European Journal of Obstetrics & Gynecology and Reproductive Biology xxx (xxxx) xxx

Contents lists available at ScienceDirect

European Journal of Obstetrics & Gynecology and Reproductive Biology

journal homepage: www.elsevier.com/locate/euro

Full length article

Clinical evaluation of a real-time optoelectronic device in cervical cancer screening

Yingting Wei [a,b], Wenjing Wang [a,b], Mengxing Cheng [a,b], Zubei Hong [a,b], Liying Gu [a,b], Jiaxin Niu [a,b], Wen Di [a,b,c], Lihua Qiu [a,b,*]

[a] Department of Obstetrics and Gynecology, Ren Ji Hospital, School of Medicine, Shanghai Jiao Tong University, Shanghai, China
[b] Shanghai Key Laboratory of Gynecologic Oncology, Ren Ji Hospital, School of Medicine, Shanghai Jiao Tong University, Shanghai, China
[c] State Key Laboratory of Oncogenes and Related Genes, Shanghai Cancer Institute, Ren Ji Hospital, School of Medicine, Shanghai Jiao Tong University, Shanghai, China

ARTICLE INFO

Article history:
Received 25 June 2021
Revised 2 September 2021
Accepted 26 September 2021
Available online xxxx

Keywords:
TruScreen
Cervical cancer screening
Cervical intraepithelial neoplasia
Real-time optoelectronic device
Artificial intelligence

ABSTRACT

Objective: Early screening and intervention are crucial for the prevention and treatment of cervical cancer. TruScreen is a real-time, intelligent, pathological diagnostic technology designed for cervical cancer screening. The aim of this study was to evaluate the clinical value of TruScreen in screening for cervical lesions.

Study design: A total of 458 women aged between 25 and 65 years were recruited to receive cervical cancer screening, including human papillomavirus (HPV) testing, cytological testing using the ThinPrep cytology test (TCT), and TruScreen from December 2018 to January 2020. The clinical performance of TruScreen, alone and in combination with HPV testing, was evaluated to detect cervical intraepithelial neoplasia grade 2 or worse (CIN2+ or CIN3+).

Results: For detection of CIN2+, the sensitivity and specificity of TruScreen were 83.78% and 78.86%, respectively. The specificity of TruScreen was significantly higher than those of HPV testing (50.59%, $P < 0.001$) and TCT (55.58%, $P < 0.001$). In high-risk HPV-positive women, the specificity of HPV testing combined with TruScreen was significantly higher than that of HPV testing combined with TCT (50% vs 39.9%, $P = 0.004$). The sensitivity of HPV testing combined with TruScreen was comparable to that of HPV testing combined with TCT (93.94% vs 87.88%, $P = 0.625$). Similar patterns were also observed for CIN3+ cases.

Conclusion: TruScreen has the potential for screening high-grade cervical precancerous lesions and may replace cytological tests as a cervical cancer screening method in China to avoid subjectivity in the interpretation of cytological tests and requirements by pathologists.

Introduction

Cervical cancer is one of the most common malignant tumours, ranking fourth in morbidity and mortality among females globally. In 2018, there were approximately 570 000 cases of cervical cancer and 311 000 related deaths [1]. Due to lack of universal access to vaccines and screening, China contributes to approximately 18.6% of the global cervical cancer burden, with 106 000 cervical cancer cases and 48 000 deaths due to cervical cancer per year [2]. Since Harald zur Hausen first described the association between human papillomavirus (HPV) and cervical cancer [3], it is now widely known that a persistent high-risk HPV (HR-HPV) infection is closely related to the occurrence of cervical cancer [4]. It is a dynamic process that takes 5–15 years for the progression of an HR-HPV infection to become precancerous lesions of cervical cancer and for the occurrence of invasive cervical cancer. Therefore, effective early screening and intervention are extremely important to reduce the morbidity and mortality rates associated with cervical cancer.

