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Review Article

Head trauma and olfactory function

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Abstract Olfactory impairment is a well-established sequela of head injury. The presence and degree of olfactory dysfunction is dependent on severity of head trauma, duration of post-traumatic amnesia, injuries obtained, and as more recently established, age. Deficits in smell can be conductive or neurosensory, contingent on location of injury. The former may be amenable to medical or surgical treatment, whereas the majority of patients with neurosensory deficits will not recover. Many patients will not seek treatment for such deficits until days, weeks, or even months after the traumatic event due to focus on more pressing injuries. Evaluation should start with a comprehensive history and physical exam. Determination of the site of injury can be aided by CT and MRI scanning. Verification of the presence of olfactory deficit, and assessment of its severity requires objective olfactory testing, which can be accomplished with a number of methods. The prognosis of posttraumatic olfactory dysfunction is unfortunate, with approximately only one third improving. Emphasis must be placed on identification of reversible causes, such as nasal bone fractures, septal deviation, or mucosal edema/hematoma. Olfactory loss is often discounted as an annoyance, rather than a major health concern by both patients and many healthcare providers. Patients with olfactory impairment have diminished quality of life, decreased satisfaction with life, and increased risk for personal injury. Paramount to the management of these patients is counseling with regard to adoption

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of compensatory strategies to avoid safety risks and maximize quality of life. Practicing otolaryngologists should have a thorough understanding of the mechanisms of traumatic olfactory dysfunction in order to effectively diagnose, manage, and counsel affected patients.

Introduction

Recent reports suggest that approximately 20.5 million adults over forty in the United States suffer from olfactory dysfunction.[1] Upper respiratory infection and head trauma are the two most common causes of chemosensory dysfunction, with the latter accounting for approximately 5%—17% of cases.[2–5] In some cases, a thorough evaluation may reveal treatable causes of such deficits. While olfactory losses may not be as conspicuous as losses of other senses, such as vision and hearing, olfactory dysfunction may have a significant negative impact on patients' quality of life and ability to accomplish activities of daily living.[6] Thus physicians tasked with evaluating head injured patients with olfactory complaints should understand the pathophysiology, diagnostic workup, and treatment of these disorders.

Mechanisms of post-traumatic olfactory disturbances

Post-traumatic anosmia has been documented in the medical literature for more than a century, with one of the first case reported in 1864 by neurologist John Hughlings Jackson.[7] He detailed a 50-year old man who suffered both concussive symptoms and anosmia after a fall from a horse.[7] Today, head injuries most commonly occur from motor vehicle accidents (51.5%), followed by domestic falls (14.5%), bicycle accidents (10.1%), pedestrian accidents (9.2%), and assaults (6.8%).[8] Olfactory impairment can result from virtually any cause of head injury, and is estimated to occur in 23.6% and 26.6% of motor vehicle accidents and domestic falls, respectively.[8] As these statistics suggest, every head trauma does not produce olfactory loss. The likelihood of post-traumatic chemosensory dysfunction has been linked to both the severity of injury and length of post-traumatic amnesia.[9,10] Reiter et al[9] and Sumner[10] reported the incidence of olfactory deficits following mild, moderate, and severe head injury to be 13%, 19%, and 25%, respectively. This was later corroborated by Costanzo et al and Zasler,[11,12] who found anosmia to occur in 0—16% of patients with mild head injury, 15%—19% of those with moderate head injury, and 25%—30% of those with severe head injury. More recently, Gudziol et al[13] investigated the prevalence of chemosensory deficits in patients with traumatic brain injury (TBI) classified by increasing time of unconsciousness from grades I through III. While only 18% of grade I TBI patients were shown to have olfactory deficits, this number increased to 57% of patients with grade II or III TBI.[13] The correlation between degree of head injury, as measured by Glascow Coma Scale (GCS) score, and degree of olfactory disturbance is well documented. Previous reports showed that among patients with mild head injury, classified by GCS 13—15, complete anosmia was seen in 13%, while difficulty with odor identification was seen in 27%.[14,15] Additionally, 11% of patients with moderate head injury (GCS 9—12) and 25% of patients with severe head injury (GCS 3—8) were totally anosmic.[14,15] While loss of smell is the most common olfactory sequela stemming from head trauma, patients may also complain of parosmia, or an abnormal odor sensation, which has been observed in 25%—33% of patients with head injuries.[2,15,16]

A functional olfactory system requires a non-obstructed nasal airway and intact neuronal pathways. Thus, traumatic injuries leading to disruption of any portion of these pathways may lead to olfactory loss. Specifically, post-traumatic olfactory dysfunction has been shown to occur secondary to three specific mechanisms: (1) sinonasal tract disruption, (2) direct shearing or stretching of olfactory nerve fibers at the cribiform plate, and (3) focal contusion or hemorrhage within the olfactory bulb and cortex (Fig. 1).

