Clinical stages of human brain abscesses on serial CT scans after contrast infusion

Computerized tomographic, neuropathological, and clinical correlations

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The authors describe a classification of human brain abscesses into stages of development as demonstrated on computerized tomography (CT) scans. The results of CT staging of 14 human brain abscesses are compared with the previously published findings in an experimental brain abscess model developed by the same authors. The CT criteria for categorizing brain abscesses into cerebritis and capsule stages were based on the pattern of contrast enhancement and the time-density curve of enhancement obtained from sequential CT scans after contrast infusion. Using these CT criteria, it was possible to accurately categorize all 14 brain abscesses into cerebritis and capsule stages. Histological examination of surgical and autopsy specimens provided immediate confirmation of the abscess stage in six patients. Indirect staging, based on surgical findings and/or subsequent autopsy findings, was possible in eight patients. Corticosteroid administration greatly reduced contrast enhancement in the cerebritis stage, but had little effect in the capsule stage. A systematic approach utilizing CT for establishing the diagnosis, staging, and treatment planning of brain abscess is proposed.

KEY WORDS • brain abscess • computerized tomography • cerebritis • capsule formation • ring-like contrast enhancement • time-density curve of ring contrast enhancement

The authors have previously reported the results of an experimental model of brain abscess in which the neuropathological findings at sequential stages of abscess evolution were compared with findings on computerized tomography (CT) scans. The evolution of a brain abscess was divided into four stages based on histological criteria: early cerebritis, late cerebritis, early capsule formation, and late capsule formation. The results of sequential CT scans over the 1st hour after infusion of contrast material showed two significant differences between the cerebritis and encapsulation stages of brain abscess development: 1) the pattern of enhancement, and 2) the time-density curve of contrast enhancement.

In the cerebritis stages, the ring of enhancement was narrowest immediately after contrast medium was injected. The most peripheral aspect of the ring enhanced first (10 minutes), with the inner portion enhancing more over time (30 to 60 minutes) resulting in partial to complete filling in of the central lucency. As the abscess became encapsulated, the central lucency no longer filled in on delayed scans, providing that the necrotic center was large enough to image.

The time-density curve of contrast enhancement in the cerebritis stages showed that the density of the ring enhancement increased over the first 10 to 20 minutes and then plateaued for an hour. Lesions in the beginning capsule formation stage showed rapid ring contrast enhancement (at 5 to 10 minutes) and then began to fade rapidly by 30 minutes.

The purpose of the present investigation was to see if there is a correlation between the results of these experimental brain abscess studies and the evolution of brain abscess in humans. In addition, we examined the effect of corticosteroids on contrast enhancement in the different stages of human brain abscess development and compared them with experimental brain abscess studies. The results of these studies suggest a sys-
tematic approach to the diagnosis, staging, and treatment planning of brain abscess with the aid of CT scanning.

Clinical Material and Methods

Summary of Cases

Fourteen patients with brain abscess are the basis of this study (Table 1). Seven patients were immunocompromised, three of whom were heart transplant recipients. The remaining immunocompromised patients had underlying diseases (chronic Epstein-Barr virus infection, acute lymphocytic leukemia, chronic lymphocytic leukemia, and sarcoid). Three patients had congenital cyanotic heart disease. One patient had incompletely treated tuberculous meningitis. Another patient had direct extension of infection from the frontal sinus. In one patient, the brain abscess was caused by hematogenous spread from a pulmonary site of primary infection. No prior history of infection could be obtained from one patient. Eight patients had a single abscess and six patients had multiple abscesses.

Surgical management was required in 12 patients (Table 2). Aspiration was performed in 10 patients (one patient had open aspiration of a posterior fossa abscess with biopsy of a portion of the capsule), aspiration followed by excision in one patient, and primary excision in one patient. Nonsurgical management using broad-spectrum antibiotic coverage was utilized in two patients with deep and small lesions (Cases 9 and 22); both were judged to be poor operative risks.

A broad spectrum of organisms was encountered in this group of patients (Table 1), including bacteria (Haemophilus influenzae, Klebsiella pneumoniae, Listeria monocytogenes, Mycobacterium tuberculosis, Bacteroides oralis, microaerophilic Streptococcus, Peptostreptococcus species, and Nocardia asteroides). Nine patients had a single organism and four had multiple organisms responsible for the brain abscesses. One patient had a sterile encapsulated abscess.

Outcome of treatment (Table 2) depended on neurological status at the time of admission, causative organism, and immunocompromised status. Three patients died acutely of their intracranial infection: one with multiple abscesses developed herniation after ventricular rupture of an abscess (Case 7), and the other two, both with underlying immunodeficiency, had incurable fungal infections (Aspergillus species in Case 5 and Fusarium oxysporum in Case 4). Two immunocompromised patients died acutely from generalized sepsis (Cases 9 and 11), making the overall mortality of this series of brain abscess 36%. Two patients died following surgery (operative mortality of 17%). One cardiac transplant recipient with Toxoplasma gondii brain abscesses died 1 year after treatment from chronic cardiac rejection (Case 13). One patient (Case 14) was lost to follow-up review, and probably died subsequently of chronic lymphocytic leukemia.

Serial Computerized Tomography

Brain CT scans were obtained on all patients and were used to follow each lesion during the course of treatment. Scans were taken before and after the rapid infusion of a bolus of contrast medium, using 1 cc/lb body weight of diatrizoate sodium (Hypaque 50%), diatrizoate meglumine solution (Hypaque meglumine 60%), or iothalamate meglumine solution (Conray 60%). In nine patients, serial CT scans were performed after contrast infusion at the following time intervals: 0 minute (immediately after injection), and at 5, 10, 20, 30, 45, and 60 minutes (hereafter called the “brain

