Aus der Klinik und Poliklinik für Hals-, Nasen- und Ohrenheilkunde der Ludwig-Maximilians-Universität München

Direktor: Prof. Dr. med. A. Berghaus

Erweiterte endoskopisch kontrollierte Nasennebenhöhlenchirurgie:

Therapieerfolg, Indikationsspektrum bei Tumor- und Schädelbasischirurgie und Einsatz der Navigation

vorgelegt von

Dr. med. G. Ledderose

aus München

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1. Einleitung

Entzündliche Erkrankungen der Nasenhaupthöhle und der Nasennebenhöhlen sind sehr häufig (Hosemann 2013, Orlandi 2016). Die Therapie ist in der Regel zunächst konservativ und besteht aus antientzündlichen und schleimhautpflegenden Maßnahmen. Bei Therapieresistenz und bei Komplikationen ist die operative Sanierung der Nasennebenhöhlen die Therapie der Wahl (Fokkens 2012).

Hierbei steht heute die Beseitigung pathologischer Prozesse durch minimal-invasive und funktionserhaltende Maßnahmen im Zentrum (Wigand 1978; Hosemann 1989; Hosemann 1993). Dieses Prinzip der minimalisierten Gewebeabtragung an anatomischen Schlüsselstellen wird mit dem Begriff *"functional endonasal sinus surgery", "FESS"* bezeichnet (Kennedy 1985). Die Operationsmethode ist komplikationsarm und führt in einem hohen Prozentsatz zu einer bleibenden Besserung der Beschwerden (Fokkens 2012; Siedek 2013).

Durch die Weiterentwicklung der Operationstechniken, der Endoskope, des Videostandards, der Operationsinstrumente und den routinemäßigen Einsatz von Navigationssystemen kann die endonasale, endoskopisch kontrollierte Operation besser, schleimhautschonender und patientenfreundlicher durchgeführt werden, so dass die Indikation zunehmend häufiger gestellt wird. Mittlerweile werden auf diese Weise auch zunehmend Eingriffe wie beispielsweise Tumor- oder Schädelbasisoperationen durchgeführt, die früher über extranasale, transfaziale oder transkranielle Zugänge vorgenommen wurden (Stammberger 1986; Fokkens 2012; Lund 2010). Das sich so laufend erweiternde operative Spektrum stellt den HNO-Chirurgen ständig vor neue Herausforderungen. Die vorliegende kummulative Arbeit befasst sich mit der Beantwortung ausgewählter Fragestellungen, die sich aus diesem Sachverhalt ergeben.

2. Fragestellungen

2.1. Klinisches Ergebnis, Patienten-Nutzen und Lebensqualität nach funktioneller endoskopischer Nasennebenhöhlenoperation

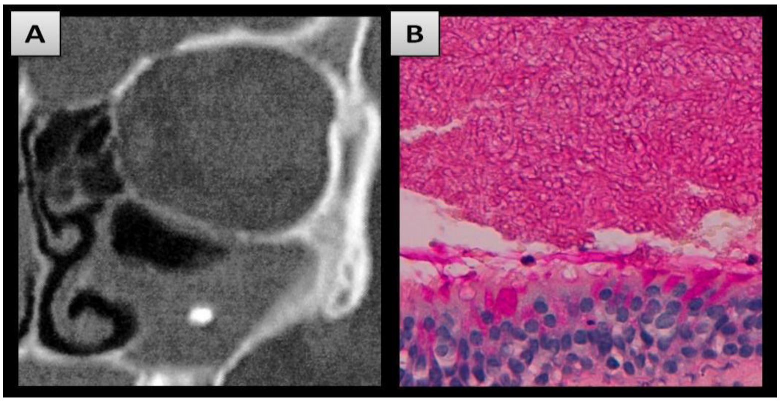
Chronisch entzündliche Nasennebenhöhlenerkrankungen äußern sich häufig unspezifisch. Beschwerden sind erschwerte bis blockierte Nasenatmung, Rhinorrhoe, Einschränkung bis Verlust des Riechvermögens und Druckgefühl über den Nasennebenhöhlen sowie Cephalgien. Da Bildgebung und klinischer Befund sehr variabel sein können und nicht notwendigerweise mit der subjektiven Beeinträchtigung durch die Erkrankung korrelieren, beruht die Einschätzung des Schweregrades zu einem nicht unbeträchtlichen Teil auf der Schilderung der Betroffenen. Das kann die Indikation, aber auch die objektive Überprüfung des therapeutischen Erfolgs nach operativer Sanierung der Nasennebenhöhlen schwierig machen (Jones 2009; Fokkens 2012).
Da chronisch entzündliche Nasennebenhöhlenerkrankungen sich hauptsächlich durch eine Beeinträchtigung der Lebensqualität äußern, ist bei der retrospektiven Analyse die Verwendung von validierten Werkzeugen unerlässlich. Obwohl die Diagnose der chronischen Sinusitis über zwei Millionen Mal pro Jahr in Deutschland gestellt wird und die Nasennebenhöhlenoperation ein vergleichsweise häufig durchgeführter Eingriff ist, sind solche Untersuchungen selten (Hosemann and Draf 2013; Lund 2014; Ledderose 2015).

<u>Es ergeben sich folgende Fragestellungen:</u>

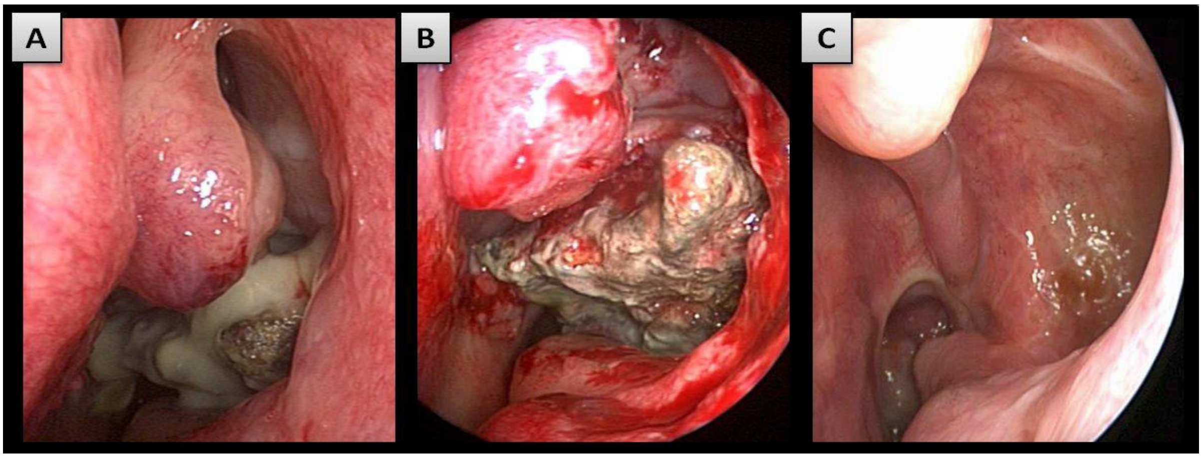
- Wie ist der Nutzen der endoskopischen Nasennebenhöhlenoperation für den Patienten einzuschätzen?
- Gibt es die Möglichkeit einer objektiven Beurteilung des Therapieerfolgs?
- Wie schätzen die Patienten den Nutzen der Operation ein?

Zur Beantwortung dieser Fragen wurde eine retrospektive Analyse an einem definierten Patientenkollektiv durchgeführt. Wir wählten das Krankheitsbild der nicht-invasiven, chronischen Pilzsinusitis aus, im englischen Sprachraum *fungus ball sinusitis* genannt (Chakrabati 2009). Diese stellt eine Sonderform einer entzündlichen Nasennebenhöhlenerkrankung dar, zeigt aber neben den genannten unspezifischen Sinusitis-Symptomen einen objektivierbaren radiologischen und eindeutigen klinischen Befund (Simmen 1998; Klossek 1997; Ferreiro 1997; Grosjean 2007; Stammberger 1984; Nicolai 2009; Broglie 2009; Pagella 2007). Dadurch bietet sich dieses spezielle Krankheitsbild an, will man die endoskopische Operationstechnik, die Verbesserung der klinischen Symptome und den Nutzen des Patienten durch eine funktionelle Nasennebenhöhlenoperation möglichst objektiv überprüfen (Lai 2011).

Es wurden 40 Patienten untersucht, die wegen einer chronischen, nicht-invasiven Pilzsinusitis operiert wurden. Es wurden die klinischen Symptome und Beschwerden der Patienten, die klinische und radiologische Präsentation des Krankheitsbildes, die Operationstechnik, die Mikrobiologie und die typische Histopathologie erfasst und analysiert.



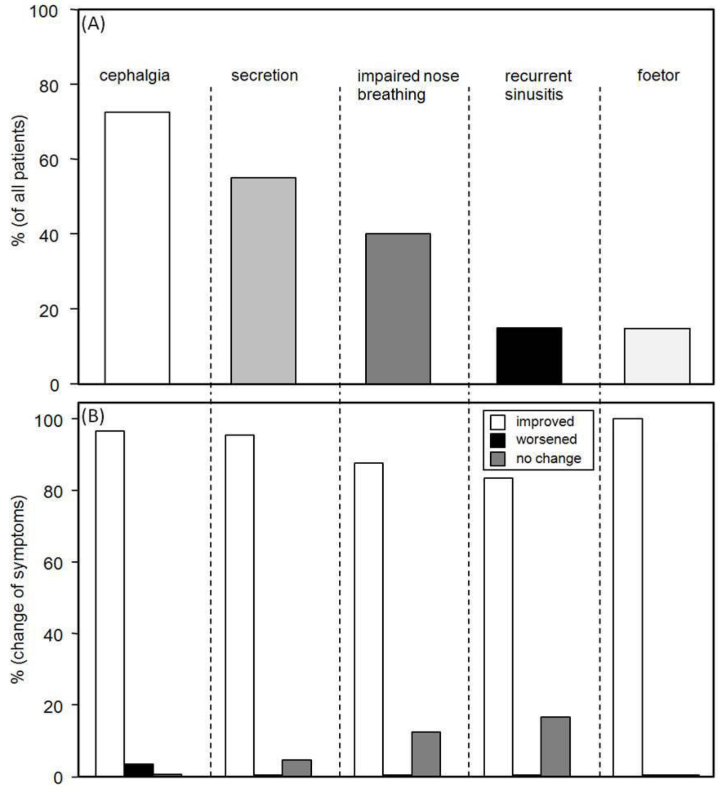
Typische CT einer chronischen, nicht-invasiven Pilzsinusitis der linken Kieferhöhle. Es zeigt sich das charakteristische "iron-like-signal" (A). In der histopathologischen Untersuchung findet sich ein dichtes Konkrement aus Pilzhyphen ohne Schleimhaut-, Gefäß- oder Knocheninfiltration (B). Die Schleimhaut weist eine leichte, begleitende Entzündung auf (Vergrößerung 400 x, PAS-Färbung)



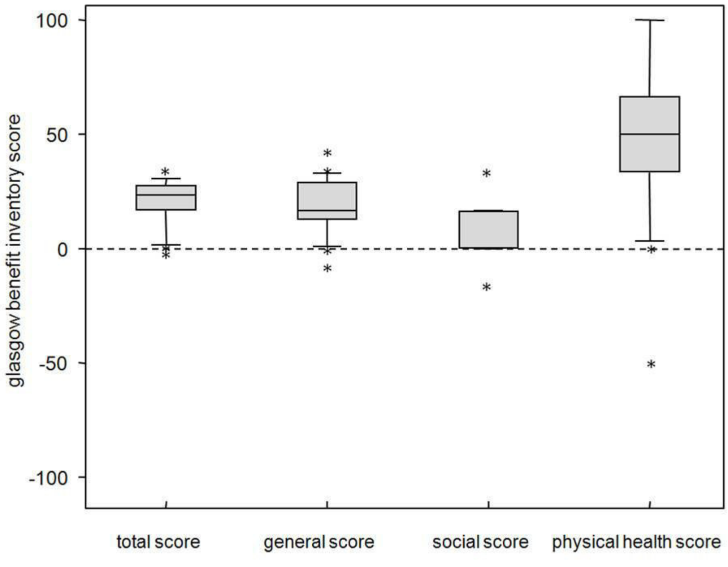
Endoskopische Entfernung eines Pilzkonkrements aus der linken Kieferhöhle. Es zeigt sich eitrige Sekretion bei der endoskopischen präoperativen Untersuchung als Zeichen der Superinfektion (A), intraoperativ zeigt sich das dicht gepackte Pilzkonkrement in der Kieferhöhle (B), in der postoperativen Nachuntersuchung findet sich kein Anhalt für eine gestörte Wundheilung oder ein Rezidiv (C).

