Diagnosis of Unintentional Subdural Anesthesia/Analgesia: Analyzing Radiographically Proven Cases to Define the Clinical Entity and to Develop a Diagnostic Algorithm

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Background and Objectives: Subdural injection is a well-known but often poorly recognized complication of neuraxial anesthesia/analgesia. This report aims to further describe the clinical presentation of subdural injection by analyzing radiographically proven cases. A new diagnostic algorithm is then proposed.

Methods: A literature search identified 70 radiographically confirmed cases of subdural injection. The prevalence of numerous presenting characteristics and their relationship to the volume of injected local anesthetics were examined. The ability of 2 previously published diagnostic paradigms to detect proven subdural injection was compared with that of a newly proposed algorithm.

Results: The dermatomal distribution of sensory blockade was excessive in 74% of cases, restricted in 17%, and neither in 9%. Motor blockade and respiratory depression were associated with larger local anesthetic injection volumes (median volume = 14 vs. 8 mL [$P < .009$] and 15 vs. 10 mL [$P < .035$], respectively), but segmental spread and cardiovascular depression were not. Only 33% of cases were positive for 2 or more of Collier's criteria; Lubenow et al.'s diagnostic paradigm detected 71% of cases. We propose a diagnostic algorithm structured as a "roadmap," whereby the clinician inputs the assumed neuraxial block (epidural vs. subarachnoid), and distribution of sensory blockade (excessive, restricted, neither). Specific minor criteria are then applied to diagnose subdural injections. This algorithm detected 93% of subdurals with excessive sensory block distribution, and all of those with restricted and normal distribution.

Conclusions: Radiographically proven subdural injections were used to further define the clinical presentation of subdural analgesia/analgesia and a new diagnostic algorithm is proposed.

Key Words: neuraxial anesthesia, neuraxial complications, subdural anesthesia, subdural catheter

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Subdural injection is a well-known complication of neuraxial anesthesia/analgesia, though it is often poorly recognized at the time of clinical presentation. The practitioner is frequently confused as to what is transpiring with his or her intended neuraxial regional anesthetic. The diagnosis can be delayed, quite often made in retrospect, or perhaps not made at all.

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The subdural space is located between the dura mater and arachnoid membrane. It is most commonly accessed unintentionally during attempted epidural catheterization. Presumed cases of subdural injection began to appear in the anesthesiology literature nearly 40 years ago,[1] and definitive, radiographically confirmed case reports followed soon thereafter.[2,3] Over the years, several landmark case reviews have further broadened our understanding of this clinical entity and defined paradigms with diagnostic indices for detection of subdural anesthesia/analgesia. C.B. Collier (the most extensively published author on the topic) described 4 clinical criteria of subdural injection a quarter century ago: (1) moderate hypotension; (2) slow onset of symptoms; (3) progressive respiratory difficulty; and (4) complete recovery in 2 hours' time.[4] A decade later, he published an analysis and review of 10 radiographically confirmed cases.[5] Lubenow et al. further expanded the diagnostic criteria nearly 2 decades ago in their landmark retrospective clinical review.[6] They defined 2 major criteria: (1) negative aspiration test; and (2) unexpected widespread sensory blockade; and 3 minor criteria: (1) delayed onset; (2) variable motor block despite small local anesthetic doses; and (3) extensive sympatholysis. The presence of both major criteria, and at least 1 minor criterion was defined as highly diagnostic of subdural injection. Definitive diagnostic imaging to confirm subdural injection was not performed.

The clinical understanding of subdural anesthesia/analgesia thus arose from a variety of case reports combined with larger clinical investigations that lacked radiographic proof of subdural injection. Over the years, radiographically proven case reports with atypical presentations began to appear in the literature,[7–10] thus necessitating a re-evaluation of the accepted diagnostic criteria. This report aims to further describe the clinical presentation of subdural anesthesia/analgesia by analyzing radiographically confirmed cases. A new diagnostic algorithm for subdural injection is then proposed.

METHODS

"PubMed" and "Medline" electronic databases were searched from their inception through February 2007, using the following 3 key phrases: "subdural anesthesia," "subdural injection," and "subdural catheter." No limits or restrictions were set for the query, which yielded 912 unique citations. A manual examination of each citation was then performed to select those with: (1) a descriptive report of subdural injection; and (2) English language full text or abstract. Citations that met the 2 inclusion criteria but lacked radiographic confirmation of subdural injection were excluded from further analysis. In this manner, 760 citations were eliminated via title or abstract review, and a further 102 citations were eliminated after full review of the paper. A careful examination of key articles' reference lists identified 6 more publications for inclusion. Thus, a total of 56 publications encompassing 69 individual cases were prepared for analysis. Finally, 1 extensively reviewed case of subdural

injection from our institution was included, for a grand total of 70 radiographically confirmed cases (Supplementary Fig. 1, http://links.lww.com/A624). A full list of these published cases with pertinent details is available in the online supplement (Supplementary Table 1, http://links.lww.com/A625).

