The Computer-aided Diagnostics of Gastric Lesions by using High Definition Narrow-band Imaging Endoscopy and Real-time Pattern Recognition System

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Abstract: High Definition (HD) and Magnified Narrow band imaging endoscopy (ME-NBI) allowed to recognizetypes of gastric lesions according modified VS-classification by professor Yao K., becausethe parameters to describe regular or irregularvascular or microsurface pattern and demarcation line in lesionswere formalized. In this work endoscopic differential criteria of benign and neoplastic epithelial lesions of stomach were obtained. Based on them classification algorithm for the real-time processing of narrow–band endoscopic images with a highly productive distributed intellectual analytic decision support system for multiscale endoscopic diagnostics is presented. We also created the electronic atlas and database to collect high resolution endoscopic images, applied and proved the differential diagnosis of gastric lesions through the computer analysis. The algorithm consistentlyused scale– invariant feature transform detector, computation of gastric mucosa pit–pattern skeletons, "Bag of visual words" method, and K–means method for key pointsclustering. Resulting classification algorithm is completely automated, performed real-time analysis, and did not require preliminary selection of interest area. Image classification accuracy was 85%.

1 INTRODUCTION

In Russia stomach cancer takes the first position in the structure of cancerdiseases (Kaprin, 2017). Every year tens of thousands of people fall ill with stomach cancer, and almost half the deaths occur (Savelyev, 2009). Gastric cancer is more often detected in the late stages of the tumor process. Treatment is expensive and despite all the efforts of surgeons and oncologists it often does not prolong the life of such patients for more than five years. The solution of the social and economic problem in this direction is the diagnosis of early gastric cancer (Japanese Gastric Cancer Association, 1998). Among the instrumental methods only upper gastrointestinal endoscopy aims to identify this disorder, as well as benign epithelial neoplasia and non-neoplastic lesions that are inclined to atypia.Gastroscopy allows directly visually evaluate the condition of the gastric mucosasurface. Correct differential diagnosis of such formations contributes to the selection of correct treatment tactic and 95% of patients' survival.

Routine white light endoscopy helps detect pathology focuses, whereas analysis of a pit and vascular pattern in mucosal structure, derived from enhancement techniques such as magnified narrow-band imaging (ME-NBI) endoscopy with video endoscopic high-resolution systems, allows to determine the types of lesions. The variety of these mucosal changes, the difficulties of their visual interpretation cause insufficient accuracy of recognition of pathological processes (Buntseva, 2014). Promising is the creation of an automated images processing during endoscopic exploration. Currently endoscopic computer-aided decision–making systems are created in different countries. Japanese specialists have achieved the most advanced results of analysis of thin structure for the revealed endoscopic lesions. Research by H. Osawa., H. Yamamoto, Y. Miura, H. Ajibe, H. Shinhata, M. Yoshizawa, K. Sunada, S. Toma, K. Satoh, and K. Sugano have shown the efficiency of computer–aided analysis of endoscopic images using digital chromoscopy in ascertainment of the

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boundaries between neoplasms and surrounding mucosa, thereby allowing determination of stomach cancer flattened forms (Osawa, 2012). R. Miyaki, S. Yoshida, S. Tanaka, Y. Kominami, Y. Sanomura, T. Matsuo, S. Oka, B. Raytchev, T. Tamaki, T. Koide, K. Kaneda, M. Yoshihara, and K. Chayama examined application of computerized image processing to endoscopy images obtained using digital chromoscopy for the purpose of detecting benign neoplasms and intramucosal early gastric cancer (Miyaki, 2013). T.C. Lee, Y.H. Lin, N. Uedo, and H.P Wang presented the previously results of computer–aided analysis of suspicious gastric carcinoma images, obtained with narrow band imaging in (Lee, 2013).Such computer–aided medical decision-support systems for endoscopy allow to keep labor costs down for endoscopy investigation. Nevertheless, theyrequire high level of endoscopist qualification to adjust analysis settings for each image. Besides, existing decision–making systems are not unified; they determine the particulartype of pathology, do not allow decision-making during the endoscopic exploration. Thedisadvantages of the existing decision–support systems mentioned abovemean that endoscopy services are very time taking.