At present, the commonly-used screening methods for cervical cancer include HPV DNA testing and cytological testing [5]. However, screening for cervical cancer is shifting from primary cytolog-

Abbreviations: ASCUS, atypical squamous cells of undetermined significance; CIN, cervical intraepithelial neoplasia; CIN2+, CIN grade 2 or worse; CIN3+, CIN grade 3 or worse; HPV, human papillomavirus; HR-HPV, high-risk HPV; HSIL, high-grade squamous intraepithelial lesion; LSIL, low-grade squamous intraepithelial lesion; NILM, negative intraepithelial lesion or malignancy; NPV, negative predictive value; PPV, positive predictive value; TCT, ThinPrep cytology test.

* Corresponding author at: Department of Obstetrics and Gynecology, Ren Ji Hospital, 160 Pujian Road, Pu-dong District, Shanghai 200127, China.

https://doi.org/10.1016/j.ejogrb.2021.09.027
2215-1532/

ical testing to primary HPV testing [6]. With advancements in science and technology, a real-time optoelectronic device, TruScreen, has attracted international attention as a novel artificial intelligence auxiliary screening method for cervical cancer, which has the advantages of real-time results, simple operation requirements, and objectivity [7]. Although TruScreen has been used clinically for the past few years, there are limited reports on the diagnostic performance of the device for cervical intraepithelial neoplasia (CIN), especially CIN grade 2 or worse (CIN2+), in China.

Our study aimed to evaluate the clinical value of TruScreen in cervical cancer screening by comparing the diagnostic performances of TruScreen, cytological testing, and HPV testing for the detection of CIN2+ and CIN grade 3 or worse (CIN3+) cases, and in particular, the detection ability of the former two methods in HR-HPV-positive Chinese women.

Materials and methods

Overview of screening methods for subjects

Women aged 25–65 years who were opportunistically screened for cervical cancer from December 2018 to January 2020 at Renji Hospital (affiliated to Shanghai Jiao Tong University School of Medicine) were included in the study. ThinPrep cytology test (TCT) and HPV genotyping were performed on all the women. Based on TCT and HPV genotyping results, the patients were divided into four groups which were subjected to stratified sampling to finally determine 458 subjects. The four groups were divided in the following manner: (1) 94 TCT atypical squamous cells of undetermined significance (ASCUS) or worse and HR-HPV-negative cases; (2) 120 TCT ASCUS or worse and HR-HPV-positive cases; (3) 123 TCT-negative and HR-HPV-negative cases; (4) 121 TCT-negative and HR-HPV-positive cases. Exclusion criteria for stratified sampling included current menstrual period during the examination period, history of hysterectomy or trachelectomy, gestation or <42 days postpartum, previous history of pelvic radiation therapy or chemotherapy, inability to cooperate with the examination for any reasons such as severe surgical or orthopaedic disease, and mental disorders.

A further cervical examination with a TruScreen real-time optoelectronic scanner was performed on these subjects. If abnormal results were obtained from TruScreen, a cervical tissue biopsy was performed in addition to HPV genotyping or TCT, and electronic colposcopy. A pathological biopsy report was obtained one week after the colposcopy examination. All tests were completed within 2–4 weeks.

TruScreen screening

The TruScreen device was supplied by TruScreen Pty Ltd (Sydney, Australia). The operator used a disposable photoelectric sensor that targeted at least 15 sites of the cervical surface in the order specified in the manual of the device. The results were obtained in real time. The results were defined as: (1) Normal (no abnormal cervical cells were found) or (2) Abnormal (abnormal cells were found in the cervix).

TCT screening

Samples were subjected to TCT in the pathology laboratory, and the results were reviewed by two pathologists before being reported. The results were analysed using the Bethesda system and graded as negative intraepithelial lesion or malignancy (NILM), ASCUS, low-grade squamous intraepithelial lesion (LSIL), high-grade squamous intraepithelial lesion (HSIL), atypical squamous cells-cannot exclude HSIL, squamous cell carcinoma, atypical glandular cells, or adenocarcinoma in situ.

