Arthroscopic view: can we see more by quantifying the image quality?

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Introduction

Minimally invasive surgery in orthopaedics (arthroscopy) has proven to be highly beneficial for patients as indicated by a decrease in morbidity and a rapid rehabilitation. Since the number of arthroscopic procedures continues to grow [3,7], reducing the operating time by optimizing the arthroscopic view would be desirable. The image quality during arthroscopic procedures is dependent on a number of factors: condition of the camera, the light source and the arthroscope, type of irrigation system, use of tourniquet, condition of the joint, portal placement, and skills of the surgeon. During arthroscopic surgery, the joint is continuously irrigated with saline fluid which reduces disturbances such as bleeding, air bubbles or debris. Even if the basic conditions are present, maintaining of a clear view is sometimes difficult [8]. To optimize the arthroscopic image quality, objective and quantitative measures are required, which at present are not available. Therefore, the goal is to develop a technique that enables objective and quantitative assessment of the arthroscopic image quality.

Approach, methods and results

The development of the technique was performed in three steps, two steps for defining arthroscopic image quality and one step for automatic detection.

Step 1

The arthroscopic image quality is primarily dependent on the presence of disturbances. A disturbance can be caused by different factors. But the only source of information is the movie of the arthroscopic view, which implies that only its effect on the view is determined. Seven types of disturbances were identified from prior observations of recorded arthroscopic knee procedures: Bleeding, Turbidity, Air Bubbles, Loose Fibrous Tissue, Attached Fibrous Tissue, Tissue too Close, and Instrument too Close (Figure 1). We propose to formulate descriptive definitions of disturbances in the arthroscopic view, which contain information on the size of the disturbed areas, and their duration. Initially, a percentage of 25% or more covering the image area was set as the threshold level for the presence of a disturbance. For the duration of a disturbance, the start time and end time were defined as the first and last image frame for which a disturbance conforms to the image area definition, respectively. With these definitions, the arthroscopic image quality was defined as good if no disturbances are present.

The unique interpretability of the definitions was evaluated with a time-action analysis, and tester agreement was assessed with the kappa statistic. A kappa value of 0.7 or more was considered to be a good agreement [1]. From ten routinely performed arthroscopic knee procedures, one minute was selected of each. The arthroscopic view was recorded in digital AVI-format (image resolution: 720 x 576, frame rate: 25 images per second). Four observers performed a time-action analysis with only the description of the disturbances at hand. For each separate disturbance, all arthroscopic images were marked as '1' if that particular disturbance was present, or marked '0' if that disturbance was absent. The kappa statistic was calculated (*Matlab*, version 7.0.4.365 (R14), The Mathworks). The main result is that the proposed descriptive definitions of disturbances show sufficient tester agreement (adjusted kappa >0.7) to qualify as uniquely interpretable. Only Turbidity showed a moderate agreement (kappa = 0.45).

Step 2

In the definition of disturbance, the required size of the disturbed area was defined arbitrarily.. A subsequent study was performed to determine quantitatively at which percentage the arthroscopic view becomes unacceptable based on expert opinions. The disturbances Tissue and Instrument too Close were discarded, as those were considered to be less relevant for clinical purposes, and the surgeon cannot always prevent them.

Thirty-two movie samples, 2 - 2.5 seconds in length, of the five disturbances were selected from videos of arthroscopic knee procedures. The movies showed disturbances covering different percentages of the image area, and were randomly presented. The average disturbance percentage of each movie was determined with *Matlab*, where in every fifth frame the disturbed area was indicated interactively. Twenty six orthopedic surgeons and thirteen residents were asked to indicate if the view was acceptable for each movie.

The most intolerable disturbance was bleeding. A clear transition from acceptable to unacceptable view was found for Bleeding (11% of covered area was acceptable; 25% not acceptable), and Air Bubbles (10% acceptable; 20% not acceptable) (Figure 2). Loose Fibrous Tissue showed a gradual transition where 25% was still accepted by a third of the surgeons. Turbidity and Attached Fibrous Tissue were tolerated up to 50% covered area by three quarter of the surgeons. Concluding, a safe value for an acceptable arthroscopic image can be set at 20% disturbed area.

