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CT: To Enhance or Not to Enhance? A Computer-Aided Study

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Statistical analysis was performed of the carefully coded results of computed tomographic scans, with and without contrast medium, of a substantial group of patients with proved diagnoses. Bayesian methods were used to provide computer-aided diagnoses with considerable success. Further analysis of these results suggested that expert advice can be provided by the computer concerning which patients would benefit diagnostically from enhancement after their plain scan description has been fed into the computer.

Wills et al. [1–3] described the creation of an expert system for the computer-aided diagnosis of cerebral tumors and other lesions using a microprocessor and a statistical model. By defining a series of binary (yes/no) signs (table 1) to describe the computed tomographic (CT) scan image, we established a data base of some 650 patients with confirmed diagnoses. Radiologists are often uncertain about whether a patient's scan would benefit from enhancement (such enhancement being uncomfortable and entailing a measurable morbidity). This paper reports our endeavors to try to determine which patient signs indicate that organic iodine enhancement may be unnecessary.

Materials and Methods

Diagnostic help given by the computer is in the form of a list of diseases, the likelihood of each being represented as a probability. "Diagnosis" in the work reported here means the determination of the presence of a tumor or other lesion, and the type within the broad classification shown in table 2. We recognize that this list is limited to broad categories, but, as data accumulate, it may easily be expanded if the method appears useful.

The change in CT scan appearance after enhancement is defined in our work by 10 signs (table 1). There are 648 patient profiles in the data base, of which 359 (55.4%) had postenhancement scans available for coding. Tables 2 and 3 show the distribution of these among the different diseases.

Inspection of results led us to adopt the following criteria as an experimental basis for further work in deciding whether or not enhancement might be worthwhile. If a case is diagnosed without enhancement, and the probability of: (1) meningioma is given as being greater than 0.85; (2) glioma is given as being greater than 0.85; or (3) any other disease is given as being greater than 0.90, then the use of enhancement will have little effect on the computer diagnosis. Only one of these conditions can be met at a time; if one or more are not met, then the advice would be to enhance. Figure 1 is a flow chart depicting this decision process.

The computer advice is based solely on whether or not enhancement is likely to lead to a modification in the diagnosis. Of course, the radiologist must always make the final decision, and for a particular patient may therefore decide not to enhance when such enhancement is judged to be an unacceptable risk.

Results

Overall

The computer differed from the radiologists as to which cases might be beneficially enhanced (table 3), and advised "do not enhance" in 37.9% of those cases actually enhanced and "enhance" in 40.5% of those not enhanced. The radiologists enhanced more cases than the computer advised in patients with meningioma (20% more than computer advised), glioma (32% more), chromophobe adenoma (15% more), metastasis (21% more), abscess (20% more), nerve VIII neurinoma (71% more), pinealoma (67% more), and atrophy (11% more) (table 3). Sometimes, no doubt, this was because the radiologist hoped to improve the probability of diagnosis, but at others it was to provide the surgeon with information over and above the diagnostic parameters "position" and "type" of lesion. Conversely, the computer advised enhancement in more cases than the radiologists for intracerebral

TABLE 1: **CT Indicators of Cerebral Tumors**

Indicator	No. Signs/Indicator
No. of lesions	3
Location	12
Unenhanced appearance	12
Enhanced appearance*	10
Others (mass effect, etc.)	6
Total	43

* The 10 signs of an enhanced appearance are: (1) homogeneity of entire lesion; (2) homogeneity with surrounding unenhanced abnormality; (3) ring with lower than brain attenuation center; (4) ring with isodense or higher than brain attenuation center; (5) multiple rings; (6) thickness of ring uniform within 25%; (7) apparently abnormal blood vessels; (8) selectivity of gray matter; (9) heterogeneity, other than above; and (10) no enhancement.