HPV testing

The liquid samples collected by the clinician were tested with the 21 HPV GenoArray Diagnostic Kit (Hybribio Ltd, Hong Kong) according to the manufacturer's instructions, and the 21 detection subtypes included 15 high-risk types (16, 18, 31, 33, 35, 39, 45, 51, 52, 53, 56, 58, 59, 66, and 68) and 6 low-risk types (6, 11, 42, 43, 44, and CP8304).

Electronic colposcopy and cervical biopsy

The cervix was examined using the acetic acid test and iodine test successively and observed with a magnification microscope. Biopsies of suspicious lesions were taken for pathological examination. In addition, endocervical curettage was performed for subjects whose cervical squamocolumnar junction could not be fully exposed. The pathological sections were reviewed by two senior attending pathologists before being reported. Histological results were included and defined as normal, condyloma change, CIN 1–3, carcinoma in situ, or invasive cancer. The end points were CIN2+ and CIN3+.

Combined screening method

To further test the ability of the TruScreen triage for CIN2+ and CIN3+ compared with that of the cytological test, 241 women with HR-HPV infection were selected among 458 participants. The indication of colposcopy referral was considered to be the positive criterion for combined screening methods. When HPV genotyping combined with TCT or TruScreen was performed in HR-HPV-positive women, the indicators for a colposcopy were HPV16/18-positive with TCT NILM or TruScreen normal results or HR-HPV-positive with TCT ASCUS-positive or TruScreen abnormal results.

Statistical analysis

IBM SPSS software (Version 23.0) was used to process the data mentioned above. The sensitivity, specificity, positive predictive value (PPV), and negative predictive value (NPV) of each screening method were calculated by using CIN2+ and CIN3+ as the gold standard. Exact McNemar's $\chi 2$ test was used to compare differences between groups. Statistical significance was recognised as $P < 0.05$.

Ethical considerations

This study was carried out according to the principles set out in the Declaration of Helsinki 1964 and all subsequent revisions. It was approved by the Renji Hospital (affiliated with Shanghai Jiao Tong University School of Medicine) Ethics Committee (Committee's reference number: 2018–211). Informed consent was obtained from all individual participants included in the study.

Results

Baseline characteristics

There were 458 subjects included in the study, with an average age of 41.52 years. Pathological results showed that there were 37 (8.08%) CIN2+ cases, including 11 (2.40%), 24 (5.24%), and 2 (0.44%) CIN2, CIN3, and cervical cancer cases, respectively. There were 69 (15.07%), 214 (46.72%), and 120 (26.20%) HPV16/18-positive, TCT

ASCUS or worse, and TruScreen abnormal cases among the 458 subjects, respectively (Table 1).

TruScreen screening results

The positive rate of TruScreen markedly increased with increasing severity of TCT diagnosis, from 14.34% (35/244) in women with NILM to 100% (8/8) in women with HSIL. Similarly, this rate increased from 25.68% (66/257) to 83.33% (20/24) and 100% (2/2) in women with normal histology results, CIN3, and cervical cancer, respectively (Table S1).

Diagnostic performance of TruScreen in detection of CIN2+ and CIN3+

For detection of CIN2+, the specificity of TruScreen (78.86%) was significantly higher than that of HPV testing (50.59%, P < 0.001) and TCT (55.58%, P < 0.001). Additionally, the sensitivity of TruScreen was 83.78%, which was similar to that of HPV testing (89.19%, P = 0.754) and TCT (72.97%, P = 0.344). The PPV of TruScreen (25.83%) was significantly higher than that of HPV testing (13.69%, P < 0.01) and TCT (12.62%, P < 0.01), while the NPV (98.22%) was similar to that of HPV testing (98.16%, P = 1.000) and TCT (95.90%, P = 0.091) (Table 2). Similar results were obtained for CIN3+ cases. When compared with HPV testing and TCT, TruScreen showed higher specificity (77.31%) and PPV (18.33%), but similar sensitivity (84.62%) and NPV (98.82%) (Table 2).

