Speculum Insertion:** A speculum is placed into the vagina by the healthcare provider. This instrument holds the vaginal walls apart, providing a clear view of the cervix.

5. **Local Anesthesia:** A local anesthetic is often administered to the cervix to numb the region and minimize unease during the procedure. Some patients may also receive medication to help them relax.
6. **LEEP Procedure:** A thin wire loop, usually made of thin electrified wire, is inserted through the speculum into the cervix. The wire loop employed to excise the abnormal cervical tissue or cells. The loop removes the affected area, which is cauterized (sealed) to control bleeding and prevent infection.
7. **Sample Collection:** The excised tissue is transferred to a pathology laboratory for analysis to confirm the presence of abnormal cells and assess the margins to ensure complete removal.
8. **Post-Procedure Care:** After the LEEP procedure, patients may experience mild cramping, spotting, or vaginal discharge. These indications are temporary and can be managed with over-the-counter pain relievers. It's essential to follow any post-procedure care instructions the healthcare provider provides.

Its advantage is a high success rate in treating precancerous or dysplastic cells. It is quick and generally tolerated by the outpatient procedure [32][33]. But it has high potential risks like infection or bleeding and narrowing of the cervix, which can affect fertility or menstruation in sporadic cases. It is a preterm birth risk, which may increase in some instances, particularly with the LEEP procedure. The LEEP procedure is an effective treatment option for managing cervical abnormalities and preventing cervical cancer. The choice of medical care, including LEEP, is decided by the severity of the cervical condition and the patient's health factors. Patients should discuss their specific cases and concerns with their healthcare provider to make decisions about their care.

6. Cone Biopsy

A cone biopsy, also known as cervical colonization or colonization of the cervix, is a surgical procedure to excise a cone-shaped piece of tissue from the cervix. This procedure is performed when there are abnormal cervical cells, often detected through cervical cancer screening tests like Pap smears or colposcopy. Cone biopsy allows for removing abnormal cells for both diagnosis and treatment purposes. Here's an overview of how a cone biopsy works:

1. **Indication:** Cone biopsy is recommended when abnormal cervical cells are identified during screening tests, and further evaluation or treatment is necessary. It is used to prevent the progression of these abnormal cells into cervical cancer.

2. **Preparation:** Before the procedure, the patient may be advised to:
    - Empty the bladder to make the cervix more accessible.
    - Avoid sexual intercourse, tampons, or vaginal creams/medications for a specified period before the procedure.
3. **Positioning:** The patient lies on an examination table with her feet in stirrups, allowing the healthcare provider clear access to the vaginal area and cervix.
4. **Local Anesthesia:** A local anesthetic is administered to the cervix to numb the region and minimize unease during the procedure.
7. **Cone Biopsy Procedure:** A scalpel, laser, or thin wire loop with an electrified wire (similar to LEEP) removes a cone-shaped piece of cervical tissue. The choice of instrument may vary depending on the healthcare provider's preference and the extent of the tissue to be released. The healthcare provider carefully removes the abnormal cervical tissue, ensuring an adequate margin of normal tissue is also excised to minimize the risk of leaving any abnormal cells behind. The tissue is forwarded to pathology laboratory for analysis to confirm the presence of abnormal cells and assess the margins for complete removal.
8. **Post-Procedure Care:** After a cone biopsy, patients may experience mild cramping, vaginal bleeding, or discharge. These symptoms are transient and can be addressed with over-the-counter pain relievers. Patients should adhere to whatever advice their healthcare professional may provide regarding post-procedure care.

Cone biopsy is an effective process for both diagnosing and treating cervical abnormalities, and it is particularly useful when the extent of abnormal tissue needs to be precisely determined [34][35]. The choice of medical care, including cone biopsy, based on the severity of the cervical condition and the patient's health factors. Patients should discuss their specific cases and concerns with their medical care provider to make informed decisions about their care. Similar to the Leep screening procedure, it also has bleeding, cervical stenosis and risk of preterm birth in future pregnancies.

7. HPV (Human Papilloma Virus) test

An HPV test is a medical screening test specifically designed to detect the presence of certain types of HPV, particularly those that are known to be high-risk and can lead to cervical cancer. It is not a test for detecting cancer cells in the cervix directly but rather a

test to identify the virus that is a significant risk factor for cervical cancer. The HPV test works in the following ways:

1. **Specimen Collection:** A pelvic examination involves a medical professional taking a cervical cell sample, much like a pap smear.
2. **Laboratory Analysis:** The laboratory receives the collected cervical cell sample, which then undergoes specialized testing to detect the existence of high-risk HPV DNA.
3. **High-Risk HPV Detection:** The test identifies explicitly high-risk HPV types, such as HPV 16 and HPV 18, which are associated to develop the cervical cancers.

It is a valuable tool for assessing a woman's risk of developing cervical cancer. High-risk HPV infection is an important risk variable for the development of cervical precancerous changes and cancer [6][36]. It detects the high-risk HPV infection early and allows for monitoring and intervention before cervical cancer develops. Many HPV infections are naturally clear on their own, but persistent infections can lead to cervical abnormalities. A positive HPV test result may prompt further evaluation, like a colposcopy or cervical biopsy, to assess the existence of abnormalities or precancerous changes. This helps in determining the appropriate course of action. Some cancer screening programs use the HPV test in conjunction with a pap smear. It can provide more comprehensive information and increase the sensitivity of cervical cancer detection. It's crucial to highlight that a positive HPV test result does not mean a woman has cervical cancer. Instead, it indicates an increased risk of developing cervical abnormalities or precancerous changes that may need further evaluation and management.

8. Digital Colposcopy

Digital colposcopy is an advanced medical imaging technique used to evaluate the cervix. It enhances the visualization of cervical tissue and allows for the capture and analysis of digital images of the cervix. This method is valuable in cervical cancer screening, particularly for identifying abnormal cervical cells or lesions. Here's an overview of digital colposcopy and its significance:

1. **Speculum Insertion:** Similar to a regular gynecological examination or pap smear, a speculum is gently embedded into the vagina to visualize the cervix.

2. **Colposcope Examination:** A colposcope is a specialized instrument with a light source and a high-resolution digital camera. The colposcope is positioned near the patient's vulva, and the healthcare provider uses it to magnify and illuminate the cervix.
3. **Digital Imaging:** The digital colposcope captures detailed, magnified cervix images in real time. These images are presented on the monitor, allowing the healthcare provider to examine the cervical tissue for abnormalities or lesions closely.