Odorant access to the olfactory cleft may be altered by soft tissue or bony trauma to the nasal cavity. Nasal trauma may lead to mucosal edema or hematoma formation that may block odorants from reaching the olfactory cleft, or cause direct damage to the olfactory neuroepithelium. Mucosal lacerations leading to synechia formation, or fractures of the nasal skeleton may disrupt airflow to the superior nasal vault and lead to olfactory complaints. Finally, nasal trauma may cause disruption of normal mucociliary function, with impaired clearance of sinonasal secretions, causing rhinosinusitis. This can lead to olfactory loss either via blockage of airflow or through increased stasis of secretions hindering odorant access to olfactory receptors. These mechanisms most often result in unilateral hyposmia, and rarely bilateral symptoms or complete anosmia.[9,11] Nevertheless, these potential etiologies of post-traumatic olfactory dysfunction are critical to diagnose, as they are potentially treatable.

Head trauma may also cause direct injury to the olfactory nerve fibers as they traverse the cribiform plate.[11,15] This may occur from midface fractures, such as naso-orbital-ethmoid fractures, or deceleration injuries producing coup and contra-coup forces on the brain, even without associated skull base fractures.[9,17,18] In the latter case, the mobility of the brain relative to the fixed position of the anterior skull base leads to stretching or shearing of the olfactory fibers at the cribiform plate.[19] Coup-contra-coup forces sufficient to injure olfactory nerve fibers can occur in motor vehicle collisions, or in more seemingly mild

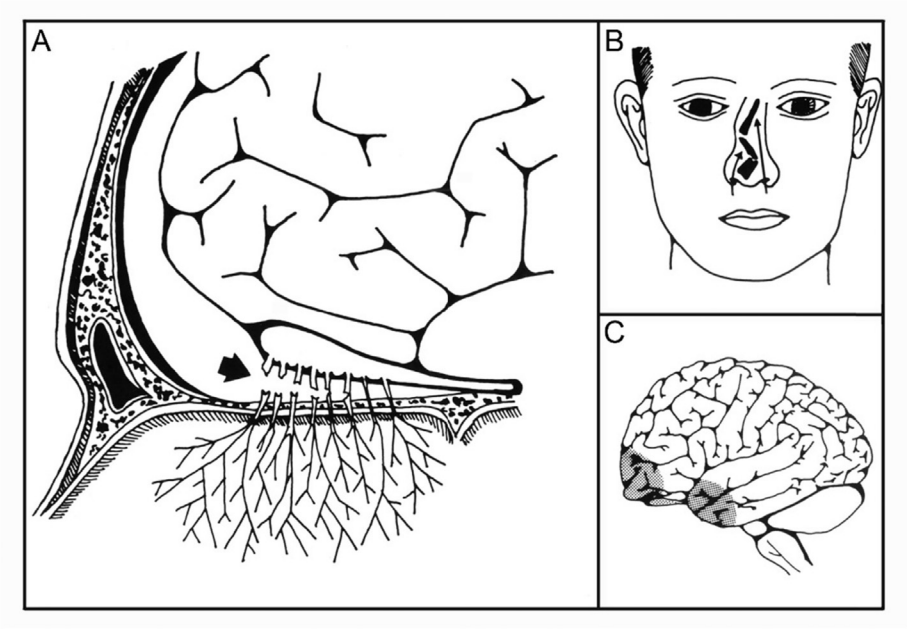

Fig. 1 Mechanisms underlying olfactory dysfunction following traumatic head injury. (A) direct shearing or tearing of olfactory nerve fibers at the cribriform plate, (B) sinonasal tract disruption, and (C) focal contusion or hemorrhage within the olfactory cortex. Adapted from Costanzo and Zasler[12] with permission, copyright, Walters Kluwer.

injuries such as ground level falls. Previous studies have demonstrated that trauma directed at the posterior skull is more likely to cause olfactory dysfunction than anteriorly based forces.[16,17] Unlike sinonasal tract disruption, shearing of olfactory fibers more commonly leads to bilateral anosmia or severe hyposmia.

