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Trauma of the Middle Ear

Clinical Findings, Postmortem Observations and Results of Experimental Studies

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Clinical Findings, Postmortem Observations and Results of Experimental Studies

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Translated from the German by *Jürgen Tonndorf*

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Foreword

Growing industrialization and the increasing number of traffic accidents often lead to middle ear trauma at different sites and of varying severity. Special problems of partial or sometimes complete destruction of the temporal bone have frequently — and often controversially — been discussed in the otological literature.

In the present book, Dr. *Strohm* describes the findings, microsurgical techniques and results in more than 800 such cases treated for middle ear trauma during the last 13 years at the ENT Clinic at Tübingen University. These cases include immediate and delay surgery (sometimes decades after the trauma) as well as facial nerve trauma and posttraumatic cholesteatoma. Early or late surgery for eardrum perforation, the reconstruction of the ossicular chain and the leakage of CSF after fracture of the base of the skull are also discussed in detail. The corrective procedures described by Dr. *Strohm* are presented clearly and the rationale behind these procedures is argued convincingly.

The chapter on trauma of the round window or its membrane might be of special interest nowadays, especially since the diagnosis 'rupture of the round window membrane' is made frequently but, in our experience, far too often.

This book provides in one comprehensive volume the principles of modern ear surgery after trauma in the era of tympanoplasty. It covers the experience gained in a great number of patients and should prove very useful to postgraduate students and to every otolaryngologist dealing with surgery of the middle ear and the skull base.

D. Plester

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M. Strohm

Contents

1. Introduction

Historically, the traumatology of the middle ear (ME) was developed in four separate phases, each of them characterized by a different attitude on the part of the otologists as regards lesions of the ME system.

During the second half of the 19th century, the first phase, basic knowledge was accumulated about the origin of skull-base fractures and their underlying mechanisms. Most of it was contributed by surgeons: simple skull fractures were differentiated from depressed fractures [294, 452]. The modes of origin of longitudinal and transverse fractures of the temporal bone (TB) and their characteristic appearances were also assessed [190, 452].

During the second phase, around the turn of the century, traumatic lesions of middle and inner ears were correlated with fractures of the skull base [20, 266]. In 1906 already, *Zalewski* [473] studied the resistance of the tympanic membrane (TM) to differences in air pressure across it; but his results did not find immediate clinical applications. The book *Die Verletzungen des Ohres* (Trauma of the Ear) by *Passow* [339] gave a comprehensive, and impressive, summary on the state-of-the-art with respect to the etiology and symptomatology of such lesions. The concepts presented appear almost modern.

Postmortem studies [443] performed on TB obtained from persons who had died following skull traumata, as well as clinical findings [267, 449, 450] led to direct surgical interventions during the third phase. Such interventions were recommended especially in those cases in which the trauma had created an open communication between the endocranium and the pneumatized mastoid spaces, constituting a life-threatening complication, real or potential. *Voss* [449, 450] therefore separated curative surgery from preventive surgery, depending on whether an otogenic intracranial infection was already present or merely imminent. The aim of the surgical intervention was the permanent eradication of infection. However, no attention was paid to the maintenance and/or restoration of the ME and its function.

Beginning in the 1950s, the concept of tympanoplasty, i.e. the preservation of function and/or its restoration by means of microsurgery of *infected* ears, was extended to the care of *traumatized* ears. This represents

the fourth phase. The introduction of the sulfonamides and the antibiotics had lessened the need for curative, and especially for preventive, surgery. Hence, microsurgical reconstruction of the ME gained in importance. *Escher*, in his 1964 monograph, entitled *Funktionelle Ohrchirurgie traumatischer Mittelohrläsionen* (Reconstructive Surgery of Traumatic Middle Ear Lesions), reviewed this topic in quite some detail. In particular he wrote: 'Such lesions are much more varied than heretofore realized; and the repair of defective middle ears may lead to considerable functional improvements. Systematic surgical interventions permit to recognize incipient destructive lesions, such as ossicular osteitis and the ingrowth of keratinizing epithelium into the middle ear, and permit their repair.'

In 1964, *Escher* [99] was still of the opinion that surgical intervention had to be postponed until the direct sequelae of the trauma had a chance to subside. More recent authors, however, demanded early surgery. *Armstrong* [13], for example, warned against this form of 'watchful neglect'. He wrote: 'Facial lacerations are carefully approximated with fine sutures to achieve a pleasing cosmetic result, but too often the tympanic membrane receives little attention... This is regrettable because it places cosmetic appearances above functional results. This double standard is encouraged by our cosmetically orientated society, that is, if it doesn't show, it doesn't matter'. This statement that originally concerned only traumatic ruptures of the TM is even more important with regard to perilymphatic fistulae and posttraumatic facial nerve (FN) palsies. The demand for early otosurgical intervention represents the most important progress in the field of surgical repair of traumatic ME lesions in the last 10 years. It was demanded that every patient, who suffered an ME trauma, should be seen by an otologist with training in ME surgery. This otologist had to make the decision whether immediate intervention is indicated or whether a wait-and-see attitude may be warranted.

