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Abstract. Oral cancer is a serious and growing problem in many developing and developed countries. To improve the cancer screening procedure, we developed a portable light-emitting-diode (LED)-induced autofluorescence (LIAF) imager that contains two wavelength LED excitation light sources and multiple filters to capture ex vivo oral tissue autofluorescence images. Compared with conventional means of oral cancer diagnosis, the LIAF imager is a smaller, faster, and more highly reliable solution. The compact design with a tiny probe allows clinicians to easily observe autofluorescence images of hidden areas located in concave deep oral cavities. The ex vivo trials conducted in Taiwan present the design and prototype of the portable LIAF imager used for analyzing 31 patients with 221 measurement points. Using the normalized factor of normal tissues under the excitation source with 365 nm of the central wavelength and without the bandpass filter, the results revealed that the sensitivity was larger than 84%, the specificity was not smaller than over 76%, the accuracy was about 80%, and the area under curve of the receiver operating characteristic (ROC) was achieved at about 87%, respectively. The fact shows the LIAF spectroscopy has the possibilities of ex vivo diagnosis and noninvasive examinations for oral cancer. © 2017 Society of Photo-Optical Instrumentation Engineers (SPIE) [DOI: 10.1117/1.JBO.22.4.045007]

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1 Introduction

Oral cancer is a serious and growing problem in the world. Over 90% of oral caners are oral squamous cell carcinoma (OSCC) in oral mucosa.1,2 The remaining oral caners are verrucous carcinoma, spindle cell carcinoma, adenosquamous carcinoma, adenoid cell carcinoma, basaloid squamous carcinoma, and mucoepidermoid carcinoma. There are three types of carcinoma including squamous cell carcinoma, verrucous carcinoma, and spindle cell carcinoma in our study. OSCC begins from premalignant squamous cells or potentially malignant squamous cells in a stratified squamous epithelium. According to the world health organization grading system, OSCC is classified into well-differentiated, moderately differentiated, and poorly differentiated types based on the degree of cell differentiation.1 In histopathology, well-differentiated squamous cell carcinoma (SCC), which resembles more likely normal squamous epithelium, has the feature of high keratinization that forms in epithelial pearls, less atypical mitotic activity, and less syncytium. Poorly differentiated SCC, which is mainly composed with immature cells, has the features of low keratinization, high atypical mitosis, more cells or nuclei with pleomorphism, and more syncytium. Moderately differentiated has the features of distinct nuclear pleomorphism, abnormal mitotic activity, and minimal keratinization.1,2 Verrucous cell carcinoma is a variant of well-differentiated SCC. It has exophytic slow-growth of keratinized stratified squamous epithelium and locally subepithelial growth in destructive and expansive types.1 Spindle cell carcinoma is a rare variant of SCC.3 It is composed of in situ or invasive squamous cell carcinoma and malignant spindle cells that constitute a mesenchymal appearance, but it is of epithelial origin.4 In clinical and histological, verrucous hyperplasia is considered to resemble verrucous carcinoma or squamous carcinoma. Compared to the invasive growth of verrucous carcinoma, verrucous hyperplasia is a superficial growth adjacent to normal epithelium.5 OSCC or premalignant OSCC almost presents the lesions which are abnormal damaged tissue or change in the tissue in oral cavity. The most common early lesions of premalignant OSCC are oral leukoplakia, oral erythroplakia, and speckled leukoplakia. The symptomatic lesions of site distribution in OSCC are classified under T category of the tumor-node-metastasis classification for malignant tumors. T1 lesions are the diameter of lesions that are 2 cm or < 2 cm. T2 lesions are of diameter between 2 to 4 cm. T3 lesions are of diameter longer than 4 cm. T4 means that the tumor invades adjacent tissues. T4a means that the tumor invades through a cortical bone, into extrinsic or deep muscle of the tongue and T4b means that the tumor invades masticator space, pterygoid plates, or skull base.2