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TABLE 2: **Breakdown of Cases Computer Would Enhance, Compared with those Enhanced in Data Base for Each Disease Category**

Disease	No. Cases in Data Base				
	Enhanced Computer Advice		**Unenhanced** Computer Advice		Totals
	Enhance	Don't Enhance	Enhance	Don't Enhance	
Meningioma	22	7	1	0	30
Glioma	45	28	3	2	78
Chromophobe adenoma	11	2	0	0	13
Metastasis	23	8	1	1	33
Eosinophil adenoma	2	0	0	0	2
Craniopharyngioma	5	0	0	0	5
Chordoma	1	0	0	0	1
Epidermoid	1	1	1	0	3
Hemangioma/Hemangioblastoma	0	2	0	0	2
Abscess	4	1	0	0	5
Hematoma, intracerebral	9	10	16	22	57
Hematoma, subdural	5	10	9	6	30
Hematoma, extradural	0	1	1	2	4
Arachnoid cyst	1	0	1	0	2
Choroid plexus papilloma	1	0	0	0	1
Neurinoma, nerve VIII	2	5	0	0	7
Pinealoma	1	2	0	0	3
Atrophy	7	33	15	107	162
Infarction	33	7	19	10	69
Hydrocephalus	7	2	16	8	33
Aneurysm ± subarachnoid hemorrhage	7	3	10	2	22
Subarachnoid hemorrhage	2	0	6	1	9
Other nontumors	34	14	18	11	77
Totals	223	136	117	172	648

TABLE 3: **Cases Computer Advised to Enhance Compared with Cases Actually Enhanced**

Disease	No. Cases (%)		
	Total Examined	Enhanced	Computer Advised Enhancement
Meningioma	30	29 (97)	23 (77)
Glioma	78	73 (94)	48 (62)
Chromophobe adenoma	13	13 (100)	11 (85)
Metastasis	33	31 (94)	24 (73)
Eosinophil adenoma	2	2 (100)	2 (100)
Craniopharyngioma	5	5 (100)	5 (100)
Chordoma	1	1 (100)	1 (100)
Epidermoid	3	2 (67)	2 (67)
Hemangioma/Hemangioblastoma	2	2 (100)	0
Abscess	5	5 (100)	4 (80)
Hematoma, intracerebral	57	19 (33)	25 (44)
Hematoma, subdural	30	15 (50)	14 (47)
Hematoma, extradural	4	1 (25)	1 (25)
Arachnoid cyst	2	1 (50)	2 (100)
Choroid plexus papilloma	1	1 (100)	1 (100)
Neurinoma, nerve VIII	7	7 (100)	2 (29)
Pinealoma	3	3 (100)	1 (33)
Atrophy	162	40 (25)	22 (14)
Infarction	69	40 (58)	52 (75)
Hydrocephalus	33	9 (27)	23 (70)
Aneurysm ± subarachnoid hemorrhage	22	10 (46)	17 (77)
Subarachnoid hemorrhage	9	2 (22)	8 (89)
Other nontumors	77	48 (62)	52 (68)
Totals	648	359 (55)	340 (53)

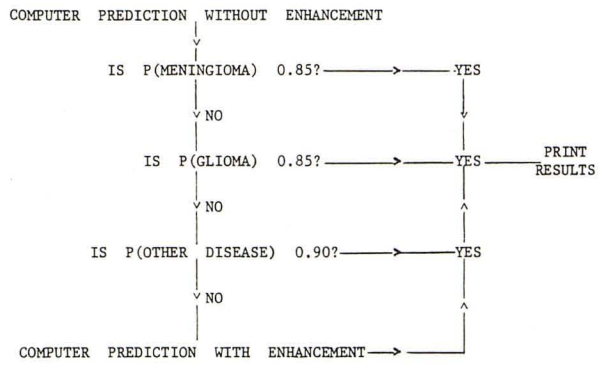

Fig. 1.—Flow chart showing decision criteria.

hematoma (11% more), infarct (17% more), hydrocephalus (42% more), aneurysm ± subarachnoid hemorrhage (32% more), and subarachnoid hemorrhage (67% more). Computer accuracy without and with enhancement is shown in table 4 for the same cases.

