Compound anterior cranial base fractures: classification using computerized tomography scanning as a basis for selection of patients for dural repair


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Objective. A classification is proposed to organize anterior cranial base fractures systematically according to their location and size. The goal of this study was to determine whether these two variables, irrespective of cerebrospinal fluid (CSF) rhinorrhea, are related to the long-term risk of posttraumatic meningitis and, hence, to standardize decision making concerning surgical repair of associated CSF fistulas.

Methods. With the aid of high-resolution thin-section coronal computerized tomography (CT) scanning, anterior cranial base fractures were classified into the following four major types: I, cribriform; II, frontoethmoidal; III, lateral frontal; and IV, complex (any combination of the other three types). Fractures with a maximum bone displacement that extended farther than 1 cm in any plane were classified as “large” and those less than 1 cm as “small.”

The authors used this classification in a study of 48 patients who were treated by conservative (20 patients) or surgical (28 patients) means. The results showed a gradation of risk: the fracture most likely to develop infection was a large cribriform (Type I) and the least likely was a small lateral frontal (Type III). Statistical analysis showed that the trend for an increased infection rate was related to the cumulative effect of three variables in the following order: 1) prolonged duration of rhinorrhea (analysis of variance [ANOVA], p = 0.017); 2) large size of fracture displacement (ANOVA, p = 0.079); and 3) fracture’s proximity to the midline (ANOVA, p = 0.015).

Conclusions. In this series, microsurgical repair was accompanied by a minimum complication rate. Hence, the authors recommend that patients with fractures that combine the aforementioned variables should be considered to have a high long-term risk of infection and their injury should be surgically repaired as soon as the posttraumatic edema has subsided. This applies to the following fractures: large cribriform (Type I) with transient rhinorrhea lasting 5 to 8 days and large frontoethmoidal (Type II) with prolonged rhinorrhea lasting longer than 8 days. Furthermore, the authors conclude that this classification can improve the management of posttraumatic CSF fistulas of the anterior cranial base and may provide insights into the mechanisms underlying their spontaneous repair and susceptibility to meningitis.

Key Words • fracture • skull base • cranial base • meningitis • aerocele • cerebrospinal fluid fistula
classification of compound anterior cranial base fractures that incorporates both location and size; these criteria were used in conjunction with other variables, such as the duration of CSF rhinorrhea, episodes of infection, or neurological state, to decide whether a patient should be treated by surgical or conservative methods. In this paper, we describe the anatomical basis and rationale for wider implementation of such a classification.

Classification of Cranial Base Fractures

Location of the Fracture

Type I. Cribiform Fracture. This is a linear fracture through the cribiform plate without involvement of the ethmoid or frontal sinuses (Fig. 1). The major problem with a Type I fracture is that the cribiform plate is thin and fragile and covered only by an arachnoidal layer without any dural investment. This juxtaposition of the arachnoid investment to bone and, especially, the absence of dura make this area highly susceptible to the formation of CSF fistulas and subsequent poor repair. It is also possible that the thin perforated cribiform plate could sustain fractures as a complication of low-impact trauma, which would not cause fractures in other more rigid portions of the anterior skull base. In addition, cribiform fractures are located below the level of the roof of the orbits and the rest of the anterior skull base. Thus, CSF tends to gravitate toward the anterior fossa midline, forming a "pool" of CSF that overlies the cribiform plate. The combined effect of gravity and normal pulsation on this collection of CSF may predispose to incomplete repair.

Type II. Frontoethmoidal Fracture. This fracture extends through the medial portion of the anterior cranial fossa floor where it directly involves the ethmoid sinuses and/or the walls of the medial frontal sinus (Fig. 2). With Type II fractures, as with Type I fractures, important risk factors are the thin structure and fragile nature of the roof of the nasal and paranasal cavities and the fracture's location below the level of the roof of the orbits and the rest of the anterior skull base. Therefore, as with Type I fractures, pooling of CSF toward the midline may prevent the commonly occurring herniation and early seal of such defects by brain or adjacent tissues. However, in contrast to Type I fractures, the region of the Type II fracture does have a dural investment. An additional factor that may have a bearing on the incidence of meningitis in these cases is the posterior position of the brain in relation to the medial frontal sinus; as a result, the potential of the brain to her-
niate through the fracture line may be dependent more on normal pulsation and to a lesser extent on the effect of gravity.