Presently, increasingly more people are suffering from oral cancer, and it has become a serious health problem in many developing and developed countries. In 2008, ∼263,000 new cases of lip and oral cavity cancer were reported in the world, and 127,000 persons died of this disease.5 In 2012, ∼300,373
new cases of this cancer were reported worldwide, and 145,353
consequent deaths occurred. The age-standardized rates of inci-
dence and mortality of oropharyngeal cancer in 2012 were 4.0
and 1.9 per 100,000 persons, respectively. From 2008 to 2012,
the reported incidence and mortality rates of oral cancer in the
United States were 11 and 2.5 cases per 100,000 persons
annually, respectively. In 2012, 291,108 persons had oral cavity
and pharynx cancers in the United States. From 2007 to 2011, in
the United States, the incidence rates for oral cavity cancer was
the 7th and 13th most common cancer in men and women,
respectively. An estimated 45,780 new cases of oral cavity and
pharynx cancers were diagnosed in the United States in 2015,
and 8650 deaths were estimated to be due to this disease. In
addition, India, Melanesia, and Taiwan have high rates of
oral cancer attributable to betel quid or betel nut chewing.10
According to a report of the Ministry of Health and Welfare
of Taiwan, the mortality rate of oral cancer in 2013 was 21.4
per 100,000 persons. In Taiwan, oral cancer is ranked as the
fifth leading cause of cancer-related death in men.11
The possible explanations for the increasing incidence of oral
cancer are as follows. First, people have insufficient awareness
of the risk factors for oral cancer, and health care workers can detect
only limited signs and symptoms of oral cancer from conven-
tional examinations. The visual inspection and digital palpation
of oral lesions in conventional examinations are insufficient for
diagnosing oral cancer.12–15 Conventional clinical examinations
that involve detecting suspicious lesions with toluidine blue stain-
ing, brush cytology, tissue chemiluminescence, and autofluores-
cence have variable effectiveness.15,16 Second, patient habits, such
as tobacco and alcohol consumption and betel nut chewing as a
cultural practice, expose the mucosal lining to carcinogens.15–17
Third, biopsies of oral lesions for diagnosing oral cancer must be
performed by specialists in hospitals. However, in developing
countries, people living in low-resource regions have inadequate
resources, specialists, and hospitals for examination, which can
delay cancer diagnosis and lead to high mortality.
Health care workers worldwide can prevent 37,000 oral cancer
deaths through simple oral visual screening annually.18 In the
United States, the five-year survival rate for oral cancer is
59%, one of the lowest among all major cancers. This rate is
persistent at ~50% to 55% because most patients are diagnosed
at an advanced stage.19,20 The survival rate for oral cancer is
35–50%, despite improvements in diagnosis and treatment.21,22
Because patients diagnosed with early lesions can be treated,
oral cancer must be detected and managed early to reduce mortal-
ity and morbidity.23,24 Therefore, the early detection of oral
cancer may be a favorable and cost-effective method to improve
the survival and quality of life of patients with oral cancer.25
However, the conventional oral examination with the visual
inspection and digital palpation of oral lesions is not an objective
and reliable method to distinguish lesions in different stages, and
it results in the delayed treatment of patients or the oral cancer
progressing to a late stage.16,19,26 Therefore, technologies
with high sensitivity and specificity have been developed to facili-
tate the early diagnosis and treatment of patients.27–31
Optical imaging assists clinicians in detecting oral cancer.
Optical imaging systems have been proposed to record the spa-
tial distribution of fluorescence images with specific emission
and excitation wavelengths in oral tissues. These systems can
noninvasively detect a region of the oral cavity mucosa to deter-
mme the changes associated with oral cancer.16,18,27,32–35
A hand-held device, the VELscope, was proposed for clinicians
to noninvasively direct the fluorescence images of oral cavity
histology,16 Roblyer proposed a simple objective method to clas-
sify regions of interest (ROIs) and evaluate the sensitivity and
specificity relative to the histopathology of oral neoplastic
lesions through multispectral digital microscopy. The results
indicated that quantitative autofluorescence imaging can pro-
vide a noninvasive and objective method for detecting oral neo-
plasia. Rahman proposed a handheld system for clinicians to
screen and detect oral cancer. This portable system is mounted
on the observer’s head and used in clinics in low-resource coun-
tries. Digital images of oral tissues captured in white-light and
fluorescence imaging modes can be used for the incorporation
of automated image analysis algorithms to improve oral cancer
detection.27 The autofluorescence images observed by the eye
through the VELscope show the characteristic region of fluo-
rescence visualization loss to indicate the development and
progression of oral neoplasia.30 Other hand-held devices based
on the autofluorescence image are Identafi 3000 (DentalEZ Inc.)
and EVINCE® (MMOptics, São Carlos, Brazil). Identafi 3000
uses fluorescence, fiber optics, and confocal microscopy to
screen and observe lesions.31 EVINCE® (MMOptics, São
Carlos, Brazil) emits light with LEDs system into tissues and
observes tissue autofluorescence through an optical filter.32 The
several studies having trials on detecting OSCC and oral poten-
tially malignant disorders (OPMD) using VELscope, Identafi,
and EVINCE seem to agree with certain consistent results in
individual research and show the possibilities of OSCC and OPMD
early detection potentially with autofluorescence imaging.16,33,35,37–39
Some studies observed the spectra of autofluorescence on
different anatomical sites and found some characteristics
between different sites. De Veld et al.33,40 observed autofluo-
rescence characteristics of different anatomical sites with seven
wavelengths excitation light source for healthy oral mucosa.
They found that the normalized spectra were similar for loca-
tions that did not include dorsal side of the tongue (DST) and
the vermilion border (VB). Furthermore, the DST and the
VB having a peak at about 635 nm were observed. Mallia et al.39
used laser-induced autofluorescence technology for early cancer
detection. This group similarly found that not only the DST and
the VB but also the lateral side of the tongue had a peak at about
635 nm with a 404-nm excitation laser diode. Because of the
same peak in malignant lesions, they excluded these sites
from the study and had a good result of detecting premalignant
and malignant tissues.
To provide clinicians with an objective and reliable method for
the accurate diagnosis of oral cancer in clinics or developing
countries, a portable detection device is required. In this paper,
we propose a portable LED-induced autofluorescence (LIAF)
imager. In a previous study, we developed an embedded relay
lens microscopic hyperspectral imaging (ERL-MHSI) system.
This system can be utilized for identifying pathological changes
and is advantageous for developing a portable LIAF imager. This
ex vivo trial conducted in Taiwan shows the design and prototype
of a portable LIAF imager used for analyzing 31 patients. Finally,
the results were analyzed using two normalized factors, where
specimens were illuminated at two excitation wavelengths, and
images were captured with or without two filters.