<table>
<thead>
<tr>
<th>Case No.</th>
<th>Age (yrs)</th>
<th>Sex</th>
<th>Predisposing Condition</th>
<th>No. of Lesions</th>
<th>Organisms</th>
</tr>
</thead>
<tbody>
<tr>
<td>1</td>
<td>3</td>
<td>M</td>
<td>cyanotic heart disease</td>
<td>single</td>
<td>Haemophilus influenzae</td>
</tr>
<tr>
<td>2</td>
<td>13, F</td>
<td></td>
<td>cyanotic heart disease</td>
<td>single multiloculated</td>
<td>microaerophilic Streptococci, Bacteroides oralis</td>
</tr>
<tr>
<td>3</td>
<td>15, F</td>
<td></td>
<td>frontal sinusitis</td>
<td>single</td>
<td>microaerophilic Streptococci, Bacteroides oralis</td>
</tr>
<tr>
<td>4</td>
<td>18, F</td>
<td></td>
<td>chronic Epstein-Barr virus</td>
<td>single, small daughter abscess</td>
<td>Fusarium oxysporum</td>
</tr>
<tr>
<td>5</td>
<td>20, M</td>
<td></td>
<td>acute lymphocytic leukemia</td>
<td>multiple</td>
<td>Aspergillus species</td>
</tr>
<tr>
<td>6</td>
<td>24, M</td>
<td></td>
<td>none</td>
<td>single</td>
<td>sterile</td>
</tr>
<tr>
<td>7</td>
<td>31, M</td>
<td></td>
<td>pneumonia &amp; pleural effusion</td>
<td>multiple</td>
<td>Bacteroides oralis, Fusobacterium species, Peptostreptococcus species</td>
</tr>
<tr>
<td>8</td>
<td>37, M</td>
<td></td>
<td>cardiac transplant</td>
<td>single multiloculated</td>
<td>Listeria monocytogenes</td>
</tr>
<tr>
<td>9</td>
<td>39, M</td>
<td></td>
<td>sarcoid</td>
<td>multiple</td>
<td>probable Nocardia asteroides</td>
</tr>
<tr>
<td>10</td>
<td>40, M</td>
<td></td>
<td>tuberculosis</td>
<td>multiple</td>
<td>Mycobacterium tuberculosis, Streptococcus viridans, Enterobacter cloacae</td>
</tr>
<tr>
<td>11</td>
<td>42, M</td>
<td></td>
<td>cardiac transplant</td>
<td>single</td>
<td>Klebsiella pneumoniae</td>
</tr>
<tr>
<td>12</td>
<td>43, M</td>
<td></td>
<td>cyanotic heart disease</td>
<td>single</td>
<td>Fusobacterium species</td>
</tr>
<tr>
<td>13</td>
<td>54, M</td>
<td></td>
<td>cardiac transplant</td>
<td>multiple</td>
<td>Toxoplasma gondii</td>
</tr>
<tr>
<td>14</td>
<td>61, F</td>
<td></td>
<td>chronic lymphocytic leukemia</td>
<td>multiple</td>
<td>Nocardia asteroides</td>
</tr>
</tbody>
</table>
R. H. Britt and D. R. Enzmann

**TABLE 2**

**Classification of brain abscess based on CT, surgical, and pathological findings and outcome in 14 patients**

<table>
<thead>
<tr>
<th>Case No.</th>
<th>Initial CT Classification</th>
<th>Surgery</th>
<th>Surgical Findings</th>
<th>Pathology</th>
<th>Final Classification</th>
<th>Outcome</th>
</tr>
</thead>
<tbody>
<tr>
<td>1</td>
<td>capsule</td>
<td>aspiration</td>
<td>no resistance; pus</td>
<td>capsule formation incomplete on ventricular side; no significant mature collagen formation</td>
<td>early capsule</td>
<td>alive</td>
</tr>
<tr>
<td>2</td>
<td>capsule</td>
<td>aspiration</td>
<td>no resistance; pus</td>
<td>cerbritis; hyphae growing in thrombosed blood vessels; infarction</td>
<td>early capsule</td>
<td>alive</td>
</tr>
<tr>
<td>3</td>
<td>cerbritis</td>
<td>aspiration</td>
<td>resistance; pus</td>
<td>cerbritis</td>
<td>early capsule</td>
<td>died</td>
</tr>
<tr>
<td>4</td>
<td>capsule</td>
<td>aspiration</td>
<td>resistance; pus</td>
<td>cerbritis; hyphae growing in thrombosed blood vessels; infarction</td>
<td>early capsule</td>
<td>died</td>
</tr>
<tr>
<td>5</td>
<td>cerbritis</td>
<td>aspiration</td>
<td></td>
<td>cerbritis; hyphae growing in thrombosed blood vessels; infarction</td>
<td>early cerbritis</td>
<td>died</td>
</tr>
<tr>
<td>6</td>
<td>capsule</td>
<td>excision</td>
<td>firm encapsulated mass; pus</td>
<td>thick collagen capsule</td>
<td>late capsule</td>
<td>alive</td>
</tr>
<tr>
<td>7</td>
<td>a) cerbritis</td>
<td>aspiration</td>
<td>no resistance; pus</td>
<td>a) early cerbritis at level of ventricular rupture</td>
<td>a) early cerbritis</td>
<td>died</td>
</tr>
<tr>
<td></td>
<td>b) capsule</td>
<td>aspiration</td>
<td></td>
<td>b) early capsule superiority thin collagen capsule</td>
<td>late capsule</td>
<td>alive</td>
</tr>
<tr>
<td>8</td>
<td>capsule</td>
<td>aspiration, then excision</td>
<td>pus on aspiration; excised encapsulated abscess</td>
<td>thin collagen capsule</td>
<td>late capsule formation</td>
<td>alive</td>
</tr>
<tr>
<td>9</td>
<td>cerbritis</td>
<td>none</td>
<td></td>
<td>organisms characteristic of <em>Nocardi</em>ia &amp; multiple small granulomas at autopsy</td>
<td>cerbritis</td>
<td>died</td>
</tr>
<tr>
<td>10</td>
<td>capsule</td>
<td>posterior fossa craniotomy</td>
<td>firm capsule visualized; pus</td>
<td>collagen capsule</td>
<td>late capsule</td>
<td>alive</td>
</tr>
<tr>
<td>11</td>
<td>cerbritis</td>
<td>none</td>
<td></td>
<td>thin collagen capsule at autopsy</td>
<td>cerbritis</td>
<td>died</td>
</tr>
<tr>
<td>12</td>
<td>capsule</td>
<td>aspiration</td>
<td>resistance; pus</td>
<td>thin collagen capsule at autopsy</td>
<td>late capsule</td>
<td>alive</td>
</tr>
<tr>
<td>13</td>
<td>cerbritis</td>
<td>aspiration</td>
<td>no resistance; fragmented white matter</td>
<td>thin capsule 1 yr later at autopsy</td>
<td>early cerbritis</td>
<td>died</td>
</tr>
<tr>
<td>14</td>
<td>capsule</td>
<td>aspiration</td>
<td>firm resistance</td>
<td></td>
<td>late capsule</td>
<td>lost to follow-up</td>
</tr>
</tbody>
</table>

*CT = computerized tomography.*

abscess protocol*). In three patients the initial CT study included contrast scans at 10 to 15 minutes and 70 and 90 minutes. Scans were performed on the GE 8800 or EMI model 1005 scanners.

In staging human brain abscesses, the same two criteria which were used in the staging of experimental brain abscesses were applied: 1) pattern of contrast enhancement, and 2) time-density curve of contrast enhancement. The degree of ring contrast enhancement was quantitated by measuring the number of CT units (scale -1000 to +1000) above baseline value. The baseline value in CT units for normal brain at the location of each brain abscess was measured at the analogous location in the contralateral hemisphere. Patients were placed into either the cerbritis or capsule stage based on the initial CT scan findings (Table 2).

In the cerebritis stage, the same two criteria which were used in the staging of human brain abscesses were applied: 1) pattern of contrast enhancement, and 2) time-density curve of contrast enhancement. The degree of ring contrast enhancement was quantitated by measuring the number of CT units (scale -1000 to +1000) above baseline value. The baseline value in CT units for normal brain at the location of each brain abscess was measured at the analogous location in the contralateral hemisphere. Patients were placed into either the cerbritis or capsule stage based on the initial CT scan findings (Table 2).