Diagnostic performance of a combination of HPV testing and TruScreen to detect CIN2+ and CIN3+

In combined screening trials of 241 HR-HPV-positive women, there were 154 (63.90%) and 135 (56.02%) patients screened through HPV genotyping and TCT or HPV genotyping and TruScreen, respectively, who met the criteria for a colposcopy referral (Table 3).

Women with HR-HPV-positive results were further triaged by TruScreen or TCT. HR-HPV-positive women with a further triage with TruScreen had a lower positive rate (56.02%), but higher specificity and similar sensitivity than the group screened with the current cervical cancer screening strategy based on TCT triage for HPV primary screening (Table 3). For detection of CIN2+ with TruScreen, HR-HPV-positive women had a higher specificity (50% vs 39.9%, P = 0.004), PPV (22.96% vs 18.83%, P < 0.001), and NPV (98.11% vs 95.4%, P < 0.001) than HR-HPV-positive women screened with TCT, while the sensitivity of the two screening methods was similar (93.94% vs 87.88%, P = 0.625) (Table 3). For CIN3+ detection, the sensitivity was equal for both strategies (95.45%), while HR-HPV-positive-women screened with TruScreen exhibited a significantly higher specificity (47.95% vs 39.27%, P = 0.011), PPV (15.56% vs 13.64%, P < 0.001), and NPV (99.06% vs 98.85%, P < 0.001) than HR-HPV-positive women screened with TCT (Table 3).

Discussion

Early screening and intervention are key to preventing and treating cervical cancer. Large-scale and effective cervical cancer screening and the application of the HPV vaccine have greatly reduced cervical cancer rates in many countries [8]. However, in most developing countries, cervical cancer rates remain high [9], which may be due to lacking economic capacity, limited health care, inadequate cancer screening, and lack of universal access to vaccines. In China, although there have been substantial morbidity and mortality due to HPV-associated cervical cancer cases, both the vaccination rates and screening coverage remain low. The current rate of cervical cancer screening in Chinese women is 21.4% [10]. Notably, the HPV vaccine is expensive and only available in limited supply, despite it being imported into China in recent years [11]. Because of these factors, most Chinese women are still not vaccinated.

Cytological detection methods are widely used in clinical practice, but it often takes several days to receive results due to the delay associated with transporting samples to laboratories for analysis and reporting. Furthermore, cytological testing results are easily affected by subjective factors such as sampling and differing expertise in reading pathological results, resulting in low sensitivities and high rates of missed diagnoses [12]. In one study [13], sensitivities of the liquid-based cytology examinations were in the ranges of 52%–94% and 52%–98% for the detection of CIN2+ and CIN3+, respectively. Furthermore, specificities were in the range of 73%–97% for the detection of CIN2+. HPV testing is more sensitive than cytological methods for the detection of high-grade intraepithelial neoplasia of the cervix [14]. Notably, most HPV infections are transient, resulting in high false-positive rates of HPV testing. The number of individuals referred for a colposcopy due to positive HPV test results was twice as high as that for cytology [15]. This leads to unnecessary testing and treatment for overdiagnosis and increases the physical, psychological, and economic burden on patients. Therefore, it is imperative to find an efficient adjuvant screening method to improve the diagnostic accuracy of cervical precancerous lesions.

TruScreen is a real-time optoelectronic intelligent screening technology for cervical cancer and precancerous lesions. This technology has an objective, self-checking digital system that can be used by medical or paramedical staff with minimal training and without the infrastructure and resource costs associated with

Table 1
Distribution of HR-HPV, TCT and TruScreen by Histological Results among 458 Women.

