Journal of Biomedical & Clinical Research
Journal of Medical University of Pleven

Journal of Biomedical and Clinical Research 18: 47–53 (2025)
DOI: 10.3897/jbcr.e144006

Research Article

Artificial intelligence analysis of the transformation zone of the uterine cervix

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Summary

Cervical cancer remains a leading cause of morbidity and mortality among women worldwide, particularly in regions with limited access to advanced medical care. Accurate and timely diagnosis of precancerous changes in the cervix is critical for effective prevention and treatment. This study introduces a deep learning algorithm for colposcopic analysis of the transformation zone of the uterine cervix. Intel & MobileODT Cervical Cancer Screening competition provided a comprehensive dataset designed to advance the application of artificial intelligence (AI) in classifying transformation zones (TZ) of the cervix, a key site where precancerous changes develop due to Human Papillomavirus (HPV) infection. This study highlights the significance of TZ classification for targeted biopsy during colposcopy, a gold-standard diagnostic method. However, challenges such as clinician's subjectivity and interobserver variability, false negatives and positives interpretations limited accessibility, and resource intensity have spurred the integration of AI into colposcopic evaluations. The dataset comprises diverse cervical images, categorized into three types of TZs, enabling the development of AI models to distinguish between these categories. By leveraging deep learning algorithms, AI has demonstrated potential in enhancing the sensitivity and specificity of colposcopic findings while mitigating subjectivity and observer dependency. This abstract outlines the anatomical basis of cervical pathology, the critical role of colposcopy in diagnosing transformation zone abnormalities, and the transformative potential of AI in improving cervical cancer screening processes. The integration of AI-assisted tools could significantly improve diagnostic accuracy, reduce invasive procedures, and enhance access to cervical cancer prevention measures, particularly in underserved regions.

Key words: AI, cancer screening, cervical cancer, precancerous changes

Academic editor: Pencho Tonchev
Received: 10 December 2024
Accepted: 11 December 2024
Published: 26 February 2025

Citation: Prandzhev GD, Gortchev GA, Dimitrov DD, Miltchev RI, Rangelov D, Tomov ST (2025) Artificial intelligence analysis of the transformation zone of the uterine cervix: Colposcopic cervical categorization and integration of deep learning. Journal of Biomedical and Clinical Research 18: 47–53. https://doi.org/10.3897/jbcr.e144006

Introduction

This study aims to utilize a colposcopic database to facilitate the development of innovative artificial intelligence (AI) models capable of automatically classifying different types of cervical transformation zones (TZ). Colposcopy is a diagnostic procedure that uses a magnifying instrument with an integrated light source, allowing for detailed visualization of the cervical epithelium. It is typically employed following abnormal results from screening methods such as Human Papillomavirus (HPV) testing and Pap smear. The area where the ectocervical and endocervical epithelium meet is called a transformation zone. This is a dynamic region where the HPV can disrupt the normal processes of metaplasia between the columnar and squamous epithelium of the cervix, leading to abnormal cell changes and dysplasia. The digital archive includes a wide variety of images captured with different colposcopic devices and under varying conditions, posing challenges for visual processing and classification algorithms. The data are categorized into three groups according to the type of TZ, which allows the development of deep learning models capable of accurately distinguishing one from another. This work represents an important step towards improving the accuracy and efficiency of early colposcopic detection of precancerous cervical changes, especially in regions with limited medical resources.

Material and methods

The dataset used in this study is part of the Intel & MobileODT Cervical Cancer Screening competition, held on the Kaggle platform (Ben et al. 2017). The constructed database contains 8727 images that have been classified into three different categories, labeled as TZ type 1, TZ type 2, and TZ type 3. The classification used is in the context of developing artificial intelligence models that aim to automatically recognize and classify the different ectocervical anatomy. The dataset offers a structured and labeled framework that can support accurate colposcopic analysis of the uterine cervix and scientific research in this field. For the purpose of this study, the publicly available dataset was expanded and differentiated into three sets - for training, validation and model testing. Train/loss, validation/loss and metric/accuracy plots were used to illustrate the results.