Die Einschätzung des Operationserfolges durch die Patienten wurde postoperativ mithilfe des sogenannten SNOT-20-Fragebogens ("Sinonasal Outcome Test") erfasst. Dieser Fragebogen ist etabliert und wird häufig in Studien für die selbständige Beurteilung des subjektiven Operationserfolges durch den Patienten eingesetzt (Piccirillo 2002; Pynnonen 2009). Anders als andere Lebensqualitätsfragebögen für sinonasale Beschwerden ist dieser Fragebogen nicht in Untergruppen oder -domänen unterteilt. Die Patienten können ihren Gesundheitszustand bezogen auf die rhinosinusitischen Beschwerden durch die Angabe der Schwere der Symptome spezifizieren. Die Skala reicht von 0 bis fünf, wobei der höhere Wert für eine Zunahme der Beschwerden steht. Der Unterschied zwischen den prä- und postoperativen Punktwerten ergibt den Operationserfolg. Verwendet wurde eine modifizierte deutsche Version des SNOT-20-Fragebogens, der zusätzliche Fragen zur Nasenatmungsbehinderung, dem Fötor ex naso und Geruchs- bzw. Geschmacksverlust beinhaltete. Der SNOT-20 kann mit anderen Messinstrumenten kombiniert werden, um eine möglichst komplette Erfassung der gesundheitsbezogenen Lebensqualität zu erreichen (Piccirillo 2002).

Dementsprechend wurde zusätzlich ein validiertes Instrument zur Erfassung der gesundheitsbezogenen Lebensqualität, der Glasgow Benefit Inventory (GBI), zur Beurteilung der Operation angepasst und ebenfalls dem Patienten vorgelegt. Der GBI ist charakterisiert durch seine Sensitivität für chronische Erkrankungen, wie sie häufig in der HNO-Heilkunde gesehen werden. Die Analyse des Gesundheitszustandes nach einer chirurgischen Intervention basiert auf der allgemeinen Wahrnehmung des Wohlbefindens, das sich aus körperlichen, psychischen und sozialen Anteilen zusammensetzt (Robinson 1992; Browning 1991). Der GBI erfasst Rohdaten, aus denen ein Gesamtscore sowie Unterskalen für soziale Unterstützung und körperliche Gesundheit berechnet werden können. Die Werte können zwischen -100 (maximal negativer Effekt der Intervention) über 0 (kein Effekt) bis +100 (maximal positiver Effekt der Intervention) liegen. Auch wenn der GBI in der HNO-Heilkunde vor allem in der plastischen Chirurgie etabliert ist (Braun 2010), existieren bereits einige wenige Untersuchungen in der Rhino- und Sinuschirurgie (Konstantinidis 2005; Salama 2009; Salhab 2004; Newton 2008). Ähnlich wie in vergleichbaren Studien zeigte sich nach der Auswertung des SNOT20-Fragebogens eine große Mehrheit der Patienten zufrieden mit dem Operationsergebnis; eine deutliche Verbesserung der präoperativen Symptome konnte festgestellt werden (Fokkens 2012). Die Ermittlung der GBI-Scores zeigte eine deutliche Verbesserung des allgemeinen Wohlbefindens und besonders der gesundheitsbezogenen Lebensqualität. Die Werte waren vergleichbar mit Ergebnissen, die nach Polypenentfernung gemessen wurden (Newton 2008).



Subjektive Beschwerden bei Pilzballsinusitis. Präoperativer Befund (A) und die subjektive Veränderung der Symptome ca. 12 Monate nach der endoskopischen Nasennebenhöhlenoperation (B), jeweils erfasst durch den modifizierten SNOT-20-Fragebogen.



Veränderung der Lebensqualität durch die Nebenhöhlenoperation, erfasst durch den Glasgow Benefit Inventory Fragebogen. Die Skala reicht von -100 (maximal negativer Effekt), über 0 (kein Effekt), bis +100 (maximal positiver Effekt). Mit Ausnahme des social support score war der positive Effekt der Operation statistisch signifikant. ($p < 0.05$).

Wir konnten zeigen, dass die operative Sanierung einer nicht-invasiven, chronischen Pilzsinusitis im Rahmen einer funktionellen endoskopisch kontrollierten Nasennebenhöhlenoperation die Therapie der Wahl darstellt. Der Eingriff ist komplikationsarm, Rezidive wurden in der untersuchten Patientengruppe nicht beobachtet. Mit validierten Instrumenten konnte nachgewiesen werden, dass der Eingriff zuverlässig zu einer hohen Patientenzufriedenheit führt und mit einer deutlichen Zunahme der gesundheitsbezogenen Lebensqualität verbunden ist (Ledderose 2012a).

Originalarbeit:

Ledderose GJ, Braun T, Betz CS, Stelter K, Leunig A. Functional endoscopic surgery of paranasal fungus ball: clinical outcome, patient benefit and health-related quality of life. Eur Arch Otorhinolaryngol 2011

Originalarbeiten zu angrenzenden Themengebieten:

Ledderose GJ und Leunig A, Pilzerkrankungen der Nase und Nasennebenhöhlen. Von der harmlosen Besiedelung bis zur tödlichen Infektion. HNO-Nachrichten 2012

Ledderose GJ, Berghaus A. Blocked nose: differential diagnosis. MMW Fortschr Med. 2015

Ledderose GJ. Die verstopfte Nase. MMW Fortschr Med. 2016. Review.

Englhard AS, Wiedmann M, **Ledderose GJ**, Lemieux B, Badran A, Chen Z, Betz CS, Wong BJ. Imaging of the internal nasal valve using long-range Fourier domain optical coherence tomography. Laryngoscope. 2016

2.2 Endoskopische Chirurgie von Tumoren der Nasennebenhöhlen

Die operative Entfernung von Tumoren der Nasennebenhöhlen ist häufig anspruchsvoll und risikoreich wegen der Nähe zu wichtigen Strukturen wie dem Gehirn und dem Auge. Die herkömmlich in der Regel bevorzugten extranasalen Zugänge wurden in den letzten Jahren mehr und mehr abgelöst durch endoskopisch kontrollierte Operationstechniken, hauptsächlich um eine geringere Morbidität zu erzielen. Im 2010 erschienenen *"European position paper on endoscopic management of tumours of the nose, paranasal sinuses and skull base"* (Lund 2010) wurde dieser Wandel in der Operationstechnik zum ersten Mal systematisch untersucht. Gleichzeitig wurden Anforderungen für zukünftige Studien formuliert. Angesichts der Seltenheit der verschiedenen Krankheitsentitäten besteht der Bedarf für große Fallserien zu gut- wie bösartigen Nasennebenhöhlentumoren, um Epidemiologie, klinisches Erscheinungsbild, Wachstumsverhalten und histopathologische Muster zu analysieren und die geeigneten Therapiestrategien festzulegen. Besonders der Behandlungseffekt und die Limitationen der endoskopischen Techniken sollen zukünftig gezielt untersucht werden (Lund 2010; Draf und Berghaus 1993).

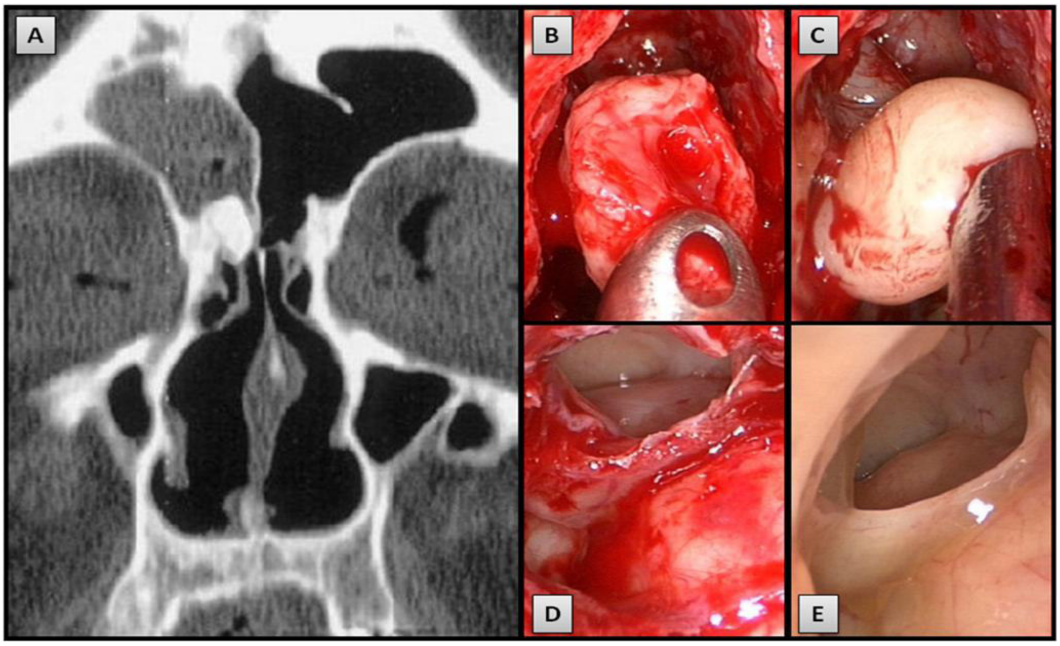
2.2.1 Endoskopische Chirurgie von gutartigen sinonasalen Tumoren

<u>In der Behandlung der gutartigen Nasennebenhöhlentumoren ergeben sich folgende Fragestellungen:</u>

- Welche gutartigen Tumoren eignen sich für die endoskopisch kontrollierte, endonasale Resektion?
- Können auch Tumoren in schwer zugänglichen Bereichen der Nasennebenhöhlen (z.B. der Stirnhöhle) endoskopisch operiert werden?
- Können gutartige Tumoren, die früher über extranasale Operationszugänge entfernt wurden, heutzutage endoskopisch operiert werden? Kam es zu einer Erweiterung des Indikationsspektrums für die endoskopische Chirurgie?
- Können gutartige Tumoren endoskopisch entfernt werden, auch wenn sie in komplexer anatomischer Beziehung zu vitalen benachbarten Strukturen lokalisiert sind?
- Können auch stark vaskularisierte Tumoren mit potentieller Blutungsgefahr endoskopisch endonasal beherrscht werden?

Zur Beantwortung der formulierten Fragen führten wir eine Reihe retrospektiver Studien durch.

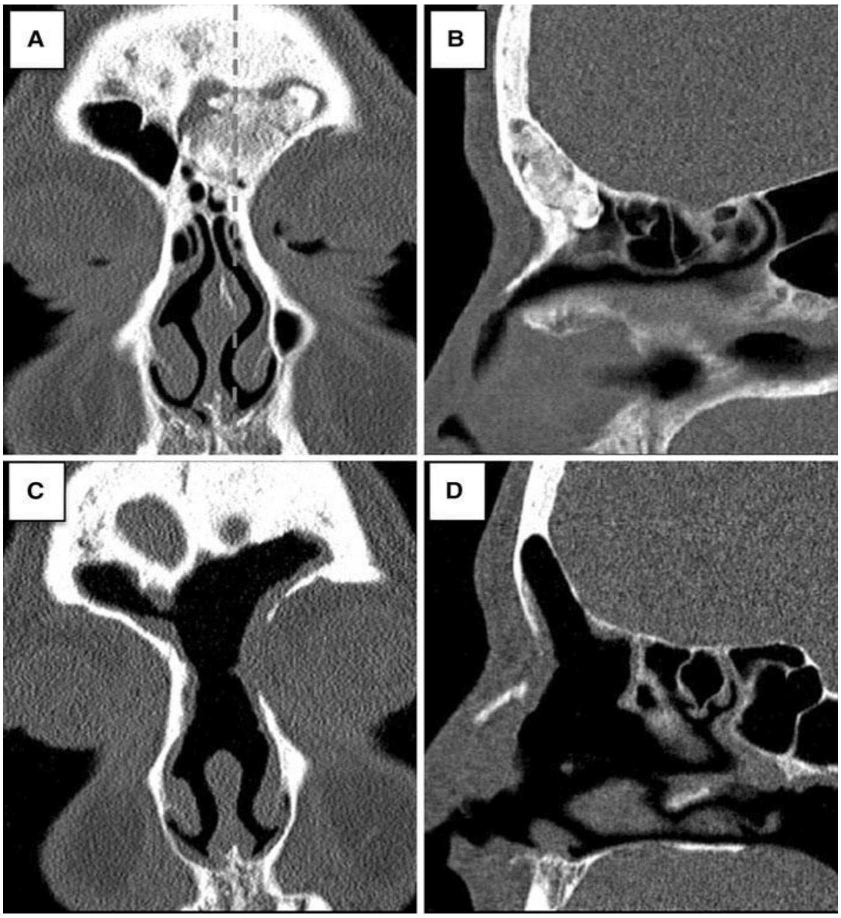
2.2.1.1 Chirurgisches Vorgehen bei frontoethmoidalen Osteomen



Endoskopische Entfernung eines Osteoms aus dem Recessus frontalis rechts (Grad II, Einteilung nach Chiu et al.). In der koronaren CT Schleimverhalt in der rechten Stirnhöhle (A). Entfernung des Osteoms (B), Drainage des retinierten Sekrets (C), Blick in die Stirnhöhle (D) and reizlose Stirnhöhle ca. ein Jahr postoperativ (E).

