Artificial Intelligence for Pathologists Is Not Near—It Is Here

Description of a Prototype That Can Transform How We Practice Pathology Tomorrow

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• ***Context.***—**Pathologists' daily tasks consist of both the professional interpretation of slides and the secretarial tasks of translating these interpretations into final pathology reports, the latter of which is a time-consuming endeavor for most pathologists.**

Objective.—**To describe an artificial intelligence that performs secretarial tasks, designated as Secretary-Mimicking Artificial Intelligence (SMILE).**

Design.—**The underling implementation of SMILE is a collection of computer programs that work in concert to "listen to" the voice commands and to "watch for" the changes of windows caused by slide bar code scanning; SMILE responds to these inputs by acting upon PowerPath Client windows (Sunquest Information Systems, Tucson, Arizona) and its Microsoft Word (Microsoft, Redmond, Washington) Add-In window, eventuating in the reports being typed and finalized. Secretary-Mimicking Artificial Intelligence also communicates relevant information to the pathologist via the computer speakers and message box on the screen.**

Results.—**Secretary-Mimicking Artificial Intelligence performs many secretarial tasks intelligently and semiautonomously, with rapidity and consistency, thus enabling pathologists to focus on slide interpretation, which results in a marked increase in productivity, decrease in errors, and reduction of stress in daily practice. Secretary-Mimicking Artificial Intelligence undergoes encounter-based learning continually, resulting in a continuous improvement in its knowledge-based intelligence.**

Conclusions.—**Artificial intelligence for pathologists is both feasible and powerful. The future widespread use of artificial intelligence in our profession is certainly going to transform how we practice pathology.**

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Voice recognition technology has started gaining popularity in pathology practice.[1–5] The prevailing opinion in the pathology community is that choosing a pathology-specific application such as VoiceOver Enterprise (Voicebrook, Inc, New Hyde Park, New York) rather than a general medical version of Dragon (Nuance Communications, Burlington, Massachusetts) is practically the one and only option for the successful transition to using voice recognition in pathology practice.[5]

I work in a pathology practice group consisting of 13 pathologists. In March 2012, a fellow pathologist introduced voice recognition to the group, using computer programs he wrote to enable the general medical version of Dragon to function at least similarly to the pathology-specific medical version of Dragon, if not better.

I volunteered in May 2012 to be the second pathologist in the group to make the transition to voice recognition. By January 2013, I had made a successful transition, experiencing a decrease in turnaround time and maintaining a similar level of productivity; however, there was a concomitant increase in both the intensity of report preparation and the number of reporting errors.

Dissatisfied with the fact that for many biopsy cases more time and effort were required to prepare the reports than to interpret the slides, and inspired by IBM's Watson (IBM, Armonk, New York), which defeated the famous *Jeopardy!* champion Ken Jennings, I started working on writing programs with elements of artificial intelligence (Secretary-Mimicking Artificial Intelligence [SMILE]) in February 2013. Since then, a fellow dermatopathologist and I have been using SMILE in daily practice. Secretary-Mimicking Artificial Intelligence became relatively mature after 4 to 5 months of initial rapid growth. Its current capabilities have exceeded my initial expectations.

This paper attempts to demonstrate the major capabilities of SMILE by using a limited number of actual cases as examples.

MATERIALS AND METHODS

Basic Specifications of Equipment and Applications

The computer workstation is a desktop PC (Lenovo, Beijing, China) with Intel (Santa Clara, California) Core i5-3470 CPU, 3.20

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Dr Ye filed a provisional patent application for the SMILE artificial intelligence on March 23, 2015.

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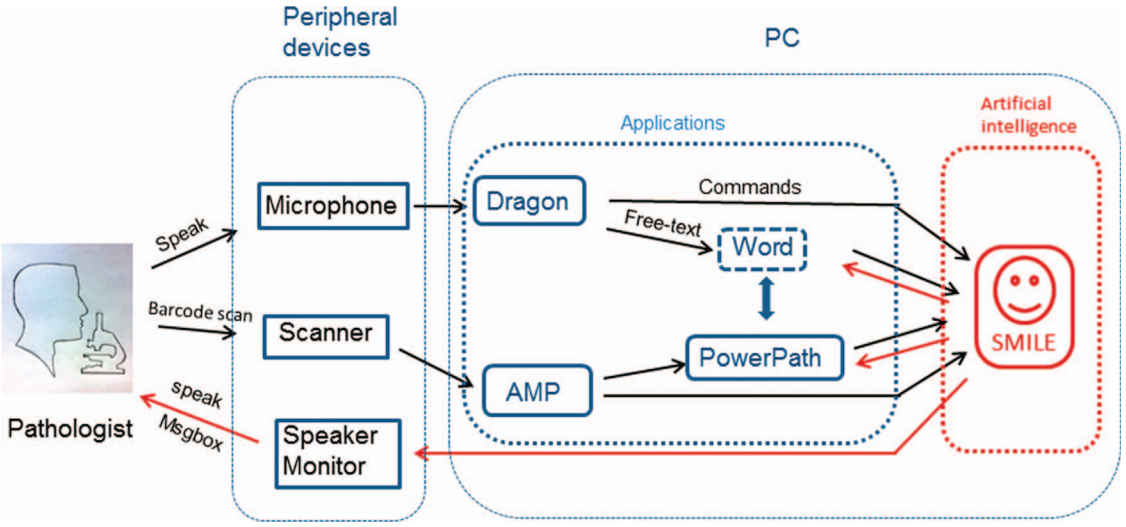


