What's so Hard About Bronchoscopic Surgery?

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Identifying the Perceptual and Cognitive Difficulties of Bronchoscopic Surgery

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This study identified aspects of bronchoscopic surgery that are the most physically and mentally demanding in order to focus future technological improvements in areas that are likely to result in the greatest gains in procedure success rate. Seventeen bronchoscopic surgeries were observed and the three participating physicians and their assisting respiratory therapists filled out questionnaires to identify areas of particular challenge. The results indicate that the greatest difficulty in performing pre-biopsy navigation is physical demand. Needle and forceps biopsies are the most difficult tasks of the procedure, where brush biopsies are the least difficult, forceps the next, and needle biopsies the most difficult. The greatest demand for all biopsies was mental. Physicians would benefit from technological developments that aided biopsy location and execution.

INTRODUCTION

Approximately 341,000 diagnostic bronchoscopic procedures were performed in non-federal hospitals in 1993 (Graves and Owings, 1997). The most common cause of death resulting from bronchoscopies is major bleeding, which occurred in about 3% of bronchoscopies. Other procedures fail because the physician is unable to take a biopsy of the appropriate area. In order to decrease the risks of the procedure and increase the success of taking biopsies, it is first necessary to determine the tasks that make the procedure difficult and vulnerable to error.

The focus of this study is to isolate the activities and characteristics of a bronchoscopic procedure that cause the most difficulty for the performing physician, require the greatest amount of the physician's attention, and require the greatest amount of time to complete. Through this information, we hope to accomplish three goals. First, to improve patient care by decreasing the incidence of characteristics that decreases the effectiveness of the bronchoscopy and/or increases the likelihood of injury and discomfort. Second, to decrease the physician's difficulty in performing the procedure and thus improve the physician's comfort and effectiveness. Finally, to develop a model with that will provide the foundation for developing future technology associated with bronchoscopic surgery.

The effectiveness of a bronchoscopy is defined here as whether or not the physician has met her/his goal for an individual procedure, and to what degree. The basic reason for performing a bronchoscopy is to locate anomalies in a patient's bronchus and if necessary, take a biopsy. An "effective" procedure is one in which the physician is able to complete these goals within a short amount of time and within one procedure. However, due to variations in patient structure and difficulties inherent in the procedure, it is sometimes necessary for a physician to spend longer amounts of time performing the procedure, and in some patients, it may be necessary to perform the procedure more than once. Increasing the effectiveness of the procedure will hopefully translate into shorter and fewer procedures for the patient. Bronchoscopic surgery is an invasive procedure, and even perfect procedures cause some degree of physical discomfort and injury to the patient, often associated with the duration of the procedure (Diette et al., 1998); (Reilly et al., 1998). In order to eventually design a system that would decrease the average bronchoscopy procedure time and thus decrease patient discomfort, we must first determine what parts of the bronchoscopy require the most time and why.

BRONCHOSCOPY: THE PROCEDURE

To fully appreciate the difficulties of performing a bronchoscopy, it is necessary to gain a basic understanding of the procedure itself. The following section provides a general description of the personnel, equipment, and activities that make up the surgery.

A bronchoscopist uses a specially designed endoscope specifically designed for viewing the bronchial tubes of the lungs to diagnosis illness and/or take tissue or fluid samples of a tissue anomaly. The physician is the main operator during the procedure; his/her job is to operate the bronchoscope and determine biopsy locations while maintaining an understanding of the patient's condition. A respiratory therapist prepares the patient for the procedure and assists the physician during the procedure.

A bronchoscope consists of a hand held control device and a long, flexible scope that is inserted into the patient's lungs. The scope has a small camera at the tip that

sends images to an external monitor. A thin channel in the bronchoscope is used to send fluids to the bronchus to clear the camera and/or tissue, suction excessive fluids from the tubes, or to pass down instruments for taking a biopsy. The control device has two levers that actuate the last few centimeters of the scope to bend the tip up and down or left and right in order to navigate past the corners of the bronchial tubes. The physician can also twist the handle to rotate the camera. Mental image rotation poses demands similar to the challenges of map orientation (Aretz, 1991) and is a potential cause of physicians "getting lost" in the patient's bronchus and requiring more time to locate their bearings within the bronchus

Our preliminary interviews with bronchoscopists indicated that needle biopsies are among the most challenging procedures. Our initial observations of several procedures revealed that the needle biopsies require the physician to note on a series of x-rays where the suspected growth lay relative to the bronchus, identify useful landmarks in the bronchus and mentally calculate an appropriate trajectory for inserting the needle relative to the bronchus landmark The following experiment was designed to investigate the bronchoscopists' anecdotal evidence and refine our understanding of the relative difficulty of different aspects of bronchoscopic surgery.