Histological and Surgical Staging of Brain Abscess

To verify the accuracy of CT staging, tissue obtained at surgery or autopsy was studied to determine the histological stage of each brain abscess. The hematoxylin and eosin stain was used to evaluate the general morphology. The stage of capsule development was determined using a stain for reticulin (the precursor of collagen), and the Masson trichrome and hematoxylin van Gieson stains for detecting the presence of mature collagen. Phosphotungstic acid hematoxylin (PTAH) was used to determine the degree of gliosis. Organisms were identified in tissue utilizing the Gram stain (for bacteria), Grocott’s methenamine silver (GMS) stain (for fungi), the Wright-Giemsa stain (for Toxoplasma...
CT staging of human brain abscesses

### TABLE 3

<table>
<thead>
<tr>
<th>Case No.</th>
<th>Pre-Contrast Scan</th>
<th>Post-Contrast Scan</th>
<th>Delayed Scan</th>
</tr>
</thead>
<tbody>
<tr>
<td>1</td>
<td>rim</td>
<td>irregular ring enhancement without diffusion</td>
<td>significant decrease in ring enhancement</td>
</tr>
<tr>
<td>2</td>
<td>rim</td>
<td>irregular ring enhancement without diffusion</td>
<td>significant decrease in ring enhancement</td>
</tr>
<tr>
<td>3</td>
<td>low density</td>
<td>diffuse ring enhancement</td>
<td>no decrease in ring enhancement; further diffusion</td>
</tr>
<tr>
<td>4</td>
<td>rim</td>
<td>ring enhancement without significant diffusion; ring thinner medially; small daughter abscess</td>
<td>decrease in ring enhancement</td>
</tr>
<tr>
<td>5</td>
<td>low density</td>
<td>ring enhancement</td>
<td>no decrease in ring enhancement</td>
</tr>
<tr>
<td>6</td>
<td>small area of high density</td>
<td>a) diffuse ring enhancement at level of ventricle</td>
<td>gradual decrease in enhancement over 1 hr</td>
</tr>
<tr>
<td>7</td>
<td>a) low density area adjacent to ventricle</td>
<td>b) ring enhancement superiorly</td>
<td></td>
</tr>
<tr>
<td>8</td>
<td>area of increased density</td>
<td>multiloculated irregular ring enhancement</td>
<td>no decrease in enhancement</td>
</tr>
<tr>
<td>9</td>
<td>small areas of low density</td>
<td>small areas of diffuse nodular enhancement</td>
<td>decrease in enhancement</td>
</tr>
<tr>
<td>10</td>
<td>rim</td>
<td>ring enhancement</td>
<td>no significant decrease in enhancement</td>
</tr>
<tr>
<td>11</td>
<td>low density</td>
<td>ring enhancement</td>
<td>decrease in enhancement</td>
</tr>
<tr>
<td>12</td>
<td>rim</td>
<td>irregular ring enhancement: thinner on ventricular surface</td>
<td></td>
</tr>
<tr>
<td>13</td>
<td>low density</td>
<td>ring enhancement</td>
<td>no decrease in enhancement</td>
</tr>
<tr>
<td>14</td>
<td>rim</td>
<td>narrow ring enhancement</td>
<td>significant decrease in ring enhancement</td>
</tr>
</tbody>
</table>

* Superscript "A" means the stage of abscess development was determined by histological examination of autopsy material. Superscript "P" means the stage was determined by microscopically examining the pathological specimen obtained at surgery. Superscript "DA" means that the patient had an autopsy subsequent to the diagnosis and treatment of brain abscess and could not be used for determining the initial histological stage. Note that Case 7 had a histologically verified lesion in both the early cerebritis and early capsule stages.

gondii), and the acid-fast bacteria (AFB) stain (for *Mycobacteria*). The salient histological criteria used to classify each abscess are listed in Table 4.

The findings at surgery were also used to help determine the degree of encapsulation (Table 4). If, with aspiration, firm resistance and a "pop" was felt as the ventricular needle penetrated the necrotic center, the lesion was classified in the late capsule stage. Lack of resistance placed the lesion into either the cerebritis or early capsule stages. Intermediate resistance placed lesions in the early capsule stage. The operative findings at excision are also listed in Table 4. Excision permitted histological confirmation of the abscess stage of development.

### Results

**Summary of Findings**

Using the "brain abscess protocol," CT proved to be an accurate method of staging brain abscess. Abscesses

### TABLE 4

<table>
<thead>
<tr>
<th>Stage of Brain Abscess</th>
<th>Histological Criteria</th>
<th>Surgical Criteria</th>
</tr>
</thead>
<tbody>
<tr>
<td>early cerebritis</td>
<td>area of inflammatory response poorly demarcated from surrounding brain (Cases 5, 7)</td>
<td>no resistance; fragmented white matter; necrotic tissue (Case 13)</td>
</tr>
<tr>
<td>late cerebritis</td>
<td>fibroblasts appear on margin of developing necrotic center &amp; lie down a reticulin matrix (the precursor of collagen)</td>
<td>no resistance; necrotic material, edematous white matter, &amp;/or possible pus aspirated (Cases 3, 9, 11)</td>
</tr>
<tr>
<td>early capsule</td>
<td>increase in new blood vessels with migration of additional fibroblasts surrounding necrotic center; reticulin network surrounds necrotic center, but is less developed along ventricular surface; mature collagen present in scattered areas of developing capsule (Cases 6, 7)</td>
<td>may or may not show resistance; pus aspirated (Cases 1, 2, 4, 7)</td>
</tr>
<tr>
<td>late capsule</td>
<td>a collagen capsule surrounds necrotic center; a zone of gliosis forms around collagen capsule (Cases 6, 8, 10)</td>
<td>firm resistance &amp; &quot;pop&quot; when needle penetrates through capsule into necrotic center; pus aspirated (Cases 10, 12, 14)</td>
</tr>
</tbody>
</table>

* Superscript "A" means the stage of abscess development was determined by histological examination of autopsy material. Superscript "P" means the stage was determined by microscopically examining the pathological specimen obtained at surgery. Superscript "DA" means that the patient had an autopsy subsequent to the diagnosis and treatment of brain abscess and could not be used for determining the initial histological stage. Note that Case 7 had a histologically verified lesion in both the early cerebritis and early capsule stages.

were categorized initially into either cerebritis or capsule stages based on the CT criteria outlined in the Methods section (Table 2). Six patients were thought to have lesions in the cerebritis stage (Cases 3, 5, 7, 9, 11, and 13) and nine patients were thought to have encapsulated abscesses (Cases 1, 2, 4, 6, 7, 8, 10, 12, and 14). One patient with multiple abscesses (Case 7) was believed to have lesions in two stages of development. Subsequent histological examination and/or the findings at surgery verified that the initial staging based on CT criteria was accurate in all 14 patients (Table 2).