It provides a magnified and well-illuminated view of the cervix, allowing healthcare providers to detect neoplasm that may not be visible to the naked eye [37][38]. The digital images obtained during the procedure can be saved and used for documentation, comparison during follow-up visits, and consultation with other healthcare professionals. It is typically a painless procedure and does not require anesthesia or special preparation. If abnormal areas or lesions are identified during the colposcopy, the healthcare provider can precisely target these areas for biopsy. This helps in obtaining tissue samples for further evaluation and diagnosis. It is precious in cervical cancer examination, as it aids in the early recognition of precancerous and allows for timely intervention to prevent the progression of cervical cancer. For individuals with known cervical abnormalities or those at higher risk, digital colposcopy can be used for ongoing monitoring and assessment of treatment effectiveness. It improves the accuracy of cervical examinations, enhances the visualization of cervical tissue, and facilitates the early detection and management of cervical abnormalities. It is an essential component of comprehensive cervical cancer screening programs and provides critical information for healthcare to make determination about patient care.

9. Smart Colposcopy

Smart colposcopy is an innovative medical technology that leverages artificial intelligence (AI) to enhance the visual screening and analysis of cancer. This advanced tool is similar to digital colposcopy but incorporates AI algorithms to assist healthcare providers in interpreting cervical images. Here's an overview of smart colposcopy and its significance in cervical cancer screening:

1. **Speculum Insertion:** As with traditional colposcopy and digital colposcopy, a speculum is placed into the vagina to visualize the cervix.
2. **Colposcope Examination:** A specialized colposcope with digital imaging capabilities is used to capture high-resolution of the cervix.

3. **AI analysis:** The digital images are processed and analyzed in real-time using AI algorithms. These AI algorithms can assist in identifying and highlighting areas of the cervix that may have abnormalities or lesions. The AI-generated findings are presented to the healthcare provider in real-time, aiding in their assessment and decision-making process.

This method leverages AI to provide real-time assistance to healthcare providers during the examination. It can aid in identify potential areas of concern more accurately and efficiently. The integration of AI can enhance the cervical cancer screening effectiveness by reducing the potential for human error in interpreting images. AI algorithms objectively assess cervical images, which can be particularly valuable in cases where multiple healthcare providers' interpretations may vary. It aids in the early identification of anomalies in the cervical region and lesions, allowing for timely intervention and prevention of the progression of cervical cancer. The digital images and AI-generated findings can be shared with patients to educate them about their condition and treatment options. It often includes data management features, allowing for storing and retrieving patient information and images for follow-up visits and research purposes. Smart colposcopy represents a significant advancement in cervical cancer screening technology. Combining digital imaging with AI analysis can enhance the precision and effectiveness of cervical examinations, ultimately benefiting patient care and outcomes. It is an exciting development in the ongoing initiatives to lessen the occurrence of cervical cancer through early detection and intervention [39][40]. The screening methods involved in precancerous detection as shown in the Figure 1.4.

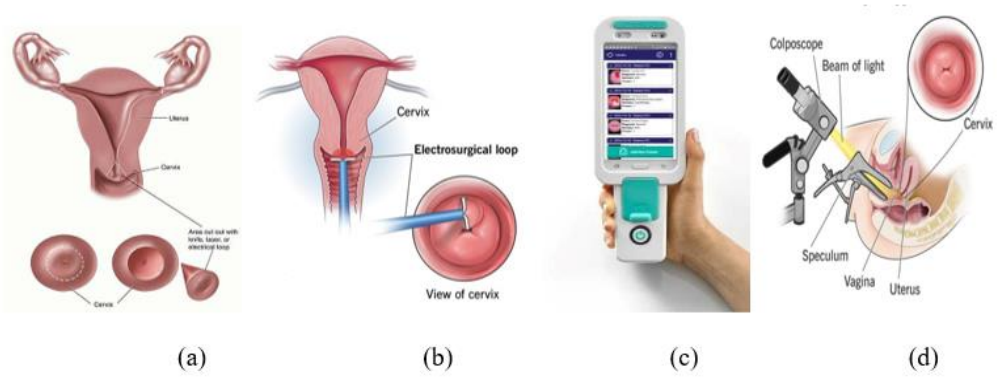


Figure1.4 Screening Method Involved in the Precancerous Detection. (a) Cone Biospy. (b) LEEP method (c) Smart Colposcopy (d) Colposcopy.

1.3. Cervical Cancer Screening Approaches Process for Tribes in Sub-Saharan Africa and Asia

An adequate number of screening campaigns were conducted with questionnaires and pap smear screening methods. But still, many tribal women refused to get screened, which increases cervical cancer in many tribal women, and they are still unaware of cancer. An investigation was carried out for the existence of HPV16 and HPV18 for tribal and nontribal peoples of Andaman and Nicobar Islands. There are six tribal communities, 555 islands, and 356,000 people living there. This study was conducted for married women in the age bracket of 20-60 years with the indication of vaginal discharge, bleeding for the tribal and nontribal women. The tribal and nontribal women diagnosed in the G.B. Pant Hospital in Port Blair in the Andaman and Nicobar Islands and BJR Hospital Car Nicobar were considered for this study. For this study, the gynecological approach involved collecting samples, conducting cervical smear tests, and gathering statistical data from the medical records. From the study, it is observed that 110 women were screened, of whom 67 non-tribal women and 43 tribal women were selected. From nontribal, four women were affected by HPV16 and one tribal woman was affected by HPV 18 [41].

A prevalence study was conducted in the Idukki District of Kerala by randomly selecting 430 women from the tribal women in Marayoor panchayat for the age category of 30-40 years. The population growth and the factors affecting the program for cancer examination are collected. Of the total of 430 tribal women, 5% of women have experienced the papanicolaou test, 25.6% are less aware of cervical cancer, 22.67% were affected by inadequate clinics, and 9.55% due to humiliation from society [42]. A screening camp was arranged in the southern coastal Karnataka district of Udupi with three groups of tribe's people of "*Koraga, Marathi Naika, and Malekudiya*" from July 2014 to June 2017. The tribal women between the age bracket of 20 - 65 years were selected, and 1140 tribal women were given the papanicolaou smear test. Most tribal women were in the age bracket of 31-45 years, and the average age of their marriage was 25. Eighty percent of these tribal women use handmade sanitary napkins, and the mean of their first pregnancy was 22.50%. From the total of 1140 tribal women, 77.60% of the participants have severe lower backache and 29.00% of the women with white discharge per vagina, and 25.90 % of women with irregular menstrual activities. Of the screened women, 12.40% have microbial infections, 23.60% have some changes in the cervix portion, and 2.00% have anomalies around the cervix [13][4].