	Total NO. (%)	Normal NO.(%)	CIN1 NO.(%)	CIN2 NO.(%)	CIN3 NO.(%)	Cancer NO.(%)
HR-HPV						
Negative	217(47.38)	88(34.24)	7(15.22)	0	3(12.50)	1(50)
HPV16/18+	69(15.07)	36 (14.01)	11(23.91)	7(63.64)	14(58.33)	1(50)
non-HPV 16/18+	172(37.55)	133(51.75)	28(60.87)	4(36.36)	7(29.17)	0
TCT						
NILM	244(53.28)	101(39.30)	15(32.61)	6(54.55)	4(16.67)	0
ASCUS	145(31.66)	112(43.58)	21(45.65)	2(18.18)	8(33.33)	2(100)
LSIL or worse	69(15.07)	44(17.12)	10(21.74)	3(27.27)	12(50)	0
TruScreen						
Normal	338(73.80)	191(74.32)	23(50)	2(18.18)	4(16.67)	0
Abnormal	120(26.20)	66 (25.68)	23(50)	9(81.82)	20(83.33)	2(100)
Total	458	257(56.11)	46(10)	11(2.40)	24(5.24)	2(0.44)

HR-HPV: high-risk human papillomavirus; TCT: ThinPrep cytology test; CIN: cervical intraepithelial neoplasia; NILM: negative intraepithelial lesion or malignancy; ASCUS: atypical squamous cells of undetermined significance; LSIL: low-grade squamous intraepithelial lesion.

Table 2
Clinical Performance of HPV testing, TCT and TruScreen for Detection of CIN2+ and CIN3+.

	HPV testing		TCT		TruScreen		P value	
	NO. of Positive/N	Estimate% (95% CI)	NO. of Positive/N	Estimate% (95% CI)	NO. of Positive/N	Estimate% (95% CI)	P1	P2
Threshold	HR-HPV-positive		ASCUS+		Abnormal			
Detection of CIN2+ (N = 37)								
Sensitivity	33/37	89.19(74.58, 96.97)	27/37	72.97(55.88, 86.21)	31/37	83.78(67.99, 93.81)	0.754	0.344
Specificity	213/421	50.59(45.71, 55.47)	234/421	55.58(50.69, 60.39)	332/421	78.86(74.64, 82.66)	<0.001	<0.001
PPV	33/241	13.69(9.62, 18.69)	27/214	12.62(8.48, 17.82)	31/120	25.83(18.28, 34.62)	0.004	0.002
NPV	213/217	98.16(95.35, 99.50)	234/244	95.90(92.59, 98.02)	332/338	98.22(96.18, 99.35)	1.000	0.091
Detection of CIN3+ (N = 26)								
Sensitivity	22/26	84.62(65.13, 95.64)	22/26	84.62(65.13, 95.64)	22/26	84.62(65.13, 95.64)	1.000	1.000
Specificity	213/432	49.31(44.49, 54.13)	240/432	55.56(50.73, 60.30)	334/432	77.31(73.07, 81.18)	<0.001	<0.001
PPV	22/241	9.13(5.81, 13.49)	22/214	10.28(6.56, 15.15)	22/120	18.33(11.86, 26.43)	0.012	0.037
NPV	213/217	98.16(95.35, 99.50)	240/244	98.36(95.86, 99.55)	334/338	98.82(97, 99.68)	0.718	0.726

P1 indicates the comparison between HPV testing and TruScreen.
P2 indicates the comparison between TCT and TruScreen.
CI: confidence interval; PPV: Positive predictive value; NPV: Negative predictive value; HR-HPV: high-risk human papillomavirus; TCT: ThinPrep cytology test; CIN: cervical intraepithelial neoplasia; ASCUS: atypical squamous cells of undetermined significance.

Table 3
Clinical Performance of HPV genotyping combined with TruScreen or TCT in HR-HPV-positive women for Detection of CIN2+ and CIN3+.