Immediate confirmation of the degree of encapsulation was possible in six patients, by examining brain abscess tissue excised at surgery in three patients (Cases 6, 8, and 10) and from autopsy material in the three patients (Cases 4, 5, and 7) who died acutely (Table 4). In three other patients (Cases 9, 11, and 13), material obtained at autopsy could be correlated with CT scans obtained during or after treatment. In five patients, the degree of encapsulation could be determined only indirectly by assessing if there was any capsular resistance of the ventricular needle entering the necrotic center. In two abscesses (Cases 12 and 14), a tough well defined capsule was encountered. In three patients, no resistance was appreciated (Cases 1, 2, and 3) which could place these lesions into either the cerebritis or early capsule stages (Table 4).

By combining CT scan findings, surgical observations, and histological examination, patients could be classified into one of four stages of brain abscess development: early cerebritis, late cerebritis, early capsule formation, or late capsule formation (Tables 2 and 5). Histologically verified abscesses included two lesions in the early cerebritis stage (Cases 5 and 7); two lesions in the early capsule formation stage (Cases 4 and 7); and three well encapsulated abscesses (Cases 6, 8, and 10). More indirect evidence (surgical findings, CT scan appearance, and/or subsequent autopsy findings) was used to classify the remaining eight patients. Two patients (Cases 1 and 2), with a faint rim on the pre-contrast scan suggestive of a capsule and a time-density curve showing significant fading of enhancement, lacked "capsular" resistance to needle aspiration. These lesions were classified in the early capsule stage. Patients with CT criteria of cerebritis and lack of "capsular" resistance were placed in the late cerebritis stage (Cases 3, 9, 11, and 13). In two patients (Cases 12 and 14), firm resistance to needle penetration of the abscess occurred at the time of aspiration. These abscesses were classified in the late capsule stage.

**Stages of Human Brain Abscess Development**

**Early and Late Cerebritis Stages.** The pre-contrast CT scans in the early and late cerebritis stages show an ill-defined area of low density (Fig. 1 left scans). However, this area of low attenuation may be nonhomogeneous in density (Fig. 2 upper left scan). The patterns of contrast enhancement in the cerebritis stages are greatly variable. It depends whether the scan is obtained early or late during the course of cerebritis (Table 6). The CT appearance of the earliest phase of cerebritis in humans shows only an irregular area of low density which does not enhance with contrast material (Fig. 1 upper scans). This finding was seen in only one patient in this study who presented with a seizure and headache during an acute episode of frontal sinusitis (Case 3). The initial CT scans (Fig. 1 upper scans) were initially thought to be normal. In retrospect, the area of low density in the right frontal fossa was not a partial volume artifact of CT. Despite the administration of antibiotics, the patient developed increasing headache 12 days later. Repeat CT scans showed findings more characteristic of the cerebritis stage. The area of low density on the pre-contrast scan was enlarged compared with the scan 12 days earlier (Fig. 1 lower left). With contrast infusion, a typical pattern of ring enhancement was seen. The ring was thick and diffuse on the scan obtained immediately after contrast infusion (Fig. 1 lower center). On the delayed scan obtained at 90 minutes, there was further diffusion of contrast material (Fig. 1 lower right). If the area of the developing necrotic center was still small, the CT scan showed a solid nodular pattern of enhancement (Fig. 3A).

The density of the necrotic or lucent center was variable with lesions in the cerebritis stage. An extremely low-density or "black" center correlated well with the presence of purulent material (Fig. 1). However, the presence of necrotic brain and pus also corresponded to a density which was closer to that of normal brain (see Fig. 2 upper center). In immunocompromised patients, it was not possible to determine whether necrotic material or edematous infected white matter would be aspirated from the "lucent" center. For example, in a patient with a Toxoplasma gondii abscess that was thought to be in the late cerebritis stage (Fig. 3B), the aspirate from the lesion showed only necrotic white matter. However, the diagnosis was made by...
CT staging of human brain abscesses

FIG. 1. Computerized tomography (CT) findings in the early and late cerebritis stages in the development of a brain abscess (Case 3). The initial CT scans (upper row) showed a small area of low density near the floor of the right frontal fossa which did not enhance with contrast material. A second scan 12 days later (lower row) showed a larger irregular area of low density on the non-infused scan. With contrast infusion, there was immediate development of a thick diffuse ring (10 minutes) which did not fade on the delayed scan (90 minutes). The delayed scan shows some diffusion of the contrast material. The black low-density center correlated with the finding of 8 cc of pus when the lesion was aspirated. Marked cerebral edema surrounded the area of contrast enhancement.

Histological identification of typical *Toxoplasma gondii* extracellular and intracellular trophozoites and pseudocysts in the aspirate.7

In order to differentiate whether a developing abscess was in the cerebritis or capsule stage, delayed CT scans after infusion of contrast material were obtained. In the cerebritis stage, the intensity of ring enhancement did not decrease on the delayed scans at 60 to 90 minutes (Fig. 1 lower right). Figure 4 shows the mean and standard deviation of the time-density curve of contrast enhancement for three patients with lesions in the cerebritis stage.

Figures 2 and 5 illustrate the CT and pathological correlations of a large abscess in which the cortical side of the abscess was in the early capsule stage and the ventricular side of the abscess in the deep white matter was in the early cerebritis stage (Case 7). The CT scans reflected these histological differences. This patient died from ventricular rupture of this abscess. The pre- and post-contrast CT scans corresponding to the area of early cerebritis are illustrated in Fig. 2 (upper). The pre-contrast scan (Fig. 2 upper left) showed an extensive region of low density in the left parietal and occipital lobes surrounding an area of near-normal density (necrotic brain). The left lateral ventricle was compressed by mass effect. With contrast infusion, a diffuse thick pattern of ring-like contrast enhancement was seen (Fig. 2 upper center).

The gross pathology (Fig. 2 upper) showed an area of necrosis that extended into the lateral ventricle. Microscopically, the area was composed of necrotic material and infiltration of inflammatory cells into the surrounding brain (Fig. 5A). Perivascular cuffing or "cerebritis" was seen extending for a significant distance from the necrotic center (Fig. 5B) and correlated well with the diameter and geometry of ring enhancement seen on CT of this patient (Fig. 2 upper center). Histologically, a reticulin stain (Fig. 5C) showed only a few small scattered blood vessels. There was no evidence that fibroblasts had migrated into the area to begin...
Ring enhancement was not always diffuse in the cerebritis stage. The pattern of enhancement in some immunocompromised patients with “opportunistic” infections showed some variation from typical pyogenic infection, with either a thin ring (Fig. 3C) or a ring of medium thickness (Fig. 3B). Pathological examination of the lesion, which demonstrated thin ring contrast enhancement, was performed shortly after the CT scan in Fig. 3C was obtained. The patient died from disseminated aspergillosis (Case 5). Histologically, there was a narrow zone of “cerebritis” (Table 4) surrounding an area of infarction, which matched the thickness of the ring enhancement and its diameter on the CT scan. The contrast material did not diffuse into the lucent center (an area of early infarction with thrombosed blood vessels) for any significant distance on delayed scans. Because of the absence of fibroblasts and a negative reticulin stain, this lesion was categorized in the early cerebritis stage (Tables 4 and 5). The CT basis for classifying this lesion in the cerebritis stage was the time-density curve of enhancement which showed no diminution on delayed scans.