Results and discussion

The present study was based on an extra-large modification of basic YOLOv8 model, a framework characterized by high accuracy, speed, and flexibility, suitable for analysis of medical images. The publicly available dataset was expanded up to 18 292 images, modified and then divided into three, with a ratio of 87:8:5 for the respective subsequent tasks – training, validation and model testing. The model provided sufficient grounds to draw conclusions about the usefulness of the developed mechanisms for dataset extension, through appropriate transformations. The results obtained from the training-based recognition capabilities on an extended dataset—derived from a more limited number of primary images to achieve larger sets of objects for training, validation, and testing—showed good initial recognition performance, reaching up to 72–75%.

The train/loss and validation/loss plots illustrate how the loss changes during training and how the model handles the validation dataset with the modified dataset. In addition, plots for the accuracy metric (metric/accuracy) show how the accuracy of the model changes during training (Fig. 1).

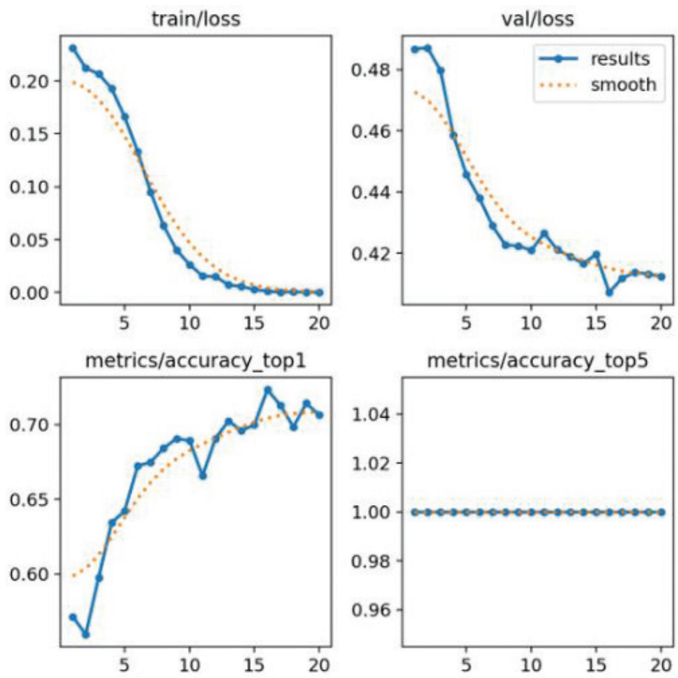

Figure 1. Train/loss, validation/loss and metric/accuracy results. Train/loss, validation/loss and metric/accuracy plots for measuring the performance of the modification of the YOLOv8 model used in the study.

The uterus is a reproductive organ, the size and weight of which depend on age, number of pregnancies and hormonal status. It is formed by two main parts: an upper, widened portion - uterine body, and a lower, narrowed structure - cervix, with the isthmus situated between them. The cervix is a fibromuscular structure composed of an inner and outer part, containing the cervical canal that connects the uterine cavity to the vagina. It has an average length of approximately 4 cm and a thickness of about 3 cm. The endocervix is lined by columnar (glandular) epithelium and the ectocervix by squamous cell epithelium. The two cell layers are in continuous interaction, expressed in metaplasia processes, and the place of contact between them is called the squamocolumnar junction (SCJ). This boundary is not static and its location and size vary depending on age, childbirth history and hormonal status. As a result of its displacement, a new, current boundary is formed, and traces of its previous localization remain behind it. The space between them is called the transformation zone (TZ) (Fig. 2). The aforementioned metaplasia takes place in it, which is the transformation and transition of one epithelium into another, in this case – columnar into squamous. These are unstable and irreversible processes that can be disrupted by the presence of bacterial and viral infection (Prendiville and Sankaranarayanan 2017).

