

The TOPOSCOUT Expert System for Stroke Localization

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Clinically, strokes are localized by the findings on neurologic examination. TOPOSCOUT is an expert system designed to diagnose the anatomic location and the corresponding vascular territory of strokes based on the clinical signs and symptoms. The inference engine of TOPOSCOUT uses a backtracking algorithm and a rule-based data base that includes associations of neurologic signs with vascular and anatomic areas. TOPOSCOUT is capable of detecting typical stroke patterns, for example, "top-of-the-basilar" or Wallenberg's syndromes. The accuracy of TOPOSCOUT's diagnoses has been tested for conformity with the final diagnoses of 129 patients in the Hamburg Stroke Data Bank, and a high level of agreement was found for hemispheric lesions. The program runs on microcomputers with MS-DOS and is intended as a practical aid for physicians not fully familiar with topologic stroke diagnosis and as an interactive teaching device. (*Stroke* 1989;20:1195-1201)

The topologic localization of stroke is based on detailed knowledge of the associations of clinical signs and symptoms with lesions of particular neuroanatomic structures. Frequently, these associations can be formulated as a rule: *If there is hemilateral impairment of sensation and no motor weakness or cognitive defects, then assume a lesion in the contralateral thalamus.* The data are subjected to multiple pattern-matching rules to arrive at the probability of the final localization. Rule-based expert systems have been used to analyze gait abnormalities, drug interactions, headache and facial pain, and other medical problems.¹⁻⁵

We present TOPOSCOUT, a prototype microcomputer-based expert system for stroke localization. TOPOSCOUT may be used independently or as a supplement to MICROSTROKE, which is an expert system for the diagnosis of stroke type.⁶

Materials and Methods

TOPOSCOUT's knowledge data base is arranged entirely in the form of rules, presently 171. All data are derived from anatomic charts and textbooks⁷⁻¹⁵

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and from 63 clinical publications. Rules are classified into six groups:

1. Signs/symptoms rules ($n=42$; an example is Rule S37 in Figure 1). TOPOSCOUT is able to find a syndrome by logical deduction from clinical signs provided by the physician-user. Thus, formulation of more complicated diagnostic rules using complex terms substituted for signs is feasible. Questions to the physician-user are avoided if their answers can be logically deduced.

2. Hemisphere/brainstem rules ($n=30$; an example is Rule H29 in Figure 1). To estimate the odds for a hemispheric vs. a brainstem lesion, TOPOSCOUT maintains one account for each location. A priori odds were taken from stroke textbooks.¹³⁻¹⁵ Depending on the signs in a given patient, TOPOSCOUT multiplies each account by a factor listed in associated rules. Relevance is an additional multiplication factor that takes into account the relative weight of a clinical item in the diagnostic decision.

3. Right/left rules ($n=21$; an example is Rule R14 in Figure 1). These rules comprise logical deductions for detection of the side of a stroke. Right- and left-sided strokes can be detected in the same patient; thus, discovery of bilateral hemispheric or brainstem lesions is possible.

4. Vascular pattern rules ($n=26$; an example is Rule V08 in Figure 1). Vascular patterns are coded into logical rules. As for the laterality of a stroke, conclusions from several rules can be considered at the same time, corresponding to the involvement of more than one vascular territory. At present, TOPOSCOUT's knowledge data base includes only patterns

RULE S37:

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IF     there is weakness in right arm
AND   there is no weakness in left arm
AND   there is weakness in right leg
AND   there is no weakness in left leg
THEN  there is right hemiparesis;

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RULE M29:

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IF     there is dysarthria
OR     there is impairment of lower cranial nerves
THEN  relevance = 2,
      multiply hemispheric account with 0.3,
      multiply brainstem account with 2.0,

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RULE R14:

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IF     the patient omits the left side of a drawn figure
AND   he displays abnormal angles and proportions in a drawn figure
THEN  assume lesion on the right (hemispheric) side;

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RULE V08:

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IF     there are no reliable signs of a lesion
      in the territory of the middle cerebral artery
AND   there is dyslexia
AND   there is no dysgraphia
THEN  assume a lesion in the territory of the
      posterior cerebral artery;

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RULE A20

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IF     there is mydriasis on the left
AND   there is paresis of left eye muscles
AND   there is ptosis on the left
AND   there is right facial weakness
AND   there is right hemiparesis
THEN  assume WEBER's syndrome on the left.