**Type III. Lateral Frontal Fracture.** This fracture extends through the lateral frontal sinus (superomedial wall of the orbit). The bone disruption occurs in the convex portion and may involve the superior or inferior walls of the lateral frontal sinus (Fig. 3). There is complete dural investment as in Type II fracture. In contrast to Type II fractures, however, the brain occupies a superior position in relation to the lateral frontal sinus and overlies the area of the bone disruption. Therefore, the potential for the brain to herniate through the defect may depend primarily on the effect of gravity, rather than on normal pulsation.

**Type IV. Complex Fracture.** This group consists of any combination of the types of fractures described earlier.

**Size of the Fracture**

The extent of cranial base disruption and displacement is estimated on high-resolution 1- to 2-mm coronal computerized tomography (CT) sections obtained in three perpendicular planes: sagittal, coronal, and axial. Depending on the extent of the displacement in any one plane, we classified the fractures into two subgroups: 1) small, measuring less than 1 cm; and 2) large, measuring more than 1 cm.

**Clinical Material and Methods**

To perform coronal CT scanning of the anterior cranial fossa, all patients were positioned prone with the neck extended to 30°. High-resolution 1- to 2-mm sections were obtained, starting at the level of the nose and proceeding posteriorly toward the posterior clinoid processes. Eight patients also underwent water-soluble contrast-enhanced cisternography. In addition to the topographical anatomy of the fracture, the duration of CSF rhinorrhea, a persistent aerocele, or episodes of intracranial infection, patient age, and overall clinical state were also taken into account. Patients were advised to undergo surgical repair if they had at least one of the following: 1) persistent rhinorrhea (>12 days); 2) episodes of intracranial infection; or 3) fractures appearing large on CT scanning. Patients with small fractures that were not associated with the aforementioned clinical findings were managed conservatively. All patients who were surgically treated underwent operation within 3 months of consultation.

Surgical repair was performed through a unilateral or bilateral frontal craniotomy after serial posttraumatic CT scans confirmed that the cerebral edema had completely resolved. With the aid of an operative microscope, gentle retraction of the frontal lobes was used to allow visualization of the bone and dural defects and the herniated brain tissue. Bone fragments that protruded intracranially were either removed or repositioned parallel to the skull base. Portions of brain that had herniated through the basal dural defects were dissected, and the defects were sealed with a pediculated pericranial flap, lyophilized dura, or porcine dermis. The membranes were placed in position and secured with sutures and bovine lyophilized thrombin/aprotinin solution (Tisseel; Immuno AG, Vienna, Austria). Outcome was classified according to the Glasgow Outcome Scale (GOS) as good recovery (Grade 5), moderate disability (Grade 4), and severe disability (Grade 3).

**Statistical Analysis**

Two methods were used for data analysis: the Pearson’s chi-square test, with and without the Yate’s continuity correction, and logistic regression using the analysis of variance (ANOVA) test to measure the association between the infection rate and the covariates of fracture type, fracture size, and duration of rhinorrhea. In the ANOVA test, a probability value of 0.1 or less indicates that a covariate has an influence on the probability of infection.

**Results**

Forty-eight patients with anterior skull base fractures were included in this study. Twenty-eight patients under-
TABLE 1

Summary of 48 patients with anterior cranial base compound fracture stratified by type and size of fracture

<table>
<thead>
<tr>
<th>Case No.</th>
<th>Age (yrs)</th>
<th>Rhinorrhea Onset†</th>
<th>Fracture Type</th>
<th>Fracture Size</th>
<th>Treatment</th>
<th>GOS Score</th>
</tr>
</thead>
<tbody>
<tr>
<td>1</td>
<td>36, M</td>
<td>—</td>
<td>small fractures</td>
<td>—</td>
<td>cons 5</td>
<td>4</td>
</tr>
<tr>
<td>2</td>
<td>37, M</td>
<td>2 (9–12)</td>
<td>large fractures</td>
<td>—</td>
<td>cons 5</td>
<td>4</td>
</tr>
<tr>
<td>3</td>
<td>61, M</td>
<td>5 (5–8)</td>
<td>Type I (cribriform)</td>
<td>small fractures</td>
<td>0 of 2 (0)</td>
<td>cons 5</td>
</tr>
<tr>
<td>4</td>
<td>7, M</td>
<td>7 (&gt;12)</td>
<td>Type II (frontoethmoidal)</td>
<td>small fractures</td>
<td>3 of 5 (60)</td>
<td>surg 5</td>
</tr>
<tr>
<td>5</td>
<td>36, F</td>
<td>3 (9–12)</td>
<td>Type III (lateral frontal)</td>
<td>large fractures</td>
<td>3 of 7 (43)</td>
<td>surg 4</td>
</tr>
<tr>
<td></td>
<td></td>
<td></td>
<td>Type IV (any combination of Types I–III)</td>
<td>large fractures</td>
<td>2 of 7 (29)</td>
<td>surg 5</td>
</tr>
</tbody>
</table>