Wir werteten die Fälle der Patienten aus, die zwischen 1996 bis 2010 wegen eines frontoethmoidalen Osteoms in der HNO-Klinik der LMU operiert worden waren. Osteome sind die häufigsten gutartigen Tumoren der Nasennebenhöhlen. Häufig bleibt dieser gutartige fibro-ossäre Tumor asymptomatisch und muss - wenn er zufällig auffällt - nicht zwangsläufig entfernt werden (Jones 2009). Osteome der Nasennebenhöhlen, die Beschwerden verursachen, sollten aber stets reseziert werden (Al-Sebeih 1998; Chen 2015; Draf und Berghaus 1993; Eller 2006). Die häufigste Lokalisation eines Nasennebenhöhlenosteoms ist der frontoethmoidale Bereich. Die Stirnhöhle ist für endoskopische Zugänge schwer erreichbar, so dass Osteome häufig über einen extranasalen Zugang entfernt werden mussten (Dubin 2006). Ein Stirnhöhlenosteom wurde erstmals im Jahre 1992 von Kennedy endonasal entfernt (Ledderose 2011a). Verbesserte Instrumente und Optiken, gewinkelte Bohrer und die Verwendung von Navigationssystemen führten dazu, dass die Anzahl der Osteome, die endonasal reseziert werden können, stetig zunahm (Lund 2010; Weber 2001; Bignami 2007; Chiu 2005). Es existieren dementsprechend recht unterschiedliche Leitlinien und Vorschläge, wann eine Osteomoperation endoskopisch durchgeführt werden sollte (Chiu 2005; Castelnuovo 2008; Chen 2004).

Wir untersuchten die größte, bis zu diesem Zeitpunkt veröffentliche Patientenkohorte mit dieser speziellen Diagnose. Es wurde neben der Epidemiologie, dem klinischen und radiologischen Bild, dem operativen Zugang und den Operationskomplikationen analysiert, welche Indikation für einen extranasalen bzw. einen endonasalen Operationszugang bestanden hatte. Zudem wurde geprüft, ob sich das Vorgehen im Laufe des Untersuchungszeitraums von 15 Jahren geändert hatte, sich also ein



CT in koronarer (A) und sagittaler Ebene (B). Etwa 50 % des Osteoms liegen lateral der gedachten sagittalen Ebene, die durch die Lamina papyracea gelegt wird. Die linke Stirnhöhle ist nahezu komplett ausgefüllt. Der postoperative Befund in koronarer (C) und sagittaler (D) Ebene fünf Monate nach operativer Entfernung des Osteoms. Der Tumor wurde ausschließlich endonasal (Mediandrainage, "modified lothrop procedure") entfernt.

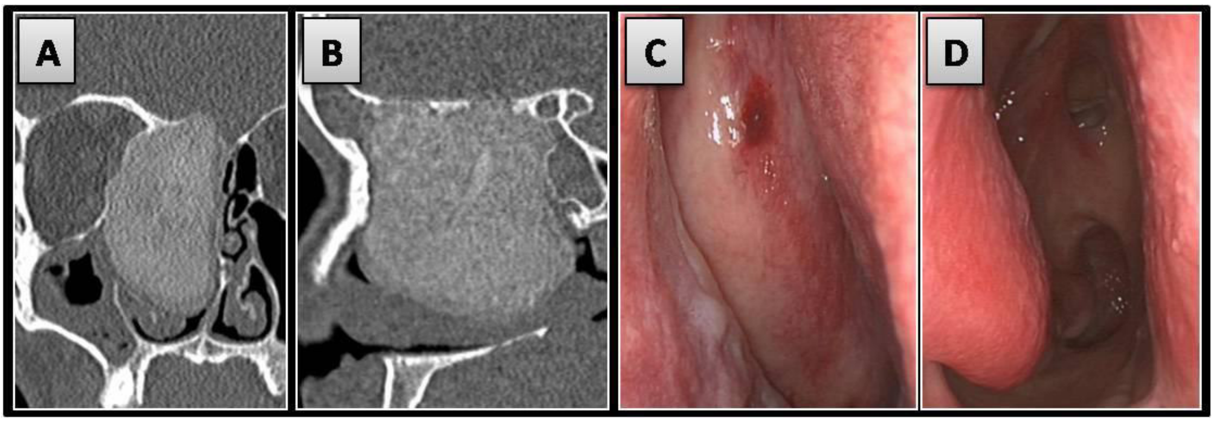
Wandel in der Indikationsstellung für einen endonasalen, endoskopischen Eingriff zeigte.
Es konnte nachgewiesen werden, dass die Entfernung eines symptomatischen Osteoms der Stirnhöhle in der Regel zu einer Symptomverbesserung führt. Die alleinige endoskopische Entfernung war häufig möglich. Die in der Literatur vorgeschlagenen Richtlinien für die endoskopische Resektion zeigten sich als nicht in jedem Fall zutreffend, so konnten beispielsweise auch große, teilweise lateral gelegene Tumoren endonasal operiert werden (Chiu 2005; Castelnuovo 2008; Chen 2004). Es bleibt allerdings zu betonen, dass geeignete technische Voraussetzungen und die entsprechende chirurgische Erfahrung unbedingte Voraussetzung sind (Briner 2005). Zudem bleibt der extranasale Zugang eine wichtige Option der Osteomchirurgie, vor allem im Bereich der Stirnhöhle (Ledderose 2011a).

Fall	OP-Jahr	Lokalisation	Grad	Ansatzstelle des Osteoms	Operatives Verfahren
1	1996	Stirnhöhle links	4	anterior, inferior, breitbasig	Bügelschnitt, median drainage III, Draf type IIA Frontoethmoidektomie, Septoplasty
2	1997	Stirnhöhle rechts	3	inferior, breitbasig	Augenbrauenrandschnitt
3	1999	Recessus frontalis links	2	posterior, gestielt	Augenbrauenrandschnitt, Draf Typ IIA Frontoethmoidektomie, Septumplastik
4	2000	Stirnhöhle links	3	inferior, breitbasig	Augenbrauenrandschnitt, Draf Typ IIA Frontoethmoidektomie, Septumplastik
5	2000	Stirnhöhle links	3	posterior, breitbasig	Augenbrauenrandschnitt, Draf Typ IIA Frontoethmoidektomie, Septumplastik
6	2000	Recessus frontalis links	1	medial, inferior, gestielt	Augenbrauenrandschnitt
7	2000	Stirnhöhle links	3	inferior, breitbasig	Augenbrauenrandschnitt, Draf Typ IIA Frontoethmoidektomie, Septumplastik
8	2001	Stirnhöhle rechts	3	gestielt, cranial	Augenbrauenrandschnitt
9	2002	Stirnhöhle rechts	3	anterior, breitbasig	Augenbrauenrandschnitt, Draf Typ IIA Frontoethmoidektomie
10	2002	Stirnhöhle rechts	3	posterior, breitbasig	Augenbrauenrandschnitt, Draf Typ IIA Frontoethmoidektomie, Septumplastik
11	2003	Recessus frontalis rechts	2	anterior, gestielt	Augenbrauenrandschnitt, Draf Typ IIA Frontoethmoidektomie
12	2003	Stirnhöhle, links	4	anterior, breitbasig	Bügelschnitt, Draf Typ IIA Frontoethmoidektomie
13	2004	Recessus frontalis rechts	1	lateral, gestielt	Draf Typ IIA Frontoethmoidektomie
14	2004	Recessus frontalis links	2	anterior, gestielt	Draf Typ IIA Frontoethmoidektomie
15	2005	Stirnhöhle links	4	posterior, breitbasig	Augenbrauenrandschnitt, Draf Typ IIA Frontoethmoidektomie
16	2006	Stirnhöhle rechts,	3	inferior, breitbasig	Augenbrauenrandschnitt
17	2006	Stirnhöhle rechts	2	medial, inferior, gestielt	Draf Typ IIA Frontoethmoidektomie
18	2007	Recessus frontalis, rechts	1	Medial, inferior, gestielt	Draf Typ IIA Frontoethmoidektomie
19	2007	Stirnhöhle links	3	Kranial, gestielt	Draf Typ IIB Frontoethmoidektomie, Septumplastik
20	2008	Stirnhöhle rechts	4	Kranial, gestielt	Augenbrauenrandschnitt
21	2009	Stirnhöhle links	4	posterior, contact to skull base, lateral breitbasig	Mediandrainage III, Septumplastik
22	2009	Stirnhöhle rechts	3	Lateral, posterior, gestielt	Draf Typ IIB Frontoethmoidektomie, Septumplastik
23	2010	Recessus frontalis, links	2	Superior, breitbasig	Draf Typ IIB Frontoethmoidektomie
24	2010	Stirnhöhle rechts	4	Lateral, breitbasig	Bügelschnitt, Draf Typ IIA Frontoethmoidektomie

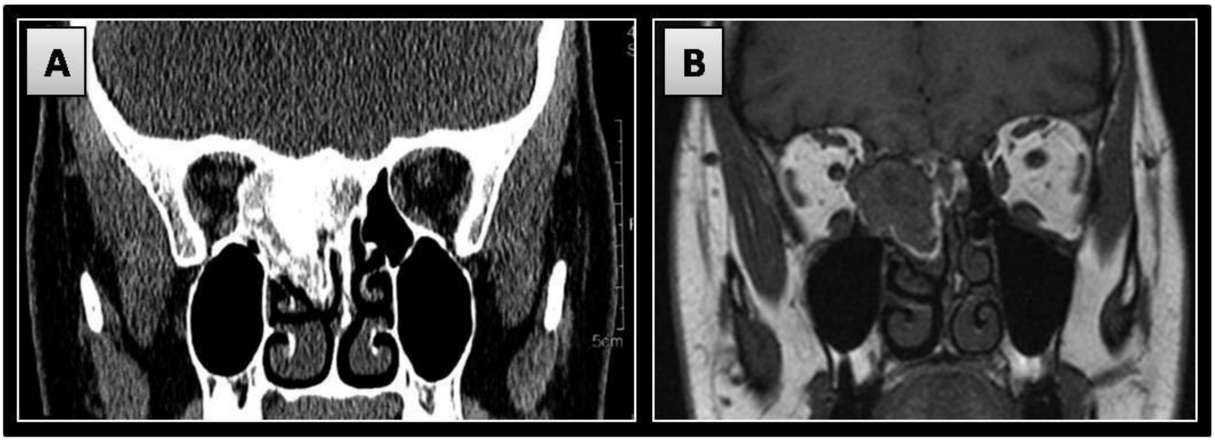
Lokalistation, Ursprung, Grad des frontoethmoidalen Osteoms (entsprechend der Klassifikation von Chiu (Chiu 2005) und der entsprechende operative Eingriff.

