Creation of a retrospective searchable neuropathologic database from print archives at Toronto's University Health Network

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University Health Network (UHN) Pathology, in its capacity of providing neuro-oncologic care, now utilizes a laboratory information system (LIS), which was instituted in September 2001. For the 75 years preceding the LIS, more than 50 000 pathology reports exist in paper format. High-throughput automated scanning of the paper archives was employed to add the most recent 30 years of paper records (30 000 neuropathology specimens) to the LIS. The searchable portable document format (PDF) files generated from the scans were filtered through a multi-tiered process driven by Java computer programs that selected relevant patient and diagnostic information. A second series of programs queried the neuropathologist-assigned diagnoses and successfully converted these to the standardized World Health Organization (WHO) format. This was achieved with a master list of key site and diagnostic terms, and prioritization rules that were determined on a trial and error basis. Categorization, verification, and consolidation were completed within 3 months and on a C$10 000 budget.

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Databases of pathology specimens can have enormous benefits for clinical use and long-term population-based research. In addition to clear economizing effects, the ease of access and searchability provided by well-organized collections of pathologic cases is highly advantageous for retrospective analyses and augmenting of sample sizes to increase the power of observation.[1] Various data mining methods could also be employed to extract previously unrecognized patterns within large data sets.[2] While databases directed toward specific research tasks and clinical outcomes have previously been described,[3–5] the electronic construction of a comprehensive pathology database from print archives has not been reported thus far. The challenge in constructing such collections lies in the organization of large amounts of data and the feasibility of digitizing paper-based records by optical character recognition (OCR). In this project, we developed a methodical and practical approach for the organization and treatment of retrospective data from print archives.

University Health Network (UHN) in Toronto provides most of the neuro-oncologic care for the southwest region of the province of Ontario. Archival material comprising paper records and corresponding glass slides and paraffin blocks for our center is available from 1932 to September 2001, at which point a laboratory information system (LIS) was implemented. Notably, the majority of the more than 50 000 records in the paper collection (up to 1993) are complemented with surgical operative reports. Here, we describe the construction of a 30 000 entry neuropathologic database from the last 30 years of paper archives at UHN and its combination with the LIS as a model for data sorting, filtration, integration, and later modification geared toward specific research tasks. Furthermore, individual entries are tagged using key diagnostic criteria to allow for greater organization within the database. The feasibility and efficacy of data annotations have been described previously.[6–8]

A cumulative 700 h of human and computer operation, a budget of C$10 000, OCR software, and a Java programming

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environment were allocated toward this project over a year-long period.