METHODS

We investigated the demands of the bronchoscopic procedure using videotape observations of 17 procedures. These data were complemented by questionnaires administered to the performing physicians.

Data Collection: Video Monitoring

To track the direction of a performing physician's attention during a procedure, we set up video cameras to record the physicians throughout the entire procedure. This has been found to be a valuable method of observing and determining errors associated with similar medical procedures (Figure 1) (Joice, Hanna, Cuschieri, 1998).

The physician stands at the head of the patient's bed facing the monitor directly or at a moderate angle. Two cameras installed in the ceiling of the bronchoscopy captured a frontal view and a profile view. Both cameras and the images from the bronchoscope were passed through a video quad multiplexor so that all three signals were recorded simultaneously on a single VCR tape. The audio signals from a lapel microphone worn by the physician were also recorded on the tape.

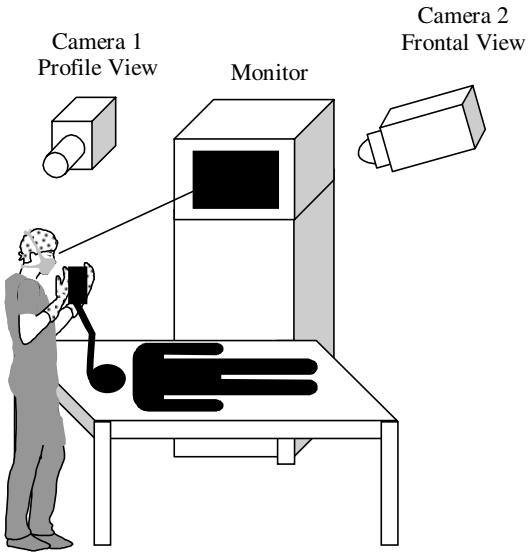

Figure 1: Video Camera Placement for Recording Procedures

Data Collection: Physician Questionnaires

Immediately following the procedure, physicians completed a questionnaire that measured their perceived difficulty of the various tasks. The questionnaire was divided into three parts. Part 1 (which was usually filled out by the respiratory therapist) asked basic questions about the patient's condition. The questions included the reason for the procedure, physical characteristics expected to be present (e.g., presence and approximate location of growths), and the type of bronchoscope used. In the physician's portion of the questionnaire, the bronchoscope procedure was broken down into 12 tasks. The tasks included navigation, positioning the scope for taking a biopsy, and taking a tissue sample. The physicians provided a workload rating of each task along with a rating of the procedure as a whole. The workload rating scale was broken down into five workload categories based on the NASA Task Load Index (TLX) scale (Hart and Staveland, 1988).The categories used were mental demand, effort demand, visual demand (the need to stay focussed on the monitor at all times), frustration and physical demand.

RESULTS

During the course of data collection, 17 bronchoscopies were observed. Since the reasons for performing each procedure varied among the patients, each procedure yielded different categories of data. Although three physicians were observed throughout the study, the three procedures performed by Physicians B and C are not included in the statistics due to the radical differences in experience and number of procedures they performed.

Out of 14 procedures, five procedures involved taking more than one type of biopsy, while nine involved

taking one type of biopsy. Of the 14 procedures requiring a single type of biopsy, 12 were forceps and two were needle biopsies.

The results of the physician questionnaire are summarized in the Figure 2. Each task has 5 bars corresponding to a different dimension of workload task rating: Mental Demand, Effort Demand, Visual Demand, Frustration, and Physical Demand, respectively. The questionnaire data was analyzed though the general linear model. The twelve tasks and the overall rating were grouped into six task categories: Pre-Biopsy Navigation, Biopsy Location, Brush Biopsy, Forceps Biopsy, Needle Biopsy, and Overall Ratings. An ANOVA revealed that workload dimensions are significantly different from each other, and the workload associated with each task category are significantly different (Table 1). There was no significant interaction between workload dimension and task category.

Table 1: Analysis of Variance for Tasks, using Adjusted SS for Tests

Source	DF	Seq SS	Adj SS	Adj MS	F	P
Workload Dimension	4	81.85	101.36	25.34	6.94	0.000
Task Category	5	699.57	565.86	113.17	30.99	0.000
Workload Dimension *Task Category	20	95.93	95.93	4.80	30.99	0.163
Error	538	1964.78	1964.78	3.65		
Total	567	2842.13				

Workload Dimensions

Tukey's test ($p < 0.05$ criterion, all tests) indicated that Frustration was significantly lower than all categories except Physical Demand, and the other terms were not statistically different. Physical Demand displayed a marginally significant difference from Mental Demand ($p < 0.1$). This indicates that the cognitive, rather than the physical aspects of bronchoscopy occupy the greater demand of the physician's facilities (Table 2).