The medical program titled "*Prevention and early detection of common cancers"* was carried out by the Palghar District, Maharashtra medical office. The questionnaire section was conducted among the tribal women to determine their understanding, viewpoints, approaches, and visualization techniques on HPV immunization. The both before and after evaluation procedures were carried out for the 76 tribal women participated in the program. Of the 76 women, 63 filled out both the pre-and post- test questionnaires. This study included 32 questions, of which 18 were about knowledge and awareness. It was identified that awareness of HPV vaccination and cervical cancer was very low among these tribal [43]. An empirical investigation was carried out in Aravalli district which is the northeastern State of Gujarat, India. From the population of 10.27 lakh-person 22.00% of the population was tribal. The data are collected using the facility inventory, a questionnaire for health care, and semi-structured interviews with the officers in charge of health. Then, secondary information was collected on the tribal people's economic circumstances. Early marriage, multiple deliveries, and illnesses contracted by intercourse were the risk factors that caused a rise in the severity of cervical cancer in this zone. Only 2.00% of health institutions in this district provided Pap smear tests, and very few tribal women get screened. This is due to the lack of screening programs and less awareness among healthcare professionals for the screening of cervical cancer [44]. A quantitative cross-sectional study was executed for the Lahu tribal women in Chiang Rai, Thailand, in 2018. Data was acquired from 650 Lahu Hill tribal women using basic random selection process. The age group between 30 and 60 years was selected, and a face-to-face interview of about 20 to 30 minutes was conducted. The knowledge score obtained for cervical cancer among tribal women was 13.29 from the total of 20. The risk of cancer among Lahu tribal women was 79.08%, and the increased risk due to early sexual activity was 78.46%. From the cross-sectional study, 96.15% have done the pap smear, and 74.31% of women had attended the screening more than once [45].

In 2008, research was carried out in Thailand's Chiang Rai district between metropolitan women and the Akha hill tribes. The screening campaign was organized for Akha women, and urban women visited the Chiangrai Prachanukroh Hospital for a pap smear test. From the Akha tribal area, 1,100 women and 1,100 women from the metropolitan area were selected. The screening findings showed that the anomalous papanicolaou test was 12.20% for Akha tribal women and 4.50% for urban women. The papanicolaou abnormalities are commonly found in the age group between 41-50 years,

4.50% for Akha women and 1.70% for urban women. The risk group's coverage women who, particularly in ethnic groupings, married young [46]. The cervical cancer screening and cross-sectional study were conducted on the women of the Hmong hill tribe in the Lomkao district under the Phetchabun province. The 547 tribal women between the ages of 30 and 60 provided the data, which were then analysed using multiple logistic regressions. Among 547 tribal women, 64.90% of women received screening. Because of the screening camp arrangement, 47.20% of women also underwent screening [47]. The longitudinal investigation was organized from September 2015 to October 2015 for women who visit ancestral churches in the Midlands city of Gweru under the Province of Zimbabwe. A total of 125 women, primarily from the Shona and Ndebele tribes in Zimbabwe, migrated from South Africa to take part in this study. The data acquired was carried out using four methods of demographic data based on three questionnaires: one about the activities, one about the attitudes of the respondents, and one about the knowledge of the respondents. The tribal women participants were 18 - 58 years old, with a mean age group of 38. This study shows that the most of the females did not get screened because they were influenced by a phobia that the pap method was traumatic, and they were frightened to get screened [48].

Based on the above study, it is inferred that tribal women who are living in developing countries are highly impacted by cervical cancer. Anguish, anxiety, and tension had an impact on tribes while they were involved in screening. The pap smear and the questionnaire section are the commonly used methods used for the purpose of protecting tribal women from and controlling cervical cancer. Many women refused to get screened because of time consumption. The following section discusses the screening method for cervical cancer in developed countries. Explore preventive measures in both settings, including vaccination programs and public health initiatives.

1.4. Cervical Cancer Examination Approach used in the Developed Nations

This approaches in developing nations typically involve combining methods to improve accessibility and effectiveness. The use of questionnaires, pap smear, and smart colposcopy can all play a role in cervical cancer examination, as shown in Figure 1.5. Here's how these components might be integrated into a screening program:

a) Questionnaires and Interview Methods

An online cross-sectional study for single, sexually active women was carried out in Japan for the age group of 20-29 by the market research company in the year 2015. The

demographic data of women with sexual behavior and psychosocial factors were collected from Japanese women. From the total participation of 700, 383 women had undergone the cervical cancer screening test. It was also analyzed that most of the women refused to attempt the screening procedure due to logistical barriers, namely cost, time, and lower confidence to take pap smears with a male physician [49].

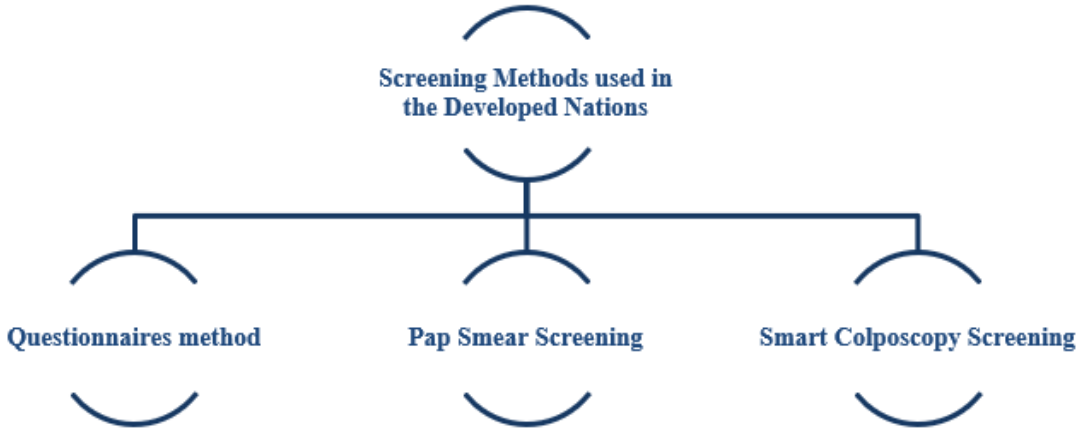


Figure. 1.5. Cervical Cancer Screening Method in Developed Countries

In Riyadh City, Saudi Arabia, an awareness campaign was conducted for HPV, and the women's attitude toward the HPV vaccine was collected. This camp was conducted from September to November 2016. Seventy-seven women aged 18-45 were considered for this study and an in-person interview were conducted. The 58 female clinical patients provided to inspect the consciousness of cancer among women and the financial obstacles that stop them from getting screened for cervical cancer [50]. An in-person interview with 580 women between the ages of 26 and 64 was done in England. The questions are based on the barriers to screening, behavior, and demographic characteristics of the women. Out of 580 women, 80.00% followed the regular screening, 15.00% in the long-delayed screening, and 2.60 % of women had never been screened. From the demographic and face-to-face interviews, most common barriers to screening are 29.00% humiliation, 21.00% shortage of time, and 14.00% agony [51]. In Europe, a broad survey on the organization's current status organized quality assurance (QA) scale in cervical cancer prevention, a program associated with cost. A thorough survey was created by conducting a systematic examination of the body of research and recommendations. The survey was given to ministries of health, programs organizers, and 34 EU and EFTA countries. Quality assurance (QA), monitoring,

and evaluation were carried out in 34 countries, and people from 29 countries submitted their responses to compare the economical of organization and QA strategies [52].