After thoroughly reviewing the background literature, 30 variables were defined and categorized; each represented a unique clinical characteristic associated with subdural anesthesia/analgesia. Several more characteristics consisting of clinically relevant combinations of individual variables were then defined. Published data from a highly regarded reference was used to classify the extent of segmental spread into 1 of 3 categories: "excessive," "restricted," or "neither."[11] All case reports were subsequently carefully reviewed and the presence or absence of each variable was recorded. The prevalence of each clinical characteristic (± standard error) was then calculated (Supplementary Table 2, http://links.lww.com/A626). The sample size for each characteristic was recorded because it was not constant, due to lack of standardized reporting and subsequent incomplete data.

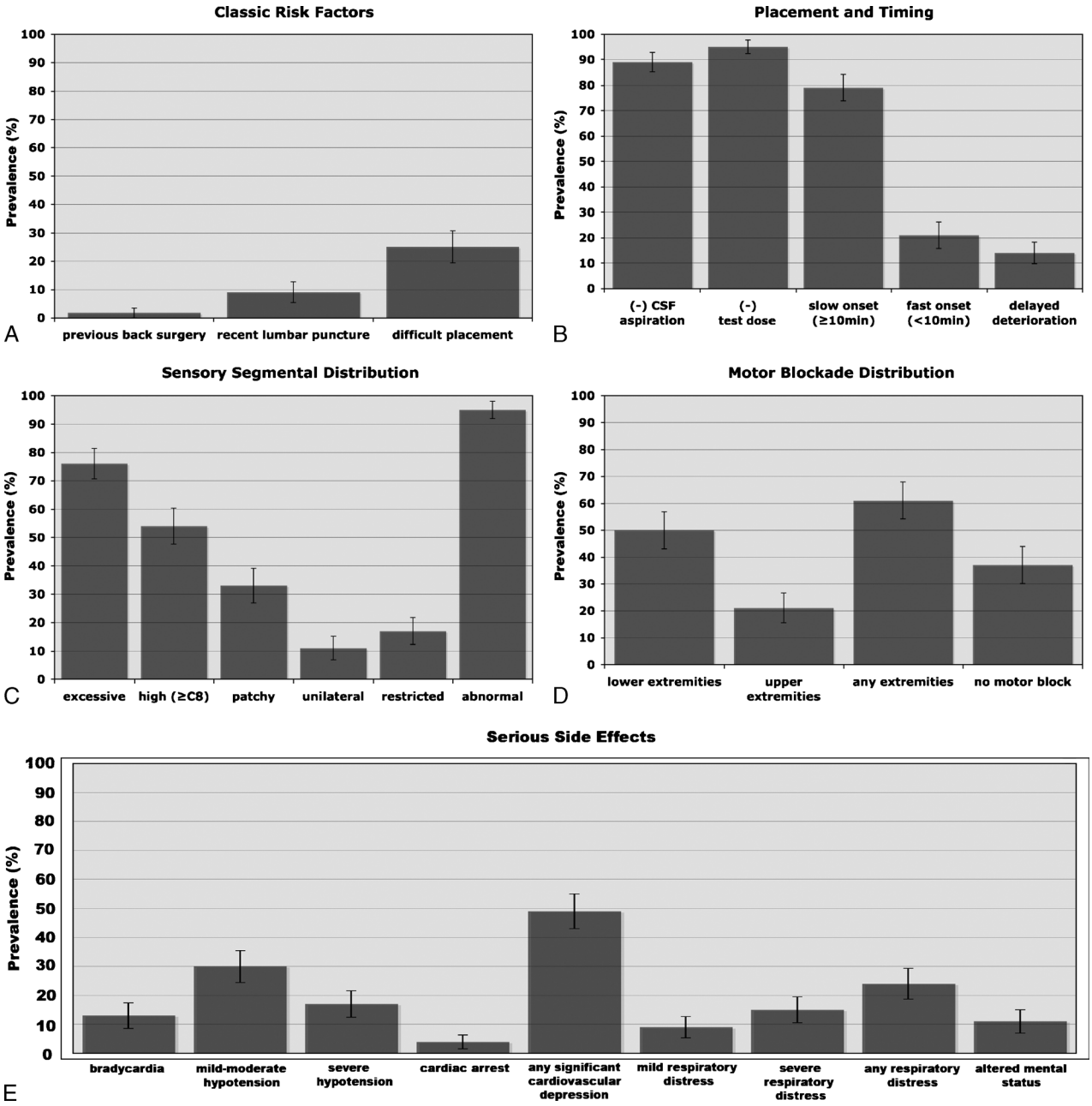

FIGURE 1. Prevalence of numerous clinical characteristics of subdural injection. (A) Highlights the prevalence of previously described ''risk factors'' for subdural cannulation. (B) Describes characteristics of block placement and timing of clinical effect. (C) Summarizes the sensory distribution of the segmental blockade. (D) Illustrates the prevalence and distribution of motor blockade. (E) Characterizes the prevalence of serious side effects reported as a result of unintentional subdural injection. CSF, cerebrospinal fluid.

The relationship between the volume of administered local anesthetic and the presence or absence of 4 key clinical events (high sensory blockade [> T1], motor blockade, respiratory compromise, and cardiovascular depression) was computed, utilizing JMP version 6 software (SAS Institute, Cary, NC). The median volume and interquartile range associated with the presence or absence of each clinical event were calculated and compared one at a time using the Wilcoxon rank sum test.

Two widely cited diagnostic indices[4,6] were applied to the data set in order to determine their effectiveness in detecting subdural anesthesia/analgesia in radiographically defined cases. A new diagnostic algorithm was then designed with the goal of better detecting cases of proven subdural injection.

RESULTS