With that in mind, the aim of this work was to develop a decision support system for endoscopic departments to diagnose precancerous and early neoplastic changes in the stomach mucosabased on the intelligent analysis of endoscopic images using computational methods, which include computer vision. We propose the method for processing narrow–band with or without magnification endoscopic images using a highly productive “Smart Endoscope” distributed intellectual analytic decision–support system for multiscale endoscopic diagnostics and surgery. This system exhibits the following advantages:ability to learn towards classify images obtained with various endoscopic methods; real–time operations that allow to make decisions on-the-fly, rather than post-test; completely automated analysis algorithms, which do not require prior selection of interest areas or additional operator training.

2 MATERIALS AND METHODS

2.1 Materials

We prospectively selected164 patients with 192 focal superficial epithelial gastric lesions. We performed 220 HD-NBI and ME-NBI endoscopic images of lesions surface. In this work we included prospectively both protruded and flat or depressed sites of damage. 220 images included 141 photos of benign lesions (hyperplastic polyps, erosions, ulcers, focuses of intestinal metaplasia) and 79 photos of neoplasia (low and high grade intraepithelial neoplasia, early gastric cancer, invasive and advanced gastric cancer).So, all images were divided into two groups according to the tactic of treatment: First group - non-neoplastic lesions (tactic – is observation); Second group - epithelial neoplasms of the stomach (tactic – is minimally invasive endoscopic,laparoscopic or open surgical treatment) (Dixon, 2002). The structure of the lesions was verified by histological examination of biopsy samples or resected portions of the mucosa.

2.2 Methods

The methods of investigation were routine white light endoscopy, high definition enhanced narrow band imaging endoscopy (with magnification from 50 to 115 times).

Statistical analysis included the application of Fisher's exact test, Cramer's criterion, the inhomogeneous sequential diagnostic Bayesian procedure (Gubler, 1978). The significance p-level was assumed to be 0.05.

On 182 (out of 220) endoscopic images the method of machine vision "Bag of visual words" was used to classify benign lesions (n=111) and epithelial neoplasms of the stomach (n=71) (Liedlgruber, 2011).

3 RESULTS

3.1 Statistical Analysis

All lesions and images we characterized with 34 criteria. Four criteria were clinical (age, gender, presence or absence of Helicobacter pylori infection, primary or residual lesion), 14 – were got during traditional endoscopy (localization, size, macrotype, number of lesions,presence or absence of fibrin, erosionof lesion surface, signs of inflammation, atrophy or intestinal metaplasia in surrounding mucosa, consistency, mobility, etc.), 16 – were got in time enhanced endoscopic explorations. These sixteen microendoscopic criteria of microsurface and microvascular pattern included specific features (such as size, shape) and features by most spreading classifications (VS-classifications by Yao K. and Kato, Kaise triad) and combined features.

We compared benign and neoplastic lesions by 34 parameters with Fisher's exact test and Cramer's conjugation coefficient.

Statistical analysis allowed to define 6 significant endoscopic criteria. On these parameters using the Bayes procedure, the probabilities of assigning images to each of the two groups were obtained. The group classified according to this decision rule was determined by the maximal probability. For differentiation benign (n=141) and neoplastic lesions (n=79) obtained sensitivity was 92%, specificity was 96% and accuracy was 94%. The parameterswere adopted for clinical use (most significant, easy and objective endoscopic signs). By comparing groups of epithelial lesions of the stomach with the exact Fisher test and the Cramer test, six statistically significant parameters were identified (table 1).

The first criterion is ***the thickness of vascular component in the lesion compared with surrounding mucosa***. In neoplastic lesions thickness of vascular component is less or heterogenous than in surrounding mucosa. And in benign lesions it is more similar.

The second criterion is ***the thickness ratio of glandular and vascular component in the lesion***. In neoplasia thickness of glandular white component is more than dark vascular component. For benign lesions thickness of glandular is less or similar to vascular component.

Next criteria are ***the thickness*** and ***contours of vascular componentin the lesion***. For benign lesions thickness of vascular component is uniform and contours are relatively smooth. For neoplasia – they are highly unequal and uneven.