Pap Smear Screening

Finland organized the pap smear screening program for the target age group of 30-64 years with a screening period of five years. These programs invited women seven times yearly to attend the screening programs, and 73.00% of women participated each time [53]. The UK screening program initially started in 1988 with the age category between 20 to 64 years and recommended to attend screening tests at regular intervals of 3 years [54]. Similarly, the "*National Screening Program*" for cervical cancer is conducted in Australia for women who are sexually active between the age bracket of 18-70 years with the routine of cervical cancer examining every two years. The "*National Cervical Screening Stage Programs*" conducted in Australia recommended 3-yearly screening to prevent cervical cancer at an early age. From the data analysis during the years 1997-2007, it is recommended that two yearly screenings had a similar effect to 3-yearly examination and helped reduce the cost of screening every two years [55]. The Egyptian health care Authority studied hospitals from August 2020 to June 2019. Women aged 25 to 64 years were selected for this study. The gynecologist collected the cervical samples by using the cytobrush and liquid-based cytology medium to detect the presence of HPV DNA. From the 1000 women who attended the screening program, 143 women were detected as HPV positive and 857 women were detected as HPV negative [56]. In Italy, 1000 women aged 25 to 64 were encouraged to participate in the pap smear every three years. The screening program was conducted in Modena in the year 1997. From the total of 1000 patients who were subjected to the examination, ten women were diagnosed with abnormal pap, and 144 women had abnormal spectroscopic patterns [57].

b) EVA System

It is also called as "*smart colposcope*", a modern technological approach developed by the *"MobileODT"*. This portable, handheld AI technology is easy to use, travels to many nations, and facilitates camp organization. In the Dominican Republic in 2021, the Israeli government provided help for the screening effort. After screening 9,000 women in the last three months, EVA Visual Screening Smart Technology has chosen to extend the programs to screen an additional 50,000 women in the upcoming six months. The dependable, quick,

and portable gadget increases patient screening and generates highly accurate clinical outcomes [58]. In 2018, China organized a screening, with the support of a foundation for "*China's Health and Gynecologic Cancers Research Foundation*" in July 2018. A total of 4000 women attended the six-day screening camp. Of them, 3886 women got HPV testing, 168 underwent EVA System-assisted colposcopy screening, and 40 received on-site dysplasia therapy [59].

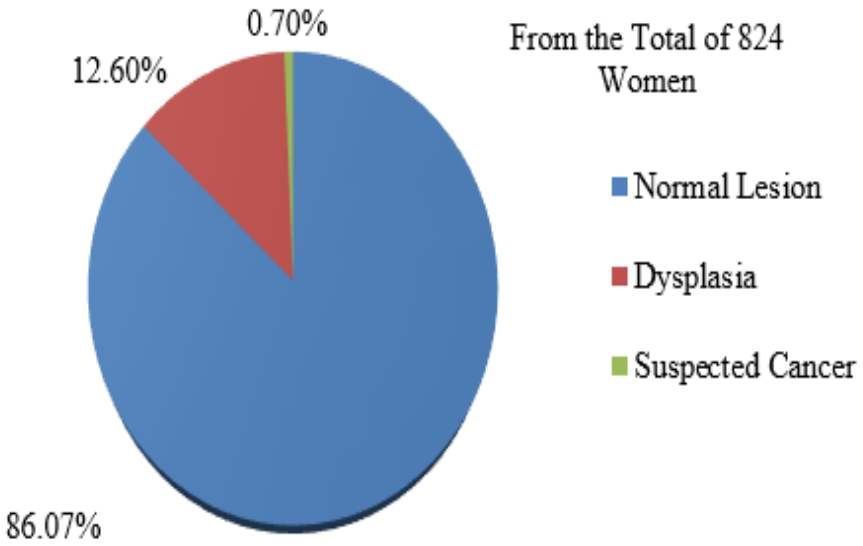


Figure. 1.6. Screening using Eva System in Kenya. It is observed that convincing tribal women to take cervical cancer screening tests is not an easy task. MobileODT device is an alternate method that overcomes the hesitation of the tribal women and motivates them to get screening because of its painful procedure.

In Kenya, a screening camp was conducted using smart colposcopy for 1155 patients and 316 stationary clinics. Out of 1155 patient, 261 women was affected with the abnormal lesion, and 25 women underwent cryotherapy. From 361 static clinics, 89 women had anomalous lesions, and 36 received cryotherapy [60]. In Kenya, the VIA screening method was conducted using EVA to screen 824 women within a week as shown in the Figure 1.6. For female patients with anomalous cervix lesions, this mobile application keeps track of their medical history and current therapies. In this study camp, 17 mobile colposcopes were deployed, and six organizations collaboratively worked with the MobileODT screening team to conduct camps. Of the overall 824 women, 86.07% had no abnormalities, 12.06% of the women had dysplasia, and 0.70% of women were suspected of cervical cancer [61], as shown in Fig. 1.5.

Inferences

Cervical cancer screenings are carried out using questionnaires, pap smear, and smart colposcopy. Demographic data, literacy, economic standing, and understanding about cervical cancer and its treatments are all included in the questionnaire. It has been noted that the questionnaire portion was mostly completed at a number of screening camps. During the programs, many women unintentionally hesitate to divulge personal details. The Pap smear, which is considered the gold standard approach for screening cervical cancer, is the procedure that follows. Using this method, a sample of tissue was taken and looked at under a microscope. Because screening is an intrusive and painful procedure, many women are reluctant to get checked. A different, more sophisticated screening technique that aids to examine the cervix area without causing much discomfort. The next section discusses the EVA system's comprehensive technical description.