By being selective, we have managed to retain accuracy (in general, it has slightly improved) while reducing the proportion of cases of certain diseases for which enhancement had been advised (tables 5 and 6).

Comments on Individual Pathologies

Meningiomas and chromophobe adenomas. Enhancement is of great help in computer diagnosis. This is in contrast to gliomas and hematomas, where little help is given.

Intracerebral hematomas. Radiologists believe it is possible to diagnose these without enhancement. Examining the individual cases, however, we note that the computer has difficulty in distinguishing purely intracerebral hematomas (the result of spontaneous hemorrhage) from those accompanying subarachnoid hemorrhage. It is chiefly these difficulties that are reflected in table 3, because in them the radiologist or the computer may suggest enhancement when the position of a hemorrhage suggests the possibility of aneurysm or angioma. However, under these circumstances, radiologists often decide not to enhance, either because an angio-

TABLE 4: **Computer Accuracy in 359 Cases**

Disease	No. Cases Examined	No. Unenhanced (N)/Enhanced (E) (%)							
		N1	E1	N2	E2	N3	E3	Total N	Total E
Meningioma	29	10 (35)	18 (62)	6 (21)	4 (14)	5 (17)	2 (7)	21 (72)	24 (83)
Glioma	73	51 (70)	56 (77)	9 (12)	4 (6)	7 (10)	6 (8)	67 (92)	66 (90)
Chromophobe adenoma	13	5 (39)	9 (69)	6 (46)	2 (15)	1 (8)	1 (8)	12 (92)	12 (92)
Metastasis	31	7 (23)	10 (32)	10 (32)	15 (48)	6 (19)	0	23 (74)	25 (81)
Eosinophil adenoma	2	1 (50)	0	0	0	0	0	1 (50)	0
Craniopharyngioma	5	2 (40)	1 (20)	0	1 (20)	0	0	2 (40)	2 (40)
Chordoma	1	0	0	0	0	0	0	0	0
Epidermoid	2	0	0	0	0	0	0	0	0
Hemangioma/Hemangioblastoma	2	2 (100)	0	0	0	0	1 (50)	2 (100)	1 (50)
Abscess	5	0	0	0	1 (20)	0	0	0	1 (50)
Hematoma, intracerebral	19	12 (63)	14 (74)	3 (16)	1 (5)	2 (11)	0	17 (90)	15 (79)
Hematoma, subdural	15	12 (80)	12 (80)	1 (7)	1 (7)	0	1 (7)	13 (87)	14 (93)
Hematoma, extradural	1	0	0	0	0	0	0	0	0
Arachnoid cyst	1	0	0	0	0	0	0	0	0
Choroid plexus papilloma	1	0	0	0	0	0	0	0	0
Neurinoma, nerve VIII	7	6 (86)	6 (86)	0	0	0	1 (14)	6 (86)	7 (100)
Pinealoma	3	2 (67)	2 (67)	0	0	0	1 (33)	2 (67)	3 (100)
Atrophy	40	31 (78)	30 (75)	2 (5)	4 (10)	4 (10)	3 (8)	37 (93)	37 (93)
Infarction	40	25 (63)	24 (60)	5 (13)	4 (10)	3 (8)	4 (10)	33 (83)	32 (80)
Hydrocephalus	9	6 (67)	6 (67)	0	0	0	1 (11)	6 (67)	7 (78)
Aneurysm ± subarachnoid hemorrhage	10	2 (20)	2 (20)	2 (20)	3 (30)	0	1 (10)	4 (40)	6 (60)
Subarachnoid hemorrhage	2	0	0	0	0	0	0	0	0
Other nontumors	48	5 (10)	9 (19)	19 (40)	17 (35)	13 (27)	14 (29)	37 (77)	40 (83)
Totals	359	179 (50)	199 (55)	63 (18)	57 (16)	41 (11)	36 (10)	283 (79)	292 (81)

gram is indicated regardless of the result, or because enhancement is judged to be an unacceptable risk.