In an effort to provide a rationale for early intervention, the patient records of the ENT Department at Tübingen University, FRG, were systematically scrutinized with particular reference to trauma of the ear and its sequelae. At this institution, microsurgery of the ear is being conducted according to quite uniform therapeutic standards. Also assessed was the diagnostic value of roentgenological examination of patients with such lesions. Postmortem studies on TM obtained from persons who had died from their injuries served to demonstrate the structural changes induced by the trauma. Lastly, experiments were conducted on lesions of the TM and those of the round window (RW) membrane and their self-repair.

2. Materials and Methods

All statements made in the present monograph concerning ME trauma are based on the evaluation of clinical observations, postmortem findings and roentgenograms; the latter are important with regard to the following two types of trauma: (1) TM lesions and (2) TB fractures, especially when they include FN injuries. For these reasons the methods of examination of all types of injuries are reported together. On the other hand, each experimental study had one specific aim; their special methodology is therefore described separately in each appropriate chapter.

2.1. Clinical Examinations

Records of all patients treated for traumatic lesions of the ear during the time period from 1968 to 1980 inclusively were culled from the departmental archives and from the operating-room repository. From each patient's record, the following information, if available, was extracted: (1) past history; (2) findings on admission, including pure-tone audiograms and X-ray pictures; (3) reports on clinical management and/or surgical interventions, and (4) clinical findings and the final audiogram at the time of discharge. The entire information could not be collected in every case. For example, the past history of patients seen only in the clinic on referral from other departments was no longer available, since it had only been given on the referral slip. Furthermore, audiological and X-ray examinations had, in many cases, already been performed by the referring physician; hence, there was no appropriate record in the departmental archives. Lastly, some patients did not present themselves for the final examination.

Some patients were included in the present study even when their records were incomplete. The reports and findings that were available served to answer some questions, e.g. about the frequency of the various causes of different lesions or about their location.

The present study comprises a total of 691 patients; 463 of them had undergone surgery and 228 had been treated by conservative means. During the report period, otosurgery was carried out on a grand total of approximately 20,000 patients. This means that 2.3 % of all surgical interventions on the ear were carried out on account of traumatic lesions.

2.2. Postmortem Observations

During the years 1978–80, all temporal bones were removed whenever a head post was performed in the case of a fatal skull-brain trauma. The autopsies were conducted either at the Institute of Forensic Medicine or at that of Pathology of Tübingen University. There

was a total of 46 cases. Of them, 43 represented blunt skull traumata and the remaining 3 gunshot injuries. After exclusion of all material damaged during autopsy, 89 temporal bones remained for detailed examination. After fixation in formalin, the lining of the external ear canal (EEC), the TM and the course of fracture lines, if present, were examined under the operating microscope. Still under microscopic control, the soft tissues were removed from the mastoid and from the basal surface of each bone. With the aid of a surgical drill, the floor of the hypotympanum was opened from the tubal ostium all the way to the stylomastoid foramen. Removal of adjacent portions of the floor of the EEC made it possible to deflect the lower part of the TM, enabling the experimenter to inspect a large part of the ME space, including the RW niche. Fracture lines were followed by taking down the mastoid. Findings made during the course of these preparations were documented either by drawings or by photography.

2.3. Roentgenological Findings

For many patients, X-ray pictures were available in the projections of *Schüller* and/or *Stenvers*. For some patients, lateral-skull X-ray pictures also existed. All pictures were evaluated from two aspects: (1) the degree of pneumatization and (2) the diagnosis of fractures.

2.3.1. Assessment of Pneumatization

It was of interest to learn if different types of TM lesions as well as the course of their repair could be correlated with the degree of mastoid pneumatization. *Diamant* [71] demonstrated a correlation coefficient of 0.94 ± 0.14 between the projected area of the air spaces as seen in lateral skull X-rays with their extension into the pyramidal apex. *Flisberg and Zsigmond* [125] compared planimetric and volumetric measurements of the mastoid air cells; they found a similar correlation coefficient, i.e. 0.88 in normal, healthy ears. These two findings indicate that planimetric assessments of the projected areas of the 3-dimensional pneumatic air spaces on Schüller X-ray pictures render a relative, but meaningful, measure of the degree of pneumatization, although they do not give absolute volumes. This information is quite sufficient with respect to the present question, i.e. for comparing the degree of pneumatization with the vulnerability of the TM and its tendency to heal.