1.5. The Promise of Smart Colposcopy

Eva system is a digital colposcope calibration device powered by AI technology. It is a visual screening approach that captures cervix images using the EVA mobile app. It is launched globally by MobileODT, serving 40,000 patients in over 20 countries. It consists of advanced imaging and software applications with an image portal for storing cervix images in the cloud. A smartphone application uploads the cervix images to the image portal. In joining hands with WHO, MobileODT is planning to organize screening camps to eradicate cervical cancer in the year 2050 entirely all over the world. So far, 175,000+ patients have been screened, and 4800+ users are using smart colposcope [62]. It is a cost-cutting screening method and is widely used in several countries. It assists the physicians in visually assessing the cervical regions and making clinical decisions. In nations with low or middle incomes, this approach of examining cervical cancer is widely utilized, because and it can be easily portable to any region for the screening process with minimal effort [62]. This device helps capture high-quality cervix images and video with EVA's 16x optical magnification. It can also autofocus and mark the biopsy's location, a portable, cost-effective method for screening camps [63]. It is attached to the Samsung Galaxy J5 smartphone and consists of two types of lenses for the camera. The first lens focuses on the distance between the patients at 22.5-42.5 cm. The second lens is manually focused to view the cervix region of the patient, application to assist image capture and data communication.

The mobileODT cervix images are screened without disturbing the cervix images, so this is a painless method. The EVA system for cancer screening is illustrated in Figure.1.7. Compared to other methods, mobileODT is a technically advanced screening method for cervical cancer, which can be easily portable to diverse geographical locations with minimal effort. So, the screening program for tribal women can be easily organized with minimum cost and effort. The procedure and clinical set are high for the pap smear, which cannot be taken quickly to any location. The digital colposcopy is also an advanced method for screening the cervix region. But because of its vast infrastructure, it is not portable. Henceforth, the EVA system helps to overcome these barriers, and it is a handy tool during the camp program, as shown in Figure.1.7. The comparative analysis of the screening approaches used for examining the cervix images with advantages and disadvantages are represented in Table 1.1. Based on the comparative analysis, the smart colposcope is a painless, cost-efficient and less time-consuming screening procedure, motivating women to get involved in screening. Because of their limited infrastructure, fewer human resources, minimal cost, and high accuracy in detecting cervical cancer, camps can be effectively organized in any location in the world with minimal effort.

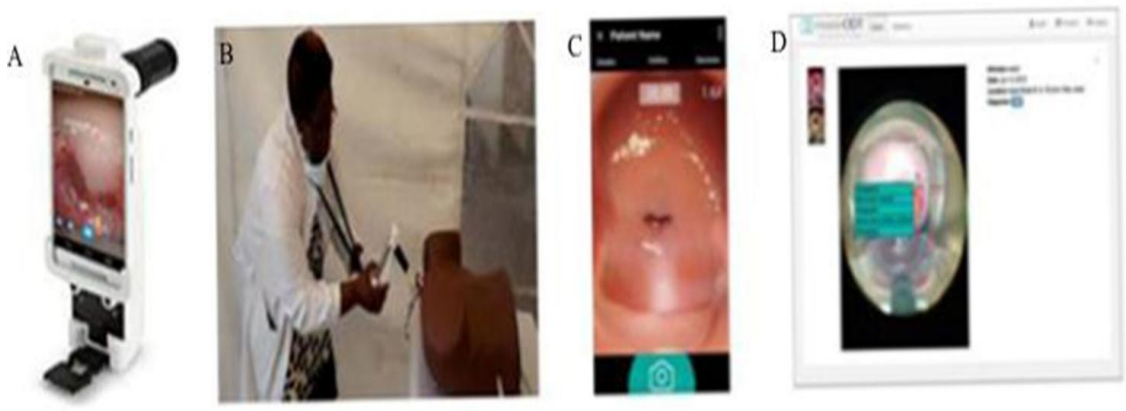


Figure.1.7 EVA system for screening Cervical Cancer. (A) Smart colposcope with focal lens and Smartphone attached with EVA with EVA application. (B) Physicians use the EVA system for the visual inspection of the cervix region. (C) Cervix images are captured using the smart colposcopy. (D) The online platform to visualize the cervix images captured through the EVA system and for the smart diagnoses through the online platform. Courtesy: Image source taken from [62][60].

Table 1.1. Comparison of the Smart Colposcopy with Other Screening Methods

Features / Method	Clinical procedure	Cost	Portability	Time	Infrastructure requirement	Human resources	Accuracy in cancer detection
Pap smear	Invasive and Painful	High	Less	More	High	More	High
Visual Inspection	Discomfort on tissue	low	Easily portable	less	less	High	Less
Liquid-based cytology	Painless	low	low	less	low	Low	Less
Colposcopy	Painless	medium	Not portable	less	High	Less	High
Smart Colposcope	Painless	High	Portable	less	Less	Less	High

In smart colposcopy images, the severity-based classification is done based on the grading process. The characterization in colposcopy images typically involves assessing the extent and severity of CIN, which is a precancerous change in cervical tissue. The CIN is categorized into three main grades: "*CIN1, CIN2, and CIN3*", as shown in Figure 1.8. Here's an overview of these grades:

CIN1 (Cervical Intraepithelial Neoplasia 1):

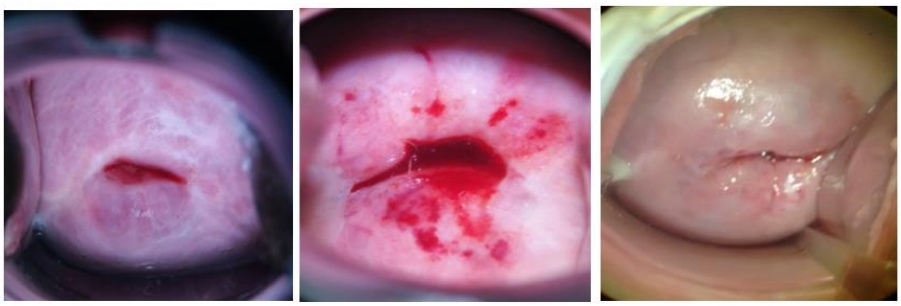
- CIN1 is characterized as a low-grade lesion.
- It represents mild dysplasia, indicating minor changes in the cervical lining.
- The abnormal cells are limited to the lower most layer of the cervical epithelium.

CIN2 (Cervical Intraepithelial Neoplasia 2):

- CIN2 is characterized as an intermediate-grade lesion.
- It signifies moderate dysplasia, meaning more significant changes in cervical cells than CIN1.
- The atypical cells affect the lower two-thirds of the cervical lining.

CIN3 (Cervical Intraepithelial Neoplasia 3):

- CIN3 is characterized as high-grade lesion.
- It represents severe dysplasia and is sometimes referred to as carcinoma in situ (CIS), which indicates a pre-invasive stage of cervical cancer.
- The atypical cells affect the entire thickness of the cervical lining.