Figure 1. *The paths of dialogue between pathologist and the Secretary-Mimicking Artificial Intelligence (SMILE). Abbreviations: AMP, advanced material processing module of PowerPath; Dragon, medical version of Dragon (Nuance Communications, Burlington, Massachusetts); PowerPath, PowerPath client (Sunquest Information Systems, Tucson, Arizona); Word: Microsoft Word (Microsoft, Redmond, Washington) Add-In for PowerPath.*

GHz, 4 GB RAM, and the headset is Plantronics Savi 440 (Plantronics, Santa Cruz, California). The pathology information system is PowerPath 10.0.0.19 (Sunquest Information Systems, Tucson, Arizona) with the advanced materials processing module. The voice recognition software is Dragon Medical Practice Edition version 11 (Nuance Communications, Burlington, Massachusetts).

The Paths of Dialogue Between the Pathologist and SMILE

Secretary-Mimicking Artificial Intelligence is a collection of approximately 20 000 lines of computer programs written in either of the 2 programming languages AutoHotkey (www.autohotkey.com, accessed October 10, 2014) or Dragon Advanced Scripting Language.

The dialogue between the pathologist and SMILE is mediated via computer peripheral devices and commercially available applications and their modules. Figure 1 diagrams the paths of such dialogues. When a pathologist scans the bar code of the first slide of either a new case or a different specimen within the same case, the advanced materials processing window and/or the PowerPath Client window change; these changes are "perceived" by SMILE. When a pathologist speaks into the microphone, if the speech is interpreted by Medical Dragon as a voice command (rather than free-text dictation), the command is "heard" by SMILE.

In response to either modality of input, SMILE can communicate to pathologists by speaking in a synthetic voice; SMILE can also effect many changes in both the PowerPath Client windows (including its child windows) and the Microsoft Word Add-In window, including, but not limited to, moving the cursor, placing the text in the active window (frequently Word Add-In for our purposes), correcting certain text in the Word document, opening a new window, and closing an existing window, activating a window that is in the background.

In free-text dictation, the text is typed directly into the active window on the screen; SMILE is not involved.

Figures Containing Case Examples

Figures containing case examples are derived from the screenshots of the cases in either the PowerPath Client window or the Microsoft Word Add-In window; they have been rendered in Microsoft Word format to allow some of the long lines in the text to wrap around so that the size of the words in the printed figures can be maintained, ensuring the readability of the figures. The patients' names and a pathologist's name in the text have been replaced by triple hash characters (###).

RESULTS

Tracing a Case From Scanning the Bar Code of the First Slide to Signing Out

Step 1. Scanning the Bar Code of the First Slide of a Case.—The pathologist initiates the dialogue by scanning the bar code of the first slide of a case. After both the advanced materials processing window and the PowerPath client window have changed, SMILE responds by announcing the name of the patient, specimen number (such as "specimen 1") of the scanned slide, and the corresponding specimen label, such as "left back of thigh." Note that the pathologist does not always have to start with the first slide of the first specimen in a multiple-specimen case, although that is the most common way to start a case.

Secretary-Mimicking Artificial Intelligence reads the gross description of that particular specimen and announces the number of blocks (slides) corresponding to that specimen. It also detects and alerts the pathologist to the presence of certain errors, such as block designation errors and specimen dimension errors.