2 Principle and Theory
Several studies have reported that autofluorescence imaging
may detect premalignant and malignant oral tissues.16,34,36,38
A portion of photons is absorbed by fluorophores present in oral mucosal molecules when the mucosa is illuminated at blue and UV-visible wavelengths. The fluorophores emit photons with lower energy, and subsequently, the photons can be viewed as fluorescence from the oral mucosal surface. The reduced fluorophores include nicotinamide adenine dinucleotide and flavin adenine dinucleotide in the epithelium, and collagen and elastin crosslinks in the stroma have been reportedly associated with the development and progression of oral neoplasia.\textsuperscript{16,52,53}

Studies have proposed various technologies for clinicians to detect fluorescence images and diagnose oral neoplasia.\textsuperscript{54,55} Optical spectroscopy has been proposed to assist in the diagnosis of oral lesions.\textsuperscript{19,33,56,57} We previously developed the ERL-MHSI system (Fig. 1).\textsuperscript{58} This system provides high spectral and spatial resolutions of the spectrum, and the morphological diagnosis of cancer can be performed in the transmittance and fluorescence modes under illumination with halogen and xenon lamps, respectively. The fluorescence images of cells or tissues can be identified as normal or abnormal. In the previous study, we demonstrated the efficiency of the ERL-MHSI system by diagnosing early stage oral cancer in 20 mice in vitro. The spatial distribution of tissue fluorescence at specific excitation wavelengths can be recorded, and the correlation between the fluorescence intensities of normal and abnormal cells is analyzed for the early detection of oral cancer. The correlation function $c(f, g)$ is shown as Eq. (1),

$$c(f, g) = \int f(\lambda)d\lambda \otimes \int g(\lambda)d\lambda$$  \hspace{1cm} (1)$$

where $f(\lambda)$ and $g(\lambda)$ are the fluorescence intensities of normal and abnormal cells, and $\lambda$ is the wavelength. The fractal dimension is utilized to analyze the differences in morphological information between normal tissue and squamous cell carcinoma. Therefore, the ERL-MHSI system can serve as a platform for exploring specific excitation wavelengths and filters for oral cancer detection.