As the current gold standard for diagnosing cervical pathology, colposcopy provides enhanced visualization of the transformation zone, where most of the cervical pathologies originate. The detection of atypical colposcopic findings facilitates timely collection of targeted biopsies that confirms the presence or absence of dysplastic cells. The histology report is essential for determining the necessity and extent of destructive procedures to prevent progression to an invasive disease. Colposcopy sensitivity ranges from 30% to 90%, while specificity varies from 40% to 95% (Origoni et al. 2023). It is important for the clinician to distinguish the types of transformation zones, to correctly assess the visible

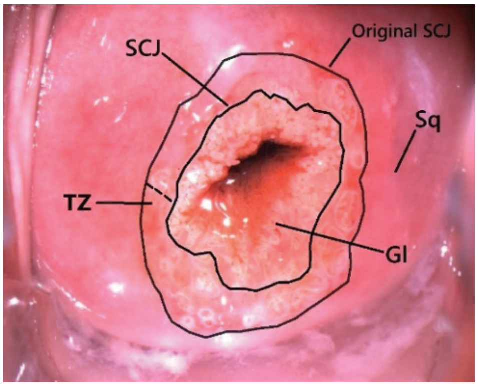

Figure 2. Colposcopic anatomy of the cervix. **TZ** – Transformation zone **Sq** – Squamous cell epithelium, the lining of the ectocervix **Gl** – Glandular (Columnar) epithelium, the lining of the endocervix **SCJ** – current squamocolumnar junction **Original SCJ** – original border squamocolumnar junction.

cervical findings and their relation to the TZ. Depending on the location of SCJ, we observe three types of transformation zones - type 1, type 2 and type 3.

In type 1, the SCJ is located entirely on the ectocervix and is fully visible on colposcopic examination (Fig. 3).

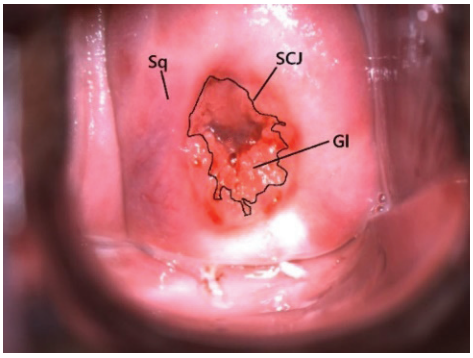

Figure 3. Type 1 transformation zone. Completely visible, fully ectocervical localization with clear squamocolumnar junction.

Type 2 – The SCJ is not completely visible because part of it is located endocervically, but can be visualized using a cervical speculum (Fig. 4).

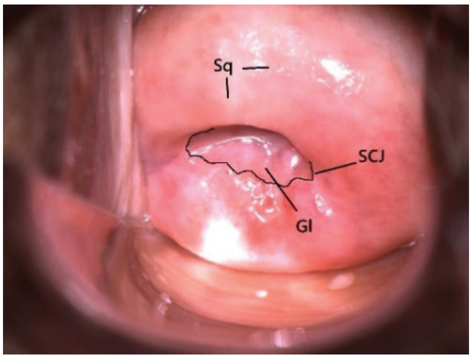

Figure 4. Type 2 transformation zone. Partly visible, ectocervical localization with an endocervical component. The transformation zone cannot be adequately interpreted without the use of cervical speculum.

Type 3 – The SCJ cannot be identified because it is located in the cervical canal and is invisible on colposcopic examination (Fig. 5).

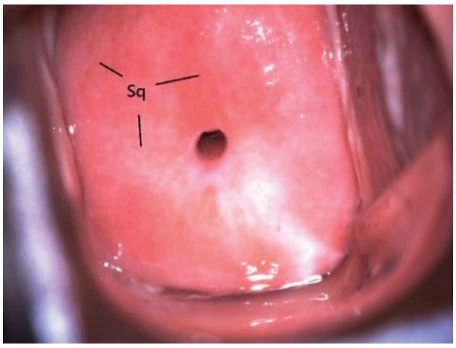

Figure 5. Type 3 transformation zone. Completely invisible, fully endocervical localization without any sign of squamocolumnar junction. Interpretation of the transformation zone is not feasible.