Step 2. Getting From PowerPath Into Microsoft Word.—Once the pathologist is ready to dictate, a command such as "Diagnosis" or "Begin dictation" can be spoken into the microphone. In executing this command, SMILE opens the Microsoft Word Add-In window for the case from the PowerPath Client window. The specimen list is read by SMILE from the preliminary report (located after "TISSUE/SPECIMEN:" at the top of all of the case example figures, such as "1. Left upper chest: 2. Left back of thigh" in Figure 2, A). The standardized header is automatically typed for each specimen, including the specimen type (such as skin), site, and procedure. The cursor then stops at the correct location within the report for the pathologist to dictate the diagnosis for the specimen corresponding to the slide with the most recently scanned bar code. Figure 2, B, shows the screenshot of a 2-specimen case after slide 1A was scanned and the command "Diagnosis" was executed.

During this process, certain reproducible typographic or voice recognition errors in the clinical information and gross description in the preliminary report are corrected auto-

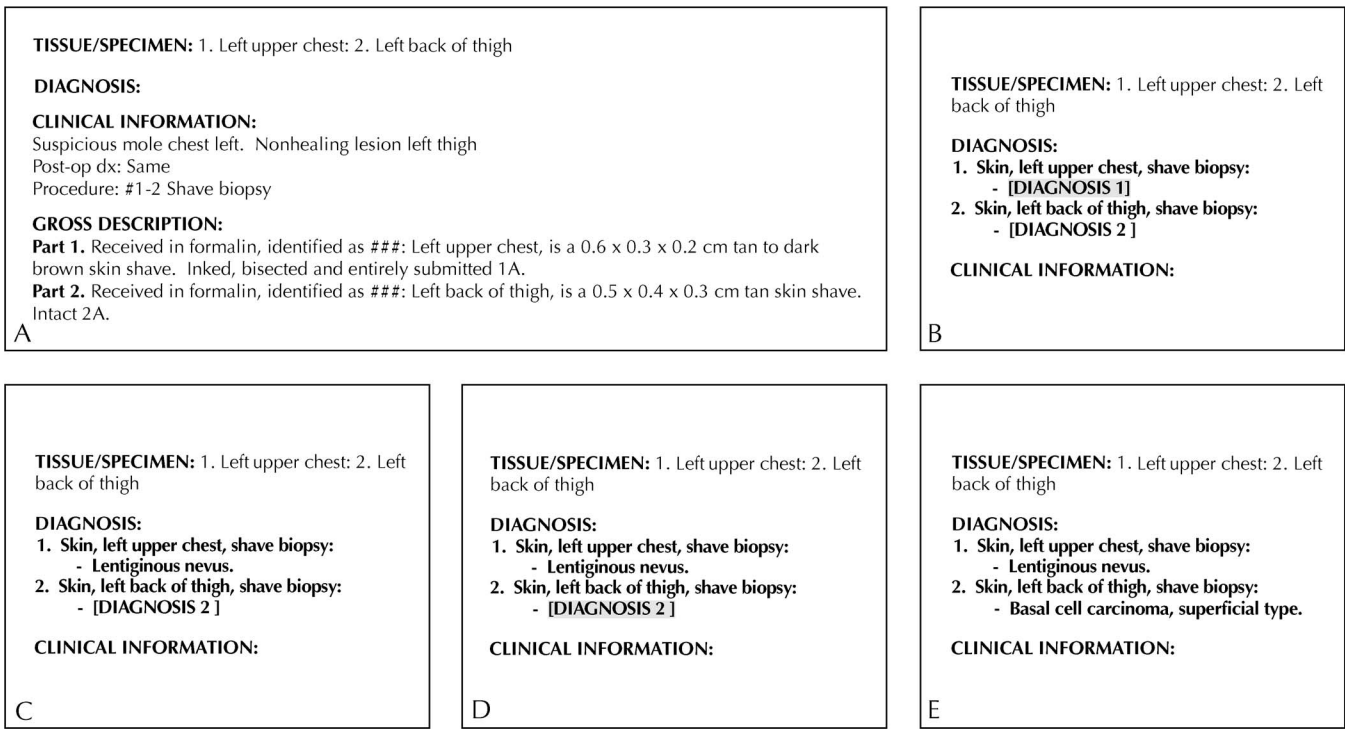


Figure 2. *Sequential changes of a case after certain actions by the pathologist: scanning the bar code of slide 1A (A), command "DIAGNOSIS" (B), free-text dictation (C), scanning the bar code of slide 2A (D), and either command "superficial BCC" or free-text dictation (E). The patients' names and/or a pathologist's name have been replaced by triple hash characters (###). Abbreviations: dx, diagnosis; post-op, postoperative.*

matically and the corresponding announcement is heard. For instance, SMILE automatically corrects "allergic content dermatitis" to "allergic contact dermatitis." Similarly, if the specimen list has certain spelling errors, SMILE types in the correctly spelled term in the diagnosis header, and notifies the pathologist of such change(s). An example is "marlar cheek" to "malar cheek."