Table 2: Mean Ratings for Each Workload Dimension

Workload	Mean	St. Dev
Mental Demand	2.684	2.518
Effort Demand	2.681	2.365
Visual Demand	2.769	2.490
Frustration	1.797	2.365
Physical Demand	2.342	1.396

Task Categories

Tukey's test indicates that the least difficult tasks were Pre-Biopsy Navigation, followed by Brush Biopsy and Biopsy Location. The highest workload scores were Forceps Biopsy, Needle Biopsy, and Overall Rating, respectively (Table 3). Pre-Biopsy Navigation and Biopsy Location were significantly less difficult than every other

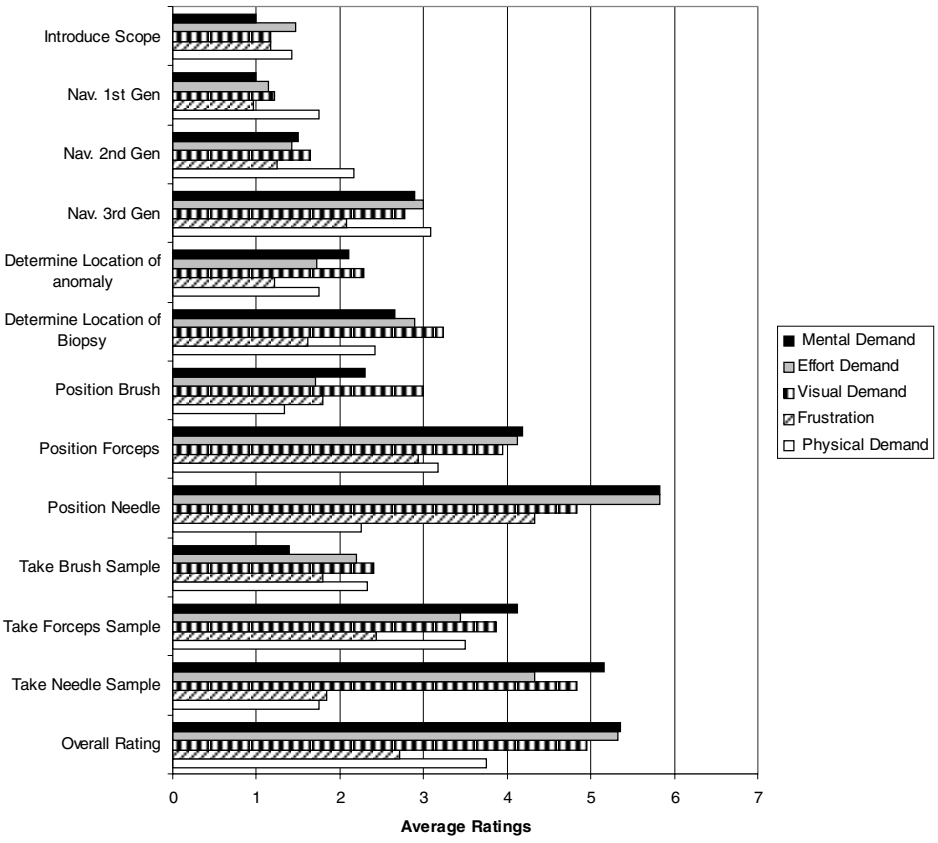

Figure 2: Average Workload Ratings for Each Task

task category except Brush Biopsy. Forceps Biopsy and Needle Biopsy were scored higher than Brush Biopsy, but were not significantly different from each other. The Overall Rating was significantly greater than every task category except Forceps and Needle Biopsy.

Table 3: Mean Ratings for Each Task Category

Task	Mean	St. Dev
Pre-Biopsy Navigation	1.297	1.341
Biopsy Location	2.362	2.104
Brush Biopsy	2.043	1.307
Forceps Biopsy	3.609	2.378
Needle Biopsy	4.250	2.378
Overall Ratings	4.506	2.219

Pre-Biopsy Navigation and Biopsy Location

Pre-Biopsy Navigation and Biopsy Location represent activities that are performed prior to taking a biopsy. The tasks that made up Pre-Biopsy Navigation were Introducing the Scope, First Generation Navigation, and Second Generation Navigation. The tasks that made up Biopsy Location were Third Generation Navigation, Locating the Anomaly, and Determining the Biopsy Location. It is important to note that Pre-Biopsy Navigation is a routine procedure in which bronchial passages are examined in the same order for each patient. Biopsy Location involves more variety than Pre-Biopsy navigation, but is still performed in virtually every bronchoscopy.

Videotaped data revealed that the pre-biopsy activities of the bronchoscopy lasted an average of 9.6 minutes. On average, this accounted for 38% of the total procedure time. In most of the procedures, the camera images are moving constantly with very few if any stationary or occluded images (the following section will discuss the occurrence of stationary and occluded images occurred mostly in conjunction with biopsies).