Fluorescence imaging is widely used in biochemical invasive biopsy to enhance fluorescence images; however, autofluorescence is a more favorable method for in vivo examination. The ERL-MHSI system is large, and hyperspectral image data are extensive. Moreover, only in vitro trials can be conducted with the ERL-MHSI system. Therefore, the LIAF imager is proposed as a portable device that can be used in vivo. Based on the ERL-MHSI system, the design of a portable LIAF imager with specific excitation wavelengths and specific filters is introduced in the next section.

### 3 Design and Embodiment

The proposed portable LIAF imager contains two key components: two wavelengths LED excitation light sources to induce autofluorescence and multiple filters for capturing specific fluorescence images. Figure 2 shows a block diagram of the system, and Fig. 3 shows the construction of the LIAF imager. The LED light source in the imager is used for excitation. A rotary filter ring is integrated with the detector head for users to select the bandpass filter of interest. The probe in front of the LED light source is used for fixing the object distance and blocking ambient light. The filter ring behind the LED light source can be rotated by the fingers to change filters, and the filter location is fixed by positioning beads. The excitation light emitted from the
light source is projected on the target on the oral mucosal surface; autofluorescence is subsequently induced from this surface and passes through the probe. The light source has a hole in the middle (Fig. 3). Finally, the imager contains a lens, and a color complementary metal-oxide semiconductor (CMOS) captures the fluorescence images. Figure 4 shows an embodiment of the portable LIAF imager.

The LED light source has two excitation wavelength regions: 350 to 380 nm (L1) and 390 to 425 nm (L2). The rotary filter ring contains three bandpass filters, with wavelength regions of ∼490 to 590 nm (F_I), 590 to 690 nm (F_II), and 650 to 750 nm (F_III). The resolution of the imaging module is 1600 × 1200. In Fig. 5(a), red (R), green (G), and blue (B) spectral responses of the CMOS are marked as a solid line, and the transmittance of the bandpass filters is marked as dashed lines. Figure 5(b) shows the combinations of the RGB responses and transmittance of the filters. The combinations of G × F_I, R × F_II, and R × F_III were larger than those of other combinations, and their bandwidths were less than 100 nm. According to a screening result of the ERL-MHSI system, the representative autofluorescence spectra of normal and tumor tissues under L1 exciting light source have the peaks and gaps at about 525, 635, and 695 nm. Therefore, these three bands were chosen to be observed.

4 Materials and Methods

The study was conducted at China Medical University Hospital, Taichung City, Taiwan. This study recruited patients who were referred to the Department of Otolaryngology-Head and Neck Surgery at the mentioned hospital because of suspicious oral lesions or those who were waiting to undergo head and neck surgery in the hospital ward. The study was reviewed and approved by the Institutional Review Board of China Medical University Hospital, and the imaging analysis was reviewed and approved by the Department of Electrical and Computer Engineering, National Chiao-Tung University, Taiwan. Written informed consent was obtained from all patients. Patients in the region who were aged 20 to 100 years and were scheduled for surgery to remove a previously diagnosed oral squamous carcinoma were eligible to participate in the study (Table 1).

Table 1 The characteristic of 31 subjects.

| Characteristic | Male | Female |
|---------------|------|--------|
| Number        | 30   | 1      |
| Age, mean ± SD| 54.9 ± 11.73 | 76 ± 0  |

The patients underwent standard-of-care surgery to remove oral neoplastic lesions. After surgical resection, the resected specimens were recorded using a camera. The specimens were obtained from the patients with squamous cell carcinomas after surgery and were transferred to the Biomedical Engineering R&D Center, China Medical University Hospital.

Thirty-one specimens from the subject’s oral cavity lesions of the 31 patients were surgically obtained by clinicians. After the clinician excised the tumor from the patient, the clinician selected four to nine points in the normal and tumor regions in a specimen [Fig. 6(a)] and started to acquire images immediately. Each selected point was photographed with two excitation light wavelengths (L1 and L2) through three channels (bandpass

Fig. 4 Portable LIAF imager.

![Fig. 4 Portable LIAF imager.](image)

Fig. 5 (a) RGB responses of the CMOS and the transmittance of three bandpass filters and (b) the combinations of CMOS RGB responses and the transmittance of the three filters.