MATERIALS AND METHODS

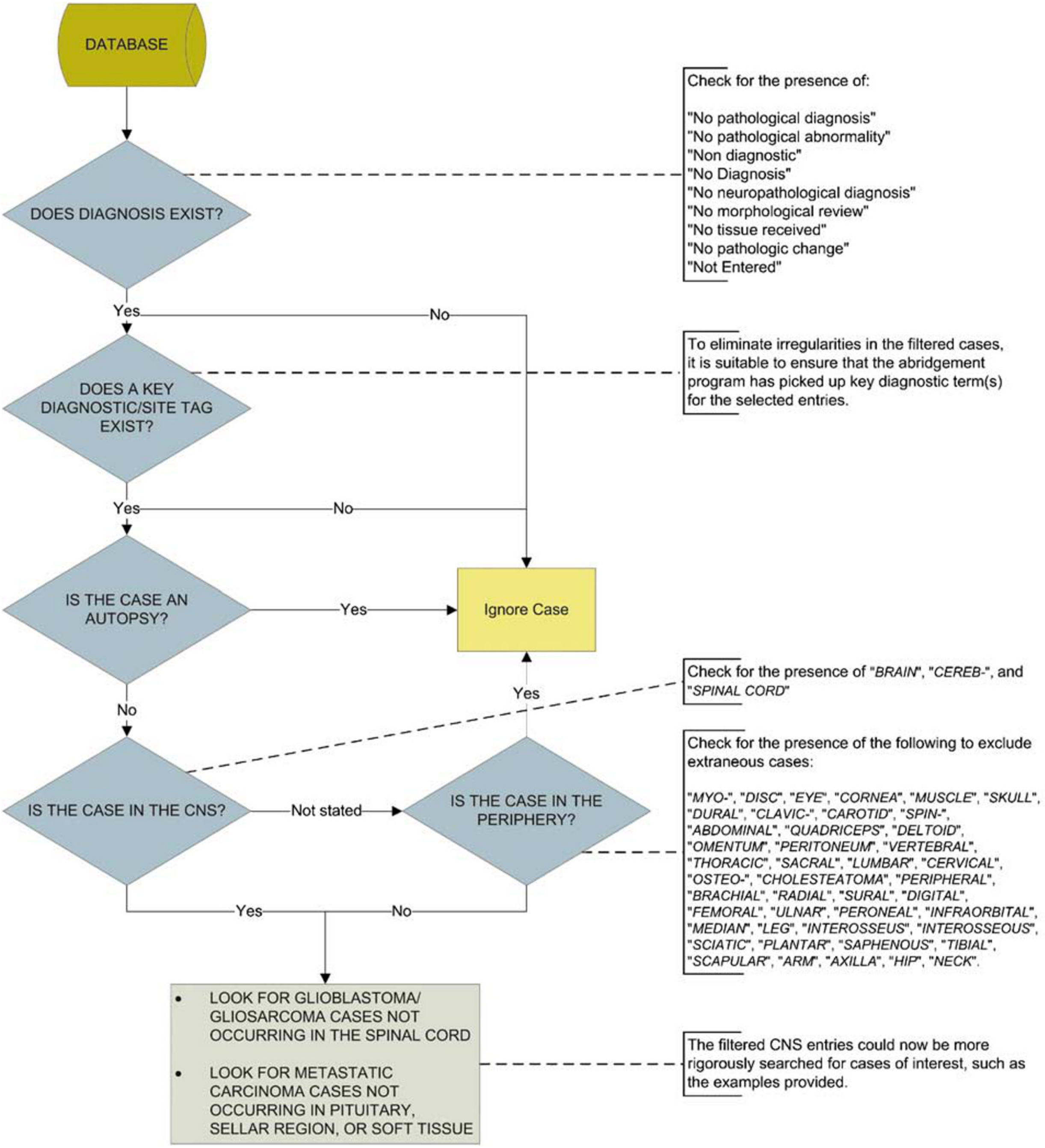
High-throughput scanning was performed by LASON Canada Inc. (Toronto, ON, Canada), a document management company, generating searchable portable document format (PDF) files (Table 1). Full text recognition was carried out on the files using the commercially available OCR software ScanSoft OmniPage Professional 15 (Nuance Communications, Burlington, MA, USA). Subsequently, a first tier of Java programs designed at our lab distilled patient demographic (ie case number, accession date, patient name, age, gender, medical record number, and pathologist) and diagnostic information (ie clinical history, neuropathologic diagnosis, microscopic description, and comment). Standardization and filtration according to the World Health Organization (WHO)[9] classification were then performed. To that end, each entry within the database was automatically tagged with key neuropathologic diagnostic and site-of-occurrence terms. All input and output data utilized by the Java programs were mediated through simple text files. The organized and filtered results were first imported into a spreadsheet, after which the data could be exported into higher level database environments depending on the research and/or clinical needs.

Reports obtained from the LIS were also organized and abridged in a similar manner and added to the data extracted

Table 1 Pathology data digitization and organization model

Procedure	Specifications
1 Raw paper records	Bound surgical pathology and autopsy reports
2 Near high-resolution image scans	Commercial scans at 200 DPI, first as TIFF and then converted to readable PDF (LASON Canada Inc., Toronto, ON, Canada)
3 Correct page rotation and clarity filtrations	Automatic search of the PDF images to find and rectify incorrectly rotated pages and eliminate incomprehensible pages
4 OCR	OCR using ScanSoft OmniPage Professional 15 (Nuance Communications, Burlington, MA, USA) to generate reliable text from the PDF
5 Record formatting-change recognition and grouping	Java-based (Sun Microsystems, Santa Clara, CA, USA) in-lab designed program to recognize and group pathology reports of the same format (reports which utilized identical templates)
6 Grouping-based field-specific programmatic deciphering	Java-based in-lab designed programs, each geared towards a specific group of similar reports, to extract patient information, diagnosis, microscopic information, and pathologist's comments from the reports
7 Creation of rudimentary organized outputs	Export of the program outputs to Microsoft Excel (Microsoft, Redmond, WA, USA), with each column corresponding to one extracted attribute
8 Redundant ($\geqslant$2) manual error-correction and image cross-referencing	2 × redundant manual check of extracted data against scanned images, with greater emphasis on years of low OCR yield
9 Consistency check of redundant manual inputs, and consequent feedback	Java-based program to look for discrepancies among manual corrections so as to ensure optimal accuracy
10 Abridgement of diagnoses into key diagnostic and site terms	Java-based program to abridge diagnosis paragraphs into key terms based on WHO 2000 neuropathologic diagnostic designations
11 Linkage with available surgical operative reports	Each case is linked with the relevant fully searchable surgical report, if available
12 Integration with existing electronic databases	Existing radiology/oncology databases could be easily linked to the spreadsheet, and the data could be annotated with genomic information, etc
13 Evolution into higher level database environments	Export of data to Microsoft Access, allowing for a more robust database environment
14 Constant filtered addition of new and revised data	If new pathology reports cannot be directly entered into the database and/or the scanning process is performed in multiple steps, the database could be easily expanded to include the additional data when they become available

DPI, dots per inch; OCR, optical character recognition; PDF, portable document format; TIFF, tagged image file format; WHO, World Health Organization.