Classic risk factors for subdural injection, such as previous back surgery,[6,12] recent lumbar puncture,[13] or difficult block placement,[12,14] were absent in the majority of cases (Fig. 1A). Sixty-two cases (89%) reported the inability to aspirate cerebrospinal fluid (CSF) from the catheter, and 59 cases (95%) reported a negative subarachnoid and intravenous test dose. Eight cases (11%) described free-flowing CSF during catheter aspiration yet inadequate neuraxial blockade after local anesthetic injection. Three cases (5%), in which CSF could not be aspirated, described a positive subarachnoid test dose (Fig. 1B).

Onset of neuraxial blockade was slow (≥10 minutes) in 48 cases (79%), and fast (<10 minutes) in 13 cases (21%). Ten cases (14%) described uneventful initiation of anesthesia/analgesia that later deteriorated, usually following bolus redosing (Fig. 1B). In 45 cases (74%), sensory segmental spread was excessive, with 33 cases (54%) describing blockade extending into the cervical and/or cranial nerve distributions. Sensory segmental spread was restricted in 11 cases (17%) because a dose of local anesthetic deemed appropriate for the presumed subarachnoid or epidural block delivered only a narrow segmental sensory deficit or none at all. Sensory spread was patchy/asymmetrical in 20 cases (33%), and unilateral in 7 cases (11%) (Fig. 1C). Motor blockade was present in 31 cases (61%); the lower extremities were involved twice as often as the upper extremities. Eighteen cases (37%) described grossly normal motor function in the presence of a sensory blockade (Fig. 1D). Significant cardiovascular depression (bradycardia, hypotension, and/or cardiac arrest) accompanied subdural injection in 34 cases (49%). Sixteen cases (24%) described respiratory compromise that frequently required mechanical ventilation. Significant mental status changes were noted in 7 cases (11%), and 1 patient (1.4%) suffered a permanent neurological injury (Fig. 1E). No deaths were reported.

Cases that described either a high sensory blockade or significant cardiovascular depression did not receive larger volumes of local anesthetics (median volume in mL [first, third quartile]) compared with those without such unwanted effects (high sensory block: yes = 12 [8, 15] mL vs. no = 12 [5, 16] mL $P = .553$; Cardiovascular depression: yes = 12 [8, 15] mL vs. no = 14 [6, 20] mL, $P = .442$). Patients with motor blockade or respiratory compromise received significantly larger anesthetic volumes compared with those without such side effects (motor