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RULE M09

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IF     the cholesterol level is elevated
THEN  relevance = 1,
      multiply MCA account with 1.3;
      multiply ICA account with 5.3.

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FIGURE 1. Excerpt from TOPOSCOUT's knowledge data base.

for the main stems of the hemispheric cerebral arteries, the anterior cerebral artery (ACA), the middle cerebral artery (MCA), and the posterior cerebral artery (PCA). Although in 90% of patients the PCA arises from the basilar artery,¹³ the PCA is analyzed with the ACA and MCA as a cortical supply vessel. So far, TOPOSCOUT cannot distinguish segments and branches of these main arteries. The knowledge data base includes rules that take into account the age-dependent frequency distribution of vascular territories involved in stroke samples.¹⁶

5. Anatomic pattern rules ($n=28$; an example is Rule A20 in Figure 1). These rules comprise patterns of neurologic signs associated with particular anatomic areas. For example, TOPOSCOUT can detect thalamic stroke and specific brainstem lesions such as Wallenberg's syndrome. We have included rules that provide a tolerance in diagnosis in case a single sign usually associated with a particular syndrome is missing, but the presence of other signs yields a high probability for this syndrome.

6. MCA/ICA rules ($n=24$; an example is Rule M09 in Figure 1). If stroke in the territory of the

MCA is assumed and if there are no signs of an embolic source in the heart or proximal vascular system, a particular set of rules is activated. TOPOSCOUT tries to assign the vascular lesion to either the internal carotid artery (ICA) or the MCA; data were derived from an investigation of occlusive disease of the MCA by Caplan et al.¹⁷ Similar to the estimation of hemispheric vs. brainstem lesion, accounts for both vessels are maintained, resulting in final odds for an ICA vs. an MCA lesion.

TOPOSCOUT's inference engine is based on a backtracking algorithm and is the section of the computer program that includes the specific problem-solving capabilities of the expert system. A backtracking mechanism¹⁸⁻²⁰ is a specific method of problem solving in which the expert system starts with the final goal (G). For TOPOSCOUT, G is to detect stroke laterality, hemispheric vs. brainstem location, and vascular and anatomic patterns. The inference engine searches the data base for rules for which the conclusion is $R1 \rightarrow G$. To establish these rules, the inference engine looks for other rules that yield the premises of the first ones ($R2 \rightarrow R1$). In this