2.2.1.2 Behandlungsstrategie bei sinonasalen ossifzierenden Fibromen

In einer weiteren retrospektiven Studie wurden die Patientenfälle mit der Diagnose eines ossifizierenden Fibroms der Nasennebenhöhlen untersucht. Wie das Osteom wird auch das ossifizierende Fibrom zu den fibroossären Läsionen gezählt. Im Kopfbereich ist es ein sehr seltener Tumor, der gehäuft Kinder und junge Erwachsene betrifft (Eller 2006; Lund 2010). Gefunden wird es meist im zahntragenden Kieferbereich und nur sehr selten in der Nasenhaupthöhle oder den Nebenhöhlen. Hier stellt es allerdings aufgrund der anatomisch komplexen Region eine besondere Herausforderung für den behandelnden Arzt dar. Schon die Diagnose kann sich schwierig gestalten und basiert auf klinischem Befund, der Bildgebung, der Lokalisierung, dem Wachstumsverhalten, dem Alter des Betroffenen und der histopathologischen Beurteilung (Bertrand 1993). Aufgrund des lokal aggressiven Wachstumsmusters und der potentiellen Komplikationen ist in der Regel die operative Entfernung eines ossifizierenden Fibroms indiziert; anders als beim Osteom und der fibrösen Dysplasie (Al-Sebeih und Desrosiers 1998; Commins 1998; London 2002), wo die operative Therapie nur bei spezifischen Beschwerden empfohlen wird (Bertrand 1993; Lund 2010; Jurado-Ramos 2009). Der Eingriff kann sich aufgrund des komplizierten Wachstumsverhaltens entlang der Schädelbasis und der Augenhöhle und der guten Durchblutung des Tumors häufig schwierig und anspruchsvoll gestalten. Da diese Tumorentität sehr selten ist, müssen Therapieempfehlungen bisher anhand von einzelnen Fallbeschreibungen gegeben werden (Caylakli 2004; Jurado-Ramos 2009; London 2002). Gerade bei jungen Patienten ist eine möglichst geringe Morbidität und Narbenbildung anzustreben.



Ossifizierendes Fibrom: Die CT zeigt eine große, hyperdense, verdrängend wachsende Raumforderung im Siebbeinbereich und der Nasenhaupthöhle rechts. Die Orbita ist imprimiert, es liegt ein langstreckiger Kontakt zur Schädelbasis vor. Die Dura erscheint teilweise angehoben (A, B). Endoskopisch zeigt sich ein großer, rötlich-weißer Tumor (C). Sieben Monate nach endoskopisch kontrollierter, endonasaler Resektion zeigt sich kein Anhalt für ein Rezidiv (D).

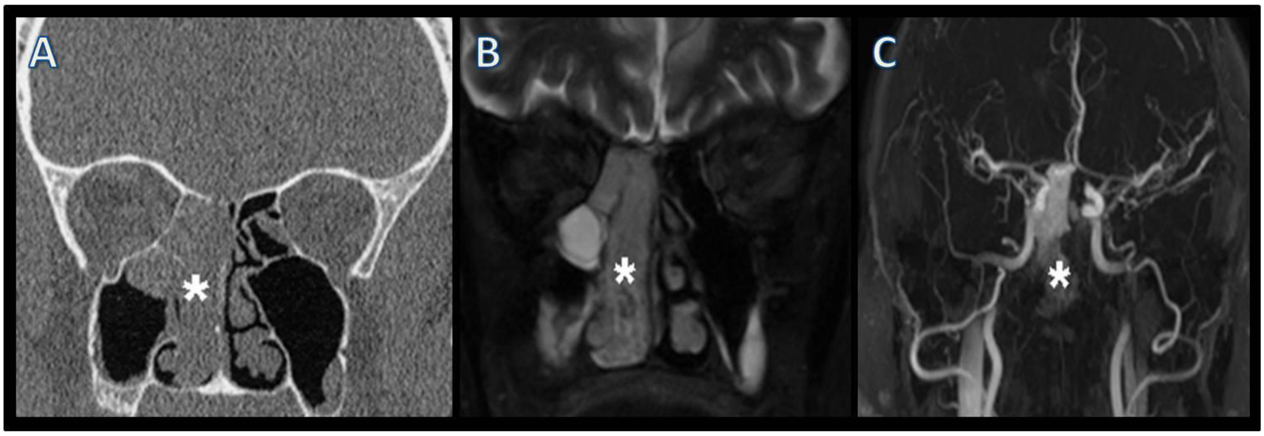


Die CT zeigt einen umschriebenen Tumor im rechten Siebbeinzellsystem mit Ausdehnung in die Keilbeinhöhle einer 45 jährigen Patientin. Die mediale Wand der Orbita ist etwas verdrängt, die Schädelbasis weitstreckig involviert (A). Die histopatholgische Untersuchung der Probeentnahme ergab ein "Cemento-ossifizierendes Fibrom". Die Kontroll-MRT etwa zwei Jahre nach Diagnosestellung zeigt keine messbare Größenzunahme (B).

Wir konnten zeigen, dass in den untersuchten Fällen jeweils eine endonasale endoskopische Operation möglich war. Bei den erwachsenen Patienten, die auf eigenen Wunsch nicht operiert worden waren, zeigte sich in der Nachbeobachtung bildmorphologisch keinerlei Wachstumstendenz, so dass bei diesem speziellen Subtyp des ossifzierenden Fibroms nach histologischer Sicherung durch eine Probeentnahme und entsprechender Aufklärung des Patienten möglicherweise eine abwartende Haltung ("watchful waiting") gewählt werden kann (Ledderose 2011b).

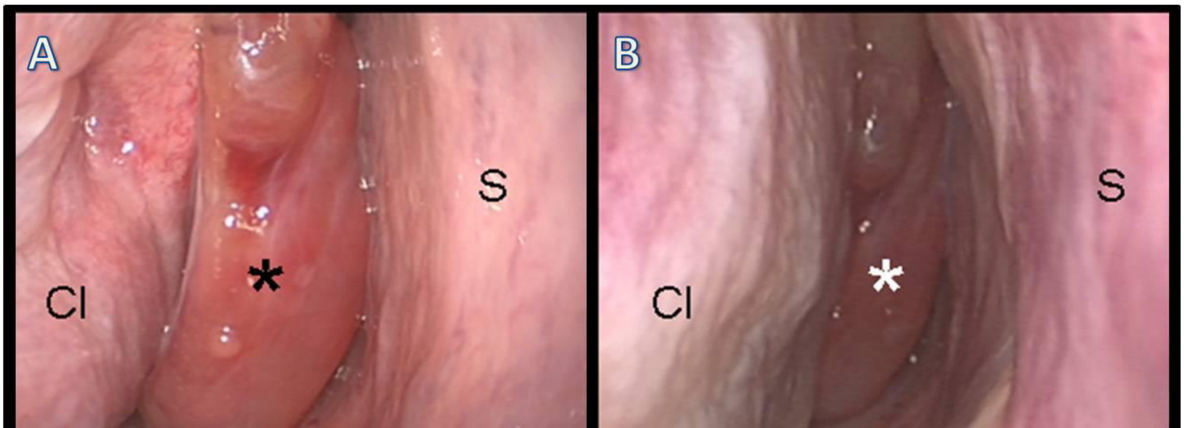
2.2.1.3 Endoskopische Resektion des sinonasalen Hämangioperizytoms

Ein weiterer Tumor, der in den Nasennebenhöhlen auftreten kann, ist das sinonasale Hämangioperizytom. Es wird nach Empfehlung der WHO wegen seiner Ähnlichkeit zu Paragangliomen auch Glomangioperizytom genannt (Stout 1942; Tse 2002). Der Tumor zeigt eine reiche arterielle Blutversorgung und ist damit dem juvenilen Angiofibrom vergleichbar. Häufig sind großlumige Versorgungsgefäße aus der Arteria carotis externa oder der Arteria carotis interna. Therapie der Wahl ist aufgrund der Klinik und der geringen Metastasierungstendenz (ca. 5 %) die operative Entfernung (Lund 2010). Die lokale Ausdehnung mit knöcherner Arrosion im Siebbein und der Keilbeinhöhle mit Kontakt zur Schädelbasis, dem Sehnerven und der A. carotis interna und besonders die notwendige Kontrolle des Risikos von schweren Blutungen machen eine operative Entfernung anspruchsvoll (Mosesson 1995). Es wird empfohlen, besonders gut vaskularisierte Tumoren zur besseren Kontrolle der versorgenden Blutgefäße über einen extranasalen Zugang zu operieren (Bhattacharyya 1997; Stout 1949).



Radiologische Befunde beim Hämangioperizytom. CT (A), MRT(B), MR-Angiographie (C). Es zeigt sich eine umschriebene, submuköse, eher heterogene Weichgewebesmasse, die die rechte Nasenhaupthöhle, die Siebbeinzellen und die Keilbeinhöhle sowie den Nasopharynx betrifft. Nach Kontrastmittelgabe wird ein starkes Enhancement festgestellt (∗ Tumor).

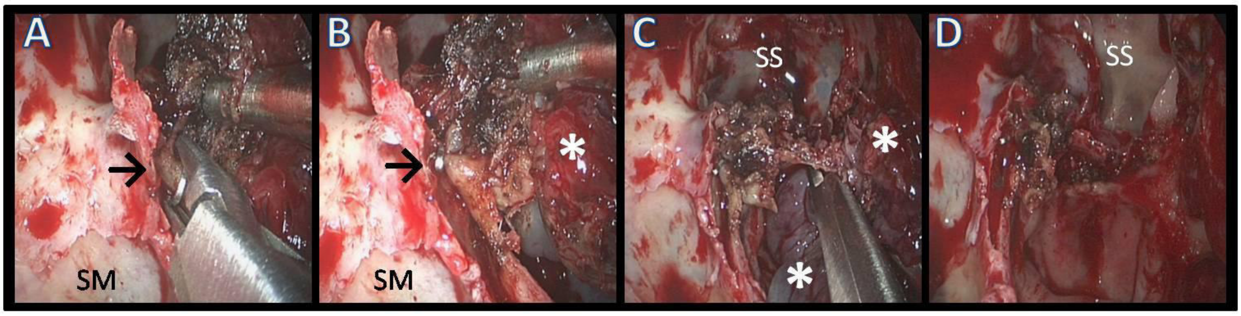
Bisher wurde daher nur etwa ein Fünftel der publizierten Fälle endoskopisch kontrolliert operiert. Weil ein Lokalrezidiv in fast fünfzig Prozent nach Resektion auftreten kann, sollte der operative Eingriff wegen der Gutartigkeit des Tumors möglichst schonend, ohne entstellende Narben und mit geringer Morbidität behaftet sein, aber dennoch ausreichend radikal vorgenommen werden (Sabini 1998). Wir untersuchten die Möglichkeit einer präoperativen, interventionellen Embolisierung zur Reduktion der intraoperativen Blutung und der anschließenden endoskopischen Resektion.



Endoskopisches Bild eines Hämangioperizytoms in der linken Nasenhaupthöhle, mit Ausdehnung in die Siebbeinzellen und die Keilbeinhöhle (A). Nach der Embolisation ist der Tumor deutlich geschrumpft (B). Nasenseptum (S), untere Nasenmuschel (CI), mittlere Nasenmuschel (CM), Tumor (∗).

Es zeigte sich, dass durch die präoperative Embolisation das Tumorvolumen und damit auch das Resektionsgebiet deutlich reduziert und das Risiko einer schweren intraoperativen Blutung verringert werden kann und die komplette endonasale, endoskopische Entfernung des Tumors ohne

Komplikation möglich ist. Entgegen der bisherigen Empfehlungen kann also auch bei großen, gut vaskularisierten Tumoren nach der interventionellen Embolisation eine endoskopische Resektion mit den entsprechenden Vorteilen für den Patienten möglich sein (Ledderose 2013).



Endoskopische Resektion nach Embolisierung. Nach der Resektion des hinteren Septums zeigt sich der an der Rhinobasis und der lateralen Nasenwand gestielte Tumor. Die versorgenden Gefäße werden dargestellt und unterbunden (A, B). Der Tumor kann anschließend komplett endonasal entfernt werden C, D). Kieferhöhle (SM), Keilbeinhöhle (SS), Tumor (∗).

<u>Originalarbeiten:</u>

Ledderose GJ, Betz CS, Stelter K, Leunig A. Surgical management of osteomas of the frontal recess and sinus: extending the limits of the endoscopic approach. Eur Arch Otorhinolaryngol. 2010

Ledderose GJ, Stelter K, Becker S, Leunig A. Paranasal ossifying fibroma: endoscopic resection or wait and scan. Eur Arch Otorhinolaryngol. 2011

Ledderose GJ, Gellrich D, Holtmannspötter M, Leunig A. Endoscopic Resection of Sinonasal Hemangiopericytoma following Preoperative Embolisation: A Case Report and Literature Review. Case Reports in Otolaryngology. 2013

<u>Originalarbeit zu einem angrenzenden Themengebiet:</u>

Ledderose GJ, Link V. A blocked frontal sinus with orbital swelling. Laryngorhinootologie. 2017

2.2.2 Endoskopische Chirurgie von bösartigen sinonasalen Tumoren

Bösartige Tumoren der Nasenhaupt- und -nebenhöhlen machen nur etwa drei Prozent aller Tumoren im HNO-Gebiet aus. Meist handelt es sich um Plattenepithelkarzinome, jedoch gibt es ein breites Spektrum an verschiedenen bösartigen Entitäten. Die anatomische Nähe zu Schädelbasis, Hirn, Augenhöhle und Auge, Arteria carotis interna und Sinus cavernosus macht bei größeren Prozessen die vollständige Resektion im Gesunden schwierig (Ledderose 2015). Große Sicherheitsabstände sind in der Regel nicht möglich. Dazu kommt, dass sinonasale Tumoren dazu tendieren, zunächst asymptomatisch zu wachsen und erst dann aufzufallen, wenn eine fortgeschrittene lokale Infiltration vorliegt (Nicolai 2008). Diese Tatsachen und die häufigen lokalen Rezidive führen zu einer meist sehr schlechten Prognose (Bossi 2016).