The pathologist can now start to dictate the diagnosis for the specimen.

Step 3. Continuing Dictating the Diagnosis for Other Specimen(s) in the Same Case.—After the pathologist finishes dictating the diagnosis for a specimen (Figure 2, C) and scans the first slide of a different specimen, SMILE reads the corresponding gross description for that specimen, and does the specimen-specific error checking in a way identical to those in steps 1 and 2. The cursor automatically moves to the correct location for dictating the diagnosis (Figure 2, D), ensuring that the diagnosis is entered into the intended specimen. If the specimen corresponding to the scanned slide has already had its diagnosis transcribed, the cursor moves to the end of that diagnosis. This further ensures that the diagnosis is always transcribed for the intended specimen without conscious effort from the pathologist.

Step 4. Signing Out a Transcribed Case.—After the pathologist finishes dictating the diagnosis for all the specimens (Figure 2, E), one can finalize the case by giving a command such as "Release case." Secretary-Mimicking Artificial Intelligence checks to see if there are brackets in the report or other features indicating that the report is not ready to be finalized, such as red-colored words or certain warning phrases. If any of the items mentioned above are present, the command is aborted and these issues need to be resolved before the command is allowed to finalize the case.

Secretary-Mimicking Artificial Intelligence also makes sure that slides for all the blocks from the case are scanned before it allows the pathologist to finalize the case, thus preventing the case from being finalized before all the slides have been reviewed. The opposite side of this same mechanism catches block labeling errors whenever more slides are scanned than the gross description indicates.

If none of the above issues exist or the issues have been resolved, SMILE then checks and corrects the pathologist's dictation for voice errors that involve nonsensical combination of correct words or grammatical errors, such as "melanin A" instead of "Melan A," or "clinical inflammation" instead of "clinical information," or "may suggests" instead of "may suggest."

If the case passes all of the checks mentioned above, either absent initially or corrected subsequently, the command "Release case" then allows the case to be signed out.

Automatic Header Typing Explained

One of the most pivotal components of SMILE is its ability to automatically type in the headers of the specimens, including obtaining the starting material from the specimen list; expanding the abbreviations; removing extraneous words such as "mole," "BCCA," "lesion," and so on; rearranging the order of the words; adding the tissue source, such as skin, in front of the label when indicated; and, most challengingly, putting in the correct procedure for each header, particularly in multiple-specimen cases. Currently, roughly 8 000 lines of computer code are devoted to this purpose.