Lastly, post-traumatic olfactory dysfunction may arise from damage to central components of olfactory pathways. Given their location relative to the skull base, the temporal lobes and fronto-orbital region are the central olfactory cortices most likely involved with traumatic contusion or hemorrhage.[11] Injury to the olfactory system can be seen without involvement of other intracranial structures, possibly due to the relative vulnerability of these regions to ischemic or compressive forces.[11,20] Due to the extensive bilateral cortical projections, intracranial damage to the olfactory system rarely results in complete anosmia.[11,21,22] Rather, these lesions more commonly result in impairment of olfactory recognition.[11,14,21,23] Furthermore, as the fronto-orbital region is commonly involved, post-traumatic anosmia may provide a subtle clue to concomitant executive dysfunction.[24] Even if neuropsychological examinations are normal, the presence of post-traumatic anosmia may suggest frontal lobe injury and portend higher risk of subtle neurocognitive or future vocational difficulties.[3,25–27]

Although somewhat common following head trauma, post-traumatic olfactory dysfunction often goes initially undetected. Although reports vary, an estimated 5% of patients with head trauma will suffer from olfactory impairment.[12] Understandably, life threatening neurological and orthopedic injuries are given top priority in the initial stabilization and management of trauma patients. Furthermore, in some the need for prolonged intubation or sedation, as well as the cognitive impairment that can occur following head trauma, limits a patient's own recognition of olfactory deficits. Olfactory deficits thus often go undiscovered until days or even weeks after the inciting event. Gudziol et al[13] found that while 28.4% of patients with traumatic brain injury had olfactory dysfunction by objective testing, only 6.3% initially reported any subjective loss. Self-assessment of olfactory function thus does not appear to be reliable, further emphasizing the need for a methodical workup of this patient population.

Clinical evaluation

The evaluation of the head-injured patient with an olfactory deficit should begin with an exhaustive history. The patient's prior olfactory function should be as curtained to exclude pre-existing deficits from prior head injury or non-traumatic etiologies, such as aging, neurodegenerative disease, rhinosinusitis, viral upper respiratory infections, or medications. Additionally, prior head and neck irradiation or surgical interventions should be discussed as mucociliary dysfunction or sinonasal scarring from such causes may contribute to baseline deficits. The nature of olfactory dysfunction should be explored to include the degree, laterality, and qualitative nature of disturbances. Presence of complete or partial loss of smell, as well as unilaterality or bilaterality, can provide clues to the location of injury. Unilateral symptoms may suggest sinonasal tract disruption, while bilateral dysfunction points to cerebral lesions or shearing of fibers at the cribiform plate. The latter mechanism may be further suggested by patient complaints of a salty or metallic taste in the mouth or clear rhinorrhea, symptoms suggestive of cerebrospinal fluid leak, which can result from fractures at the anterior skull base.[15,28] The nature of the head injury and duration, if any, of post-

traumatic amnesia should also be ascertained. Studies have demonstrated that occipital forces are more likely to cause olfactory dysfunction than frontal strikes.[16,17] Green et al[26] demonstrated that patients with amnesia lasting 10 days or more were six times more likely to have olfactory dysfunction than patients without amnesia. A complete review of systems should be obtained, as post-traumatic anosmia has been associated with hearing impairment (41%), tinnitus (22.6%), disequilibrium (14.2%), and visual disturbances (2.8%).[11,15,17]

Physical examination should begin with comprehensive examination of the head, looking for signs of injury such as lacerations, ecchymosis, asymmetries, palpable bony step-offs, and telecanthus. Nasal endoscopy should be performed with focus on the integrity of the olfactory cleft, as well as identification of sources of nasal blockage such as mucosal edema, inferior turbinate hypertrophy, septal deviation or hematoma, nasal polyposis, or rhinosinusitis. If patient tolerance allows, nasal endoscopy should be performed both prior to and after topical decongestion to determine the degree of reversible mucosal edema, and thus the potential efficacy of topical decongestants or steroids.

Imaging is critical for identifying potential injuries to the olfactory system. As the initial evaluation of trauma patients often includes neuroimaging, these studies, although often not optimal resolution or orientation, should be reviewed as a starting point. In cases where initial head scans are suggestive of injury but inconclusive, sinonasal structures are incompletely visualized, or functional deficits exist without explanation, dedicated imaging is indicated. High resolution, thin-cut (1 mm or less) CT scanning of the maxillofacial region is the imaging modality of choice. This allows visualization of soft tissue and bony deformities of both the sinonasal cavity and anterior skull base. Intravenous contrast is not necessary for identification of sinonasal pathology. For suspected cortical injuries, and especially in the presence of other neurological findings, magnetic resonance imaging (MRI) is indicated for its ability to demonstrate subtle cerebral lesions including intraparenchymal hematomas or contusion.[22,29]