DATABASE
DOES DIAGNOSIS EXIST?
Yes
No
DOES A KEY DIAGNOSTIC/SITE TAG EXIST?
Yes
No
IS THE CASE AN AUTOPSY?
Yes
Ignore Case
No
Yes
IS THE CASE IN THE CNS?
Not stated
IS THE CASE IN THE PERIPHERY?
Yes
No
• LOOK FOR GLIOBLASTOMA/ GLIOSARCOMA CASES NOT OCCURRING IN THE SPINAL CORD
• LOOK FOR METASTATIC CARCINOMA CASES NOT OCCURRING IN PITUITARY, SELLAR REGION, OR SOFT TISSUE

Check for the presence of:

"No pathological diagnosis"
"No pathological abnormality"
"Non diagnostic"
"No Diagnosis"
"No neuropathological diagnosis"
"No morphological review"
"No tissue received"
"No pathologic change"
"Not Entered"

To eliminate irregularities in the filtered cases, it is suitable to ensure that the abridgement program has picked up key diagnostic term(s) for the selected entries.

Check for the presence of "*BRAIN*", "*CEREB-*", and "*SPINAL CORD*"

Check for the presence of the following to exclude extraneous cases:

"*MYO-*", "*DISC*", "*EYE*", "*CORNEA*", "*MUSCLE*", "*SKULL*", "*DURAL*", "*CLAVIC-*", "*CAROTID*", "*SPIN-*", "*ABDOMINAL*", "*QUADRICEPS*", "*DELTOID*", "*OMENTUM*", "*PERITONEUM*", "*VERTEBRAL*", "*THORACIC*", "*SACRAL*", "*LUMBAR*", "*CERVICAL*", "*OSTEO-*", "*CHOLESTEATOMA*", "*PERIPHERAL*", "*BRACHIAL*", "*RADIAL*", "*SURAL*", "*DIGITAL*", "*FEMORAL*", "*ULNAR*", "*PERONEAL*", "*INFRAORBITAL*", "*MEDIAN*", "*LEG*", "*INTEROSSEUS*", "*INTEROSSEOUS*", "*SCIATIC*", "*PLANTAR*", "*SAPHENOUS*", "*TIBIAL*", "*SCAPULAR*", "*ARM*", "*AXILLA*", "*HIP*", "*NECK*".

The filtered CNS entries could now be more rigorously searched for cases of interest, such as the examples provided.

Figure 1 Sample search algorithm utilized for the database to select specific cases of malignant gliomas and metastatic carcinomas. Some root terms were used as search words (right column) to provide redundancy in search selection results.

from the scanned archives. To examine the searchability of the database and its potential in the selection of research-specific cases, we devised a sample algorithm and corresponding Java program which used the WHO diagnostic tags along with other criteria to generate a filtered list of malignant glioma and metastatic carcinoma cases (Figure 1). To protect patient confidentiality, cases were de-identified (patient names and medical record numbers were blocked).

RESULTS

From 49 326 scanned archived pages, in addition to reports extracted from the LIS (September 2001 to January 2007), a total of 29 080 cases were appended to the database. A cumulative 700 h of human and computer operation have been clocked. Of the approximately 450 h of direct human intervention, 58% of the time was allocated toward programming and systematization, while the rest was