There are two potential sources of error in the planimetric evaluation of Schüller X-ray pictures:

(1) They are not teleprojections, i.e. the object is not projected in its true size; rather, they are divergent projections, i.e. the projected picture is larger than the object. Nevertheless, if the same, identical equipment is used throughout the series, the magnification should remain about constant. For the equipment used in our department, the range of variation was calculated. It amounted to approximately ± 0.25%. Suffice it to say, however, that neither the magnification nor its range of variation are of any significance, as long as one is only interested in the *relative* extent of pneumatization.

(2) The direction of the projection may vary slightly from one patient to another since it is determined by a number of landmarks on the skull that may differ in different patients. Somewhat schematically, one may regard the air spaces as forming a pyramid with its base parallel to the lateral surface of the mastoid. Since the center of the X-ray beam does not always coincide with the axis of the pyramid, the projection of its base (which yields the

desired measure of the degree of pneumatization) might be distorted. Calculations indicated that the resulting error was not larger than approximately ± 0.28%.

These two considerations demonstrate that the planimetric evaluation of routine Schüller roentgenograms renders an index number that is sufficiently accurate for the purpose at hand, i.e. to indicate the relative volume of the mastoid air spaces.

2.3.2. Diagnosis of Fractures

It was of further interest to learn if and to what degree of confidence the existence of a fracture line could be established and its course determined on the basis of routine, clinical X-ray pictures. In contrast to the planimetric assessment of mastoid pneumatization there was no other objective method available for the verification of suspected fracture lines. Hence, the possibility existed that the evaluation of the X-ray pictures might be influenced, even in a subconscious manner, by other clinical details known to the reviewer. To avoid this potential pitfall, the evaluation was done in a blind-study fashion: A medical student collated all clinical and surgical records of patients with skull traumata, for whom X-ray pictures were available. He then forwarded nothing but the roentgenograms to the author for their evaluation. Finally, drawings made of the X-ray findings were correlated with the clinical records.

Note. Results obtained by various authors will be quoted in the chapters discussing the resistance of the TM and of the RW membrane to differential pressures across them, as well as in those chapters describing the general effects of barotrauma. For proper comparison of the different results obtained from the literature, the following relations were used:

$$1 \text{ bar} = 1{,}000 \text{ mbar} = 1.019 \text{ at}$$
$$= 760 \text{ mm Hg} = 750 \text{ Torr} = 14.5 \text{ psi}$$
$$= 10^6 \text{ dyn/cm}^2 = 100 \text{ N/cm}^2 = 100 \text{ kPa}.$$

For example, 180 dB SPL are aproximately equivalent to an absolute pressure of 2×10^5 dyn/cm^2; and 200 dB SPL to an absolute pressure of 2×10^6 dyn/cm^2 = 2 at.

3. Tympanic Membrane Lesions

Strictly speaking, EEC injuries should not be included under the heading of *Trauma to the Middle Ear*. Their descriptions are therefore omitted from the present monograph. Admittedly, EEC lesions often extend into the ME (e.g. a cholesteatoma behind an EEC stenosis; fractures of the EEC walls as part of a longitudinal TB fracture). These lesions will be handled in the appropriate chapters on ME pathology.

The discussion of ME lesions must logically start with those of the TM, its most accessible part.

3.1. Etiology

Injuries via the EEC can directly affect the TM. They may be mechanical or thermal in nature; or they might have been produced by an air pressure differential across the membrane, brought about by changes in atmospheric pressure that are not compensated by identical changes in ME pressure. Furthermore, TM lesions may result from transient osseous deformations produced by a blunt skull trauma. *Passow* [339], after a perusal of the pertinent literature, gave the relative incidence of TM lesions as 0.43–2.16% of all disorders of the ear. His higher number agrees well with that of the Tübingen ENT Department (2.3%; cf. chapter 2.1 above).