![Fig. 5](image)

Fig. 6 Clinicians selected 4 to 9 points as measurement points depending on the area of the specimen, (a) the selection of eight measurement points on this specimen are marked with “o,” and (b) each of the selected points will be captured at two excitation light source (L1 and L2) through three channels (bandpass filter F_1, F_2, and F_3) and a channel without filter.
5 Results and Analysis

Tables 2 and 3 summarize the anatomical sites and histopathological diagnoses of the 31 specimens with 228 measurement points. The anatomical sites were located in the buccal cavity (n = 12), gum (n = 5), tongue (n = 8), lip (n = 2), and palate (n = 4). A total of 117 and 111 measurement points were imaged from the normal and tumor regions, respectively.

The experimental data analysis procedure is shown in Fig. 7. First, the effects of dark current noise were removed if the CMOS sensor detected the intensity of the dark current effects under a probe without any excitation. The images were captured from the normal and tumor regions of the specimen. Second, because of the limitation of the probe range, the ROIs of both normal and tumor images inside the probe range were selected [Fig. 6(a)]. Each intensity value of ROI in the captured images was calculated, and the values were normalized as red, green, and blue intensities as well as red-to-green, red-to-blue, or green-to-blue ratios of the ROI. Third, the mean value of ROI in normal or tumor images was the normalized factor. Fourth, each value of ROI was normalized by the normal and tumor factors, respectively. Based on the data in the last step, a scatter plot was plotted, and the Gaussian distribution of normal and tumor tissues was evaluated. Finally, the receiver operating characteristic (ROC) curve was plotted with various thresholds, where the x- and y-axes of the ROC denote specificity (%) and sensitivity (%), respectively. The sensitivity, specificity, and accuracy were determined at various thresholds.

Figure 8 shows representative images of tumor and normal tissues illuminated with L1 and L2 with or without the filters. The images without the filters were clearer than those with the filters because the filters block fluorescence into the CMOS.

Some images were captured incorrectly because the investigator was removed out the analysis procedure. The valid images of normal and tumor tissues illuminated with both L1 and L2 were captured without the filters for 221 and 191 measurement points from 31 and 30 specimens, respectively. The valid images of normal and tumor tissues illuminated with L2 alone were captured with the filters F_I and F_II for 196 measurement points from 30 specimens and 189 measurement points from 30 specimens.

Data on the blue intensity of normal and tumor tissues illuminated with L1 without the filters are used to represent the result of the analysis. The scatter plot of this case (Fig. 9) was evaluated by using the first five steps of the analysis procedure.

### Table 2: Anatomic sites of the 31 subjects.

| Anatomic site | Specimen number | Measurement point number of normal region | Measurement point number of tumor region |
|--------------|----------------|------------------------------------------|----------------------------------------|
| Buccal       | 12             | 45                                       | 44                                     |
| Gum          | 5              | 19                                       | 19                                     |
| Tongue       | 8              | 33                                       | 29                                     |
| Lips         | 2              | 5                                        | 5                                      |
| Palate       | 4              | 15                                       | 14                                     |
| Total        | 31             | 117                                      | 111                                    |

### Table 3: Histopathological diagnoses of the 31 anatomic sites.

| Diagnosis               | Specimen number | Measurement point number of normal region | Measurement point number of tumor region |
|-------------------------|-----------------|------------------------------------------|----------------------------------------|
| Squamous cell carcinoma | 26              | 97                                       | 92                                     |
| Spindle cell carcinoma  | 1               | 4                                        | 4                                      |
| Verrucous carcinoma     | 2               | 8                                        | 7                                      |
| Verrucous hyperplasia   | 2               | 8                                        | 8                                      |
| Total                   | 31              | 117                                      | 111                                    |

Fig. 8 The representative images of tumor tissues (T) and normal tissues (N) illuminated with L1 and L2 excitations without or with the bandpass filter F_1, F_2, or F_3.
The 218 measurement points of the ROI in normal and tumor regions are marked as “o” and “x,” respectively. The P values of Kolmogorov–Smirnov (KS) tests for both normal and tumor regions exceeded 0.05. Hence, the data distribution was similar to a Gaussian distribution. Moreover, the KS tests were performed for tissues illuminated with other excitation wavelengths with other filters, and all data distributions were similar to a Gaussian distribution. In Fig. 9, the solid line on the scatter plot represents the threshold defined by the crossing point marked as “filled diamond” between the Gaussian distribution of normal tissue and the Gaussian distribution of tumor tissue.