Separate Effects of Fracture Location, Fracture Size, and CSF Rhinorrhea

Fracture Location (Type of Fracture). The number of patients who developed intracranial infection in each fracture type were as follows: Type I, three of seven; Type II, four of 12; Type III, three of 13; and Type IV, five of 16. Thus, the rate of infection varied according to the site of the fracture; the farther the fracture was situated from the midline, the lower the infection rate (Tables 1 and 2).

Fracture Size. Of the 19 small fractures, four (21%), were infected and of the 29 large fractures, 11 (38%) became infected. Thus, cranial base disruption that exceeded 1 cm in any plane was associated with an increased risk of infection (Table 2).

Duration of CSF Rhinorrhea. Of the 21 patients with CSF rhinorrhea, eight developed intracranial infection. Two patients whose rhinorrhea lasted longer than 12 days went surgical repair and 20 patients were managed conservatively. The ages of the patients ranged from 3 to 68 years with a mean age of 32.5 ± 18.2 years. A bone defect consistent with CT appearance was found in all patients. However, the impression at surgery was that the coronal CT scan, despite its high resolution, underestimated the extent of bone disruption. The dural defect was found to be centered over and more extensive than the fracture in all patients. The mortality rate was zero. The olfactory nerve was preserved in 23 (82%) of 28 surgically treated patients. One patient experienced a recurrence of the CSF leak on the 6th postoperative day. His repair had been initially performed by using a pedicle of pericranium but at the second surgery porcine dermis was used. There were no other postoperative complications and no recurrence of CSF leak or meningitis following discharge from the hospital. The duration of follow-up study was 4.5 years and did not differ substantially among the various fracture types. The clinical and radiological features and fracture types are shown in Tables 1 through 3. Major variables affecting the intracranial infection rate are described below.

Table of distribution of infections by size and type of fracture.

<table>
<thead>
<tr>
<th>Fracture Type &amp; Treatment</th>
<th>All Fractures</th>
<th>Small Fracture</th>
<th>Large Fracture</th>
</tr>
</thead>
<tbody>
<tr>
<td>Type I</td>
<td>3 of 7 (43%)</td>
<td>0 of 2 (0%)</td>
<td>3 of 5 (60%)</td>
</tr>
<tr>
<td>conservative</td>
<td>3</td>
<td>2</td>
<td>1</td>
</tr>
<tr>
<td>surgical</td>
<td>4</td>
<td>0</td>
<td>4</td>
</tr>
<tr>
<td>Type II</td>
<td>4 of 12 (33%)</td>
<td>1 of 5 (20%)</td>
<td>3 of 7 (43%)</td>
</tr>
<tr>
<td>conservative</td>
<td>4</td>
<td>4</td>
<td>0</td>
</tr>
<tr>
<td>surgical</td>
<td>8</td>
<td>1</td>
<td>7</td>
</tr>
<tr>
<td>Type III</td>
<td>3 of 13 (23%)</td>
<td>1 of 6 (17%)</td>
<td>2 of 7 (29%)</td>
</tr>
<tr>
<td>conservative</td>
<td>5</td>
<td>3</td>
<td>2</td>
</tr>
<tr>
<td>surgical</td>
<td>8</td>
<td>3</td>
<td>5</td>
</tr>
<tr>
<td>Type IV</td>
<td>5 of 16 (31%)</td>
<td>2 of 6 (33%)</td>
<td>3 of 10 (30%)</td>
</tr>
<tr>
<td>conservative</td>
<td>8</td>
<td>4</td>
<td>4</td>
</tr>
<tr>
<td>surgical</td>
<td>8</td>
<td>2</td>
<td>6</td>
</tr>
</tbody>
</table>

* Analysis of the influence of size alone gives a χ² value of 0.8379 corresponding to p = 0.36. The χ² value for the whole table is 17.679 on 13 degrees of freedom corresponding to p = 0.1701.