Grundsätzlich ist festzuhalten, dass die komplette Tumorentfernung der entscheidende prognostische Parameter ist (Nicolai 2008). Aufgrund der Seltenheit der Tumoren ist die Datenlage bezüglich endoskopischer Tumorchirurgie beschränkt. Der Vergleich von zusammengefassten Fallserien mit früher publizierten Ergebnissen scheint jedoch darauf hinzudeuten, dass das krankheitsfreie Überleben nach endoskopischer Tumorresektion vergleichbar mit dem nach Operationen über konventionelle Zugänge ist (Nicolai 2007). Eine endoskopische Entfernung von bösartigen sinonasalen Tumoren wird jedoch teilweise kritisch gesehen, da die häufig geforderte en-bloc-Resektion allenfalls in Einzelfällen möglich ist. Allerdings scheint die gute endoskopische Visualisation es zu ermöglichen, eine dreidimensionale Tumorresektion mit möglichst großem Sicherheitsabstand zu erreichen (Nicolai 2011). Die Morbidität und Mortalität nach endoskopischer Resektion von sinonasalen Malignomen war in einigen Untersuchungen geringer als bei traditionellen, extranasalen Zugängen. Zumindest wird die zusätzliche Traumatisierung durch den externen Zugang bei endonasalem Vorgehen vermieden (Lund 2010; Lund 2007).

<u>In der Behandlung der bösartigen Nasennebenhöhlentumoren fokussierten wir uns auf folgende Fragestellungen:</u>

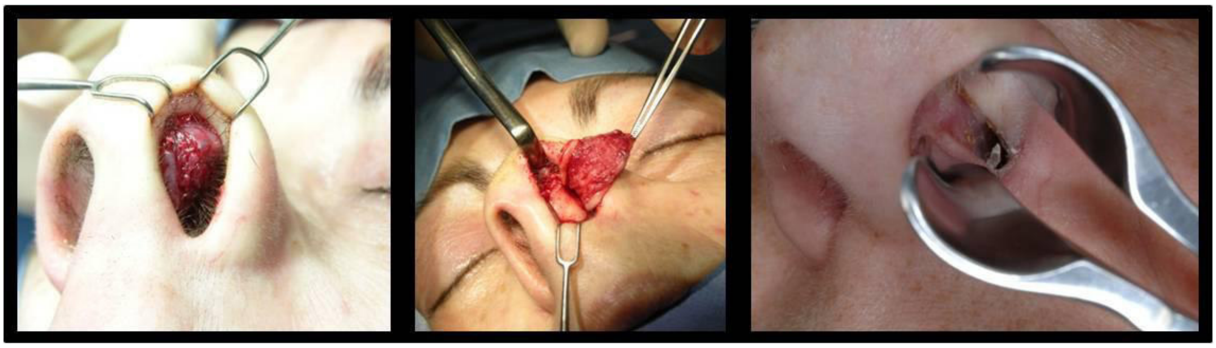
- Ist die endoskopische, endonasale Entfernung von bösartigen Tumoren ohne eine Verschlechterung der Prognose möglich, z.B. im Vergleich zur primären Strahlentherapie?
- Ist die endoskopische Resektion von malignen Tumoren der transfazialen Technik bei richtiger Indikation gleichwertig im Hinblick auf die rezidivfreie Zeit bzw. das Überleben?

2.2.2.1 Chirurgisches Vorgehen bei Karzinomen des Nasenvorhofes

Das Karzinom des Vestibulum nasi entsteht im Bereich des Übergangsepithels zwischen Nasenvorhof und Nasenhaupthöhle. Es ist vergleichsweise selten und verursacht zunächst unspezifische Symptome (Agger 2009). Das führt oft zu einer Verzögerung der definitiven Diagnose (Talmi 2011; Ledderose 2015). Während große Tumoren mit Knochen-, Knorpel- und Hautinfiltration in der Regel operativ entfernt werden, wird die Behandlung kleinerer Tumoren der Stadien 1 oder 2 kontrovers diskutiert. Prinzipiell kommen Operation oder die primäre Bestrahlung in Frage. Meist wird aufgrund der angeblich besseren kosmetischen Ergebnisse die Bestrahlung favorisiert (Agger 2009; Horsmans 1999; Wallace 2007; Wang 1976; Langendijk 2004; Chobe 1988; McCollough 1993; Patel 1992; Wong 1988), jedoch zeigen einzelne Untersuchungen, dass durch die chirurgische Entfernung gerade auch kleinerer Tumoren eine gleichwertige oder sogar bessere lokale Tumorkontrolle erreicht werden kann (Agger 2009; Dowley 2008). Zudem ist zu berücksichtigen, dass in einer retrospektiven Untersuchung nur etwa 65 % der Patienten gute kosmetische Ergebnisse nach Bestrahlung zeigten (Dowley 2008). Die Vorteile der operativen Therapie liegen auf der Hand. Der Patient wird weder den direkten noch indirekten Bestrahlungsfolgen wie Weichgewebsnekrosen oder der erheblich verlängerten Behandlungsdauer ausgesetzt (Wallace 2007). Allerdings wird durch die herkömmlich angewandten transfazialen Zugänge eine kosmetische Beeinträchtigung der meist eher jungen Patienten in Kauf genommen. Die rein endonasale Operation mit Unterstützung durch ein Endoskop kann hier eine gute Visualisierung des Tumors und damit eine sichere Resektion bei gleichzeitiger Reduktion der Narbenbildung und Morbidität ermöglichen. Gerade bei kleineren Tumoren ist diese Operationstechnik häufig möglich.

Nr.	Staging (UICC)	Staging (Wang)	N	Krankenhaus-aufenthalt (Tage)	Adjuvante Therapie	Follow-up (Monate)	Rezidiv
1	T1	T1	cN0	4	-	55	-
2	T2	T1	cN0	5	-	50	-
3	T2	T1	pN1	10	Bestrahlung	45	-
4	T2	T1	cN0	4	-	40	-
5	T1	T1	cN0	3	-	38	-
6	T1	T1	cN0	2	-	36	-
7	T2	T2	pN0	9	-	30	-
8	T1	T1	cN0	5	-	29	-
9	T2	T2	cN0	4	-	28	-
10	T2	T1	cN0	3	Bestrahlung	25	-
				Ø 4,9		Ø 37.6	

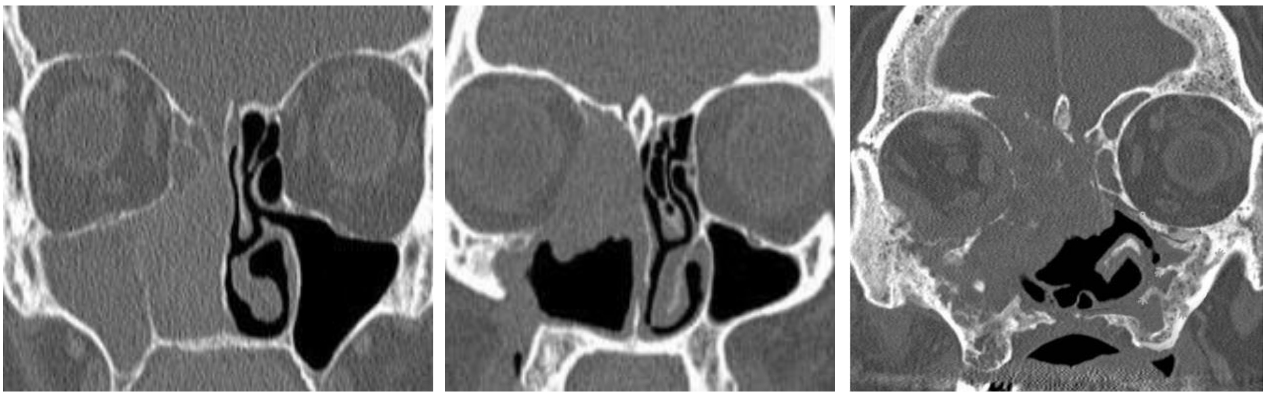
Patienten (n = 10) die wegen eines Frühkarzinoms des Nasenvorhofes endonasal operiert wurden.



Endonasale Resektion eines Vestibulum-nasi-Karzinoms (Stadium 2). Nach zwölf Monaten zeigen sich nur geringe Vernarbungen, obwohl Teile des Septum- und Flügelknorpels reseziert wurden.

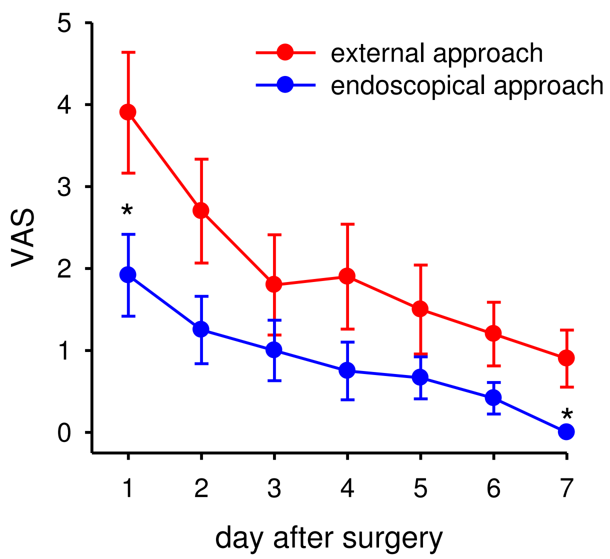
2.2.2.2 Behandlungsstrategie bei Rezidiven des sinonasalen Schleimhautmelanoms

Das sinonasale Schleimhautmelanom ist zwar selten, aber mit einer besonders schlechten Prognose gekennzeichnet, sogar im Vergleich mit anderen sinonasalen Malignomen (Chang 1998; ChiuundWeinstock 1996; Bradley 2006). Zusätzlich zu den bereits oben erwähnten anatomischen Gegebenheiten im Nebenhöhlensystem ist neben der häufig erst im fortgeschrittenen Krankheitsverlauf gestellten Diagnose insbesondere die hohe hämatogene Metastasierungsrate verantwortlich für eine 5-Jahres-Überlebensrate von nur 15 - 45 %. Manche Autoren halten diese Erkrankung sogar für generell unheilbar. Aufgrund des schlechten Ansprechens auf Bestrahlung (Gal 2011; Christopherson 2015; Lund 2012; Wada 2004; Lund 2010) wird derzeit die radikale operative Entfernung mit großem Sicherheitsabstand als Therapie der Wahl angesehen (Bridger 2005; Christopherson 2015; Gal 2011; Huang 2009; Lund 2012; Roth 2010; Thompson 2003; Wada 2004; Moreno 2010). Submuköse lymphogene Verteilung und die Möglichkeit einer intraoperativen Implantation von Melanomzellen führt zu einer ausgesprochenen Neigung des malignen Schleimhautmelanoms zum lokalen Rezidiv (Clifton 2011; Temam 2005). Das Rezidiv tritt häufig bereits wenige Monate nach der ersten Operation auf und verschlechtert die ohnehin schon schlechte Prognose dramatisch (Roth 2010; Huang 2009; Clifton 2011; Dzepina 2012).



Rezidiv eines Schleimhautmelanoms der rechten Nasenhaupt- und nebenhöhlen. Im Krankheitsverlauf zeigt sich eine deutlich zunehmende Tendenz zur lokalen Infiltration, zuletzt breitflächiger Befall von Auge und Hirn.