**Early Capsule Formation Stage.** The CT findings of a brain abscess in a pathologically proven stage of early capsule formation is illustrated in Fig. 2 (lower). On the pre-contrast scan, there was a faint ring that had a higher density than the lower density of both the surrounding edematous brain and the necrotic center. This pre-contrast ring was seen in all four patients with lesions in the early capsule stage of abscess development (Table 6). It is better illustrated in a patient (Case 1) with a brain abscess caused by *Haemophilus influenzae* (Fig. 6). Histologically, the appearance of this non-contrast ring correlated with a developing capsule wall and the inflammatory infiltrate at the margin of the necrotic center (Fig. 5D). Spindle-shaped fibroblasts were seen in the region adjacent to the necrotic center.
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(Fig. 3). The pattern of contrast enhancement on computerized tomography (CT) is illustrated in eight patients with intracranial abscesses caused by bacterial organisms (A, D, E, G, H), fungi (C, F), and protozoa (B). Three of the lesions are in the early cerebritis stage (A to C), one lesion is in the late cerebritis stage (D), two lesions are in the early capsule formation stage (E, F), and two abscesses are well encapsulated (G, H). Four of the patients had multiple abscesses (A, B, C, H) which are not all depicted in the single CT scan illustrated from each patient. A: Multiple lesions (probably due to *Nocardia asteroides*) showing nodular contrast enhancement on CT in the early cerebritis stage in an immunocompromised patient with sarcoid (Case 9). B: *Toxoplasma gondii* brain abscess in the early cerebritis stage in a cardiac transplant recipient (Case 13). C: *Aspergillus* brain abscess in the early cerebritis stage in a patient with acute lymphocytic leukemia (Case 5). D: An abscess in the late cerebritis stage caused by *Klebsiella pneumoniae* in a cardiac transplant recipient (Case 11). E: An occipital abscess caused by microaerophilic *Streptococcus* and *Bacteroides oralis* in a patient with cyanotic heart disease (Case 2). F: An immunocompromised host with chronic Epstein-Barr viral infection and an abscess caused by *Fusarium oxysporum* in the early capsule stage of development (Case 4). G: An encapsulated abscess in a patient with cyanotic heart disease caused by *Fusobacterium* species (Case 12). H: Multiple posterior fossa encapsulated brain abscesses caused by *Mycobacterium tuberculosis*, *Streptococcus viridans*, and *Enterobacter cloacae*.

(Fig. 5E) and had started to form a reticulin network (Fig. 5F). However, a significant amount of mature collagen was not present, indicating that the lesion was in the early stage of capsule formation.

The necrotic center at this stage of abscess development was either of low density (Fig. 2 lower left) or was non-homogeneous in appearance (Fig. 6). Both appearances correlated well with the presence of pus.

With contrast infusion, a well defined ring of high density formed in all four patients with abscesses in the early stage of capsule formation (see Figs. 2 lower center, 3E and F, and 6 center). This ring was most commonly thin, although in three patients it was not of uniform thickness (Figs. 3E and F and 6 center, Table 6). The ring of enhancement was often thinner on the medial or ventricular surface (Fig. 3E and F). Delayed scans after contrast enhancement showed marked reduction in the degree of enhancement in all three patients studied (Fig. 6, Table 6), and minimal diffusion of contrast material (Figs. 3E and F and 6 right).

(Fig. 4). Time-density curves of ring enhancement in the cerebritis (three patients) and capsule formation (six patients) stages of human brain abscess development are illustrated. The standard deviation is represented by the vertical bar at each time point. In the cerebritis stage, the degree of contrast enhancement was stable over 1 hour. In the capsule formation stage, there was a gradual reduction in enhancement after an initial peak at 5 to 10 minutes. CT = computerized tomography.

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FIG. 5. Photomicrographs of a human brain abscess are shown in the early cerebritis (A, B, C) and early capsule formation (D, E, F) stages (Case 7). A: Inflammatory cells were seen in the brain surrounding the area of necrosis, which is consistent with the early cerebritis stage of brain abscess formation. H & E, × 85. B: A wide area of cerebritis (perivascular cuffing) surrounded the area of liquefaction. The area of cerebritis correlated well with the pattern of diffuse contrast enhancement seen in the computerized tomography scan of this abscess (Fig. 2, upper center). H & E, × 330. C: Reticulin stain in the early cerebritis stage showed no evidence of reticulin formation. Reticulin, × 85. D: A well formed necrotic center was present (extreme right of the photomicrograph) associated with compressed acellular debris and inflammatory cells. In the surrounding brain, there was evidence of cerebritis (perivascular cuffing) and neovascularity. Adjacent to the necrotic center, there was a mixture of acute inflammatory cells, fibroblasts, and macrophages. H & E, × 85. E: Fibroblasts, seen in the areas between blood vessels, laid down a reticulin network (see F). This represents the earliest stage of capsule formation. H & E, × 330. F: Reticulin deposition was seen in the area adjacent to the necrotic center corresponding to D. Mature collagen could not be demonstrated. Reticulin, × 85.
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**Fig. 6.** Computed tomography (CT) scans obtained before and after contrast infusion showed a brain abscess caused by *Haemophilus influenzae* in a 3-year-old boy with cyanotic heart disease (Case 1). **Left:** The pre-contrast scan showed an ill-defined rim of increased density (developing capsule) compared to the low-density area surrounding this lesion (cerebral edema). The area of inhomogeneous low density inside the rim represented the pus-filled necrotic center. **Center:** The rim enhanced with contrast infusion. **Right:** The delayed scan at 70 minutes showed a significant decrease in the degree of contrast enhancement. At the time of surgery, no significant resistance was felt in penetrating the necrotic center, indicating that a mature collagen capsule had not yet developed.

**Late Capsule Stage.** In all five patients with well encapsulated brain abscesses, the collagen capsule was delineated on the pre-contrast scan because of the low-density necrotic center and the surrounding edematous brain (Figs. 7 and 8, pre-contrast scans, and Table 6). Contrast enhancement was characterized by a thin ring of high density in one patient (Fig. 7) and a ring of moderate thickness in three patients (Fig. 3G and H, Fig. 8, Table 6). In one patient, there was an area of thinner enhancement on the ventricular side indicating that there was retarded encapsulation at that site (Fig. 3G). Encapsulated lesions were multiloculated in two patients (Fig. 3E).