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were surgically treated within 3 months of trauma because of infection. The relationship between the duration of rhinorrhea and the infection rate is shown in Tables 1 and 3.

Combined Effect of Fracture Location, Fracture Size, and CSF Rhinorrhea. Analysis of the infection rates observed in the various fracture subgroups (each of which was defined by any combination of fracture size and location) shows that there is a gradation of risk. At the ends of the spectrum are the small lateral frontal (Type III) fracture, which seems to have the lowest risk (infection rate 17%) and the large cribriform (Type I) fracture, which has the highest risk (infection rate 60%). After adding the effect of CSF rhinorrhea, low- and high-risk groups can be identified. The low-risk group included all small fractures with rhinorrhea not exceeding 4 days (infection rate 18%). The high-risk group included the large Type I and II (cribriform and frontoethmoidal, that is, close to the midline) fractures associated with rhinorrhea exceeding 8 days (infection rate 100%).

Statistical Analysis

Statistical analysis indicated that the risk of infection was significantly higher in patients whose CSF rhinorrhea lasted longer than 8 days ($\chi^2$, $p < 0.05$), and there was a trend for an increasing infection rate in proportion to the duration of rhinorrhea ($\chi^2$, $p < 0.03$ for the trend) (Table 3).

In the ANOVA test, a probability value of 0.1 or less indicates that a covariate has an influence on the probability of infection. Using the ANOVA test, the analysis of whether any isolated covariate had an influence on the probability of infection showed that rhinorrhea exceeding 8 days has an effect on the risk of infection ($p = 0.017$). When considered as isolated covariates, fracture size and type were not statistically significant with respect to the risk of infection. However, results of the ANOVA test show that these covariates were significant when considered in combination with CSF rhinorrhea. Patients with a large Type I fracture and transient rhinorrhea ($< 8$ days) were at considerable risk ($p = 0.015$). Similarly, patients with a large fracture size (Type I or II) and prolonged rhinorrhea ($\geq 8$ days) were at considerable risk ($p = 0.079$).

Effect of Antibiotic Treatment

Antibiotic prophylaxis was not used routinely. Fifteen patients were treated with antibiotic medications only after they developed an infection. Ten of these patients subsequently underwent surgical repair: two with Type I fractures, three with Type II fractures, two with Type III fractures, and three with Type IV fractures. The other five patients, whose injuries included one Type I, one Type II, one Type III, and two Type IV fractures, were treated conservatively. Surgery was advised but declined by those patients who had sustained Type I or Type II fractures. The patients with Type III or Type IV fractures were severely disabled after the head injury and/or posttraumatic infection, and surgery was believed to be inappropriate for patients in that state. Patients who had infections underwent surgery after an afebrile, fully conscious state had been regained and the CSF white cell count was maintained below 100 cells/ml for at least 1 week. All operations were uneventful.

Effect of the Clinical State

All patients were surgically treated after they had recovered from their injury. Seventeen patients underwent surgery on the basis of fracture size and/or duration of CSF rhinorrhea without having suffered an intracranial infection; none became more dependent (worse than preoperatively) as a result of surgical complications. However, of the 15 patients who suffered intracranial infections prior to surgical repair, four became more disabled relative to their preinfection status.

Discussion

In a seminal publication on head injuries, Jennett and Teasdale\(^1\) pointed out that the management and repair of a basal dural tear, rather than the treatment of a CSF leak, should be the main concern of the neurosurgeon. Recent studies have supported this contention by showing that when a dural repair of CSF fistulas is undertaken, the cumulative risk of meningitis occurring within 10 years is reduced from 85 to 7%.\(^5,7\) Our experience agrees with this finding and those of many other reports that have demonstrated that compound skull base fractures can indeed be complicated by meningitis, regardless of their association with a CSF leak.\(^2,5,9,12,15,21,22,26,28\)

General Trends

Our findings indicate that certain combinations of fracture-related variables increase the long-term probability of infection. Cerebrospinal fluid rhinorrhea lasting more than 8 days was associated with a significantly higher infection rate. Although not statistically significant in isolation, two other trends emerged. First, fracture size may be important because fractures larger than 1 cm had a substantially higher infection rate. Second, the closer to the midline a fracture is located the higher is the infection rate; this may be related to the topographical proximity of such fractures to the nasal cavity. Fractures with these two criteria combined (that is, large size and proximity to the midline) have a significantly high long-term risk of infection when combined with transient rhinorrhea ($< 8$ days). Because

\[ \chi^2 = 6.2445 \text{ on 2 degrees of freedom, corresponding to } p = 0.0441. \]