	HR-HPV (+) with TruScreen		HR-HPV (+) with TCT		P value
	NO. of Positive/N	Estimate% (95% CI)	NO. of Positive/N	Estimate% (95% CI)	
Threshold	Normal TruScreen with HPV16/18 positive, or Abnormal TruScreen with HR-HPV-positive		NILM of TCT with HPV16/18 positive, or ASCUS+ of TCT with HR-HPV-positive		
Positive	135/241	56.02 (49.5, 62.38)	154/241	63.9(57.49, 69.97)	
Detection of CIN2+(N = 33)					
Sensitivity	31/33	93.94(79.40, 99.32)	29/33	87.88(72.07, 95.79)	0.625
Specificity	104/208	50(43.01, 56.99)	83/208	39.9(33.2, 46.9)	0.004
PPV	31/135	22.96(16.17, 30.98)	29/154	18.83(12.99, 25.91)	<0.001
NPV	104/106	98.11(93.35, 99.77)	83/87	95.4(88.64, 98.73)	<0.001
Detection of CIN3+ (N = 22)					
Sensitivity	21/22	95.45(76.49, >99.99)	21/22	95.45(76.49, >99.99)	1.000
Specificity	105/219	47.95(41.17, 54.78)	86/219	39.27(32.76, 46.08)	0.011
PPV	21/135	15.56(9.89, 22.79)	21/154	13.64(8.64, 20.09)	<0.001
NPV	105/106	99.06(94.86, 99.98)	86/87	98.85(93.76, 99.97)	<0.001

P value indicates comparison between TruScreen and TCT in HR-HPV positive women.
CI: confidence interval; PPV: Positive predictive value; NPV: Negative predictive value; HR-HPV: high-risk human papillomavirus; TCT: ThinPrep cytology test; CIN: cervical intraepithelial neoplasia; NILM: negative intraepithelial lesion or malignancy; ASCUS: atypical squamous cells of undetermined significance.

cytology-based screening. TruScreen has been used as an adjunct to cervical cancer screening tools in clinical studies [16]. Abdul et al. [17] found that the sensitivity and specificity of TruScreen detection of CIN2/3 were 74% and 53%, respectively. Similarly, another multicentre evaluation showed a sensitivity of 70% for the detection of CIN2/3 by TruScreen [18]. In our study, the sensitivity and specificity findings presented in Table 2 indicate that TruScreen performs well as a primary screening tool for detecting CIN2+ and CIN3+.

Our study further evaluated the clinical performance of TruScreen for the detection of CIN2+ and CIN3+ in HR-HPV-positive women and compared it with that of TCT. For detection of CIN2+, TruScreen showed a higher specificity, PPV, and NPV than TCT, while the sensitivities of both methods were similar. Similar patterns were observed for the detection of CIN3+.

There was a rare report on the diagnostic value of TruScreen triage of primary HPV screening for cervical cancer. In a study by Pruski et al. [19], wherein the threshold of HPV testing combined with the optoelectronic method was either the HR-HPV or optoelectronic method being abnormal, which was different from that in our study, and the sensitivity of HPV testing in combination with the optoelectronic method for the detection of CIN2/3 was 100%. In another recent study, wherein the threshold of HPV testing combined with TruScreen was similar to that in our study, the sensitivity and specificity for identifying women with CIN2+ were 96.3% and 36.8%, respectively [20]. These results suggested that the detection value of HR-HPV-positive samples with a further triage with TruScreen is no worse than that of the current cervical cancer screening strategy based on TCT triage of HPV primary screening for cervical cancer.

However, TruScreen cannot grade cervical abnormalities as with TCT. Although TruScreen costs the same as HPV testing and is slightly more expensive than TCT, TruScreen has been covered by medical insurance in some parts of China, such as Jiangsu, Shandong, and Hebei provinces. As more medical institutions introduce TruScreen and more people use it for cervical cancer screening, we believe that this technology will soon be included in health care in other parts of China. Furthermore, TruScreen has the advantages of real-time results, objectivity, non-invasiveness, portability, and a simple operation method that does not require advanced operator ability. To select a reasonable cervical cancer screening method, it is important to consider not only the screening indices (such as sensitivity and specificity) of the method, but also the applicability of the method (including cost, efficiency, and patient experience) [21]. Patient experience is improved because TruScreen is more acceptable to women than a cytological test because no cervical tissue needs to be taken during the test, meaning minimal to no discomfort. Furthermore, real-time results are provided, so instead of patients needing to wait for test results to come back and make another appointment, they can ask their doctor right away if they need further treatment. To some extent, this can also avoid the anxiety that can arise while waiting for the report.