(a) (b) (c)

Figure 1.8 Grading of Smart colposcopy Images. (a) CIN1 (b) CIN2 (c) CIN3

Grading CIN lesions is essential in determining the appropriate treatment and follow-up plan for individuals with abnormal cervical findings. CIN1 lesions often resolve spontaneously or with minimal intervention, while CIN2 and CIN3 lesions may require more aggressive treatments, such as cervical excision, to prevent progression to invasive cervical cancer. In colposcopy, healthcare providers use a colposcope to examine the cervix and closely identify anomalous region. Deep learning algorithms are used to automate the grading of smart colposcopy. During the grading, there is a challenge called specular reflection (SR), which affects the grading quality by appearing similar to the cancer region or covering a certain region of the images.

1.6. Technical Challenges Faced in Smart Colposcopy Images

Smart colposcopy consists of a 13mp resolution camera to capture the cervix region of the images with a magnification range for operating distance: 250–400 mm. The device is equipped with a 6000K 3W LED light to focus on the cervix region and incorporates a wire grid polarizer to reduce glare [64. The technical challenge faced in smart colposcopy is the formation of specular reflection (SR) on the cervix images that appear as intense white pixels in some areas of the cervix images. The moisture content in the cervix tissue causes SR, where it absorbs light from the surrounding region and reflects the light, forming SR in the digital images of the cervix, as shown in Figure .1.9 [65].

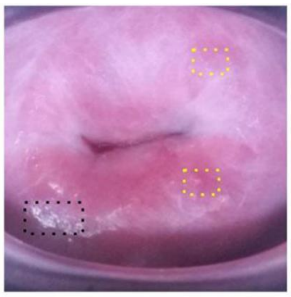


Figure. 1.9. Specular Reflection on the Cervix Images (Black dotted box) Captured Through the Smart Colposcope Collected from the Kaggle dataset. The Cervix's Acetowhite Region (yellow dotted box) Resembles the Specular Reflection.

Applying acetic acid to the area of cervix leads to changes of color in the anomalous cells that absorb acetic acid and turn into the acetowhite region. It helps to identify the abnormal lesion on the cervix, but this SR appears similar to the acetowhite region. It causes difficulty for the physician to analyze the cervix images for cancer grading.

1.7. Statement of Research Problem

Cervical cancer continues to be a major worldwide health concern., with its prevalence affecting women worldwide. Timely detection and accurate diagnosis are pivotal for effective treatment and improved patient outcomes. In this context, the quality of diagnostic tools and their images are paramount. This research addresses a pressing issue related to enhancing smart colposcopy images, aiming to improve the grading of colposcopy image accuracy by identifying and mitigating SR. It is often observed as bright white regions within colposcopy images, poses a formidable challenge to the diagnostic process. These reflections can obscure critical areas of interest, particularly those associated with potential neoplastic growth. Physicians heavily rely on these images to identify and delineate regions of concern, and the presence of SR introduces a significant source of ambiguity, making the labelling of neoplasm regions a complex and sometimes error-prone task.

Smart colposcopy leverages artificial intelligence (AI) to aid in diagnosing and grading cervical cancer. The AI-based tools automate the grading and annotation of potential cancerous regions in the captured colposcopy images. However, the quality of the input images directly influences the accuracy and reliability of AI-based predictions. The grading quality is compromised when glare regions caused by SR are present in these images. In some cases, these glare regions closely resemble cancerous areas, which can lead

to misdiagnosis when interpreted by the AI. Understanding the nature and impact of SR is essential to improving cervical cancer grading. It occurs when light is incident on a smooth, reflective surface at an angle equal to the angle of reflection. This phenomenon results in bright white areas appearing on the colposcopy images, masking critical details and introducing uncertainty into the diagnostic process. The proposed research seeks to develop advanced image processing techniques and algorithms specifically tailored to identify and remove SR from colposcopy images. Furthermore, this research endeavors to improve the integration of smart colposcopy images into AI-based diagnostic systems. It involves the development of robust image preprocessing methods that can effectively handle glare regions. Enhancing the quality of input images can significantly minimize chances of misdiagnoses and enhance the overall performance of AI algorithms tasked with cancer grading. The expected outcomes of this research are twofold. First, it aims to provide medical practitioners with enhanced colposcopy images that are free from the interference of SR. This improvement will lead to more accurate and confident diagnoses, potentially identifying cervical cancer at earlier stages. Second, by refining the integration of smart colposcopy images into AI-driven diagnostic systems, this research can contribute to developing more reliable and trustworthy automated tools. These tools can assist healthcare professionals by offering complementary insights and facilitating expedited diagnoses.

In conclusion, the research problem pertains to enhancing smart colposcopy images for improved cervical cancer grading process. The presence of SR within these images poses significant challenges to medical practitioners and AI-based diagnostic systems. Addressing this problem is crucial to advancing cervical cancer diagnostics, ultimately resulting in better patient cares. By developing specialized image processing techniques and improved integration with AI tools, this research endeavors to lower the impact of SR and enhance the overall quality of cervical cancer diagnosis.

1.8. Objective of this Research Work

Primary Objective

- Detection and removal of the specular reflection (SR) region from the smart colposcopy images to enhance the grading of cervical cancer.

Secondary Objectives:

- To develop a framework for the identification of specular reflection region on the smart colposcopy images

- To build a model for filling the removed specular reflection regions with neighboring pixel on smart colposcopy images.

1.9 Significance of Research

The significance of the research work is listed below:

- **Improved Diagnostic Accuracy**: This research can significantly reinforce the accuracy of cervical cancer diagnosis. Mitigating the interference of SR ensures that diagnosticians have access to more transparent and informative colposcopy images. This clarity enables them to make more accurate judgments about the presence and extent of neoplastic growth, leading to better patient outcomes.
- **Early Detection:** Early detection is critical in effectively treating cervical cancer. The research addresses the challenge of SR that obscure crucial details in colposcopy images. As a result, physicians can identify cancerous regions at earlier stages, when intervention is most successful, potentially saving lives.
- **Reduced Misdiagnosis**: Specular reflections often resemble cancerous areas, leading to potential misdiagnoses. By developing specialized algorithms and techniques to remove these artifacts, the research helps reduce the likelihood of misdiagnosis, ensuring that patients receive appropriate treatment and avoiding unnecessary anxiety and medical procedures.
- **Enhanced AI-based Tools**: Smart colposcopy images are the foundation for AI-based diagnostic tools in cervical cancer grading and annotation. Improving the quality of input images by eliminating glare regions ensures the reliability and accuracy of these AI tools. This research contributes to developing trustworthy automated systems to assist healthcare professionals in their diagnostic process.
- **Patient Outcome**: The significance of this research stems from its capacity to improve patient outcomes. Accurate diagnosis is crucial in providing timely and effective treatment. By addressing the challenges posed by SR, the research enhances the quality of care received by patients, potentially reducing the morbidity and mortality associated with cervical cancer.
- **Resource Efficiency**: Misdiagnoses and the need for repeated tests and treatments can strain healthcare resources. By reducing misdiagnoses and unnecessary medical procedures, the research can contribute to resource efficiency within healthcare systems, optimizing the allocation of resources for better patient care.