In a few other cases of intracerebral hematoma there is no surrounding low attenuation, and the scan descriptors, especially in the frontal region, may be identical to those of a meningioma. This leads the computer to suggest enhancement. Distinction from meningioma might be helped if we could divide the well defined, homogeneous, high-attenuation lesions into two categories. This is the next logical step of our work. As radiologists know, higher attenuations usually indicate hematoma, while less high ones may indicate meningioma.

Infarcts. When space-occupying they look very like gliomas and therefore have similar descriptors. Enhancement is advised by the computer because of mathematically low diagnostic probabilities. However, when enhancement has been carried out it has been found to add marginally to the confusion and to further decrease the probability of correct diagnosis in infarction cases. This may occur also if the radiologist chooses enhancement without the aid of computed diagnosis. On the other hand, when an infarct is not space-occupying, it is usually correctly diagnosed by the computer on the unenhanced scan.

Other suprasellar lesions. Confusion occurs when there is blood in the chiasmatic cistern. As yet we have no way of telling the computer the shape of a suprasellar high-attenuation lesion, and therefore it has no data to help to distinguish between certain diseases. Because it is unsure of diagnosis it advises enhancement.

Nerve VIII neurinomas. Most of our nerve VIII neurinomas were large, and we may have oversimplified their diagnosis by encoding the enhanced and unenhanced scans at the same session. Having seen the tumor with enhancement, one can usually detect it on review of the unenhanced scan.

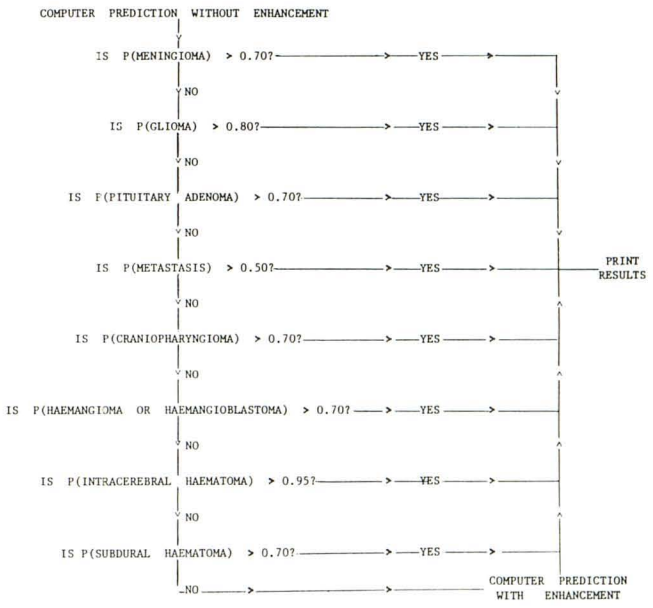

Fig. 2.—Flow chart showing new criteria for choice of whether or not to advise enhancement.

Further Developments

Since the work described in the previous sections was completed, further modifications have been introduced: (1) the method