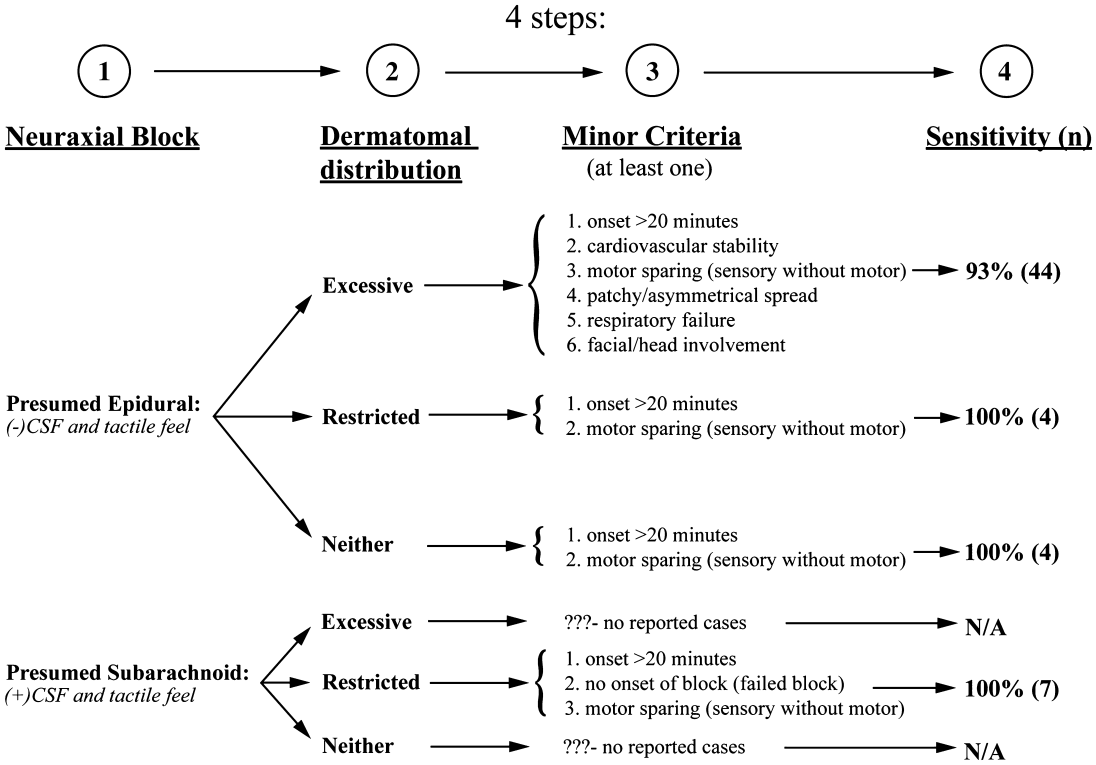

FIGURE 2. A 4-step diagnostic algorithm designed to detect subdural injection. In the first step the practitioner determines whether the neuraxial block in question is presumed to be epidural or subarachnoid based on the tactile feel at insertion and absence or presence of cerebrospinal fluid. The second step requires the provider to define the dermatomal spread as excessive, restricted, or neither. Minor criteria are then applied in step 3; at least 1 criterion is needed for the diagnosis to be made. The final step (4) displays the sensitivity of the test for diagnosing subdural injection in that subcategory, and the number of cases from which it was derived.

block: yes = 14 [19, 16] mL vs. no = 8 [4, 12] mL, $P < .009$; respiratory compromise: yes = 15 [12, 16] vs. no = 10 [5, 15] mL, $P < .035$).

Three quarters of the proven subdural cases presented clinically with at least 1 of Collier's 4 indices. However, only a third of the cases described the presence of 2 or more indices, and a quarter had none of the 4 indices. Application of Lubenow et al.'s diagnostic criteria correctly diagnosed 45 cases (71%) of subdural injection, but failed to detect 18 cases (29%); 7 cases lacked sufficient data and therefore were excluded from evaluation. As a clinical test, Lubenow et al.'s criteria were 71% sensitive for detecting subdural injection.

Given the heterogeneous presentation of subdural injection, a diagnostic algorithm modeled after a "clinical road map" was developed (Fig. 2). The neuraxial block in question is first categorized as "presumed epidural" or "presumed subarachnoid," based on tactile feel during placement, and the absence or presence of free-flowing CSF during catheter aspiration, respectively. Next, the dermatomal distribution of the neuraxial block of interest is categorized as "excessive," "restricted," or "neither," based on the expected distribution for the dose given.[11] Once subcategorized, minor criteria specific to the particular clinical presentation are applied to the block in question; the presence of at least 1 minor criterion is highly suggestive of subdural injection. When applied to the data set, the diagnostic algorithm detected subdural injection during presumed epidural blockade with the following sensitivities: excessive distribution 93% (n = 44), restricted distribution 100% (n = 4), neither 100% (n = 4). For presumed subarachnoid injection, the test was 100% sensitive (n = 7) for detecting subdural injection in blocks with restricted dermatomal sensory loss. Because no cases of subdural injection with free-flowing CSF and "excessive" or "neither excessive nor restricted" distributions were reported, no diagnostic minor criteria could be determined for these theoretical categories. Eleven cases were excluded from analysis because detailed data about the block's clinical characteristics, including the precise sensory distribution, were lacking.