- **Global Health Impact**: The research has the potential to benefit women worldwide by improving the quality of cervical cancer diagnostics. This impact extends to regions with limited access to specialized medical facilities, where accurate diagnosis can be particularly challenging.

In summary, the research on improving smart colposcopy images by detecting and removing SR holds great significance in enhancing cervical cancer diagnostics, reducing misdiagnosis, improving patient outcomes, and advancing the capabilities of AI-based diagnostic tools. Its impact extends to healthcare efficiency, global health, interdisciplinary collaboration, and future research opportunities in medical imaging.

1.10. Research Gap

The research gap is listed below:

- The existing landscape of cervical cancer diagnostics using smart colposcopy images highlights a critical research gap that necessitates detecting and removing SR.
- Specular reflections, manifested as bright white regions within colposcopy images, have remained a persistent challenge in the field.
- These reflections obscure vital details within the images, making it difficult for medical practitioners to identify and label neoplastic regions accurately.
- Additionally, SR adversely affect the performance of AI-based diagnostic tools, potentially leading to misdiagnoses.
- The need to address this research gap becomes evident when considering the profound implications for patient care, early detection, and the advancement of diagnostic technology.

1.11. The Rationale of the Study

The rationale of the study includes the following:

- **Enhancing the grading accuracy**: The primary rationale for this study is to significantly enhance the grading accuracy of smart colposcopy images through the detection and removal of SR. By eliminating these artifacts, healthcare professionals gain access to more transparent and informative images, facilitating more precise diagnoses.
- **Early detection and diagnosis**: Timely detection is paramount in cervical cancer management. This research aims to remove barriers posed by SR, allowing

physicians to identify neoplastic growth at earlier stages when interventions are most effective. It can lead to improved patient outcomes and reduced morbidity and mortality rates.

- **AI-Based Diagnostic Tools**: Smart colposcopy images form the foundation of AI-based diagnostic tools for cervical cancer grading and annotation. The study's rationale includes enhancing the reliability and accuracy of these AI tools. Removing glare regions ensures that automated systems provide trustworthy assistance to healthcare professionals, augmenting their diagnostic capabilities.
- **Reducing Misdiagnosis**: Specular reflections (SR) often mimic cancerous areas, leading to potential misdiagnoses. The study's rationale is rooted in reducing the likelihood of misdiagnosis ensuring that patients receive appropriate and timely treatment. It not only benefits patients but also alleviates anxiety and reduces the strain on healthcare resources associated with misdiagnoses.
- **Resource Optimization**: The study contributes to resource optimization within healthcare systems by reducing misdiagnoses and unnecessary medical procedures. It rationalizes resource allocation, making healthcare more efficient and cost-effective.
- **Global Health Impact**: Cervical cancer affects women worldwide, including those in regions with limited access to specialized medical facilities. The rationale of this study extends to its potential global health impact, benefiting women across diverse healthcare settings.

In summary, this study addresses a critical research gap by focusing on detecting and removing SR in smart colposcopy images. Its rationale is deeply rooted in the need for improved diagnostic accuracy, early detection, and enhanced AI-based tools, ultimately benefiting patient care, healthcare efficiency, and global health efforts while fostering interdisciplinary collaboration and innovation in medical imaging research.

1.12. Data Collection & Ground Truth Labeling

Data collection is a pivotal and foundational step in scientific research. In medical imaging and diagnosis, the standard and diversity of the collected data are paramount for achieving research objectives, advancing medical knowledge, and improving healthcare outcomes. This research endeavors to shed light on the meticulous data collection process, highlighting two key datasets that serve as the backbone of our investigation. These

datasets, sourced from reputable online repositories, play a pivotal role in our efforts to address a critical issue in colposcopy image analysis - the removal of SR or glare regions.

Figure.1.10 Dataset Collection from the Kaggle

1.12.1. Description of Data Source

The Kaggle dataset comprises a rich collection of smart colposcopy images representing varying stages of cervical cancer, including CIN1, CIN2, and CIN3 [66], as shown in Figure 1.10. While invaluable for diagnostic purposes, these images often suffer from glare regions, which can obscure critical details and impede accurate analysis.

Ground Truth Labeling – (Manual Annotation of Specular Reflection (SR))

The meticulous process of ground truth labeling, a pivotal component of our research, was carried out under the expertise and guidance of an image processing expert. This section discusses obtaining ground truth data for SR regions in smart colposcopy images. It is a critical factor in colposcopy image analysis, but unfortunately, pre-existing ground truth images for these reflections were not available for our research. There are only two categories of the pixel which falls in which one falls in the SR region and other falls in the non-SR region. As there are only two categories of pixels with the consultation of the image processing expert, manual annotation is performed to differentiate the reflection from the entire images. The annotated images generated are taken as ground truth dataset for validation purpose in smart colposcopy images. These annotated images are validated by the medical practices to validate to check whether any acetowhite regions are marked during the reflection annotation process. These annotated images are invaluable for training and evaluating deep learning models and conducting further analysis in our research work. The annotated data of the reflection region is marked on the images, as indicated in Figure 1.11.

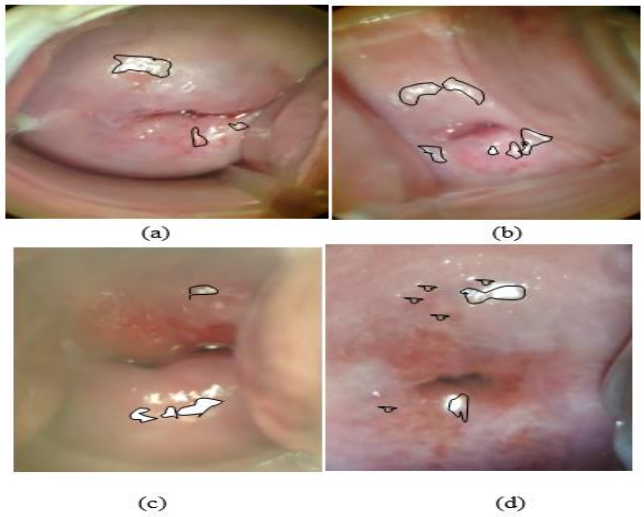


Figure.1.11. Labeled SR Region on the Images

1.13. Chapter Organization

The thesis is organized into the following chapters: Introduction, Literature Review, Intensity based threshold method, Deep Learning segmentation model, Deep Learning inpainting model, Grading of Smart colposcopy images, Conclusion, and Further Work and Research Contribution.