TABLE 5: **Computer Accuracy with Selective Enhancement**

Disease	No. Cases Examined	Correct Diagnosis Predicted (%)			
		1st	2d	3d	Totals
Meningioma	29	18 (62)	3 (10)	2 (7)	23 (79)
Glioma	73	56 (77)	5 (7)	5 (7)	66 (90)
Pituitary adenoma	15	10 (77)	1 (8)	1 (8)	12 (92)
Metastasis	31	10 (32)	14 (45)	1 (3)	25 (81)
Craniopharyngioma	5	1 (40)	1 (40)	0	2 (40)
Chordoma	1	0	0	0	0
Epidermoid	2	0	0	0	0
Hemangioma/Hemangioblastoma	2	2 (100)	0	0	2 (100)
Abscess	5	0	1 (20)	0	1 (20)
Hematoma, intracerebral	19	14 (74)	0	1 (5)	15 (79)
Hematoma, subdural	15	12 (80)	1 (7)	1 (7)	14 (93)
Hematoma, extradural	1	0	0	0	0
Arachnoid cyst	1	0	0	0	0
Choroid plexus papilloma	1	0	0	0	0
Neurinoma, nerve VIII	7	6 (86)	0	1 (14)	7 (100)
Pinealoma	3	2 (67)	0	1 (33)	3 (100)
Atrophy	40	31 (78)	2 (5)	4 (10)	37 (93)
Infarction	40	24 (60)	4 (10)	2 (5)	30 (75)
Hydrocephalus	9	6 (67)	0	1 (11)	7 (78)
Aneurysm ± subarachnoid hemorrhage	10	2 (20)	3 (30)	0	5 (50)
Subarachnoid hemorrhage	2	0	0	0	0
Other nontumors	48	9 (19)	18 (38)	12 (25)	39 (81)
Totals	359	203 (57)	53 (15)	32 (9)	288 (80)

TABLE 6: **First Place Prediction Using a Modified Data Base**

Disease	No. Cases (%)			
	Total Enhanced	Unchanged	Selectively Enhanced	Totals
Meningioma	17 (59)	12 (41)	17 (59)	29
Glioma	54 (75)	56 (78)	54 (75)	72
Pituitary adenoma	10 (67)	9 (60)	10 (67)	15
Metastasis	13 (48)	12 (44)	14 (52)	27
Craniopharyngioma	2 (40)	1 (20)	1 (20)	5
Chordoma	0	0	0	1
Epidermoid	0	0	0	2
Hemangioma/Hemangioblastoma	0	0	0	2
Abscess	0	0	0	4
Hematoma, intracerebral	13 (68)	12 (63)	13 (68)	19
Hematoma, subdural	12 (80)	12 (80)	12 (80)	15
Hematoma, extradural	0	0	0	1
Arachnoid cyst	0	0	0	1
Choroid plexus papilloma	0	0	0	1
Neurinoma, nerve VIII	6 (86)	7 (100)	7 (100)	7
Pinealoma	2 (67)	2 (67)	2 (67)	3
Atrophy	31 (80)	31 (80)	31 (80)	39
Infarction	22 (54)	29 (71)	29 (71)	41
Hydrocephalus	6 (75)	6 (75)	6 (75)	8
Aneurysm ± subarachnoid hemorrhage	2 (20)	2 (20)	2 (20)	10
Subarachnoid hemorrhage	0	1 (50)	1 (50)	2
Other nontumors	19 (41)	23 (50)	23 (50)	46
Totals	209 (60)	215 (61)	222 (63)	350

for coding multiple lesions has been improved; (2) a process has been introduced to help solve the problem of over- and underprediction of certain diseases (e.g., there were 15 cases of pituitary adenoma in the data, yet it was predicted 27 times); and (3) we have examined cases where enhancement changed one wrong prediction to another, changed a correct diagnosis to an incorrect one, or made diagnosis more confusing by lowering probabilities.

Table 6 shows first-place predictions for all unenhanced, enhanced, and selectively enhanced cases using new criteria (fig. 2) on the modified data base containing 350 postenhancement scans. It also shows that for some diseases (e.g., meningioma) enhancement is necessary for diagnosis, while for others (e.g., infarction) it can add to the confusion. By choosing the criteria carefully, we can suggest when enhancement could be advantageous or when it is unlikely to be of diagnostic value. Using our latest modified criteria, the computer advised enhancement in only 109 (31.1%) of the radiologist-enhanced cases. Despite this drop we have managed to improve first-place accuracy of computer-assisted diagnosis, which, in some cases, we believe matches or exceeds that of unaided radiologists.

Editor's Note: This work reflects the views of the computer programmer and advisers. The computer is not more or less "intelligent" than the radiologist, but responds to the information afforded it and to how it is programmed to respond. In truth, does not the computer just add consistency to a series of preagreed conditions? (A. E. R.)

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