Dies muss bedacht werden, wenn die Resektion eines Lokalrezidivs geplant wird. Um die radikale Entfernung zu erreichen, werden allgemein die transfazialen oder transkraniellen Operationen als Goldstandard angesehen (Bradley 2006). Das bedeutet jedoch häufig verstümmelnde Eingriffe wie beispielsweise die partielle oder komplette Ablatio der äußeren Nase oder die Entfernung des Auges. Bedenkt man die schlechte Prognose des Lokalrezidivs, muss in jedem Einzelfall geprüft werden, ob ein derartig radikaler Eingriff gerechtfertigt ist. Eine Alternative stellt die endoskopisch kontrollierte Resektion des sichtbaren Tumorgewebes dar, die oft möglich ist (Lund 2012). Störende Symptome wie Nasenatmungsbehinderung und Nasenbluten können so zuverlässig gelindert werden (Lund 2007; Nicolai 2008). Studien, die sich gezielt mit der operativen Therapie des malignen Schleimhautmelanoms der Nasennebenhöhlen befassen, existierten bisher nicht. Wir untersuchten das Outcome von Patienten, die wegen eines Schleimhautmelanom-Rezidivs im Bereich der Nasennebenhöhlen operiert worden waren. Besonderes Augenmerk lag auf der Analyse des Einflusses der gewählten Operationsmethode. Das durchschnittliche krankheitsfreie Überleben sowie das durchschnittliche Überleben war ohne signifikanten Unterschied in beiden Gruppen und vergleichbar mit vorhergehenden Berichten (Bridger 2005; Huang 2009; Christopherson 2015; Roth 2010; Thompson 2014). Hervorzuheben ist, dass durch die endoskopische Operationstechnik die Lebensqualität der Betroffenen weniger beeinträchtigt wurde. Die Patienten litten weniger unter Schmerzen und äußerlichen Entstellungen und waren deutlich kürzer hospitalisiert. Ebenso war die notwendige Wundpflege wesentlich weniger umfangreich. Nicht die Operationsmethode war für die Überlebensrate und das Outcome entscheidend, sondern vor allem die Fernmetastasierung.

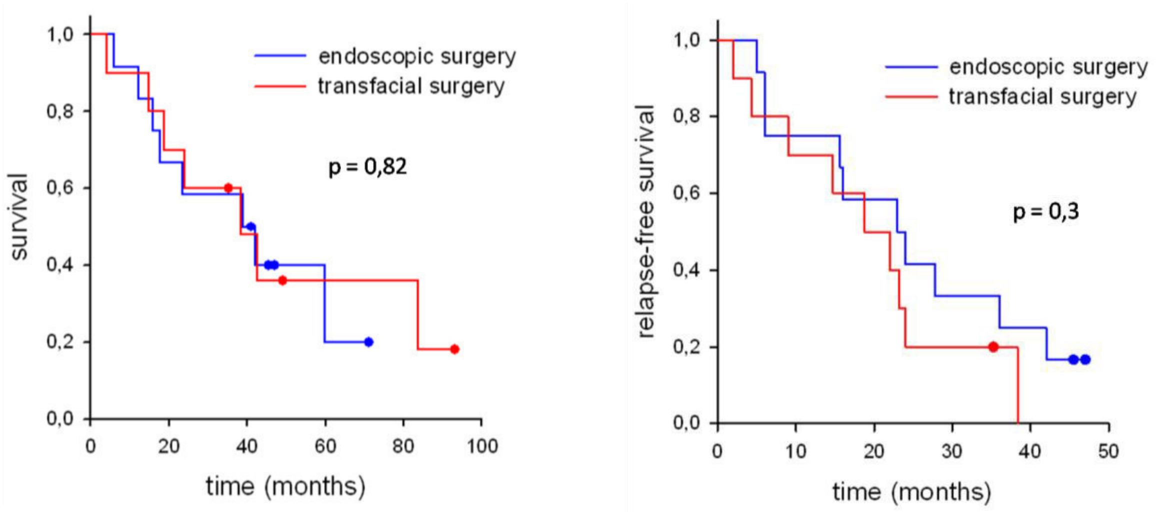


Postoperativer Schmerz nach extra- bzw. endonasaler Operation bei Rezidiv eines malignen Schleimhautmelanoms der Nasennebenhöhlen, erfasst durch die Verwendung einer visuellen Analog-Skala (VAS).

Natürlich bleibt die komplette Resektion des Lokalrezidivs eines Schleimhautmelanoms der Nasennebenhöhlen das erste therapeutische Ziel. Dies kann aber häufig mit der vergleichsweise schonenden endoskopischen Operationstechnik erreicht werden, die eine exzellente Visualisierung ermöglicht, weniger Schmerzen verursacht, keine äußerlich entstellende Verstümmelungen hinterlässt und deutlich weniger postoperative Wundpflege benötigt als die konventionelle Chiurgie. Die Möglichkeit einer endoskopischen Resektion sollte in jedem Fall sorgfältig bedacht werden, da diese Operationsmethode höchstwahrscheinlich die Prognose nicht verschlechtert, aber zu einer verbesserten Lebensqualität der schwerkranken Patienten beitragen kann (Ledderose 2015).

Überleben

krankheitsfreies Überleben



Kaplan-Meier-Kurve der 22 Patienten, die wegen eines Schleimhautmelanom-Rezidivs der Nasennebenöhlen operiert worden waren. Krankheits-freies Intervall (A) und Überleben (B) getrennt nach operativer Technik (extranasaler Zugang, n = 10; endoskopischer Zugang, n = 12).

Jahr der Rezidiv -OP	Histologie	OP-Technik	TNM UICC 2009	Infiltration: Periorbita (E) oder Dura (D)	"clear margins"	Fernmetastasen	Krankheitsverlauf
2002	amelanotisch	transfazial (Weber-Ferguson)	T3N0	-	nein	pulmonal	Tod mit Lokalrezidiv und Fernmetastasen
2003	amelanotisch	transfazial (midface degloving) und zusätzlich subcranial	T4bN0	D	nein	keine	Tod mit Lokalrezidiv
2003	amelanotisch	transfazial (laterale Rhinotomie, Ablatio nasi)	T3N0	-	ja	zerebral, Skelett	Tod mit Lokalrezidiv und Fernmetastasen
2003	amelanotisch	transfazial (Weber-Ferguson, Enukleation)	T4bN0	D, E	nein	pulmonal	Tod mit Lokalrezidiv und Fernmetastasen nach einer weiteren Operation
2004	amelanotisch	transfazial (Weber-Ferguson), Enukleation	T4aN0	E	ja	pulmonal	Tod mit Lokalrezidiv und Fernmetastasen
2004	melanotisch	transfazial (midface degloving, Enukleation)	T4aN0	E	ja	zerebral	Tod mit Lokalrezidiv und Fernmetastasen
2005	melanotisch	transfazial (Weber-Ferguson, Enukleation)	T4bN0	D, E	nein	keine	Tod mit Lokalrezidiv
2006	amelanotisch	transfazial (laterale Rhinotomie)	T3N0	-	nein	keine	Zwei weitere Operationen, aktuell rezidivfrei
2009	melanotisch	transfazial (laterale Rhinotomie)	T3N0	-	ja	keine	Rezidivfrei
2010	amelanotisch	transfazial (Weber-Ferguson)	T4bN0	D	nein	keine	Rezidivfrei

Histologie, Operationstechnik, Infiltration, Fernmetastasen, Histopathologische Beurteilung des Resektionsstatus und Follow-Up der Patienten nach extranasaler Operation.

Jahr der Rezidiv-OP	Histologie	OP-Technik	TNM UICC 2009	Infiltration: Periorbita (E) oder Dura (D)	"clear margins"	Fernmetastasen	Krankheitsverlauf
2002	amelanotisch	endoskopische Resektion	T3N0	-	ja	zerebral, hepatisch, Skelett	Tod mit Lokalrezidiv und Fernmetastasen
2004	amelanotisch	endoskopische Resektion	T3N0	-	nein	pulmonal	Tod mit Lokalrezidiv und Fernmetastasen
2007	melanotisch	endoskopische Resektion	T4aN0	-	nein	hepatisch	Tod mit Lokalrezidiv und Fernmetastasen
2007	amelanotisch	endoskopische Resektion	T4aN0	-	nein	pulmonal	Tod mit Lokalrezidiv und Fernmetastasen
2008	amelanotisch	endoskopische Resektion	T3N0	D	nein	pulmonal	Tod mit Lokalrezidiv
2008	amelanotisch	endoskopische Resektion	T3N0	D	nein	keine	Eine weitere Operation, Rezidivfrei
2008	amelanotisch	endoskopische Resektion	T4aN0	E	nein	pulmonal	Tod mit Lokalrezidiv und Fernmetastasen
2008	melanotisch	endoskopische Resektion	T4bN1* (*level 2a)	D,E	nein	pulmonal, zerebral	lokal rezidivfrei nach einer weiteren Operation; Tod mit Fernmetastasen
2010	amelanotisch	endoskopische Resektion	T3N0	-	ja	keine	Rezidivfrei
2010	melanotisch	endoskopische Resektion	T4bN0	D	nein	keine	Rezidivfrei
2010	melanotisch	endoskopische Resektion	T3N0	-	nein	keine	Rezidivfrei
2010	melanotisch	endoskopische Resektion	T4aN0	D	nein	zerebral	Tod mit Lokalrezidiv und Fernmetastasen

Histologie, Operationstechnik, Infiltration, Fernmetastasen, Histopathologische Beurteilung des Resektionsstatus und Follow-Up der Patienten nach endonasaler Operation.

Originalarbeiten:

Ledderose GJ, Reu S, Englhard AS, Krause E. Endonasal resection of early stage squamous cell carcinoma of the nasal vestibule. Eur Arch Otorhinolaryngol 2013

Ledderose GJ, Leunig A. Surgical Management of recurrent sinonasal mucosal melanoma: endoscopic or transfacial resection. Eur Arch Otorhinolaryngol 2014

Originalarbeit zu angrenzenden Themen:

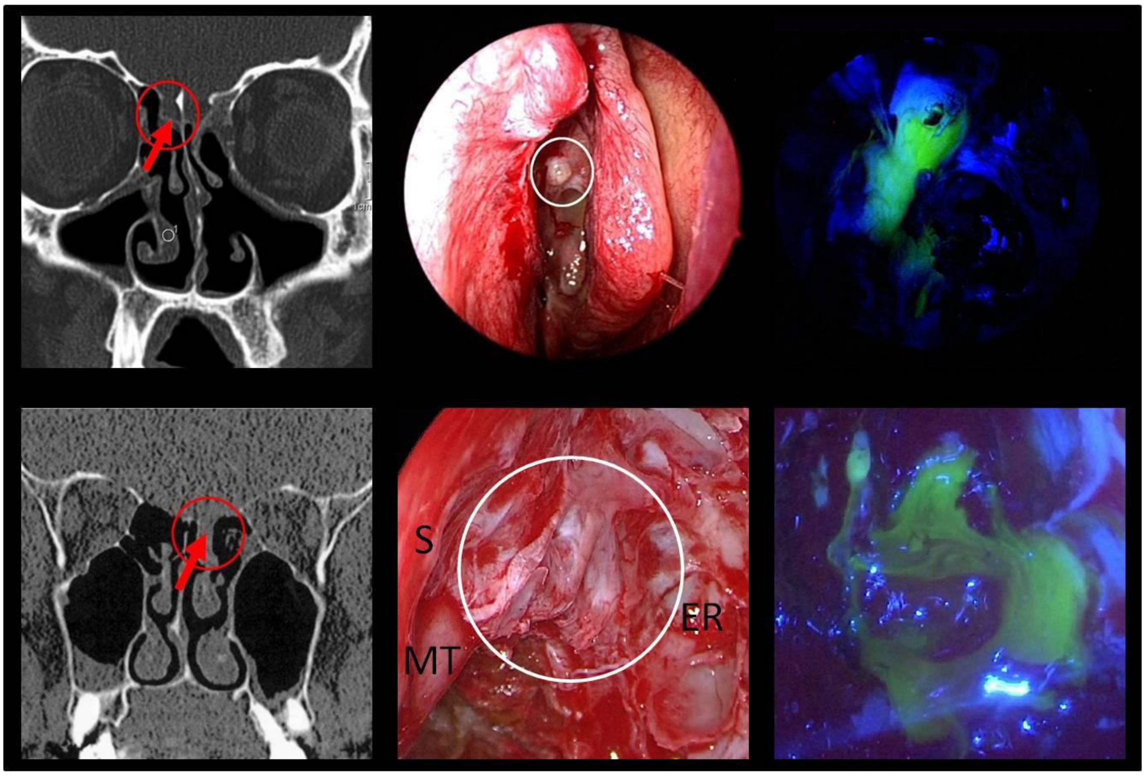
Ledderose GJ, Englhard AS. Isolated Nasal Tip Metastasis from Esophageal Squamous Cell Carcinoma: Case Report and Literature Review. Case Reports in Otolaryngology 2015