3.1.1. Lesions of Mechanical Origin

As is well known, attempts to clean the EEC are the most frequent causes of mechanically induced TM injuries. The instruments used for that purpose include cotton applicators and others that are even less suitable, such as hair pins, rat-tail combs, matches, etc. [75, 357, 397, 459]. Long, slender particles of matter, such as twigs or pieces of straw, may accidentally enter the EEC and perforate the TM [51, 75, 339]. Since the EEC is slightly S-shaped, the *posterosuperior* quadrant of the TM lies directly in the projection of the canal axis. Theoretically at least, this portion of the TM should

be especially vulnerable. A number of authors [13, 51, 81, 287] called attention to this fact, mentioning the potential danger to the ME structures behind it. *Zaufal* [475–477] and *Passow* [339], however, found that lesions produced mechanically via the EEC are more frequently located in the *anteroinferior* quadrant. After conducting experiments in cadaver ears, they concluded that instruments introduced into the EEC are reflected by the posterior wall in a generally anteroinferior direction. It was only after pushing the tragus anteriorly that they were able to perforate the posterior portion of the TM.

In addition to sharp tools that may perforate the TM directly, small foreign bodies are capable of doing the same, such as pieces of cerumen, cotton plugs, insects and various things children put into the EEC during play (pebbles, beans, buds of pussy willows, etc.). A foreign body wedged into the EEC, especially when it is liable to swell up, may cause an infectious edema, involve the TM, and lead to a suppurative otitis media and even to a mastoiditis [313]. *Chalier and Rousset* [cited after 313] described the case of a child, 3 years of age, who died from tetanus contracted after a pebble had been put into his EEC. Earlier, *Kiesselbach* [239] had collected 13 similar cases from the literature; foreign bodies lodged in the EEC had been the causes of death in all of them.

Often, it is not the foreign body that ruptures the TM directly, but rather misguided attempts to remove it. Into this category belong manipulations in the EEC of a frightened child that cries and fights the physician [397], and also attempts to remove a foreign body by means of a forceps. Frequently, such attempts succeed only in pushing the material deeper and deeper into the EEC and finally through the TM into the ME [221].

Laceration of the TM during the course of a successful extraction is probably a rare event. *Mosher* [313] described the extraction of a tick, the head of which was so deeply buried in the TM that a piece of it was torn out during the removal of the arthropode.

Finally, although it is certainly the method of choice for cleaning the EEC, even irrigating it may occasionally lacerate the TM, especially when the canula is accidentally pushed too deeply into the EEC [99]. Strictly speaking, such TM lesions are not really caused by the foreign object itself; rather, they are iatrogenic in nature.

3.1.2. Lesions of Thermal Origin

A foreign body intruding into the EEC, without touching the walls, should not be expected to possess sufficient kinetic energy to directly pene-

trate the TM. Nevertheless, serious injuries are produced by hot particles, such as arcs from a grindstone, or red-glowing pieces of metal or cinder entering the EEC during welding or steel-pouring operations. The first description of a TM lesion produced in this manner was given by *Alexander* [3]. While steel was being poured, a drop of liquid metal was flung into the left EEC of the patient, immediately making him unconscious. Later on, he suffered from dizziness, and the ear in question became deaf; there was fetid discharge and a facial palsy. Since no lesions could be seen in the EEC, the patient's account met initially with skepticism. Surgery, however, uncovered a grain-sized piece of metal lying in the hypotympanum.

Papers published later (3 cases [165]; 1 case [275]) reported TM burns that had left the EEC completely untouched. *Güttich* [165] thought that some protection might be provided by the ceruminal lining of the canal walls. His other notion, i.e. that this might be due to the ballistic curve of the object flying through an EEC that is likewise curved, appears to be rather farfetched.

Heermann [186] culled 15 cases of TM or ME burns respectively from the records of the Krupp Hospital, Essen, FRG. All of these injuries had been incurred during ore-smelting or metal-pouring operations. The author was able to demonstrate that the seriousness of the injury was correlated with the size of the foreign body (i.e. probably with its thermal capacity). The absolute temperatures are invariably so high — 1,200°C during welding operations [304] — that small individual differences do not appear to play a role.

Several, more extensive series were published later (11 cases [133]; 8 cases [288]; 13 cases [313]; 44 cases [371]; 32 cases [446]). All of their authors reported essentially the same findings: as a rule, the left ear was involved (although the right ear in left-handers). The perforation was usually located in the anteroinferior quadrant. In the case of very small foreign bodies, the perforation did not become visible until a few days had elapsed following the original injury [371, 446]. Cerumen, if present, protected the ear canal by slowing down the speed of the intruding object [371, 446]. *Mosher* [313] expressed the opinion that a strong serous discharge from the ear might dislodge a foreign body. *Schein* [371] never detected a foreign body in the ME. *Heermann* [186], however, had to remove one each from the ME of 2 of his patients. In some cases, the inner ear was also found to be involved [186, 288, 446]. *Heermann* [186] furthermore saw an FN disruption caused by a piece of hot metal and also a posttraumatic meningitis that led to the death of the patient.