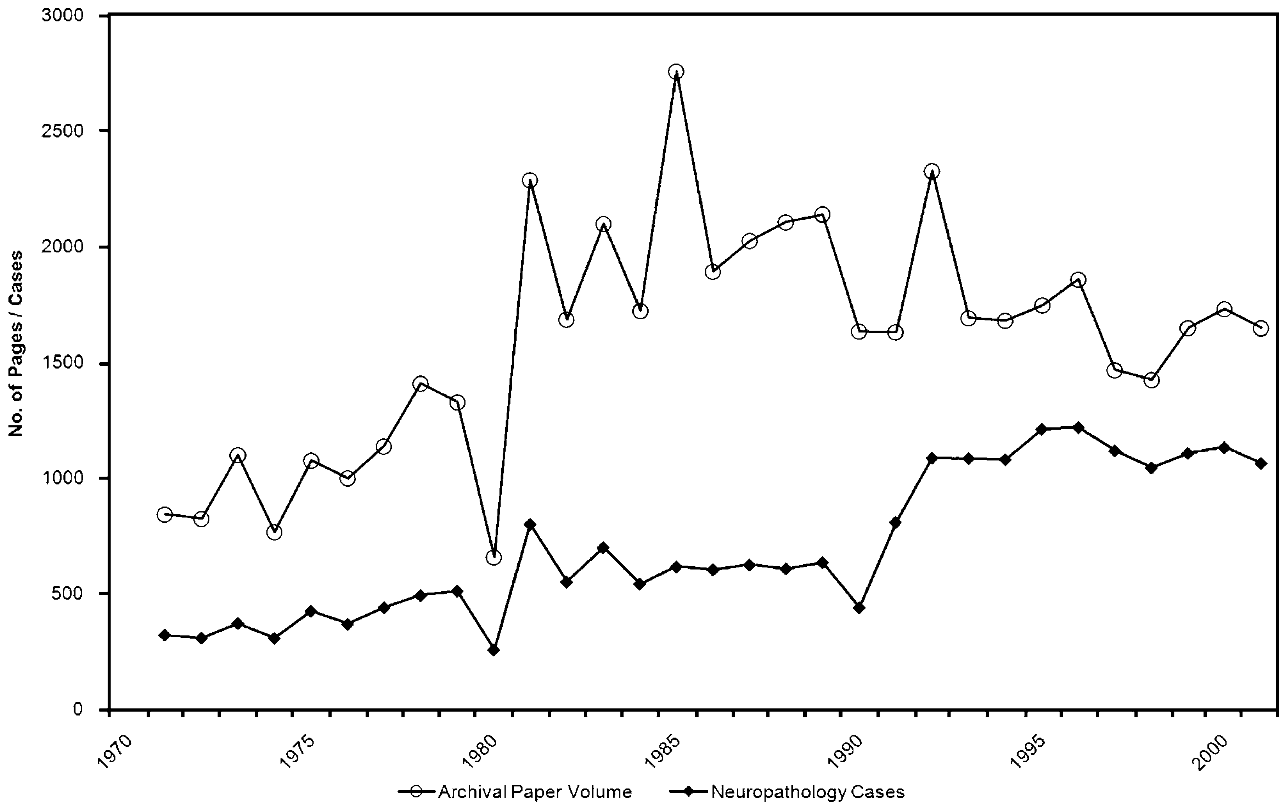


Figure 2 Annual neuropathology archival paper volume and number of cases at University Health Network.