2.3 Endoskopische Versorgung von iatrogenen Schädelbasisperforationen

Liquorfisteln im Bereich der vorderen Schädelbasis werden je nach Ätiologie in nicht-traumatische und traumatische Gruppen unterschieden (Har-El 1999). Die häufigste traumatische Ursache ist mittlerweile die intraoperative Verletzung der Rhinobasis während einer Nasennebenhöhlenoperation. Einerseits wurden die traumatischen Schädelbasisverletzungen durch Unfälle etwas seltener (Psaltis 2012), andererseits nimmt die Häufigkeit der Operationen zur Therapie von chronisch-entzündlichen Nasennebenhöhlenerkrankung stetig zu (Bhattacharyya 2010; Martin 2006; Hosemann 2013). Die Häufigkeit für manifeste, klinisch relevante Liquorfisteln, die während dieser Operation auftreten, liegt zwischen 0,2 und 0,8 % (Dalziel 2006; Rudert 1997; Platt 2007; Vleming 1992). Während Schädelbasisverletzungen mit und ohne Liquorfluss, die sofort erfolgreich abgedeckt werden können, als leichte Komplikation gelten (Hosemann und Draf 2013; Rombout 2001), stellen Duradefekte, die nicht erkannt werden, ein erhebliches Risiko für den Betroffenen dar (Daudia 2007; Eljamel 1990) und müssen als schwerwiegende Komplikation gewertet werden (Siedek 2013). Um zu verhindern, dass es während einer Nebenhöhlenoperation zu einer Schädelbasisverletzung kommt, ist es entscheidend, die Risikofaktoren zu kennen, die eine solche Verletzung begünstigen. Ebenso ist es wichtig zu wissen, wo die Prädilektionsstellen für Liquorfisteln in der vorderen Schädelbasis liegen (Grevers 2001; Schlosser 2002; Tabaee 2006; Stammberger 1997; Weber 1996). Die erfolgreiche Therapie ist von der präzisen Lokalisation der Fistel, von der gewählten operativen Technik und der entsprechenden Nachbehandlung abhängig (Castelnuovo 2001; Locatelli 2006; Fokkens 2012). Wir führten eine Analyse der Patienten durch, die in den letzten 15 Jahren aufgrund einer iatrogen im Rahmen einer Nasennebenhöhlenoperation verursachten Liquorfistel operativ behandelt wurden. Untersuchungsziele waren die Identifikation von Risikofaktoren, die genaue Lokalisation der Schädelbasisperforationen sowie die Diagnostik, die angewendeten Verschlusstechniken, Komplikationen, Nachbehandlung und Erfolgsrate.

<u>Es ergeben sich folgende Fragestellungen:</u>

- Kann die Komplikation einer intraoperativen Schädelbasisverletzung im Rahmen einer Nebenhöhlenoperation endoskopisch kontrolliert werden?
- Welche Patienten sind besonders gefährdet?
- Welche anatomischen Bereiche der Schädelbasis sind Prädilektionsstellen für Verletzungen?
- Welche endoskopisch kontrollierten Techniken kommen bei der Duraplastik zum Einsatz?



Kleinere Schädelbasisverletzung während einer endoskopischen Nasennebenhöhlenoperation:

Obere Reihe: In der CT zeigt sich kein offensichtlicher Defekt (links). Endoskopisch findet sich eine weißliche Vorwölbung an der lateralen Lamelle der Lamina cribrosa rechts (Mitte). Intrathekale Anwendung von Natrium-Fluorescein und der entsprechende Filter enthüllt den Liquorfluss (rechts).

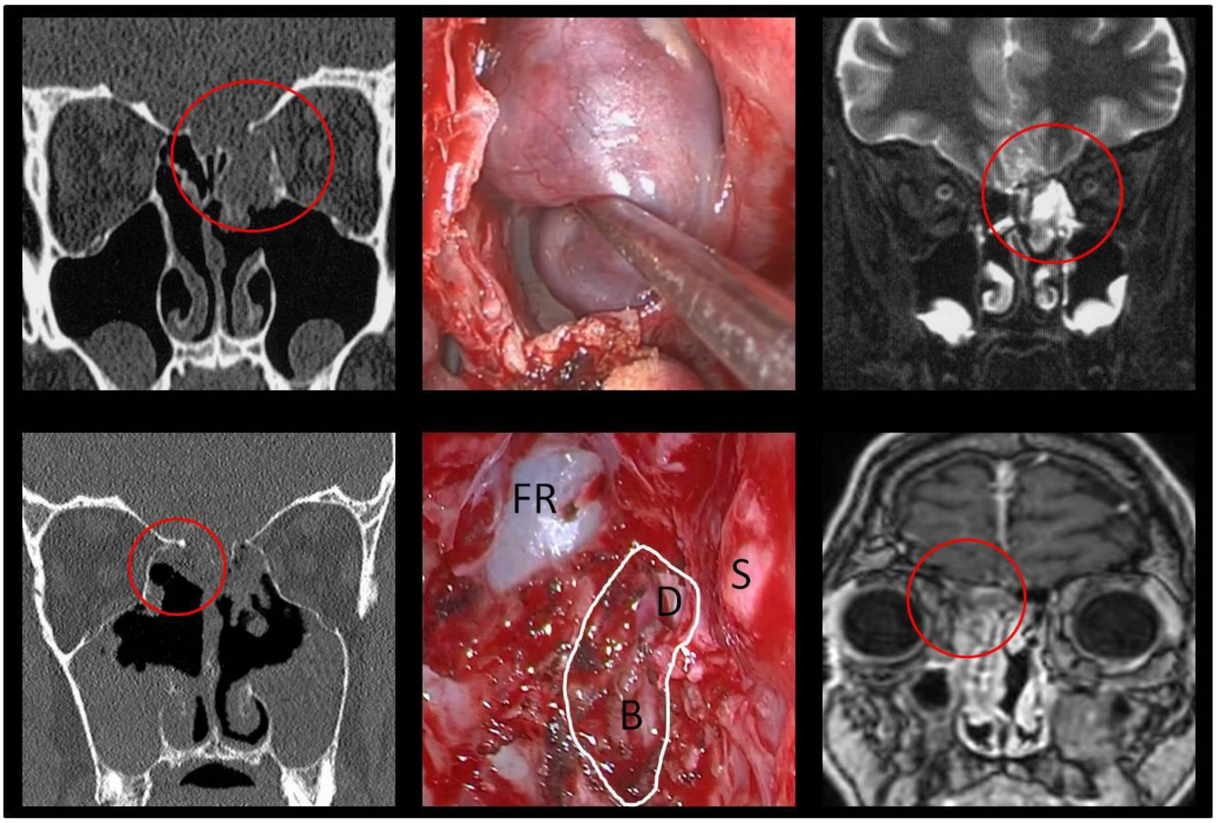
Untere Reihe: Die CT zeigt einen knöchernen Defekt in der lateralen Lamelle der Lamina cribrosa links (links). Endoskopisch zeigt sich die Dura freiliegend (S: Septum, MT: mittlere Muschel, ER: Siebbeindach). Intrathekale Anwendung von Natrium-Fluorescein und der entsprechende Filter enthüllt den Liquorfluss (rechts).

Entscheidend in der Therapie von Schädelbasisverletzungen ist die eindeutige Diagnose. Während eine Liquorfistel intraoperativ häufig bereits durch das sogenannte „wash out“- Phänomen auffällt (Stankiewicz 2004; Stankiewicz 2011), können sich unentdeckt gebliebene Fisteln erst viel später bemerkbar machen. Wässrige Rhinorrhoe, Kopfschmerzen oder die Meningitis sind auch in unserer Studie bestätigte typische Symptome. Bemerkenswert ist, dass diese Zeichen auch noch nach Monaten und Jahren auftreten können (Hudgins 1992). Zur Bestätigung einer manifesten Liquorfistel hat sich neben der endoskopischen Untersuchung die laborchemische Testung auf beta-2-Transferrin oder das Beta-Trace-Protein bewährt. Hiermit gelingt mit hoher Zuverlässigkeit der Liquornachweis. Die geeignete Bildgebung ist zur Fisteldarstellung obligat. Bei geringer Schichtdicke gelingt es in vielen Fällen, Fisteln in der hochauflösenden CT zu detektieren (La Fata 2008). Unserer Erfahrung nach kann die zusätzliche, hochauflösende MRT mit entsprechender Kontrastierung in den Fällen helfen, wo der Duradefekt im CT nicht zu erkennen ist. Natrium-Fluorescein kann intrathekal verabreicht werden, um das Leck zu erkennen, was besonders während der endoskopisch kontrollierten Defektdeckung praktikabel ist (Schlosser 2002), weil so die Identifikation von Lecks und die Reparatur in einem Eingriff ermöglicht wird und außerdem der Operationserfolg überprüft werden kann (Castelnuovo 2001). Es ist allerdings anzumerken, dass es nicht in allen Fällen gelingt, den Defekt darzustellen. Die Verwendung einer postoperativ genutzten Lumbaldrainage zeigte in unserer Untersuchung keinen Vorteil. Die meisten Autoren stimmen darin überein, dass die Lumbaldrainage routinemäßig nicht indiziert ist (Ulualp 2008; Lee 2007; Caballero 2012). Anatomisch ist die schwächste Stelle der Rhinobasis im Bereich der lateralen Lamelle der Lamina cribrosa zu finden (Sprinzl 1999; Zeifer 2002). Hier geht die mittlere Muschel in die Schädelbasis über und der Knochen ist nur etwa 0,05 mm dick (Schlosser 2004). Andere Autoren geben allgemein das vordere Siebbeindach als häufige Defektlokalisation, aber auch die Keilbeinhöhle an. Nicht alle Autoren bestätigen, dass die rechte Seite bevorzugt betroffen ist (Castelnuovo 2001; Locatelli 2006; Lanza 1996; Stammberger 1997). Als Risikofaktoren für eine Durafistel werden anatomische Varianten wie ein tiefstehendes, asymmetrisches Siebbeindach („dangerous ethmoid“), eine tiefstehende Lamina cribrosa in Relation zum Siebbeindach und eine steile Schädelbasis in sagittaler Ebene angesehen. Diese Varianten treten in etwa 10 % auf (Keros 1962; Lee 2007; Lebowitz 2001; Heaton 2012; Dessi 1994). Eine erschwerte Orientierung durch ausgeprägte entzündliche Erkrankungen oder eine veränderte Anatomie mit fehlenden Landmarken durch Voroperationen werden ebenfalls als Risiko genannt (Castelnuovo 2001; Locatelli 2006; Psaltis 2012; Vleming 1992; Siedek 2013; Heaton 2012; Hopkins 2006; Lund 1997; Lund 2000; Schnipper 2004; Weber 1998). Das verwendete Deckungsmaterial ist von der Lokalisation, der Größe des Lecks und der Anatomie des Patienten abhängig. Zudem spielen individuelle Vorlieben des Chirurgen eine Rolle (Locatelli 2006). Es werden verschiedenste Materialien wie homo- bzw. autologe Faszie, freie oder gestielte Schleimhauttransplantate, Fibrinkleber und Fibrinogen/Thrombin-Präparate eingesetzt. Der operative Erfolg erscheint dadurch nicht beeinflusst. Die operativen Techniken selbst sind heterogen, meist wird eine Kombination aus

Onlay- und Underlay-Technik angewendet (Psaltis 2012). Initial wichtig ist die Exposition des Defekts durch das Befreien der Knochenränder von Schleimhaut (Hegazy 2000; Platt 2007; Casiano 1999). Nach unseren Erfahrungen bietet sich bei Defekten im Siebbeindach und in der Keilbeinhöhle eine Kombination aus Onlay- und Underlay-Technik an. Im Bereich der lateralen Lamelle der Lamina cribrosa ist eine Underlay-Technik aber meist schwierig, da hier die Dura dem sehr dünnen Knochen eng anliegt, so dass durch Manipulation der Defekt rasch vergrößert werden kann. Deshalb ist hier der alleinige Onlay-Verschluss Methode der Wahl. Größere rekonstruktive Maßnahmen, wie etwa mit einem nasoseptalen Lappen sind selten notwendig. Unabhängig von der genauen Verschlusstechnik sowie der ausgewählten Deckungsmaterialien wird der Erfolg der endoskopisch kontrollierten Duraplastik mit etwa 90 - 97 % angegeben (Castelnuovo 2001; Locatelli 2006; Hegazy 2000; Platt 2009; Mirza 2005; Meco 2004; McMains 2004). In dem von uns untersuchten Patientengut wurden ein Primärerfolg von 87% und ein Erfolg nach Revision von 100 % erreicht. Wichtig ist hier ein entsprechend langer Nachbeobachtungszeitraum, da es auch noch nach bis zu zwei Jahren zu einer erneuten Liquorfistel kommen kann (Lund 1997; Lund 2000). Auch wenn manche Autoren zunächst ein abwartendes, konservatives Vorgehen propagieren (Platt 2009; Hegazy 2000; Casiano 1999; Warnecke 2004), schließen wir uns angesichts einer spontanen Heilungsrate von nur etwa einem Drittel (DelGaudio 2008), der hohen Erfolgsrate und des meist komplikationslosen Verlaufs der Empfehlung für die endoskopische, endonasale operative Versorgung einer persistierenden Liquorrhoe an.