Our study had a few limitations. We had a limited number of subjects and future studies are needed to confirm the clinical value of TruScreen as a screening tool for cervical cancer in a larger population. Additionally, TruScreen was not performed simultaneously with HPV testing and TCT, which may have resulted in a biased observation.

Conclusions

In conclusion, our study assessed the clinical value of TruScreen in the detection of CIN2+ and CIN3+, either alone or as triage in HR-HPV-positive women. The results show that the TruScreen device has the potential to be used as a screening tool for cervical cancer. This provides an additional option for appropriate cervical cancer screening methods in China.

CRediT authorship contribution statement

Yingting Wei:,**Wenjing Wang:**,**Mengxing Cheng:**,**Zubei Hong:**, **Liying Gu:**,**Jiaxin Niu:**,**Wen Di:**,**Lihua Qiu:**.

Declaration of Competing Interest

The authors declare that they have no known competing financial interests or personal relationships that could have appeared to influence the work reported in this paper.

Acknowledgements

Not applicable.

Availability of data and materials

All data generated or analysed during this study are included in this published article and its supplementary information files.

Consent for publication

Not applicable.

Funding

This work was financially supported by the Science and Technology Commission of Shanghai Municipality (Nos. 18411963100 and 18441904800), the National Key Research and Development Program (863) of China (No. 2016YFC1302900), the National Natural Science Foundation of China (Nos. 81772770 and 81874101), the Shanghai Municipal Commission of Health and Family Planning (Nos. 2017ZZ02016 and ZY[2018-2020]-FWTX-3006), the Shanghai Municipal Key Clinical Specialty and the Program of Shanghai Hospital Development Center (No. 16CR2001A).

Authors' contributions

WD and LQ designed and supervised the project. WW, ZH, LG, MC, and JN collected the clinical samples. YW and WW gathered and processed the data. YW performed the data analysis. YW and WW drafted the manuscript. All authors reviewed, discussed, and edited the final version of the manuscript. YW and WW are co-first authors and contributed equally to this article.

Appendix A. Supplementary data

Supplementary data to this article can be found online at https://doi.org/10.1016/j.ejogrb.2021.09.027.