Brush Biopsy, Forceps Biopsy, and Needle Biopsy

Each biopsy category is composed of Positioning the Instrument and Taking the Biopsy. Biopsy task categories received the overall highest difficulty ratings of all of the tasks. Forceps Biopsies were performed the most frequently, followed by Brush Biopsies. Needle Biopsies were performed the least often. Each biopsy differs in method and purpose. Brush biopsies involve rubbing a brush against an area of the bronchus to collect cell and fluid samples. Forceps biopsies are taken by removing a sample of surface tissue using a small set of clamps. Needle biopsies are performed by inserting a needle into the bronchial wall to obtain a tissue sample below the surface of the bronchus.

Analysis of the video data revealed several factors that contributed to the high workload scores of the biopsy tasks, as well as the difference in the difficulty of different forms of biopsy. The brush was the only type of biopsy that required only one attempt in a given procedure. Brush biopsies did not take up a great deal of the total procedure time. On average, brush biopsies required 1.7 minutes of activity. The brush biopsy simply consisted of inserting a brush into a narrow passage and manipulated back and forth. In contrast, forceps biopsies took an average completion time of 3.1 minutes to complete and required an average of 3.7 attempts per procedure. Needle biopsies lasted an average of 4.9 minutes and required an average of 5.3 attempts per procedure.

During the process of taking biopsies, there was an average of 4 minutes of stationary time (time where the physician kept the camera in one area of the bronchus) per procedure, usually preceding a biopsy attempt. 40% of this stationary time involved the physician communicating with the respiratory therapist or an attending physician, while 60% involved no communication whatsoever. During these periods, the physician was usually either waiting to be given biopsy instruments or taking very brief eye breaks from looking at the monitor.

The problem of occluded camera images also occurred following biopsy attempts, usually due to bleeding. Six procedures experienced prolonged periods of occluded images in conjunction with taking a biopsy; the average number of occluded images was 3.3 per procedure. Occluded images usually took up less than 1 minute of procedure time.

Overall Ratings

An interesting characteristic of the mean Overall Rating is that it exceeds the mean ratings for every other task. The Overall Rating was significantly greater than all task ratings except for that of Forceps and Needle biopsy. Overall Rating, then, is not simply the sum or weighted average of the component tasks. This score may reflect the challenges that emerge when tasks are combined in the procedures. It is also possible that this difference is due to external factors that were not explicitly addressed in the questionnaire (for example, specific obstacles noted in the video data).

DISCUSSION

While Pre-Biopsy Navigation is almost entirely a pre-set mental process, biopsy presents a greater cognitive strain on the physician. Biopsy locations and requirements vary from patient to patient and their spatial and depth constraints demand different actions. Not only does this variance contribute to the workload of the biopsy, it accounts for the slightly higher workload associated with Biopsy Location; a task category that combines the mental mapping of the bronchial tree with the mental location of a particular site that changes from patient to patient. Considering the questionnaire results, number of attempts,

and duration of completion time, brush biopsies presented the lowest workload to physicians, followed by forceps biopsies and needle biopsies.

The difference in workload of brush biopsies with other forms may lie in the basic difference in procedure and aim among the different forms. Brush biopsies cover the greatest surface area, needle biopsies the greatest depth. While forceps biopsies are performed the most frequently, they require a more tightly constrained area of biopsy, which may account for their greater difficulty. Needle biopsies require the physician to mentally determine the location of an anomaly located below the bronchial surface and they are performed the most infrequently of the three forms of biopsy. In this case, the physician is hampered not only by the restrictive nature of the procedure, but also by the difference in experience between needle and other biopsies. Whether or not the lack of statistical distinction between forceps and needle biopsy was due to a real difference in workload or a lack of variance in procedure is an interesting question that would be answered by analyzing the reported difficulty of equal numbers of forceps and needle biopsy procedures.

It is interesting that the overall procedure rating exceeded the ratings of most individual tasks, with the exception of the needle biopsy. There are several factors, mostly in the videotaped data that may account for this discrepancy. Factors such as procedure length, number of attempts, and number of different forms of biopsy per procedure were not addressed by the questionnaire. The greater overall difficulty ratings may reflect these aforementioned factors. This would also account for the lack of distinction between the Overall Rating score and the reported workload of two of the three forms of biopsy. Thus, while individual task difficulty ratings provide a basis for comparison to each other, the overall difficulty rating of a whole task in this case was not the sum of its parts.

Current technological developments in the area of bronchoscopy are designed to increase the physician's ability to navigate the bronchial tree and discover and diagnose anomalies. Physicians would benefit from advances aimed at easing the workload associated with taking forceps and needle biopsies; especially in positioning the instrument. Such a development has the potential to lead to procedures with a shorter duration, fewer biopsy attempts, and ultimately, an easier workload for the physician that would translate to health benefits for the patients.

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