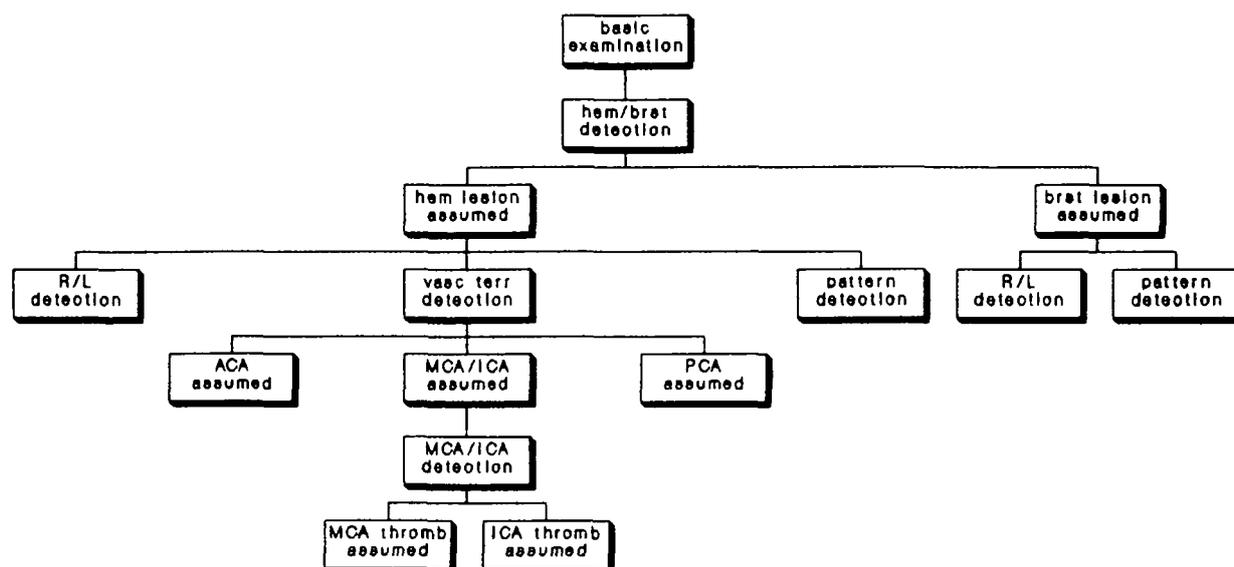


FIGURE 2. Flowchart of TOPOSCOUT's program architecture. *hem*, hemispheric; *brst*, brainstem; *R/L*, right vs. left; *vasc terr*, vascular territory; *ACA*, anterior cerebral artery; *MCA*, middle cerebral artery; *ICA*, internal carotid artery; *PCA*, posterior cerebral artery; *thromb*, thrombosis.

way, TOPOSCOUT backtracks to rules the premises of which are facts (F) about the current patient obtained by the physician-user. G is then concluded by chaining the conclusions $F \rightarrow \dots R2 \rightarrow R1 \rightarrow G$. The inference engine includes 52 rules strictly separated from the knowledge data base. As described above, the heuristic character of TOPOSCOUT allows none, one, or more than one solution for the problems right/left, vascular pattern, and anatomic pattern. Mathematical calculations are restricted to the solution of the problems hemispheric vs. brainstem and MCA vs. ICA lesion. The inference engine has access to an ASCII-text file that contains information used for explanatory and educational purposes.

TOPOSCOUT asks the physician-user interactively for details of the neurologic examination, usually in a multiple-choice format. Some questions are omitted if the answer can be deduced logically. We included clinical items from the questionnaire of Ropper et al²¹ for computer-assisted data acquisition in a neurologic intensive care unit. TOPOSCOUT does not use laboratory findings.

TOPOSCOUT is linked to a data base in which all personal cases, including the physician-user's final diagnoses confirmed by laboratory studies, are stored. To assess the validity of TOPOSCOUT's diagnoses, control programs calculating success rates have been implemented. In addition, special sub-routines are capable of retrieving data on authentic cases from large stroke registries, passing them to TOPOSCOUT, and driving the expert system in an automatic fashion.

TOPOSCOUT's programs are written with the VP-Expert²² expert system development shell. An IBM-compatible microcomputer with a floppy disk drive is required.

Results

Operating TOPOSCOUT is easy; no knowledge of computers is required. Figure 2 shows a flowchart of the program architecture. TOPOSCOUT starts with acquisition of data about a patient's neurologic signs (Figure 3). The physician-user selects one of the options presented in a multiple-choice format. Numerical input is required for some questions such as age. A summary of the patient's findings is displayed and simultaneously written to a disk file for later review.

Initially, the system estimates odds for stroke localization in the cerebral hemispheres vs. in the brainstem. In both instances, TOPOSCOUT tries to determine the side of the stroke. For hemispheric lesions, TOPOSCOUT looks for patterns of signs associated with territories of the main cerebral arteries. If involvement of the MCA is assumed, TOPOSCOUT attempts to distinguish between a vascular lesion in the ICA or the MCA. For this purpose, historic and clinical data about the patient is requested. In addition, the patient's data profile is reviewed for patterns of signs associated with specific anatomic areas. If the presence of a particular syndrome is suspected and TOPOSCOUT needs more information to prove or refute it, the physician-user is consulted again. It takes approximately 3–4 minutes to enter data for a patient.

At the end of the session, TOPOSCOUT has summed up all entered information to present its final diagnosis (Figure 4), which comprises odds for hemispheric vs. brainstem lesions and TOPOSCOUT's prediction including the supposed side of the stroke, an anatomic pattern if present, and TOPOSCOUT's estimation of the involvement of large arteries, combined with their age-matched odds.

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How about facial weakness ?
no weakness          L weakness <---      R weakness
bilateral weakness

How about facial sensation ?
normal <---          L impairment      R impairment
bilateral impairment

How about the lower cranial nerves ?
no deficit <---      L impairment      R impairment
bilateral impairment

Do nystagmus or vertigo exist ?
no <---              yes

Is there dysarthria ?
no <---              yes
    
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Enter to select  END to complete  /Q to Quit  ? for Unknown
    
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FIGURE 3. Excerpt from sample session: TOPOSCOUT's data acquisition. L, left; R, right.