The best case showed that sensitivity was 84.68%, specificity was 76.24%, and accuracy was 80.66%. The solid line in Fig. 11 shows the ROC, and the area under the curve (AUC) of the ROC was 87.56%. In a similar analysis procedure, the valid images were analyzed, and the results are presented in Table 4, where NF_T and NF_N indicate the normalized factors for tumor and normal tissues, respectively. The AUC is a quantitative index for estimating the performance of the specific excitation wavelengths and filters. Table 5 shows the discrimination by the
AUC that occurs in different ranges. Some sensitivities based on the tumor normalization factor exceeded 80%. The AUC in 18 cases was higher than 80%, presented in bold in Table 4. The illumination of tissues with L1 without the filters resulted in the better diagnostic accuracy for oral cancer. Furthermore, we randomly picked five points to do the blind test for the best case. The threshold was determined by other unpicked measurement points in the same case. Table 6 shows the result of the blind test. The sensitivity, specificity, and accuracy were the same in 100%. The AUC of the ROC was about 81%.

Table 4  The results of six types analysis of L1 and L2 excitation without the filter and L2 excitation with F_I filter and F_II filter, where NF_T means the normalized factor of tumor tissues and NF_N means the normalized factor of normal tissues.

|       | L1 | L2   | L2_F_I | L2_F_II |
|-------|----|------|--------|---------|
|       | NF_T | NF_N | NF_T | NF_N | NF_T | NF_N | NF_T | NF_N |
| R     | Threshold | 1.29 | 0.80 | 1.47 | 0.84 | 0.97 | 0.97 | 1.09 | 0.89 |
|       | Se (%)  | 96.40 | 81.98 | 96.00 | 85.00 | 91.35 | 15.38 | 83.50 | 25.24 |
|       | Sp (%)  | 60.00 | 72.28 | 56.04 | 63.74 | 21.21 | 89.13 | 26.74 | 88.37 |
|       | Accuracy (%) | 78.28 | 77.36 | 76.96 | 74.87 | 57.14 | 50.00 | 57.67 | 53.97 |
|       | AUC (%)  | **85.19** | **83.91** | **87.57** | **80.03** | 50.73 | 52.75 | 60.51 | 63.63 |
| G     | Threshold | 1.13 | 0.87 | 1.73 | 0.87 | 1.24 | 0.82 | 1.08 | 1.08 |
|       | Se (%)  | 90.99 | 45.95 | 97.00 | 85.00 | 95.19 | 69.23 | 93.20 | 19.42 |
|       | Sp (%)  | 41.67 | 82.86 | 48.35 | 53.85 | 51.09 | 71.74 | 16.28 | 94.19 |
|       | Accuracy (%) | 66.67 | 63.89 | 73.82 | 70.16 | 74.49 | 70.41 | 58.20 | 53.44 |
|       | AUC (%)  | 67.63 | 67.57 | **89.94** | 73.38 | **85.05** | 77.54 | 57.08 | 51.37 |
| B     | Threshold | 1.09 | 0.91 | 1.20 | 0.85 | 0.97 | 0.97 | 1.08 | 1.08 |
|       | Se (%)  | 92.70 | 84.68 | 94.00 | 65.00 | 91.35 | 21.15 | 88.35 | 38.83 |
|       | Sp (%)  | 69.52 | 76.24 | 68.13 | 90.11 | 23.91 | 88.04 | 38.37 | 91.86 |
|       | Accuracy (%) | 81.48 | 80.66 | 81.68 | 76.96 | 59.69 | 52.55 | 65.61 | 62.96 |
|       | AUC (%)  | **87.32** | **87.56** | **84.70** | **83.29** | **52.69** | **55.08** | 65.50 | 68.30 |
| R/G   | Threshold | 1.21 | 0.83 | 1.31 | 1.38 | 0.85 | 1.44 | 1.12 | 0.85 |
|       | Se (%)  | 90.09 | 76.58 | 93.00 | 26.00 | 89.42 | 36.54 | 86.41 | 25.24 |
|       | Sp (%)  | 58.33 | 72.82 | 23.08 | 92.31 | 58.70 | 93.48 | 27.91 | 90.70 |
|       | Accuracy (%) | 74.43 | 74.77 | 59.69 | 57.59 | 75.00 | 63.27 | 59.79 | 55.03 |
|       | AUC (%)  | **85.00** | **82.42** | **58.47** | **61.60** | **80.97** | **80.42** | **58.03** | **59.52** |
| R/B   | Threshold | 1.18 | 0.84 | 1.34 | 0.85 | 1.04 | 0.96 | 1.11 | 0.86 |
|       | Se (%)  | 92.79 | 69.37 | 96.00 | 58.00 | 91.35 | 27.88 | 82.52 | 32.04 |
|       | Sp (%)  | 56.31 | 85.58 | 42.86 | 64.84 | 21.74 | 90.22 | 26.74 | 89.53 |
|       | Accuracy (%) | 75.23 | 77.21 | 70.68 | 61.26 | 58.67 | 57.14 | 57.14 | 58.20 |
|       | AUC (%)  | **80.55** | **78.57** | **81.75** | **64.30** | **53.84** | **55.47** | 63.85 | 64.96 |
| G/B   | Threshold | 0.94 | 1.11 | 1.61 | 0.70 | 1.25 | 0.82 | 1.08 | 0.97 |
|       | Se (%)  | 73.87 | 42.34 | 98.00 | 52.00 | 95.19 | 66.35 | 94.17 | 49.51 |
|       | Sp (%)  | 57.66 | 88.07 | 35.16 | 67.03 | 51.09 | 70.65 | 26.74 | 67.44 |
|       | Accuracy (%) | 65.77 | 65.00 | 68.06 | 59.16 | 74.49 | 68.37 | 63.49 | 57.67 |
|       | AUC (%)  | 68.94 | 64.30 | **86.59** | **57.31** | **84.73** | **76.75** | 61.05 | 57.35 |
6 Discussion
This paper proposes a portable LIAF imager composed of a two wavelength LED excitation light source and multiple filters for oral cancer detection. Combinations of LED wavelengths and filter transmittance in the LIAF imager were explored using the ERL-MHSI system. Because this system is large and involves extensive hyperspectral imaging data, the LIAF imager is proposed as a compact device for in vitro application. It has a probe for fixing the objective length, thus providing protection from ambient light. Clinicians can easily observe the autofluorescence images of the hidden area located in a concave deep oral cavity, such as the deep port between the gums, gingiva, and mouth lining, by using the probe. In addition, VELscope, Identafi 3000, EVINCE, and the LIAF imager devices using different wavelength light sources and bandpass filters are according to the results of their studies. The efficiency of using different wavelength light sources or combined with bandpass filters for early detection needs more examination and studies for evidence. VELscope, Identafi 3000, and EVINCE mainly depend on fluorescence visualization of human eyes. Differently, LIAF is using RGB CMOS in order to acquire the quantitative data of the autofluorescence images. Therefore, the data are stored in a database and used to develop and improve the algorithm regarding early oral cancer analysis and detection.