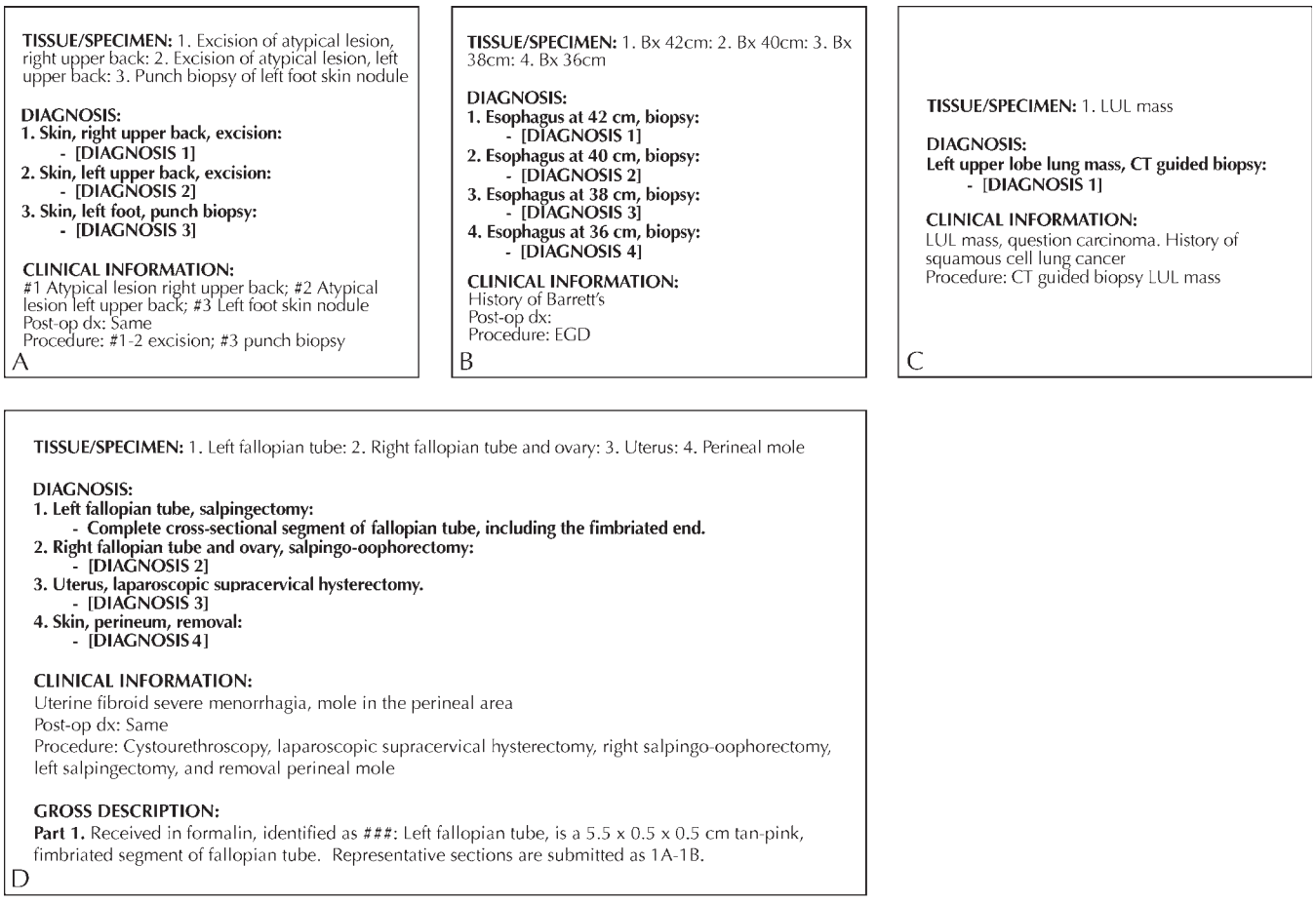


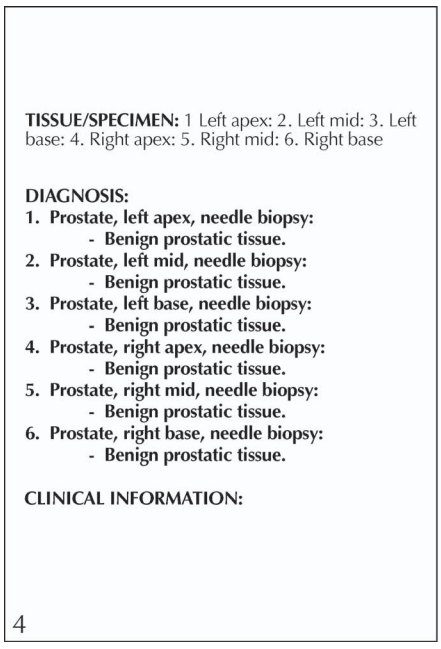
Figure 3. *Standardization of specimen description in the headers by Secretary-Mimicking Artificial Intelligence (SMILE). Removal of diagnoses and procedures and addition of "Skin," (A), addition of "Esophagus at" (B), expansion of "LUL" to "Left upper lobe lung" (C), and a case demonstrating that many decisions were made correctly by SMILE (D). The patients' names and/or a pathologist's name have been replaced by triple hash characters (###). Abbreviations: CT, computerized tomography; dx, diagnosis; EGD, esophagogastroduodenoscopy; post-op, postoperative.*

Figure 3 shows the standardization of the specimen designation, including removal of extraneous words, expansion of abbreviations, addition of word(s), and addition of the procedure to produce the specimen header. Figure 3, A, shows the removal of many redundant words, including description, diagnosis, and procedures. Figure 3, B, shows an example in which SMILE added the word "Esophagus at" to the specimen label (SMILE knows that it should not be "Colon at"), a decision based on reading the text under "CLINICAL INFORMATION." Figure 3, C shows the expansion of "LUL" into "Left upper lobe lung" rather than "Skin, left upper lid," again based on the reading of both the clinical information and the gross description. The example in Figure 3, D, required SMILE to make numerous decisions correctly. Four different procedures needed to be extracted from the clinical information, and each one of them was assigned correctly to a specimen. For specimen 4, 3 more decisions were made: the word "mole" was removed; the word "Perineal" was changed from adjective form to the noun form "Perineum"; and, because SMILE decided that the specimen is skin, "Skin" was added to the front of the specimen header. In addition, SMILE looked at the gross description and decided to type in the default diagnosis for specimen 1. Because this case required an unusually large number of decisions to be made, I was pleasantly surprised when all the headers turned out to be correct. In most other cases, far fewer decisions need to be made by SMILE when typing the headers.