Before leaving TOPOSCOUT, the physician-user is prompted to enter the clinical diagnosis based on results of laboratory studies, if available. This authentic information is also stored in the disk file.

TOPOSCOUT is able to explain its conclusions. Comments about particular keywords include information about the pertinent literature taken into account at different phases of diagnosis.

To test the quality of TOPOSCOUT's diagnoses, we have transferred data on 129 patients from the Hamburg Stroke Data Bank²³ to TOPOSCOUT's control unit. TOPOSCOUT's diagnoses were compared with the final diagnoses in the stroke registry based on the results of laboratory examinations. TOPOSCOUT recognized 87% of all hemispheric strokes regardless of side (76% of right hemispheric strokes and 74% of left hemispheric strokes) and 56% of all brainstem strokes regardless of side (56% of right brainstem strokes and 50% of left brainstem strokes). TOPOSCOUT identified 86% of all MCA-territory strokes regardless of side (76% of right MCA strokes and 73% of left MCA strokes) and 41% of all PCA-territory strokes regardless of side (50% of right PCA strokes and 36% of left PCA strokes). There were no ACA-territory strokes.

Discussion

TOPOSCOUT is a microcomputer-based expert system designed to assist physicians in diagnosis of the topology of stroke using information entirely avail-

able at the bedside. Simulating the human diagnostic approach, TOPOSCOUT's pattern-matching algorithms can direct the physician-user's attention to syndromes that may occasionally be overlooked. TOPOSCOUT's topologic knowledge data base represents a fast and easily accessible reference for physicians involved in the management of stroke patients. Like many other expert systems in medicine,²⁴ TOPOSCOUT serves as a tool for clinical teaching and may be useful for planning further diagnostic procedures. In addition, since all data of personal cases, including the final diagnoses confirmed by laboratory studies, are stored, TOPOSCOUT provides a stroke registry.

Since the computer file encompasses the complete neurologic status of a patient, the physician-user wastes less time with handwritten charts. Taking into account the fast retrieval of the personal stroke registry, we believe that the few minutes spent for data entry are well invested and do not slow down the physician-user in the setting of a busy practice.

TOPOSCOUT's inference engine has been developed applying artificial intelligence techniques in a medical diagnostic process.^{25,26} The inference engine comprises goal-directed programming, pattern matching abilities, and explanatory capabilities. These methods must be distinguished from decision-support programs based on statistical procedures.²⁷⁻²⁹ We consider statistically based meth-

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Odds for hemispheric lesion: 88.3
Odds for brainstem lesion   11.7
    
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Predicting lesion in right hemisphere.
Pattern: Pure motor stroke (basis pontis/internal capsule).
    
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Predicting lesion in ACA territory.      (age-matched odds: 6%)
Predicting lesion in MCA territory: yes  (age-matched odds: 81%)
Predicting lesion in PCA territory.      (age-matched odds: 13%)
    
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FIGURE 4. Excerpt from sample session: TOPOSCOUT's diagnosis. ACA, anterior cerebral artery; MCA, middle cerebral artery; PCA, posterior cerebral artery.

ods, especially Bayesian techniques,^{30,31} to be inadequate tools for a topologic diagnosis-support system; the set of topologic hypotheses is generally not exhaustive and mutually exclusive as assumed by Bayesian statistics.^{29,32} Thus, the frequent involvement of two or more cerebral territories by a stroke contradicts the assumption of only one correct diagnosis in each case as required by most statistical procedures. In TOPOSCOUT, mathematical calculation is limited to a few minor problems in which general objections to statistical procedures do not have to be considered. Adversely, the MICRO-STROKE expert system for the diagnosis of stroke type uses modified Bayesian inference techniques.⁶

The backtracking algorithm was selected to restrict data acquisition to those questions that are needed to pursue relevant goals. TOPOSCOUT skips queries if pertinent information is supplied by other answers or if questions seem to be of limited value in the current diagnostic process; for example, not all neuropsychological phenomena³³ are requested for each patient. However, the inference engine simulates forward-chaining features by requiring the physician-user to enter complete results of a neurologic examination, providing the stroke registry capability. In this way, later reassessment of TOPOSCOUT's decision-making process is feasible.