DISCUSSION

This analysis of radiographically proven subdural injections clearly demonstrates the heterogeneous nature of their clinical presentations. Previous publications have alluded to this fact,[6,15] but we believe this review is the first to quantify the prevalence of individual clinical characteristics.

Although the number of involved dermatomal segments differed greatly among reported cases, no cause for this observation could be identified. Surprisingly, volume of injected local anesthetic seemed to play no role in determining the extent of sensorimotor blockade and concomitant cardiovascular depression. This unpredictable relationship between volume of injected local anesthetic and block height contrasts sharply with the predictable behavior of epidural neuraxial blockade.

Recent advances in the understanding of the mechanism of subdural injection may shed light onto the nature of this unexpected finding. Rather than being a potential space with a fixed capacity, the subdural compartment is actually a traumatic meningeal dissection that occurs between the dural and arachnoid layers.[16,17] Anatomic variability of the dissection plane may explain why some patients presented with very high blocks while others presented with quite restricted spread.

Equally intriguing is the reported subset of subdural catheters (11%) from which CSF was freely aspirated. Though this arachnoid disruption could in theory facilitate local anesthetic entry into the subarachnoid space, no clinical or radiographic evidence of such a phenomenon was seen. On the contrary, the overwhelming majority of these cases presented as either failed or restricted blocks, and none demonstrated sudden onset or dense motor blockade characteristic of subarachnoid blockade. Such findings lend credence to what physicians had hypothesized long ago, namely that subdural injection is 1 mechanism for the "failed spinal block."[18,19]

The proposed diagnostic algorithm was designed to detect subdural cases presenting with free-flowing CSF, or restricted segmental spread, in addition to the "classic" pattern of excessive blockade. Deliberately incorporating such criteria into the algorithm increased the test's sensitivity, and possibly its clinical utility when compared with Collier or Lubenow et al.'s tests. Collier's 4 criteria lacked a diagnostic algorithm, leaving the clinician wondering how to apply them appropriately. Furthermore, only a third of subdural cases presented with 2 or more criteria, making Collier's test too insensitive for clinical use. Lubenow et al.'s diagnostic algorithm, by definition, excluded all blocks that presented with either free-flowing CSF or restricted spread, thus limiting the test's sensitivity.

The present algorithm subdivided potential subdural cases into clinically relevant and easily recognizable categories. A "road map" was then constructed to direct the practitioner to the correct set of minor diagnostic criteria. Such a structure allowed this algorithm to detect nearly all cases of proven subdural injections regardless of their clinical presentation. Because only proven subdural injections were included in the analysis, the results may not be generalized to all subdural cases, most of which are diagnosed purely on clinical grounds without imaging. However, given that the clinical diagnosis of subdural injection can itself be questioned, we chose to include only radiographically proven cases (the gold standard).

Because our methodology incorporated only proven subdural cases, we recognize that this is a sensitivity study, and not a study of positive or negative predictive value. We predict that the proposed algorithm is also specific for subdural injection because presence of the minor criteria would be unusual for the presumed neuraxial block in question. Though we recognize the difficulty of performing routine radiographic examinations in clinical practice, we nevertheless hope that future investigations will define the proposed algorithm's specificity and positive/negative predictive values.

Though some practitioners may argue that the diagnosis of subdural injection after block activation is merely of intellectual significance, we feel otherwise. In this series, 10 cases (14%) of seemingly uneventful neuraxial blockade deteriorated unexpectedly, some many hours later. Extension of a previously confined subdural dissection could possibly explain these observations. Clinicians often reduce local anesthetic volume when dermatomal spread is excessive or increase it when restricted. Such practices may not be safe in the subdural space because they may contribute to further propagation of the dural dissection over time. These possibilities must be considered before sending patients with uncharacteristic neuraxial blocks to the floor, where the level of blockade may not be continuously evaluated, and where medical response time may be delayed. Thus, diagnosis of subdural anesthesia/analgesia is critical if these catheters are to be discontinued prior to discharging a patient from one's immediate care.

In conclusion, radiographically proven cases of subdural injection were utilized to further define the clinical presentation of subdural anesthesia/analgesia, and a new diagnostic algorithm is proposed.

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