Composite Commands That Enable SMILE to Be More Efficient and More Intelligent

Composite commands that sequentially concatenate the commands mentioned above enable SMILE to perform tasks even more efficiently. After scanning the bar code of the slide, one can skip the step of saying the command "Diagnosis." Instead, a command such as "IDN congenital" causes SMILE to type the diagnosis of "Intradermal melanocytic nevus with congenital features" for that specimen. For a single-specimen case, if no more dictation is needed, "Release case" finalizes the case. That is to say, 2 consecutive commands are all it takes for some simple cases.

To increase the efficiency further, one can use a single command to finish a straightforward 1-specimen case. For instance, "Release case IDN congenital" finalizes a single skin biopsy with the diagnosis of "Intradermal melanocytic nevus with congenital features." After the command is issued, SMILE starts to perform the required actions sequentially and the pathologist can start looking at the slide(s) of the next case without scanning the slide(s). When no warning or correction is involved, it takes SMILE 11



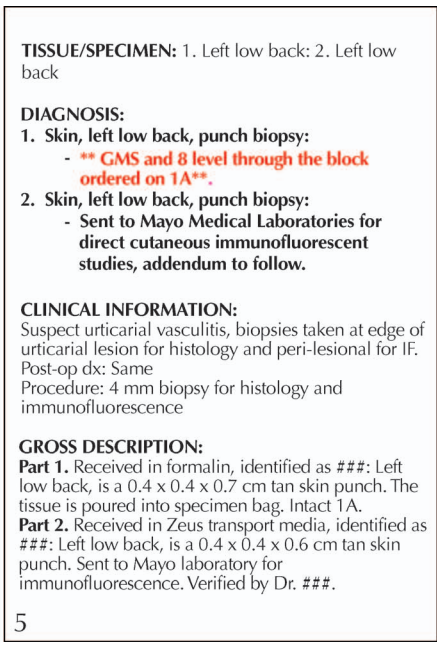


Figure 4. *Diagnosis for a 6-specimen prostate biopsy case. The text beneath "DIAGNOSIS" can be generated in various ways.*

Figure 5. *A case example demonstrating the execution of the command "Skin protocol 1." The patients' names and/or a pathologist's name have been replaced by triple hash characters (###). Abbreviations: dx, diagnosis; GMS, Gomori methenamine silver; IF, immunofluorescence; post-op, postoperative.*

seconds to complete the actions. As soon as SMILE announces the status for the current case as "Final," the pathologist can scan the bar code of a slide from the next case to bring up the case information of the next case to the computer screen. Secretary-Mimicking Artificial Intelligence is intelligent enough that if a case has any automatic correction or warning, the execution stops at the step right before finalizing the case, giving the pathologist a chance to make sure that everything is correct before signing out. In a busy day when I interpret skin cases only, approximately a third of the cases are completed using a single command. For these cases, only a minimal amount of time and effort is devoted to report preparation.

Some composite commands enable SMILE to "understand" the intent of the pathologists more intelligently. For instance, in a case of 6-specimen prostate biopsy, a command like "Benign prostatic tissue times 6" finishes typing the diagnosis of the entire case (Figure 4). Alternatively, if one has already dictated "Benign prostatic tissue" for any specimen, scanning a slide from the next specimen and issuing the command "Repeat diagnosis times 5" produces the same result shown in Figure 4. If the case has one specimen with cancer and all the others are benign, one can scan the specimen slide with cancer, then say "Others benign prostatic tissue"; all other specimens receive the diagnosis of "Benign prostatic tissue" and the cursor stops at the specimen with cancer. One can then proceed with the free-text diagnosis for that particular specimen. In short, the variability is numerous, and SMILE is very successful in mimicking human secretaries in "understanding" the pathologist's intent.

In multipart prostate biopsy cases (eg, cases with 6 or 12 specimens), a single malignant diagnosis could be lost amid all the benign diagnoses if it is located near the end of the diagnosis (eg, diagnosis for specimen 11 or 12 of a 12-specimen prostate biopsy case) and all the other preceding diagnoses are benign. A command such as "Prioritize diagnosis 12" can be used to lift that singular malignant diagnosis from its sequential location in the report and place it conspicuously in the very beginning of the diagnosis field above the diagnosis for specimen 1, so as to ensure that the clinician will not miss that diagnosis.