Published programs for computer-assisted topologic diagnosis in neurology can be classified into two groups based on their neuroanatomic expertise.³⁴ In one group, knowledge data bases interpret the spatial representation of neuroanatomic items and their relations.³⁴⁻³⁹ In the second group, knowledge data bases are constructed by associations of neuroanatomic items with clinical signs without considering the structural or functional relations of anatomy. Localization is predicted by recognizing patterns of clinical findings.⁴⁰⁻⁴³ TOPOSCOUT belongs to this second group. The lack of total knowledge of neural connections in the central nervous system precludes storage of all structural and functional relations in a data base. Pattern recognition is an appropriate approach for this representation of rudimentary knowledge, and pattern matching provides the capability to detect lesions at multiple locations. However, TOPOSCOUT shares the disadvantage of all expert systems based on associations of neuroanatomic items with clinical signs: it is limited to recognizing common clinical patterns and is unable to diagnose patients whose syndromes have not been previously described or have not been included in the rule-based system.

At present, there are still other drawbacks to our expert system. One serious handicap is that validity control has shown poor detection of brainstem lesions and involvement of the PCA. Too few rules (31) have been implemented concerning topologic diagnosis of brainstem lesions (compared with 72 rules for hemispheric lesions). If a symptom could be caused by a hemispheric or a brainstem lesion,

the former location is often falsely favored by TOPOSCOUT because of probability assignment and disregard of pertinent cosymptoms. Infratentorial topologic diagnosis forms an obstacle not only for TOPOSCOUT but for other systems as well. For example, PAL was correct in detecting posterior fossa strokes in only 53% of cases.^{42,43} Posterior circulation stroke is more heterogeneous than anterior circulation stroke. A larger registry of patients with vertebrobasilar stroke will be needed to amplify TOPOSCOUT's rule system.

Most diagnostic failures were caused by TOPOSCOUT's insufficient tolerance. Stroke location was often not correctly detected because an appropriate minor symptom was missing, prompting the definite rejection of this location despite other evidence. Some rules adhere too closely to logical links of clinical and anatomic items, a fact that uncovers a general disadvantage of rule-based systems. TOPOSCOUT was helpless in identifying lesions associated with a broad spectrum of clinical symptoms, such as caudate infarcts.⁴⁴ We must improve our knowledge data base to include more rules that take into account variability of clinical syndromes.

Furthermore, the knowledge data base should be expanded to include clinical patterns of stroke in cerebral arteries supplying brainstem structures and patterns associated with stroke in terminal parts of hemispheric arteries. Lacunar infarcts should be identified by TOPOSCOUT. Additional improvement will be achieved by using TOPOSCOUT's self-learning characteristics when data from past consultations are included in current diagnostic decisions.

The rules implemented in this prototype expert system should be regarded as preliminary. They are still inadequate concerning consistency, completeness, and independence. We will attempt to overcome these shortcomings by applying knowledge acquisition and verification tools.^{3,45,46}

Since 1979, numerous expert systems have been successfully developed with expert system shells (software tools for developing expert systems).⁴⁷⁻⁴⁹ In contrast, such a shell seems to be too inflexible for this specific stroke localization problem. In particular, inclusion of tolerance in the mechanism of pattern recognition seems to pose severe problems for a shell. To provide TOPOSCOUT with full deductive reasoning capabilities, the expert system is translated into PROLOG.⁵⁰ In the future, a prospective study will be carried out to verify the validity of the program.

This prototype expert system suggests that computer-assisted stroke localization is feasible at the bedside and that, with further improvement, TOPOSCOUT holds promise as a tool in the clinical routine of stroke diagnosis. Finally, we clearly do not deny that skillful and experienced neurologists, with their present 80-86% accuracy rate,⁵¹ have legitimate reasons to criticize the competence of the newborn TOPOSCOUT. But we also want to emphasize that these authorities decided for good reasons

to spend a considerable number of years as medical students, residents and, possibly, stroke fellows. Therefore, we believe that it is tolerable to accept a training period of several years for the development of an expert system's software and expansion of its knowledge data base before it is compared with the most competent in the field.

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