In neoplastic lesions we can frequently see the thick findings like ***blackbright sticks (individualvessels)***. In benign lesions, usually, there are notblack individualvessels.

And the last criterion is ***the demarcation line***. Similar to VS-classification it is specific for neoplastic lesions.

The practical check of these criteria in our clinic showed high accuracy and interobserver agreement.

We checked these 6 microendoscopic features for differentiation 40 endoscopic images (21 benign, 19 neoplastic lesions) by 3 experts (accuracy was 100%), 2 low experienceddoctors (accuracy was 92-95%, interobserver agreement (IA) coefficient was equal 0,75) and 2 inexperienced in HD-NBI endoscopy doctors (accuracy was 95-98%, IA coefficient was equal 0,85).

Table 1: Endoscopic differential parameters.

Endoscopic parameter	Benign lesions	Epithelial neoplasia
The thickness of vascular component (area between the glands) as compared with surrounding mucosa	More or similar	Less or heterogeneous
The thickness ratio of glandular (G) and vascular (V) component	G is less or similar than V	G is more than V
The thickness of vascular component	Relatively uniform	Highly unequal
The contours of vascular component	Relatively smooth	Highly uneven, jagged, wavy
The thickened individual vessels as bright sticks	No	Yes
The demarcation line	No	Yes

3.2 Real-Time Pattern Recognition Analysis

The electronic atlas includes white light and magnified NBI endoscopic images of benign lesions (hyperplasia, inflammation, atrophy, intestinal metaplasia), low and high grade intraepithelial neoplasia, early gastric cancerand advanced stomach adenocarcinoma. All images with delineated regions of interest are accompanied by expert’s description of the clinical parameters, macroscopic and microscopic structure features of the lesion, including the vascular and surface patterns, and histological structure of the lesion.

With the help of the algorithm of computer vision it became possible to divide endoscopic images into groups of non-neoplastic lesions of the mucosa and epithelial gastric neoplasms. The use of the "Bag of visual words" method for the mathematical representation of images of focal superficial epithelial stomach lesions included the steps of detecting key points (SNoL-detector), mathematical description (SIFT, Scale-invariant feature transform descriptor) and clustering of local characteristics in the key points area (hierarchical k-means method) and constructing visual words dictionary (Canny, 1986;Liedlgruber, 2011).

At the first stage, the endoscopic image was delivered to the automated endoscopist’sworkplace, where it was transformed in gray levels. Gaussian blurring was then applied using values of blur radius from the certain range with the present step value. That produced the “pyramid” of Gaussians.

There are two object types present on endoscopic images (photos and videos) of stomach mucosa microstructure – glands, which are the bright areas, and vessels – dark areas surrounded by glands. Use of FAGF (Fast Anisotropic Gauss Filtering) to source images allowedto select of vessels and glandsbetter (Geusebroek, 2003). At the next processing step, the image was binarized.

After applying a median filter with a 3x3 window, the pit skeleton wasoutput using the FFPT (Fast fully parallel thinning) algorithm(Guo, 1992).

The elementary unit of a skeleton is its branch or rib, which characterizes a pit or a vessel on ainitial image. Intersections and endpoints of skeleton ribs become key points of the analyzed image.

Further image processing was performed by selection and classification of local image features using the SIFT descriptors(Lowe, 2004). SIFT descriptors of local image features were built. Produced local feature descriptors were invariant for scaling, shifting, rotation and changing illumination direction. The local feature area relevant to point blur radius is covered by a 4x4 grid (16 cells in total). For each grid cell, Histograms of Oriented Gradients (HOGs) were built for eight directions. After that, vectors for the cells combined into a single 128–dimensional vector (8x16), which was used to describe a key point (Lingua, 2009).

The set of key point vectors was processed using the “Bag of visual words” algorithm (Liedlgruber, 2011). Histogram of key points distribution by defined groups was built for each image. Key points selected by a computer on images were placed into clustersin a 128–dimensional space using clustering cloud of points by applying the hierarchical k–means method. It was found that, for the endoscopic examinations relevant, the number of clusters should be equal to 1000. The number of key points that were placed into each cluster was determined and a histogram illustrated distribution of the points for analyzed image by clusters and characterized image as a wholewas built. The histogram was represented by a vector in a 1000–dimensional space (vector coordinate values showed the number of key points falling into relevant clusters). Image classification was performed by placing a multidimensional vector into a classification space produced from the training set by the Support Vector Machines Method (SVM).