While history and physical examination are invaluable in the assessment of post-traumatic anosmia to identify causative etiologies, confirmation of a deficit and quantification of its degree can only be achieved with objective olfactory testing. Many tests are available, differing widely in nature of testing, equipment required, and ease of administration. Note that while a brief overview of olfactory testing methods is provided here, further detail may be found in the Measurement of Chemosensory Function chapter in this volume. A simple, low cost test of olfactory function readily applicable to evaluation of patients in the emergency department or inpatient wards is the alcohol sniff test.[30] This test uses only a standard alcohol pad, and requires determining the distance from the nose at which a patient can smell alcohol as the pad is brought closer to the patient's nostril. While this does not allow quantification of degree of loss or detection of malingering, it does permit determination of unilaterality when performed on each side independently. However, results should be interpreted with caution, as stimulation of the trigeminal system may be misinterpreted as olfactory stimulation, yielding false positive results. The University of Pennsylvania Smell Identification Test (UPSIT) is another commonly used assessment tool, consisting of forty "scratch and sniff" odorants, for each of which the patient is required to select one of four possible answers for each odor.[31] Shorter 12 and even 3 item variants of this test are also available and may serve as more efficient screening tools depending on setting. The University of Connecticut Chemosensory Clinical Research Center test (CCCRC) uses serial dilutions of butanol to measure detection threshold, and ten jars of recognizable odor stimuli to assess odor identification.[32–34] Low identification scores have been found to be indicative of brain injury, while abnormal detection thresholds may reflect impaired olfactory bipolar-receptor cell function.[12] Sniffin' Sticks are another test of chemosensory performance in which odor dispensing felt-tip pens are used to test odor threshold, discrimination, and identification.[35]

The detection of malingering is a crucial aspect of evaluation of patients with post-traumatic olfactory disorders. Not infrequently patients with traumatic injuries may be involved in litigation, for which financial incentives might exist to increase the apparent debility resulting from the injury. This may impact the entire patient evaluation. Doty et al reported that chemosensory maligners are more likely to underreport sinonasal issues, such as allergies, sinusitis, or history of previous otolaryngologic procedures, in an attempt to reduce the possibility for alternate explanations for their olfactory dysfunction.[36] Further, savvy malingerers may falsify their responses during olfactory testing to lead to over-estimation of olfactory deficits. Fortunately, the forced choice nature used in odor identification components of the CCRC, UPSIT, and Sniffin' Sticks test systems allows for detection of malingers. With forced choice paradigms, patients with complete anosmia providing random guesses for each odor would be expected to get a certain percent of items correct, depending on the number of choices offered. Thus patients scoring dramatically less than the anticipated random score should be suspected for malingering. In addition, use of trigeminal stimulants may provide additional cues. Patients attempting to overstate deficits may indicate inability to "smell" trigeminal stimulants, which their likely intact trigeminal system should be able to readily detect. Subtle facial reactions may further suggest detection of such stimulants in the face of patient denial of such.

Treatment

For most patients with post-traumatic olfactory disturbances, treatment is ineffectual in increasing likelihood, extent, or speed of recovery. Fortunately for some, spontaneous recovery of some degree of function may occur. In a study of traumatic olfactory disturbances, Doty et al[16] noted that several years after the inciting event, 36% of patients had minor improvement, 45% experienced no change, and 18% suffered worsening function. Duncan et al[2] re-evaluated head trauma patients with UPSIT up to five years after injury, and noted improved scores in 35%. Although on aggregate the improvements noted were statistically significant, they were not felt to be clinically significant, as the majority of patients did not move to a

Table 1 Counseling suggestions for patients with impaired olfaction.

- Install and routinely check smoke detectors. Consider carbon monoxide detectors
- Provide adequate ventilation when working with household chemicals (e.g. bleach, ammonia)
- Be vigilant when using gas appliances
- When cooking never leave pots and pans unattended
- Self-monitor weight and appetite for changes
- Consult with a friend or family member if concerned about personal hygiene issues
- Establish routines to assure food safety (check expiration dates and label foods)
- Avoid over seasoning when preparing meals (excessive salt, hot spices)
- Use color and texture to enhance enjoyment of foods (e.g. add color peppers, croutons to salads)

higher functional diagnostic category (i.e., anosmia to hyposmia).[2] Likewise, Costanzo and Becker[8,11] reported that 33% of patients with post-traumatic anosmia improved, while 27% worsened. They also observed that recovery was most likely to occur soon after injury, such that further improvement was unlikely to occur after one year.[8,11] These findings correspond to earlier literature, wherein 39% of patients with improved olfactory function recovered sensation within the first ten weeks.[10] More recently, Drummond et al[37] investigated the progression of olfactory impairment six months after head trauma, finding that only 25% of patients recovered to normal olfaction. Additionally, the more severe the initial olfactory impairment, the less likelihood for recovery.[37] Further support for these findings was provided by London et al,[38] who found that improvement after olfactory dysfunction was related to patient age, time between inciting event and initial baseline testing, and severity of dysfunction.