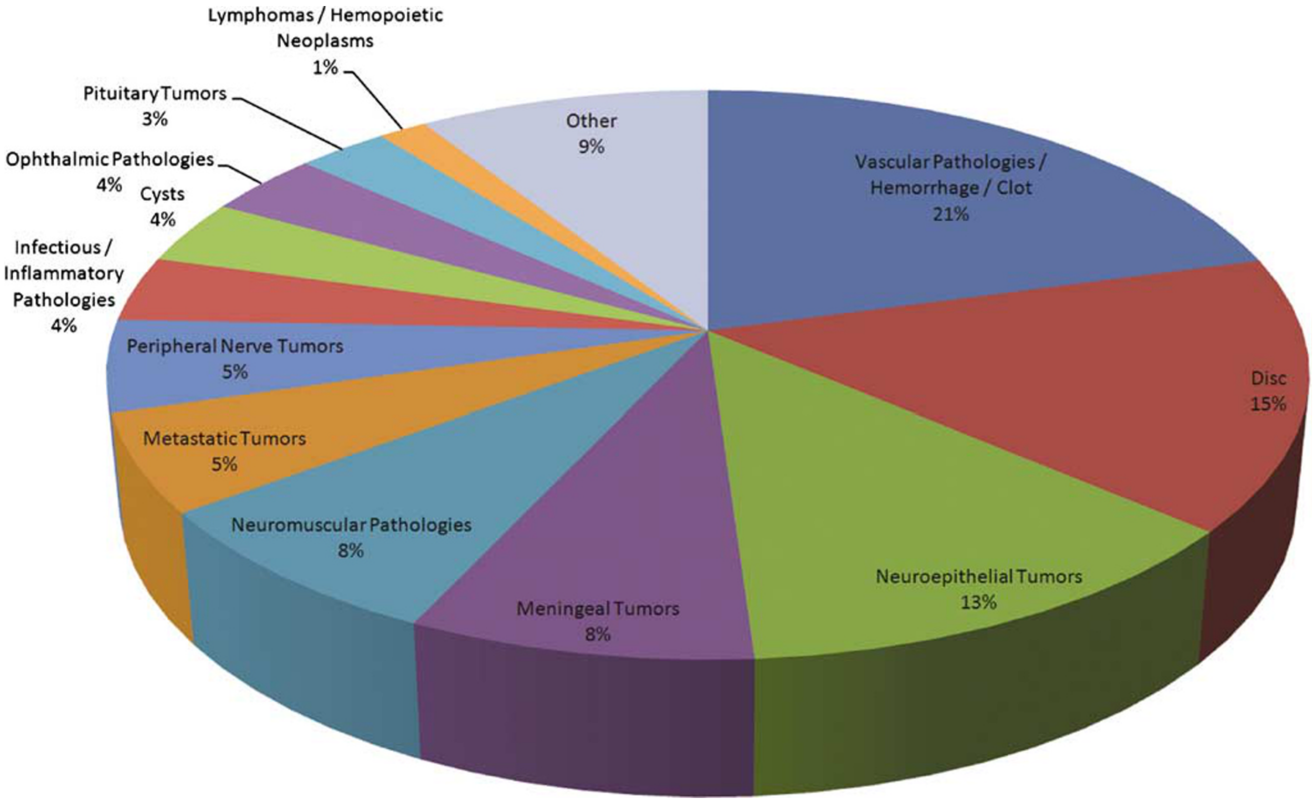


Figure 3 Distribution of neuropathologic diagnoses in the database.

distributed between manual verification and consolidation of extracted data.

On the basis of the statistics of the scanned pages and extracted information, trends for the number of archived neurosurgical pages and neuropathology cases were compared over the period 1971–2001 (Figure 2). Although the pathology specimens show a general rise in number, the pattern in paper volume is unremarkable. The steady decrease in the number of archived pages after 1985 is largely due to the gradual omission of operative records from the archive. Furthermore, a chart depicting the distribution of neuropathologic diagnoses contained in the database is provided (Figure 3).

Possible errors in the digitization of records necessitated a manual cross-check of the extracted data (Table 1). This proved to be a rate-limiting step. Verification of dates, names, and diagnoses against scanned paper records required allocation of approximately 1 h for every 150 cases or 40% of the total human time input.

DISCUSSION

We have demonstrated a novel and highly economical method for the creation of a fully searchable database of pathology records from paper archives with a minimum of human input and correction time. The process does not require application in contiguous intervals, and as such can be utilized on multiple platforms. Access to the data collection can provide many opportunities for epidemiologic and retrospective research. Reviews on specific central nervous system neoplasms and the corresponding neurosurgical approaches are among a number of current studies made possible on account of the database. Correlation of tumors with demographic data such as age and gender, and analysis of the associated changes over time in such relations have also been undertaken.

The manual verification process was the most time-consuming stage. Breaking down the task into smaller segments with a more efficient redundancy function could have improved the outcome. The relatively low quality of some older documents might have been the main contributing factor to the poor OCR output of the corresponding reports. Scanning was performed at 200 dots per inch (DPI), but could be extended to 600 DPI without much compromise in scanning speed. A larger budget could allow for the use of digital camera equipment, which greatly increases the quality and speed of the scans without the necessity of cutting the paper volumes.[10] However, since the quality of the 200 DPI scans and the format of reports might vary in a predictable fashion, more complex programs with learnability functions could be devised to maintain the low cost of the scanning process. This could allow for the automatic flagging of recurrent errors. The feasibility of this approach is currently under investigation. Alternatively, teachable programs could automate the manual checking of the digitized data following expert supervision on the initial runs.

In addition to the database applications currently in use, a multitude of other research tasks await assessment. The importance of pathological classifications and the introduction of immunohistochemical techniques could be evaluated from both a medical and economical point of view. Furthermore, the availability of surgical operative reports for the majority of cases in our collection can enhance the study of surgical methods. Linkage of the neuropathology database to other clinical data banks such as cancer registries can allow for more comprehensive epidemiologic studies. Additionally, linkage with tumor banks may enable the annotation of the database with genomic information. Higher level database environments can allow for such interconnections among databases in multiple institutions, and thereby facilitate the analysis of familial syndromes and cooccurrence of specific malignancies from multiple dimensions. Moreover, the database environment could be adapted if necessary to optimally suit the requirements of the researcher. Finally, to sustain the high research potential provided by the database, an efficient mechanism for constant addition of new cases and ongoing revision of previous records based on updated diagnostic information is imperative.

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DISCLOSURE/DUALITY OF INTEREST

The authors have no duality of interest to declare.

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