Aimed to test the suggested method, a set of 182 endoscopic images was selected. Images featured different lesions of gastric mucosa, validated by means of histological examination. Images were also obtained using high-resolution narrow–band endoscopy. There were 111 images of non-neoplastic gastric epithelial lesions, and 71 images of different epithelial neoplasms of high and low grade, of early and advanced gastric cancer. The scientific and clinical goal for computer-aided analytic system was to evaluate and differentiate focal lesions of gastric mucosa as non-neoplastic or stomach epithelial neoplasms (figure 1).

Recognition algorithm applying results demonstrate that in 85% of the cases it did perform correct image classification, placing image into First orSecond group. Average image analysis time was less than 30 seconds, and,in fact, that allows using the algorithm for real-time analysis of endoscopic images(Stepanov, 2016). A positive assessment of the current results was approved by practicing endoscopists.

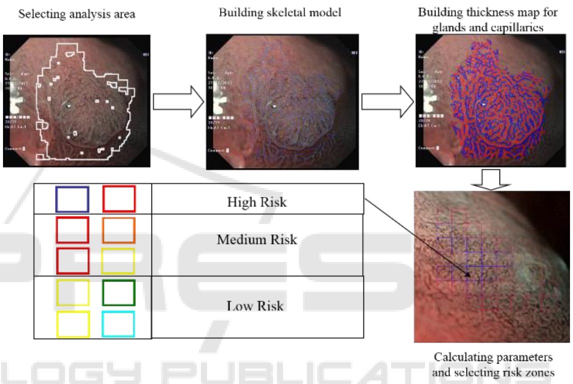

Figure 1: Classification algorithm for morphological analysis of capillary and gland microstructure of stomach.

4 CONCLUSIONS

In accordance with the statistical analysis six microendoscopic features of gastric lesions were proven most significant for effective differential diagnosis between benign and neoplastic epithelial gastric lesions. These features can be successfully used by nonexperience doctors and also for creating the decision support system, including through the computer analysis.

Also, the electronic database will be useful for e-learning of specialists in gastrointestinal endoscopy thanks to function of similar endoscopic images search. However, the main goal of this atlas and database in future is to provide the direct computer-aided image analysis during endoscopic investigation for predicting the histological structure of the epithelial lesions and choosing the correct treatment strategy

Effective results of application of the decisive rule and high accuracy of the mathematical algorithm for the classification of epithelial neoplasms and non-tumor lesions of the stomach show the fundamental possibility of formalizing the microendoscopic structure of the formations, and hence the possibility of developing their objective clinical classification and decision support system for the doctor.

The decision support system with automatic image identification soon will become an indispensable part of endoscopic video systems

A method for processing narrow–band endoscopic images using a highly productive distributed intellectual analytic decision–making system was presented. This method allows improving accuracy and helps avoiding subjectivity in real-time classification of endoscopic images. It possesses the following distinctive features:

1. Key points are selected in real time due to application of FFPT algorithm.
2. Use of SIFT descriptors allows real-time selection and vectorization of local image features invariant to scale, shift, rotation and illumination.
3. Application of the “Bag of visual words” approach enables processing the whole image of a mucosal neoplasm (and not just the part of it examined using histological methods).
4. Use of SVM method for building classification space.

Examination of a suggested computer algorithm using 182 endoscopic images todetermine the neoplasia demonstrated that the accuracy of correct recognition reaches 85%.

That allows formalization of pit and vessel pattern descriptors for gastric epithelial neoplasms, and, in turn, development of a precise and objective clinical classification. Algorithm efficiency can be improved by breaking image sets into a larger number of subgroups according to histological data. That requires processing wide image set for each subgroup. It is important that the algorithm is fast and efficient. That allows using it for processing video streams and endoscopic images in real time.

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