SMILE's Versatility and Autonomy Relieve Pathologists From the Burden of Numerous Mundane Tasks

Secretary-Mimicking Artificial Intelligence is versatile in meeting the needs or preferences of both clinicians and pathologists, as well as the specific requirements of certain cases. For example, a dermatologist requested that for multiple-specimen cases, the sequential designation use capitalized letters rather than the usual Arabic numerals in order for our pathology report to fit well with the designation of specimens/lesions in his electronic medical record; also, he did not want the header to start with "Skin." Secretary-Mimicking Artificial Intelligence takes care of this specific request on every multiple-specimen case from his office, automatically generating headers such as "A. Right distal dorsal forearm, punch biopsy:" instead of our usual format of "1. Skin, right distal dorsal forearm, punch biopsy:." Another example is that rare physicians insist on a microscopic description for every case from them; a reminder, "Please dictate a microscopic description," is heard for this type of case.

Pathologist-specific composite commands can be easily constructed. For instance, many times a day, when encountering punch biopsies for certain inflammatory dermatoses, I tend to order a Gomori methenamine silver (GMS) stain and then level through the entire punch biopsy in 8 levels. A command called "Skin protocol 1" orders GMS and leveling through the block in 8 levels sequentially, then performs the action triggered by the command "Diagnosis" (ie, types in the header and does the regular checking, proofreading, and announcing if applicable, as described above), then types in red-colored font "** GMS and 8 levels through the blocks ordered on 1A **" in the diagnosis field, and saves the case (Figure 5). In this particular example, the diagnosis for the send-out specimen, that is, specimen 2, is also automatically typed by SMILE (Figure 5).

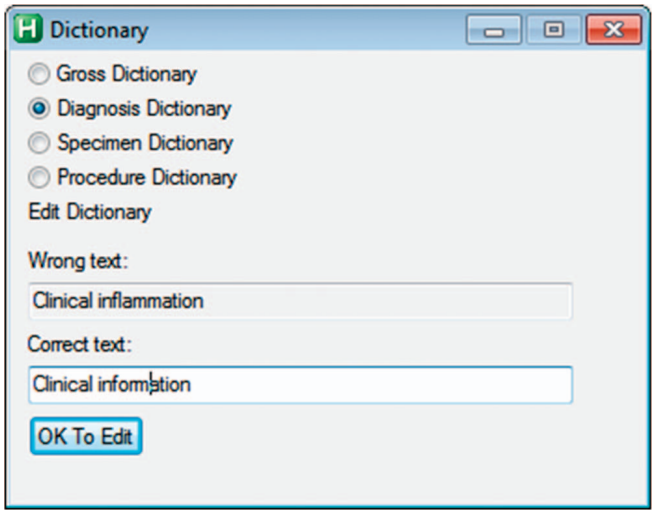


Figure 6. *Screenshot of a graphical user interface for Secretary-Mimicking Artificial Intelligence to receive and memorize instruction from the user.*

Case-specific reminders are also in use, such as a reminder to repeat the HER2 test in the excision specimen in grade III breast cancer cases if HER2 is negative in the biopsy and a reminder to submit more tissue in order to obtain more than 12 lymph nodes in the colectomy specimen for colon cancer.

Secretary-Mimicking Artificial Intelligence is autonomous in making many decisions. For example, in certain types of specimens, more than 90% of the time the diagnosis is the same. Hearing the command "Diagnosis," SMILE not only puts in the header, but also types in the default diagnosis. An example is shown in Figure 5. Such specimens include, but are not limited to, the absolute majority of the gross examination–only specimens, vas deferens, fallopian tubes for tubal ligation, cardiac valves, and sleeve gastrectomy specimens for morbid obesity. These automatically typed diagnoses can be customized for individual pathologists.

Graphical User Interface Enables Users to Improve and Customize SMILE

The ability of SMILE to correct spelling errors in the specimen list and nonsensical word combination errors in clinical information, gross description, and final diagnosis dictation can be enhanced by using a graphical user interface (GUI), enabling nonprogramming users to improve SMILE's intelligence over time. Figure 6 shows the screenshot of such an interface. For example, during the dictation, a nonsensical combination of "Clinical inflammation" was noted. The text "Clinical inflammation" was highlighted using the mouse, and then a GUI was brought up by pressing a hot key defined by SMILE. "Clinical inflammation" automatically appeared in both the boxes for the "Wrong text" and the "Correct text." The text in the "Correct text" box was changed to "Clinical information" by me (Figure 6). Clicking the button "OK to Edit" triggered both the correction of the text in the report and the deposition of this knowledge into the SMILE knowledge repertoire (in the form of a dictionary). From then on, if the same error occurs in the text in a future case, SMILE will have the ability to make an automatic correction when the user saves the case or releases the case and then notify the user of such an action through a message box.