The time-density curve showed that peak enhancement occurred soon (5 to 10 minutes) after infusion, and subsequently decayed at varying rates (Figs. 4 and 7). Delayed scans (30 to 60 minutes after contrast infusion) showed a significant reduction in the degree of contrast enhancement and virtually no diffusion of contrast material into the central region (Fig. 7, 60-minute scan). In comparing the time-density curves of the cerebritis and capsule stages, the decrease in the intensity of enhancement was not statistically different at any one time. However, it was visually apparent that, for all lesions in the capsule stage, fading of enhancement occurred over 30 to 60 minutes (Fig. 4).

**Fig. 7.** Serial computerized tomography (CT) scans after contrast infusion are seen in a patient with chronic lymphocytic leukemia and multiple *Nocardia asteroides* brain abscesses (Case 14). On the pre-contrast scan, well defined thin rims (capsules) were seen in both hemispheres. After contrast infusion, the vascular capsules showed thin uniform ring enhancement patterns that reached their peak in intensity at 5 to 10 minutes. The delayed CT scan at 45 minutes showed a significant decrease in the degree of enhancement and no diffusion of contrast material. The patient had a firm capsule at the time of aspiration of the large right frontoparietal abscess.
Upper: Serial computerized tomography scans obtained after contrast infusion of a well encapsulated sterile brain abscess in Case 6 showed that contrast material did not diffuse into the lucent center. The intensity of the contrast enhancement gradually faded over 45 minutes. This lesion was excised for diagnosis since the patient had no prior history of infection.

Lower: A trichrome stain of the abscess showed a thick collagen capsule.

**TABLE 6**

Summary of results of CT scanning in 14 patients with brain abscess

<table>
<thead>
<tr>
<th>Computerized Tomography (CT) Finding</th>
<th>Early Cerebritis</th>
<th>Late Cerebritis</th>
<th>Early Capsule</th>
<th>Late Capsule</th>
</tr>
</thead>
<tbody>
<tr>
<td>precontrast CT scan area of low density</td>
<td>4 (3)</td>
<td>0</td>
<td>0</td>
<td>0</td>
</tr>
<tr>
<td>ring of high density patterns of contrast enhancement</td>
<td>0</td>
<td>0</td>
<td>4</td>
<td>5</td>
</tr>
<tr>
<td>none</td>
<td>1 (3)</td>
<td>0</td>
<td>0</td>
<td>0</td>
</tr>
<tr>
<td>diffuse ring</td>
<td>1 (7)</td>
<td>1 (3)</td>
<td>0</td>
<td>0</td>
</tr>
<tr>
<td>nodular</td>
<td>0</td>
<td>1 (9)</td>
<td>0</td>
<td>0</td>
</tr>
<tr>
<td>ring</td>
<td>1 (13)</td>
<td>1 (11)</td>
<td>1 (7)</td>
<td>2 (6)</td>
</tr>
<tr>
<td>thin ring</td>
<td>1 (5)</td>
<td>0</td>
<td>0</td>
<td>1 (4)</td>
</tr>
<tr>
<td>irregular</td>
<td>0</td>
<td>0</td>
<td>3 (1, 2, 4)</td>
<td>1 (12)</td>
</tr>
<tr>
<td>multiloculated ring</td>
<td>0</td>
<td>0</td>
<td>3</td>
<td>5</td>
</tr>
<tr>
<td>delayed CT scan no. studied</td>
<td>1</td>
<td>3</td>
<td>3</td>
<td>4</td>
</tr>
<tr>
<td>no change or slight decay since initial scan</td>
<td>1</td>
<td>3</td>
<td>0</td>
<td>0</td>
</tr>
<tr>
<td>decay of enhancement</td>
<td>0</td>
<td>0</td>
<td>3</td>
<td>4</td>
</tr>
<tr>
<td>abscess stage proven pathologically</td>
<td>2</td>
<td>0</td>
<td>2</td>
<td>3</td>
</tr>
<tr>
<td>total stages</td>
<td>4</td>
<td>3</td>
<td>4</td>
<td>5</td>
</tr>
</tbody>
</table>

* Numbers in parentheses are case numbers. Superscript "D" means delayed CT scan obtained 30 to 90 minutes after contrast infusion. Superscript "P" means that the case was pathologically staged shortly after the CT scan. Case 3 had CT scans at the beginning of the early cerebritis stage and again 12 days later (presumably in the late cerebritis stage). Case 7 had a histologically verified lesion in both the early cerebritis and early capsule stages.

Figure 8 illustrates the CT and gross pathological findings of a well encapsulated abscess that was excised. The patient (Case 6) had a history of seizures and no evidence of past or current infection. Because the abscess was small, the pre-contrast scan showed a small area of high density surrounded by an area of lower density (Table 6). With contrast infusion a small ring of enhancement formed. On delayed scans, there was minimal diffusion of contrast material into the necrotic center and the intensity of enhancement began to fade within 30 minutes (Fig. 8).

In healed abscesses, the collagen capsule was isodense with the normal brain and was not visualized in the absence of edema. Contrast infusion did not result in any enhancement.

**Effect of Corticosteroids on Contrast Enhancement**

Three patients with lesions in the cerebritis stage all showed significant reduction in contrast enhancement after starting corticosteroid therapy (Cases 7, 9, and 11). Figure 9 shows the CT scan of a patient with multiple brain abscesses who was initially treated non-surgically with antibiotics and steroids at an outside hospital. Six days after therapy was started, a repeat CT scan showed a significant reduction in the degree of contrast enhancement (Fig. 9 center). However, the diameter of the lesions showed no change. This patient was not treated surgically until after ventricular rupture and herniation. The CT scan obtained just prior to surgery showed significant enlargement of the lesions with an increase in the degree of contrast enhancement compared with the previous CT scans (Fig. 9 upper right). The upper portion of this abscess was in the early capsule formation stage, whereas the lower portion of the abscess, at the point of ventricular rupture, was in
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Fig. 9. Computerized tomography appearance of multiple brain abscesses in the cerebritis stage before (Day 1) and after 6 days of dexamethasone. Steroid administration resulted in significantly reduced contrast enhancement. One should not interpret this finding as evidence for resolving infection. There is no change in the size of the two lesions. This patient was unfortunately treated only with antibiotics and continued steroids until sudden deterioration occurred on Day 14. On the third CT scan obtained after transfer to our institution, note the diminished degree of contrast enhancement in the portion of the abscess in the early cerebritis stage (lower right) compared with the more intense degree of enhancement seen in the portion of the abscess in the early capsule formation stage (upper right).

Discussion

Computerized tomography has become the principal diagnostic test in establishing the diagnosis of brain abscess, by virtue of its accuracy in determining the location and size of each lesion.6,14,15,17,27,30,36,42,47–49,55,60,65,73,75,77,83 This study has demonstrated that the cerebritis and capsule stages of human brain abscess can be accurately distinguished using CT scans obtained serially over the 1st hour after contrast infusion.