A more detailed analysis of all five groups showed a trend of increasing infection rate with increasing duration of rhinorrhea ($\chi^2$, $p = 0.0277954$ for the trend).
of the relatively small number of patients, statistical analysis could not distinguish between the effect of rhinorrhea that lasts for 1 to 4 days and that which lasts 5 to 8 days; hence, we recommend that one apply the aforementioned findings judiciously only to patients with transient rhinorrhea lasting for 5 to 8 days.

**High-Resolution Coronal CT Scanning Compared With Other Imaging Techniques**

In the early posttraumatic stage (≤ 3 months posttrauma) radiographic demonstration of an active CSF fistula by contrast-enhanced cisternography (CCG) was not helpful; this agrees with findings of other studies suggesting that the CCG may gradually be replaced by delineating the bone defect on coronal CT scanning.\(^1\)\(^2\)\(^3\) Direct, dynamic real-time visualization of the fistula is difficult unless the CSF leak occurs during the examination,\(^7\)\(^1\)\(^7\) and digital subtraction used during the nondrip period may fail to reveal the site of the fistula.\(^2\)\(^7\) However, compared with coronal CT scanning, CCG may be more helpful in the management of compound skull base fractures after the early posttraumatic stage. Heavily T2-weighted magnetic resonance images may be useful in demonstrating localized CSF accumulations, brain hernias, or the site of the fistula.\(^6\) Magnetic resonance imaging, however, does not yet provide detailed bone imaging to be used in a classification.

Thin-section coronal CT scanning demonstrated the topographic anatomy, morphology, and extent of the skull base disruption extremely well. Intraoperative visualization confirmed the CT findings; this agrees with findings in other studies.\(^2\)\(^3\) In all patients the dural defect was adjacent to but, importantly, larger than the fracture. It is possible that the impact of the injury causes maximum cranial and dural disruptions, which are followed immediately afterward by spontaneous cranial reduction and retraction of the dura due to its tensile properties.

**Risk of Microsurgical Repair Versus Risk of Meningitis**

Our results suggest that the risk of microsurgical repair is small if the operation is performed after the acute posttraumatic cerebral edema has subsided and that the procedure does not cause any significant increase in morbidity (posttraumatic epilepsy or anosmia) over and above that which one would expect from the original trauma itself. Thus, patients who on the basis of this classification are deemed to be high risk have a higher long-term risk of suffering neurological disability because of meningitis than as a result of surgery.\(^9\)

**Toward Standardized Management of CSF Fistulas**

Rhinorrhea, intracranial air, a fluid level in the paranasal sinuses, and antibiotic prophylaxis are important variables in the management of anterior cranial base fractures. Without reference to the fracture’s anatomy, however, the entity of “CSF fistula” is an insufficient concept to guide management decisions concerning anterior cranial base fractures. Our experience suggests that a standardized policy of surgical intervention, in patients both with or without CSF rhinorrhea, should be based on a detailed anatomical study in which modern neuroimaging is used. The proposed classification is suitable for practical use in a neurosurgical unit or radioimaging department and can facilitate comparable studies from different institutions. Importantly, the classification would make possible the accumulation of data on the risk of posttraumatic infection associated with fractures in the various regions of the skull base. Thus the likelihood of developing a future intracranial infection could be more accurately predicted and weighed against the risks of surgical repair, and patients could be offered treatment advice based on objective data, rather than on the imprecise policy currently in use.

**Conclusions**

In anterior cranial base fractures the following variables seem to induce a high long-term risk of posttraumatic meningitis: 1) proximity to the midline (this applies primarily to the cribriform [Type I] and, to a lesser degree, to the frontoethmoidal [Type II] fractures); 2) large fracture displacement (> 1 cm); and 3) prolonged rhinorrhea (lasting > 8 days).

These variables seem to have a cumulative effect. Fractures with these combined criteria should be repaired surgically as soon as the posttraumatic brain edema has subsided. These fractures include large cribriform (Type I) fractures with transient rhinorrhea (lasting 5–8 days) and large frontoethmoidal (Type II) fractures with prolonged rhinorrhea (lasting > 8 days).

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