References

[1] Bray F, Ferlay J, Soerjomataram I, Siegel RL, Torre LA, Jemal A. Global cancer statistics 2018: GLOBOCAN estimates of incidence and mortality worldwide for 36 cancers in 185 countries. CA Cancer J Clin 2018;68:394–424.
[2] Arbyn M, Weiderpass E, Bruni L, de Sanjosé S, Saraiya M, Ferlay J, et al. Estimates of incidence and mortality of cervical cancer in 2018: a worldwide analysis. Lancet Glob Health 2020;8(2):e191–203.
[3] zur Hausen H. Papillomaviruses and cancer: from basic studies to clinical application. Nature reviews. Cancer 2002;2(5):342–50.
[4] Roden RBS, Stern PL. Opportunities and challenges for human papillomavirus vaccination in cancer. Nat Rev Cancer 2018;18(4):240–54.
[5] Gynecologists TACooa. Cervical Cancer Screening and Prevention. Obstet Gynecol. 2016; 127: 1-20.
[6] Wentzensen N, Arbyn M, Berkhof J, Bower M, Canfell K, Einstein M, et al. Eurogin 2016 Roadmap: how HPV knowledge is changing screening practice. Int J Cancer 2017;140(10):2192–200.
[7] Salazar-Campos JE, Gonzalez-Enciso A, Diaz-Molina R, Lara-Hernandez ME, Coronel-Martinez J, Perez-Plasencia C, et al. Cervicouterine cancer screening - TruScreen (TM) vs. conventional cytology: pilot study. J Cytol 2018;35:143–8.
[8] Curry SJ, Krist AH, Owens DK, Barry MJ, Caughey AB, Davidson KW, et al. Screening for cervical cancer: US preventive services task force recommendation statement. JAMA 2018;320(7):674. https://doi.org/10.1001/jama.2018.10897.
[9] Vu M, Yu J, Awolude OA, Chuang L. Cervical cancer worldwide. Curr Probl Cancer 2018;42(5):457–65.
[10] Bao H, Zhang L, Wang L, Zhang M, Zhao Z, Fang L, et al. Significant variations in the cervical cancer screening rate in China by individual-level and geographical measures of socioeconomic status: a multilevel model analysis of a nationally representative survey dataset. Cancer Med 2018;7(5):2089–100.
[11] Zou Z, Fairley CK, Ong JJ, Hocking J, Canfell K, Ma X, et al. Domestic HPV vaccine price and economic returns for cervical cancer prevention in China: a cost-effectiveness analysis. Lancet Glob Health 2020;8(10):e1335–44.
[12] Wright TC, Stoler MH, Behrens CM, Sharma A, Sharma K, Apple R. Interlaboratory variation in the performance of liquid-based cytology: insights from the ATHENA trial. Int J Cancer 2014;134(8):1835–43.
[13] Koliopoulos G, Nyaga VN, Santesso N, Bryant A, Martin-Hirsch PP, Mustafa RA, et al. Cytology versus HPV testing for cervical cancer screening in the general population. Cochrane Database Syst Rev 2017;8. CD008587.
[14] Rijkaart DC, Berkhof J, Rozendaal L, van Kemenade FJ, Bulkmans NWJ, Heideman DaniëlleAM, et al. Human papillomavirus testing for the detection of high-grade cervical intraepithelial neoplasia and cancer: final results of the POBASCAM randomised controlled trial. Lancet Oncol 2012;13(1):78–88.
[15] Wright TC, Stoler MH, Behrens CM, Sharma A, Zhang G, Wright TL. Primary cervical cancer screening with human papillomavirus: end of study results from the ATHENA study using HPV as the first-line screening test. Gynecol Oncol 2015;136(2):189–97.
[16] Long S, Lei W, Feng Y, Lv D, Cai Y, Yang P. The feasibilities of TruScreen for primary cervical cancer screening: a self-controlled study. Arch Gynecol Obstet 2013;288(1):113–8.
[17] Abdul S, Brown BH, Milnes P, Tidy JA. The use of electrical impedance spectroscopy in the detection of cervical intraepithelial neoplasia. Int J Gynecol Cancer 2006;16:1823–32.
[18] Singer A, Coppleson M, Canfell K, Skladnev V, Mackellar G, Pisal N, et al. A real time optoelectronic device as an adjunct to the Pap smear for cervical screening: a multicenter evaluation. Int J Gynecol Cancer 2003;13(6):804–11.
[19] Pruski D, Kedzia W, Przybylski M, Józefiak A, Purol M, Spaczyński M. Assessment of optoelectronic method and molecular test usefulness for cervical intraepithelial neoplasia and cervical cancer detection. Ginekol Pol 2010;81:426–30.
[20] Wang Z, Kang Y, Yu F, Zhong F-H, Huang K, Zhou X, et al. TruScreen detection of cervical tissues for high-risk human papillomavirus-infected women during the COVID-19 pandemic. Future Oncol 2021;17(10):1197–207.
[21] Sawaya GF, Sanstead E, Alarid-Escudero F, Smith-McCune K, Gregorich SE, Silverberg MJ, et al. Estimated Quality of life and economic outcomes associated with 12 cervical cancer screening strategies: A cost-effectiveness analysis. JAMA Intern Med 2019;179(7):867. https://doi.org/10.1001/jamainternmed.2019.0299.