Diagnosis of Brain Abscess by CT

The CT findings of a low-density lesion with an enhancing ring and surrounding edema are hallmarks of a brain abscess.6,14,15,17,20,27,49,75,77 However, similar CT findings occur with gliomas, metastatic brain tumors, and infarcts, all of which are more common.6,30,34,65,77 In considering the differential diagnosis of lesions with ring contrast enhancement on CT, important factors that one has to consider are the clinical history, physical examination, and laboratory findings such as the complete blood count and the erythrocyte sedimentation rate.

The presence of a thin ring of uniform thickness with a smooth inner margin is highly suggestive of abscess. However, approximately 40% to 50% of brain abscesses do not have uniform ring thickness,6 a finding confirmed in this study. Generally, the ring enhancement is thinner on the ventricular or medial side of the developing abscess. Retarded capsule formation in the deep white matter results from relatively poor vascularity and hence reduced migration of fibroblasts into the area.8,80,81 Although tumors usually have thicker and more nodular rings of contrast enhancement, this study has shown that lesions in the cerebritis and early capsule formation stages can also have nodular and thick rings of contrast enhancement. An abscess caused by bacterial endocarditis may have an atypical appearance with...
TABLE 7

Staging of brain abscess using computerized tomography

<table>
<thead>
<tr>
<th>Stage of Brain Abscess</th>
<th>Pre-Contrast Scan</th>
<th>Pattern of Contrast Enhancement (10 mins)</th>
<th>Delayed Contrast Scan (30–60 mins)</th>
</tr>
</thead>
<tbody>
<tr>
<td>early cerebritis</td>
<td>irregular area of low density</td>
<td>may or may not show contrast enhancement; enhancement may be nodular, patchy, or ring-like</td>
<td>no significant decrease in contrast enhancement if present; further diffusion of contrast often occurs</td>
</tr>
<tr>
<td>late cerebritis</td>
<td>larger area of low density</td>
<td>typical ring enhancement; ring is often diffuse and thick; however, it may be thin; if lesion is small, it will appear as a solid nodule; if lesion is larger, a lucent center remains</td>
<td>no significant decrease in contrast enhancement; further diffusion of contrast often occurs</td>
</tr>
<tr>
<td>early capsule</td>
<td>developing capsule delineated as a possible faint ring surrounding a lower-density necrotic center; area of low density (edema) surrounds developing capsule</td>
<td>ring enhancement; may be thinner on ventricular or medial surface</td>
<td>decay in contrast enhancement</td>
</tr>
<tr>
<td>late capsule</td>
<td>capsule visualized as a faint ring</td>
<td>thin to moderately thick dense ring of contrast enhancement</td>
<td>decay in contrast enhancement</td>
</tr>
<tr>
<td>healed abscess</td>
<td>collagen capsule commonly isodense with surrounding brain</td>
<td>may appear as nodular contrast enhancement for 4 to 10 weeks after completion of antibiotic treatment; no contrast enhancement if cured</td>
<td></td>
</tr>
</tbody>
</table>

Staging of Brain Abscess with Serial Post-Contrast CT Scans

In previous experimental studies,\textsuperscript{8,22} we correlated the neuropathological findings at sequential stages of brain abscess development. These studies showed that the pathological development of a brain abscess would be divided into four stages based on histological criteria: early cerebritis, late cerebritis, early capsule, and late capsule stages. The formation of a collagen capsule in a developing abscess is important in limiting the spread of infection in the brain. In our experimental model using alpha-Streptococcus, the formation of a capsule required 2 weeks. Although the formation of a capsule in humans involves the same histological processes, it may occur over a longer period of time and will be dependent on a number of factors, including: 1) the offending pathogenic organism; 2) the origin of infection (direct spread versus metastasis); and 3) the patient's immunological status.

On CT scans, the cerebritis and capsule stages could be differentiated using two criteria: 1) the pattern of contrast enhancement, and 2) the time-density course of contrast enhancement (Table 7).\textsuperscript{8,22} In these experimental studies, the cerebritis stage was characterized by diffuse ring enhancement. On delayed scans, contrast material diffused into the forming necrotic center causing a nodular appearance, which in humans occurred with only small, very early lesions. On delayed CT scans at 30 to 60 minutes, the intensity of ring enhancement did not decrease significantly. In the capsule stage, contrast infusion resulted in narrow ring enhancement. On delayed scans, contrast material did not fill in the lucent (necrotic) center, and decreased in intensity over an hour.\textsuperscript{8,22} Subsequent clinical experience suggested that these criteria could be applied for determining the stage of human brain abscess.\textsuperscript{17,20} Table 7 lists the expected findings on the CT scans obtained before and after contrast infusion. In this study, there was excellent correlation between the stage of the abscesses determined by CT and the subsequent pathological and surgical findings.

Additional evidence from the clinical literature also supports the findings of this study. A case report of fatal cerebritis in a man with intracranial Clostridium septicum showed a relatively thick ring-like contrast-enhancing lesion on CT. At autopsy, no evidence of capsule formation was seen histologically.\textsuperscript{54} These findings are similar to those in one of our patients (Case 7, Figs. 2 and 4A–C, early cerebritis stage). Whelan and Hila\textsuperscript{77} reported that capsules were found in their patients only if symptoms had been present for longer than 2 weeks. They presumed that the ring contrast-enhancing lesions seen earlier in the clinical course of these patients represented lesions in the cerebritis stage.
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**CT Findings in Fungal and Parasitic Brain Abscesses**

With the emergence of a large population of immunocompromised patients, the incidence of brain abscess due to fungal, parasitic, and other opportunistic organisms is increasing. Experimental studies have shown that the increased enhancement seen in the CT scans of patients with brain abscesses is due to fungal, parasitic, and other opportunistic organisms capable of causing different patterns of central nervous system infection: brain abscess, granulomatous formation, encephalitis, meningoencephalitis, or meningitis. These infections are often not well localized and may not evolve to form a typical encapsulated abscess. The findings on CT will reflect the pathological process occurring in the brain. Experimental studies have shown that, given the same patient population in the same preoperative neurological condition, the surgical morbidity and mortality resulting from aspiration, aspiration followed by excision, and primary excision is similar.

Largely because of CT, there has been a definite trend toward the use of aspiration over excision in the surgical treatment of brain abscesses. Recent clinical series utilizing aspiration have shown excellent results in terms of morbidity and mortality. Aspiration has been successfully used to decompress and treat large abscesses (greater than 100 cc of pus). Precise CT localization of small and deep abscesses permits stereotactically guided aspiration.