Secretary-Mimicking Artificial Intelligence has recently acquired the ability to detect possible gender error in PowerPath, that is, female patient accessioned as male or vice versa. In a 3-month period since the addition of this ability, with 2 pathologists using SMILE, more than 20 gender errors were caught. I did not catch a single gender error during my more than 14 years of practice in the same group. The encounter-based learning for this capability is either through GUI by user input or, in selected situations, autonomously achieved by SMILE (detail not shown).

Customization of both the diagnoses and headers for individual pathologists is also done by using GUI. Taking headers customization as an example, a case of gastrointestinal biopsies with a specimen list of "1. Cecal polyp: 2. Sigmoid bx: 3. Upper rectal polyp" will produce 3 headers "1. Cecal polyp, biopsy:", "2. Sigmoid colon, biopsy:" and "3. Upper rectal polyp, biopsy:" for me. A third pathologist in the same group has recently started using SMILE and he has trained SMILE to produce 3 different headers "1. Mucosal polyp (cecum), biopsies:", "2. Mucosa (sigmoid colon), biopsies:" and "3. Mucosal polyp (upper rectum), biopsies:" for him automatically.

The advantage of using GUI to improve and customize SMILE is to give the power and control to the users, because no programming is required.

COMMENT

Pathologists spend many hours a day viewing slides and rendering interpretations of biopsies and surgical excision specimens. These interpretations are conveyed to our clinical colleagues in the form of final pathology reports. Translating the interpretations from the pathologists' minds into the final report is a time-consuming and mentally intensive endeavor.

Voice recognition technology has started gaining popularity in pathology practice.[1–5] Slide barcoding and scanning have also been incorporated into some pathology information systems, such as the one I am using now. The advent of these technologies has enabled me to create an artificial intelligence (SMILE) that "listens to" the voice commands and "watches for" the changes of windows associated with the slide bar code scanning. In response, SMILE performs secretarial tasks rapidly and consistently, in ways more intelligent than an average pathologist, resulting in a marked increase in productivity, decrease in errors, and reduction of stress in daily practice.

The effects of SMILE are most dramatic in the preparation of reports on biopsy specimens, such as skin, gastrointestinal, and prostate; its effects on larger cases such as a 30-slide mastectomy specimen and a 20-slide thyroidectomy specimen are relatively small. As a dermatopathologist interpreting both skin and general surgical pathology specimens, I spent about half of my time performing the secretarial tasks of report preparation. Currently, SMILE has resulted in an average time saving of 80% for report preparation, which translates into 40% reduction in the total time or a 67% increase in productivity. The magnitude of the effect depends on the case mix for the day.

Because SMILE liberates pathologists from the need to keep track of many mundane tasks and enables more "working memory" to be devoted to slide interpretation, I speculate that SMILE may also have an indirect positive effect

on the slide interpretation, that is, that it may increase the accuracy and completeness of the interpretation and decrease interpretive errors. This is in addition to the direct reduction of reporting errors as described in "Results."

Secretary-Mimicking Artificial Intelligence not only objectively increases my efficiency and decreases errors, but also enhances my subjective experience; working with SMILE is akin to working with a competent and pleasant assistant. I no longer have to dictate everything and no longer have to pay attention to all the secretarial details; SMILE takes care of many of them rapidly in an autonomous and context-dependent fashion.

Secretary-Mimicking Artificial Intelligence should be reasonably scalable, that is, adaptable to different pathology information systems and customizable for different pathologists.

The ultimate purpose of this article is not to describe SMILE in particular. Instead, I use SMILE as a functioning prototype to demonstrate that artificial intelligence for pathologists is both feasible and powerful. In an era in which pathologists are constantly asked to do more things faster, artificial intelligence can be a capable friend to help us to meet this challenge. Artificial intelligence for pathologists is not near; it is here, waiting for us to embrace, nurture, and use.

In the grand scheme of the emerging definition of computational pathology as outlined in an editorial published in a recent issue of the *Archives of Pathology & Laboratory Medicine*,[6] SMILE is subsumed within the first portion, input data sets. The remaining 4 portions of the computational pathology, in logical sequence, are data technologies, informatics, modeling/inference/prediction, and customer interfaces. The editorial states that "the creation of computational pathology will take time and sustained vision. Moreover, it will require dramatic cultural and intellectual changes in the field of pathology." The realization of the vision outlined in the editorial is crucial to making our specialty more relevant, not less relevant, in the delivery of medical care in the future. Secretary-Mimicking Artificial Intelligence represents a minute concrete step toward the realization of this overarching vision.

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