Human Papillomavirus (HPV) is a family of over 200 types of DNA viruses, about 40 of which affect the genital mucosa (Wright et al. 2015). Infection of the female genital tract with high-risk HPV types has the potential to damage the cervix. The main target is the immature metaplastic epithelium in the transformation zone, causing the development of precancerous processes called cervical intraepithelial neoplasia (CIN) or simply dysplasia. These conditions can reverse, persist, or progress to invasive carcinoma. Colposcopy is typically employed following abnormal results from cervical screening methods such as Pap smear or HPV testing. A study evaluating the effectiveness of primary HPV testing demonstrated a sensitivity of 95% for detecting CIN2+ lesions, which was notably higher than cytology (Okunade 2020). The results showed a specificity of 94%, suggesting that while HPV testing was effective in detecting high-risk cases, it also led to some false positives. The study supports it as a more reliable and efficient first-line screening method compared to traditional cytology-based approaches. In the context of co-testing, colposcopy's role remains essential for follow-up of patients with abnormal screening results. While colposcopy serves as a crucial second step in the clinical management of the cervix, the inherent subjectivity of the method poses a challenge to achieving consistent and reliable performance.

Colposcopy is a subjective gynecological examination, through which, after biopsy, we obtain the most objective information about the condition of the cervix. For a successful colposcopic examination, it is crucial to accurately identify the squamocolumnar junction, determine the type of transformation zone, assess the visible atypical patterns and their relation to the TZ, and correctly target the tissue samples. The differences in sensitivity, specificity, and accuracy of the colposcopic method are due to the individual experience of the colposcopists, their ability to assess and differentiate abnormal from atypical findings, the decision-making skills, and the level of understanding of the processes occurring in cervical cells. Moreover, this is a resource-intensive examination that requires specialized equipment and trained professionals, making it less accessible in low-resource settings. The integration of artificial intelligence with colposcopy has the potential to offset these disadvantages. Our model shows progress in this field, achieving consistent accuracy of 72-74% without fluctuations. By focusing on the accurate identification of SCJ and TZ, it provides a foundation for further accumulation and training to differentiate benign from pathological cervical images. This development addresses the limitations of human subjectivity and variability, providing a more consistent and objective approach to colposcopy.

Conclusions

The availability of accessible datasets provides the scientific community with an opportunity to test algorithms for model training using artificial intelligence methods for image recognition, classification, and segmentation. Open-access archives facilitate the development of computer vision-based methodologies, particularly when researchers have not yet accumulated sufficient data to build a dataset related to their specific task. Our initial work and experience were very promising, offering hope for further success that can significantly reduce the number of patients with invasive cervical cancer. The application of deep learning algorithms can enhance the performance of colposcopy, reducing operator subjectivity and ensuring consistent results.

Acknowledgements

The authors have no support to report apart from the information stated in Funding.

Additional information

Conflict of interest

The authors have declared that no competing interests exist.

Ethical statements

The authors declared that no clinical trials were used in the present study.

The authors declared that no experiments on humans or human tissues were performed for the present study.

Informed consent from the humans, donors or donors' representatives: University Hospital Saint Marina – Pleven.

The authors declared that no experiments on animals were performed for the present study.

The authors declared that no commercially available immortalised human and animal cell lines were used in the present study.

Funding

This research was funded by the Bulgarian National Science Fund (BNSF) through "COMPETITION FOR FINANCIAL SUPPORT FOR BASIC RESEARCH PROJECTS– 2022", project КП-06-Н63/5 from 13.12.2022 – "Application of AI Methods for Colposcopic Recognition and Categorization of Cervical Features", with a contract № BG-175467353-2022-04-0257-C01.

Author contributions

Conceptualization: STT. Data curation: RIM, GDP, DR. Formal analysis: GDP, GAG. Funding acquisition: DDD, GAG. Investigation: GDP, STT. Methodology: STT, RIM, DR. Project administration: RIM, DDD, GAG. Resources: DDD, STT. Software: DR, RIM. Supervision: STT, GAG, DDD. Validation: STT, RIM. Visualization: GDP. Writing – original draft: GDP. Writing – review and editing: GDP.

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Data availability

All of the data that support the findings of this study are available in the main text.

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