**Effect of Corticosteroids on Contrast Enhancement**

It is important to recognize that steroids may result in a significant reduction in the degree of enhancement seen in the CT scans of patients with brain abscess. Experimental studies have shown that the lesions in the cerebritis stage show significant reduction in contrast enhancement if steroids have been administered for 48 hours before the CT scan is obtained. Abscesses in the early capsule stage showed moderate reduction of contrast enhancement, but well encapsulated abscesses did not show any significant reduction in contrast enhancement over pre-steroid control CT scans. These findings were confirmed in this study. Support for these experimental findings also comes from the clinical study of Whelan and Hilal. Four patients in their study showed an increase in contrast enhancement after discontinuing steroids, despite continued clinical improvement on antibiotics. They postulated that the increased enhancement seen after discontinuing steroids represented a loss of steroid effect on the blood-brain barrier or loss of steroid suppression of the inflammatory response. In two other patients, there was an increase in the intensity of contrast enhancement with time, despite antibiotic and steroid therapy. This finding correlates well with the experimental conclusion that steroid suppression became less marked as the brain abscess evolved into the capsule formation stages. These results emphasize that a decreasing ring diameter and not the intensity of enhancement is the most important criterion for determining abscess resolution.

**CT in Clinical Management of Brain Abscess**

After making the presumptive diagnosis of a brain abscess on CT and determining its stage of development using the criteria outlined in this study, the definitive diagnosis must be established by obtaining pus or infected necrotic brain for culture. Although both aspiration and excision have been utilized successfully to diagnose and treat brain abscess, the choice of surgical approach is dependent upon the stage of the abscess at the time of diagnosis. Aspiration is strongly favored for lesions in the cerebritis stage, since minimal trauma will occur in the area of inflamed but non-necrotic brain or in areas of necrosis compared to open debridement. With well encapsulated abscesses, studies have shown that, given the same patient population in the same preoperative neurological condition, the surgical mortality resulting from aspiration, aspiration followed by excision, and primary excision is similar.

Excision of encapsulated brain abscesses is also an effective form of surgical treatment. There are certain circumstances where excision is the logical treatment of choice. In traumatic brain abscesses, there is often foreign material (bone fragments, metallic fragments, or other foreign debris) that must be debrided to prevent recurrence. Posterior fossa abscesses may
best be managed by aspirating or excising the lesion under direct visualization. A fungal abscess is a good candidate for excision if the lesion is single and easily accessible. Because of the relative and absolute resistance of many fungi to antibiotic treatment, debridement of infected brain and excision of an encapsulated fungal abscess probably improves the chance for cure.

In 1971, Heineman, et al., introduced the concept of nonsurgical management using only antibiotic therapy for early brain abscess formation. These authors reported a series of intracerebral infections, presumed to have been in the cerebritis stage of brain abscess formation, that were treated with antibiotics alone and without direct bacteriological examination of intracranial pus. This method of treatment has seen a marked increase in usage since the introduction of CT, and a number of reports have appeared in the literature in which brain abscesses have been cured with the use of antibiotics alone or in combination with corticosteroids to help reduce cerebral edema.

The role of nonsurgical management of brain abscess is controversial and fraught with many hazards. For example, the continued high mortality associated with brain abscess despite the introduction of antibiotics has been blamed on inadequate bacteriological techniques (particularly for anaerobic organisms) and on the consequent inadequate or inappropriate antibiotic coverage for the organisms causing the brain abscess. In recent series of nonoperative management of brain abscess, the presumed organism(s) were determined by culturing blood, cerebrospinal fluid, and skin lesions; some cases were treated blindly without benefit of a culture. The fact that organisms that cause brain abscesses are often multiple and anaerobic makes the probability of obtaining complete bacteriological information from these sources unlikely. In addition, lumbar puncture is a hazardous procedure in patients with brain abscess. In the immunocompromised host, the patient may have a history of several recent infections. These organisms are often opportunistic and may include higher bacterial species such as Nocardia asteroides, fungi such as Aspergillus or Candida species, or parasites such as Toxoplasma gondii. An accurate determination of causative organisms is rarely made except by direct aspiration or biopsy of the pathological area demonstrated by CT.

The neurosurgeon must continue to educate his neurological and medical colleagues that brain abscess remains primarily a surgical disease and that inappropriate delays in surgical intervention may result in ventricular rupture and herniation. Even though a number of reports have stressed nonoperative management of brain abscess, aspiration or excision was required in a number of patients in these series because of a deteriorating clinical condition, a problem in diagnosis, or for clinical cure.

The initial size of a brain abscess on CT is an important factor in the success of nonsurgical management. Rosenblum and colleagues found that appropriate medical treatment often “cured” small lesions (mean diameter 1.7 cm), but that larger lesions (mean diameter 4.2 cm) required surgical intervention. However, it is important to note that even small lesions may not respond to antibiotics and may continue to enlarge. Careful frequent neurological examination of the patient coupled with frequent CT scans is mandatory if nonoperative management is elected. If there is any evidence of neurological deterioration, CT scanning and surgical aspiration should be performed. Several studies have documented progressive enlargement of brain abscesses despite appropriate antibiotic coverage. Studies have also shown that it is possible to recover causative organisms despite therapeutic levels of antibiotics in the brain abscess fluid. It is probable that certain organisms will remain viable in the milieu of pus despite killing levels of antibiotics, and will require surgical drainage for cure.

The most suitable candidates for medical management of brain abscesses include patients with multiple lesions. The largest abscess(es) can be aspirated for bacteriological examination and decompression, and all of the lesions can be treated with appropriate antibiotic coverage.

Nonoperative management of brain abscesses includes patients with multiple lesions. The largest abscess(es) can be aspirated for bacteriological examination and decompression, and all of the lesions can be treated with appropriate antibiotic coverage.

Influence of CT on Mortality of Brain Abscess

Prior to the advent of CT, failure to identify and accurately localize brain abscess was a major factor contributing to high mortality and morbidity rates associated with brain abscess. Since the availability of CT, it has become possible to localize accurately suspected brain abscesses. Recent clinical series have shown that CT has generally resulted in lowering the incidence of mortality from brain abscess because of prompt and accurate localization of these lesions. However, in one study no
change in the mortality rate occurred following the introduction of CT. 60

Unfortunately, the past decade has seen a rapid rise in the number of immunocompromised patients and a concomitant rise in brain abscesses caused by opportunistic organisms. These infections are associated with a high mortality rate because of the inability to make an early diagnosis since the clinical presentation is often insidious, the inability of the nervous system to contain the infectious process, and the lack of effective chemotherapeutic agents in eradicating many of these organisms. In the present series of brain abscess, half of the patients were immunocompromised and four of the five deaths in this series occurred in this group. The remaining patient was initially managed nonsurgically and died from ventricular rupture of an abscess that should have been drained surgically at the time of initial CT diagnosis.

As in the past, survival and neurological outcome of patients with brain abscess will continue to depend on early diagnosis, identification of offending pathogens, and proper clinical management. The most significant need at present is for more effective chemotherapeutic agents against opportunistic organisms (particularly Aspergillus and Candida species). Neurosurgical intervention continues to be required in most patients with brain abscesses for establishing the definitive diagnosis, identifying offending organism(s), and removing pus in order to promote resolution using appropriate antibiologic therapy. Improved treatment planning can be accomplished by determining whether the brain abscess is in the cerebritis or capsule stage of development, using the CT criteria for staging described in this report.

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