The prognosis of post-traumatic anosmia is dependent on the mechanism of olfactory loss. We may speculate that some traumatic injuries causing nasal mucosal edema or hematoma may cause minor olfactory deficits that have a high chance for improvement, and resolve promptly, potentially even before patients become aware of their existence. Such mucosal swelling, if longer lasting, may be managed with topical of systemic corticosteroid therapy. Other nasal sequelae of head trauma, such as nasal septal deviation, nasal bone fractures, and rhinosinusitis secondary to post-traumatic scarring, although less likely to cause significant olfactory deficits, may be corrected surgically.[39–41] Neurosensory deficits, such as direct injury to olfactory neurons at the cribriform plate, are unfortunately not amenable to treatment. As spontaneous recovery from such injuries may occur due to regrowth of bipolar receptor cell axons, allowing the olfactory neuroepithelium to re-establish contact with the olfactory bulb, research efforts have focused on potentiating this process.[42,43] Additionally, Kobayashi and Costanzo[44] demonstrated that anti-inflammatory treatment with steroids improved neuronal recovery following olfactory nerve transection via suppression of the inflammatory reaction and reduction of glial scar formation. Similar results could also be obtained using interleukin-6 (IL-6) receptor antibodies or tumor necrosis factor-alpha (TNF-α) antagonists, as both play an important role in regulating inflammatory reaction, and treatment with steroids is not without negative side effects.[45,46] However, given the diversity of olfactory receptors, and the complex rhinotopic projections of olfactory neurons to the olfactory bulb, neuronal regeneration alone may not be adequate to restore normal function, as previous work has shown that regeneration of neurons may not restore appropriate connections to the olfactory bulb.[47]

Impact of post-traumatic olfactory disturbances

Despite the obvious contributions of the sense of smell to quality of life, the significance of olfactory dysfunction is often discounted as a public health problem.[48] Indeed, the American Medical Association permits a 1%—5% impairment rating for bilateral loss of smell and taste, while no impairment is awarded for unilateral symptoms.[49] Further, this rating fails to consider the variability in vocational impact of olfactory loss. Certainly, a chef, wine critic, plumber, or firefighter with anosmia would be far more functionally impaired than those in many other professions. Further, 34% of patients with olfactory impairment conveyed they were very or somewhat dissatisfied with life.[6] These results echo previous studies in which patients with chemosensory dysfunction were more likely to have depression than those without.[50] However, beyond vocational concerns or hedonistic value, olfactory function also has an important role in the safety of patients. Previous studies have shown that 45% of patients with olfactory impairment had experienced hazardous events attributable to their loss of smell, such as cooking-related hazards, ingestion of spoiled foods or toxic substances, inability to detect gas leaks, and inability to smell fire.[48,51] A previous study revealed that patients reported the activities most frequently impaired by chemosensory dysfunction included identification of spoiled foods (75%), detection of gas leaks (61%), quality and pleasure of eating (53%), detection of smoke (50%), ability to prepare food (49%), ability to correctly buy fresh food (36%), and aptitude in using cologne or perfume (33%).[6] Thus, paramount to the management of these patients is counseling with regard to adoption of compensatory strategies to avoid safety risks, and maximize quality of life (Table 1).

Conclusion

Traumatic head injuries not uncommonly result in some degree of olfactory dysfunction. Such deficits are often overlooked by patients and their caregivers due to focus on the initial stabilization and treatment of the patient. Thus, it is critical for the evaluating otolaryngologist to be vigilant for the presence of olfactory deficits in the head-

injured patient population. Evaluation should focus on the assessment of the severity of the loss and its impact on the patient, as well as identification of the potential cause. The latter should include detection of any potentially reversible causes, namely conductive deficits that might be responsive to medical or surgical treatment. As patients with olfactory dysfunction are at increased risk for depression, impaired quality of life, and personal injury, appropriate counseling may alleviate and minimize the impact of such deficits on patient safety and quality of life.

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