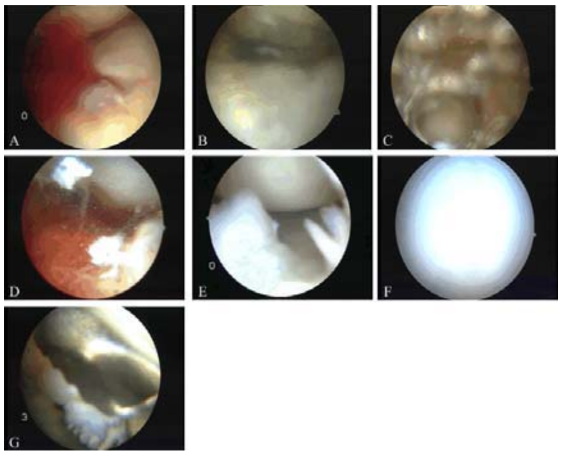

Figure 1. *Arthroscopic images represent the seven disturbances. A) Bleeding, B) Turbidity, C) Air Bubbles, D) Loose Fibrous Tissue, E) Attached Fibrous Tissue, F) Tissue too Close, and G) Instrument too Close.*

Step 3

The final step was to translate the results from step 1 and 2 into automated detection of the image quality. Initially, we focused on bleedings, as it was indicated as the most intolerable disturbance. As the background of the arthroscopic view is continuously changing, a generic feature representing blood had to be chosen for detection. A segmentation routine was designed (Matlab) that filtered a combination of Red, Green and Blue pixel levels representing the red tinctures of blood. Verification was performed by visual comparison of the segmented image with the original (Figure 3). The threshold level of 20% or more covering the image area was implemented.

Subsequently, the routine was used to analyze arthroscopic shoulder procedures, as these are known for the presence of bleedings. One surgeon performed ten shoulder arthroscopies. The preliminary results show that bleedings are less of a problem for arthroscopic rotator cuff repairs, 0% - 7% occurrence, but are frequently present in arthroscopic acromioplasty, 7% - 32% occurrence.

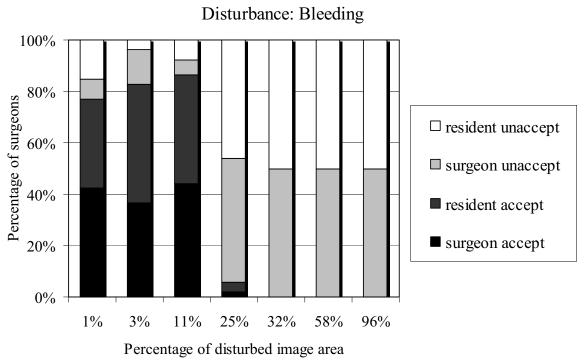

Figure 2. *Results of expert opinion on acceptability of bleeding covering a certain percentage of the image area.*

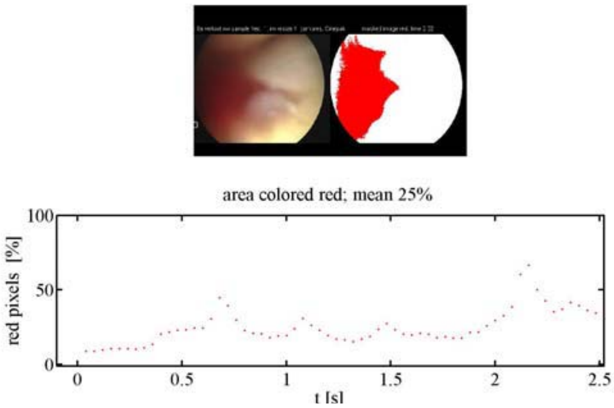

Figure 3. *Above: Automatically detected bleeding. Below: Percentage of red pixels in time for a short movie.*

Discussion

An objective and quantitative technique is developed for the analysis of arthroscopic procedures based on arthroscopic image quality. The approach can be used as a blue print for other endoscopic surgeries. For one disturbance automated detection was implemented. We aim at designing additional segmentation routines for Turbidity and Air Bubbles. The technique provides detailed information, which can be used to optimize surgical equipment such as the performance of irrigation pumps. A future direction is to develop this technique for performance monitoring of surgical skills.

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