Chapter 1: Introduction

This chapter discussed cervical cancer, its causes, and the risk factors that contribute to its development. Furthermore, it explores the various screening methods employed in detecting cervical cancer, shedding light on their significance in early diagnosis and disease management. This chapter also examines the disparities in screening practices between developing and developed countries, emphasizing the critical role of accessibility and resources in determining the efficacy of screening programs. This chapter outlines the research gap that motivated our investigation, highlighting the limitations and deficiencies in current knowledge. By addressing these gaps, our research aims to provide valuable insights into cervical cancer and its screening, potentially paving the way for improved healthcare practices and outcomes. This chapter also outlines the specific objectives of this study, delineating the goals we aim to achieve through our research endeavors. Additionally, it discusses the method employed for data collection and emphasizes the relevance and reliability of the chosen data sources. Finally, it discusses the rationale for undertaking this study, underscoring the need for a comprehensive understanding of cervical cancer and its

screening methods to inform future healthcare strategies and policies. This chapter sets the stage for the subsequent chapters, offering a foundational understanding of the research context and its importance.

Chapter 2: Literature Review

This chapter discusses the existing research and methodologies for identifying SR in smart colposcopy images. This chapter discusses threshold-based methods and their applications in various color spaces for this specific task. This chapter also discusses the transition to deep learning, exploring the segmentation models for medical image segmentation tasks. This chapter also investigates existing deep learning-based inpainting methods as a solution to address image imperfections caused by SR, providing a comprehensive overview of their use in the medical imaging domain. Lastly, the classification models are employed for grading smart colposcopy images, shedding light on the diverse approaches that have been leveraged to enhance the accuracy of diagnosis and disease severity assessment.

Chapter 3: Research Methodology

The methodology is structured into four phases, each crucial in addressing the research objectives. In Phase 1, an IBTM is used for detecting SR in the images. Phase 2 focuses on leveraging a deep learning segmentation model to delineate the reflection region within colposcopy images accurately. Phase 3 discusses the proposed deep learning inpainting techniques to restore the affected areas by SR. The advantages of deep learning in this context and the outcomes are discussed. Phase 4 concludes our research methodology, focusing on how the enhancement techniques from the previous phases positively influence the grading process.

Chapter 4: Specular Reflection Identification

This chapter focuses on developing a threshold-based method for detecting glare regions in smart colposcopy images. The chapter begins with an introduction to the importance of glare region detection in improving the accuracy of image analysis. This chapter also discusses the critical step of identifying the most suitable color space for this task and explains the reasoning behind our choice. This chapter describes the proposed threshold method, which relies on intensity values within the chosen color space to identify the reflection region. Experiments were carried out to confirm the method's efficacy, and the

results were reported. A thorough analysis of the findings is provided in the part that follows.

Chapter 5: Segmentation of Specular Reflection

Chapter 5 discusses the deep learning segmentation models for glare region segmentation in smart colposcopy images. The chapter begins with an introduction to the central focus and importance of accurate segmentation in image analysis. This chapter also describes the initial analysis of various segmentation models to identify the most suitable candidate for this specific task. The selection of the UNet model is explained in detail, supported by the analysis results that demonstrated its superior predictive performance. The fine-tuning and customization process applied to the UNet model to align it with the specific requirements of glare region segmentation. The chapter discusses the validation methodology and performance evaluation, providing concrete evidence of the model's accuracy. The customized UNet model with other UNet variations highlights the advantages and improvements achieved through customization. In conclusion, chapter 5 underscores the significance of the selected and customized UNet model in achieving precise glare region segmentation, which is pivotal for smart colposcopy image analysis.

Chapter 6: Inpainting for Image Enhancement

The chapter 6 discusses the deep learning inpainting models for glare region restoration in smart colposcopy images. The chapter starts with an introduction, underscoring the importance of inpainting in addressing image imperfections. Initially, various convolutional-based inpainting models are analyzed by explaining the criteria for selecting and comparing these models. Integration of convolutional filters and other filtering techniques in the inpainting process is discussed to highlight their role in enhancing restoration quality. This chapter proposes a bilateral-based inpainting model, which is presented as the chosen approach for glare region restoration.

Chapter 7: Enhanced Image Grading

The Chapter 7 discusses the deep learning classification models for grading smart colposcopy images. The chapter begins with an introduction, highlighting the critical role of accurate grading in cervical cancer diagnosis and its connection to image enhancement. It also discusses the methodology for training deep-learning classification models, including using enhanced and non-enhanced cervical images for training. The architecture and

configuration of the deep learning model are presented, followed by details on the experimental setup and training process. The grading results between enhanced and non-enhanced images demonstrate the impact of image enhancement on the grading process.

Chapter 8: Conclusion and further work

This chapter highlights the importance of color space selection for detecting SR in smart colposcopy images, with RGB and XYZ methods chosen for their ability to preserve original colors. It identifies the glare regions using an intensity-based threshold method, where the XYZ approach outperforms RGB in maintaining color appearance. Furthermore, UNet++ excels in glare region segmentation. The proposed bilateral convolutional inpainting model effectively removes glare regions and restores images naturally, particularly in predicting missing pixel values in larger masked areas. These methods hold promise for enhancing smart colposcopy images and finding applications in other medical imaging domains. To advance this research, future work should address limitations and investigate how enhancement techniques impact cancer detection efficiency within smart colposcopy image analysis and medical imaging.

Chapter 9: Research Contribution

The chapter 9 summarizes the contribution of each chapter. It is focused on identifying the most suitable color space and introducing an intensity-based threshold method to detect the glare regions. The Chapter 5 identified the UNet++ models as optimal for glare region segmentation. The Chapter 6 presented a highly effective bilateral convolutional inpainting model for glare removal. Finally, chapter 7 demonstrated the critical role of image enhancement in significantly improving cervical cancer grading accuracy. These cumulative contributions not only enhance smart colposcopy image analysis but also hold potential for broader application in medical imaging, underscoring the significance of this research in advancing healthcare diagnostics and image processing techniques.