Because of their betel nut chewing habit, patients in Asia have a higher risk of oral cancer than do those in the United States. Therefore, it is necessary to conduct similar ex vivo trials of oral cancer detection in Asia. In this study, 31 specimens from Taiwan were analyzed, and all sites were defined through biopsy and pathology. We analyzed two normalized factors under two excitation wavelengths with and without filters. The case with a normalized factor for normal tissue under L1 without a filter showed that sensitivity was larger than 84%, the specificity was not smaller than over 76%, the accuracy was about 80%, and the AUC of ROC curve was achieved at about 87%, respectively. Sensitivities exceeded 80% under other conditions when a tumor normalization factor was used (Table 4); the AUC in 18 cases exceeded 80% (marked in bold). The illumination of tissues with L1 without the filters resulted in better accuracy for oral cancer. If the AUC of the cases is lower than 70%, this case is not considered to be effective or usable. The AUC of almost low specificity cases were lower than 70%. However, the reason for low specificity for some cases needs to be further discussed.

In future studies, the excitation intensity of the LED light source must not only enhance the detection of oral lesions, but also modify the wavelength region of the excitation light and filters. Ex vivo trials will be implemented steadily to increase the number of subjects for increasing sensitivity, specificity, accuracy, and AUC. Moreover, on the basis of previous studies that used the ERL-MHSI system because of its higher magnification ability, oral cancer can be morphologically identified in the future.

Disclosures
The authors declare no conflicts of interest, financial or otherwise.

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