localization of CSF leak		surgical technique			material used for dura repair					failure of primary closure
		overlay	underlay	combination	TachoSil© (Fibrinogen/Thrombin)	fibrin sealant	autologous or allogenic fascia	mucous membrane flap pediculated / free	nasoseptal flap	
lateral lamella of cribriform plate	17 (53%)	15 (47%)	-	2 (6%)	16 (50%)	9 (28%)	1 (3%)	2 (6%)	-	3 (9%)
anterior ethmoid roof	9 (28%)	2 (6%)	-	7 (22%)	8 (25%)	5 (16%)	1 (3%)	-	-	-
posterior ethmoid roof	3 (9%)	1 (3%)	-	2 (6%)	2 (6%)	1 (3%)	1 (3%)	-	-	-
sphenoidal sinus	2 (6%)	-	1 (3%)	1 (3%)	1 (3%)	-	-	-	1 (3%)	-
posterior wall of frontal sinus	1 (3%)	1 (3%)		-	1 (3%)	-	-	-	-	-
overall	32 (100%)	19 (59%)	1 (3%)	12 (38%)	28 (88%)	15 (47%)	3 (9%)	2 (6%)	1 (3%)	3 (9%)

Tabelle: Lokalisation, Operationstechnik, Verschlussmaterial und Erfolgsquote bei endonasalem Schädelbasisverschluss einer intraoperativ aufgetretenen Liquorfistel.



Große Schädelbasisverletzungen während einer endoskopischen Nasennebenhöhlenoperation:

Obere Reihe: In der CT zeigt sich ein großer knöcherner Defekt (links). Endoskopisch findet sich eine graue, homogene Protrusion am Siebbeindach (Mitte). Das Kernspin zeigt eine Meningoenzephalozele (rechts).

Untere Reihe: Die CT zeigt einen knöchernen Defekt in der lateralen Lamelle der Lamina cribrosa links (links). Endoskopisch zeigt sich nicht nur ein großer knöcherner Defekt, sondern auch ein Duradefekt von mehreren Zentimetern und freiliegendes Hirn. (S: Septum, FR: Recessus frontalis, D: Dura, B: Gehirn).

<u>Originalarbeit:</u>

Ledderose GJ, Stelter K, Betz CS, Englhard AS, Ledderose C, Leunig A. Cerebrospinal fluid leaks during endoscopic sinus surgery in thirty-two patients. Clinical Otolaryngology 2017

2.4 Computer-assistierte endoskopische Nasennebenhöhlenchirurgie

Die Nasennebenhöhlen zeigen eine komplexe Anatomie, die durch die unmittelbare Nähe zur Orbita und vorderer Schädelbasis sowie durch Strukturen wie die Arteria carotis intera und den Sehnerven charakterisiert wird (Kennedy 1985; Lund 2014). Komplikationen während einer Nasennebenhöhlenoperation sind zwar sehr selten, aber zum Teil potentiell lebensgefährlich. So kommt es bei einer von 400 Operationen zu einer Verletzung der Schädelbasis (Psaltis 2012). Auch existieren zahlreiche Fallberichte über die Verletzung des Auges oder der Arteria carotis interna mit teilweise schwerwiegenden bis hin zu tödlichen Folgen für den betroffenen Patienten (May 1994). Diese Diskrepanz zwischen einer häufig notwendigen Operation - über zwei Millionen Mal wird pro Jahr die Diagnose "chronische Sinusitis" in Deutschland gestellt - und den speziellen, lebensgefährlichen Komplikationen, die intraoperativ auftreten können, wurde bereits 1929 von Mosher in einer vielzitierten Aussage charakterisiert: "*„Theoretically the operation is easy. In practice, however, it has proved to be one of the easiest operations with which to kill a patient." (Mosher, 1929).* Auch nach der umfassenden Etablierung der endoskopisch kontrollierten, endonasalen Operationstechnik wurde die Hoffnung auf eine nachhaltige Senkung der Komplikationsrate enttäuscht (May 1994). Auf der Suche nach einer weiteren Orientierungshilfe in diesem anatomisch so delikaten Gebiet kam in den letzten 15 Jahren der computer-assistierten Chirurgie wachsende Bedeutung zu (Stelter 2006; Metson 2003).

Die Verwendung eines Navigationssystems, das mittlerweile an zahlreichen Kliniken routinemäßig bei Nasennebenhöhlenoperationen eingesetzt wird (Citardi 2007), bietet die gesuchte zusätzliche Möglichkeit der Orientierung. Navigationssysteme stellen eine direkte Verbindung zwischen präoperativ gewonnenen Bilddaten (CT oder auch MRT) und der therapeutischen Intervention her. Zu Beginn der Operation muss dafür der Zusammenhang zwischen Patient und Bildanatomie hergestellt werden ("Registrierungsvorgang"). Anschließend hat der Operateur nun eine dreidimensionale Orientierungshilfe zur Verfügung und kann sich über die Position seines Operationsinstrumentes exakt informieren (Reardon 2002).

<u>Bei der Beurteilung der Einsatzmöglichkeiten von Navigationssystemen bearbeiteten wir folgende Fragestellungen:</u>

- Wie hoch ist die klinische Genauigkeit des Navigationssystems in den Nasennebenhöhlen?
- Wie kann die klinische Genauigkeit des Navigationsgerätes durch den Registrierungsvorgang beeinflusst bzw. optimiert werden?

2.5.1 Klinische Genauigkeit des Navigationssystems in den Nebenhöhlen

Es ist eine systemimmanente Eigenschaft der Navigationssysteme, dass die Korrelation zwischen Bilddaten und realer Patientenanatomie durch den Registrierungsvorgang niemals perfekt sein kann. Das bedeutet, dass der Registrierungsvorgang die klinische Genauigkeit des Navigationssystems immer stark beeinflusst und möglichst präzise sein sollte. In der HNO-Chirurgie wird seit etwa zehn Jahren häufig auf die Konturen-basierte Oberflächenregistrierung mit einem Laser zurückgegriffen, die sich durch eine hohe Praktikabilität und fehlende Invasivität im Vergleich zu herkömmlichen Methoden (Schraubenmarker, Mayfield-Klemme o.ä.) auszeichnet (Reardon 2002; Strauss 2006; Gunkel 2000). Anfängliche, nicht standardisierte Untersuchungen zeigten eine geringere Genauigkeit nach Oberflächenregistrierung gegenüber der Registrierung mit fixierten Markern (Raabe 2002; Schlaier 2002; Knott 2006). Zum Zeitpunkt unserer Untersuchung existierten keine Untersuchungen zur klinischen Genauigkeit von optischen Navigationssystemen in den Nasennebenhöhlen nach Laserregistrierung, obwohl dieses System bereits standardmäßig bei endoskopischen Nasennebenhöhlenoperationen eingesetzt wurde.

Das Ziel unserer Untersuchung war es, die klinische Genauigkeit des in unserer Klinik verwendeten Navigationssystems direkt in den Nasennebenhöhlen nach Laserregistrierung zu evaluieren. Zudem untersuchten wir den Einfluss des abgetasteten Registrierungsgebietes auf die Genauigkeit. Verwendet wurde ein passives, optisches Navigationssystem (VectorVisionCompact©, BrainLab, Feldkirchen). Wichtig beim Versuchsaufbau war die Praxisnähe, da in experimentellen Studien stets sehr hohe Genauigkeiten gemessen werden konnten, die sich im klinischen Setting nicht wiederholen ließen (Knott 2004). Um die Praxisnähe, aber auch objektive und standardisierte Messbedingungen zu garantieren wurden Kadaverschädel mit Weichteilmantel verwendet (zur Verfügung gestellt vom Anatomischen Institut der LMU München, Direktor Prof. Dr. R. Putz), die gerade bei der Oberflächenregistierung und der komplexen Nebenhöhlenanatomie den häufig verwendeten Plastikmodellen deutlich überlegen sind. Es wurden Titanschrauben in den Gesichtsknochen und den Nasennebenhöhlen fixiert. Anschließend wurden CT-Scans mit einer Schichtdicke von 1 mm durchgeführt und auf das Navigationsgerät übertragen. Die Oberflächenregistrierung wurde mit einem Laserhandstück vorgenommen. Das System korreliert aufgrund des fest fixierten Registrierungsterns, der passive optische Marker trägt, die Position des gescannten Bereichs mit den korrespondierenden Bilddaten auf dem Navigationssystem. Mit dem Oberflächenlaser abgetastet wurden Nasion, Stirn und die knöchernen Orbitabegrenzungen. Diese Bereiche sind weitgehend haarlos und die vergleichsweise dünne Haut bildet mit dem darunterliegenden konturbildenden Knochen ein individuelles räumliches Relief. Bewegungen des Weichgewebes zwischen CT-Scan und Registrierungsvorgang können so vernachlässigt werden (Gunkel 2000). Die Reflexionen des Lasers auf der Haut werden von den zwei Infrarotkameras des Navigationssystems detektiert. Sie repräsentieren die dreidimensionalen Lokalisierungsdaten, die auf das System übertragen werden. Um zu überprüfen, ob die klinische

Genauigkeit von der Konfiguration und Lokalisierung des Registrierungsgebietes im Bezug auf das Operationsfeld beeinflusst wird, wurde neben der möglichst symmetrischen, bilateralen Registrierung eine strikt einseitige Registrierung durchgeführt. Die Genauigkeit wurde nach der bereits in anderen Studien etablierten Methode bestimmt (Raabe 2002; Schlaier 2002; Khan 2003; Schmerber 2001). Das navigationsfähige Messinstrument ("Pointer") wurde in die durch die Titanschrauben sowohl endoskopisch als auch auf dem CT-Scan eindeutig identifizierbaren Messpunkte geführt. Anschließend wurde der Abstand zwischen der vom Navigationssystem angegebenen virtuellen Position und dem angesteuerten Messpunkt, also der tatsächlichen Position der Pointerspitze, gemessen. Die Messung wurde in axialer, koronarer und sagittaler Ebene durchgeführt; die höchste Zielpunktabweichung repräsentierte den Wert der klinischen Genauigkeit.

Screenshots während der Genauigkeitsmessungen in der Kieferhöhle (Überblick und Zoom 600%). Der durch eine Titanschraube markierte Zielpunkt in der linken Kieferhöhle wird mit dem Pointer angesteuert, die Zielpunktabweichung wird mithilfe der metrischen Skala ausgemessen.

Der durchschnittliche Genauigkeitswert, der in unserer Studie nach laserbasierter Oberflächenregistrierung erhoben wurde, betrug 1.13 ± 0.53 mm. Die höchsten Genauigkeitswerte konnten in der Stirnhöhle gemessen werden (0.77 mm), die geringsten im Felsenbein (1.76 mm). Diese Werte sind vergleichbar mit früher gemessenen Werten (Schlaier 2002; Khan 2003). Hier wurden allerdings fixierte Landmarken zur Registrierung verwendet. Verglichen mit anderen Genauigkeitsuntersuchungen nach laserbasierter Registrierung war die von uns ermittelte Genauigkeit wesentlich höher (Raabe 2002). Dieser Umstand kann teilweise sicherlich durch die optimierten Untersuchungsbedingungen erklärt werden. Potentielle Veränderungen in der Position der Zielpunkte zwischen CT und Messung konnte durch die Verwendung von Schädeln vehindert werden, die nicht nur ein ideales Modell für die realen Hautgegebenheiten für den Oberflächenregistrierungsprozess boten, sondern auch die Anwendung von knochenverankerten Zielschrauben erlaubten. Ausserdem machten diese speziell entworfenen Zielschrauben die exakte Definition von Messpunkten in der

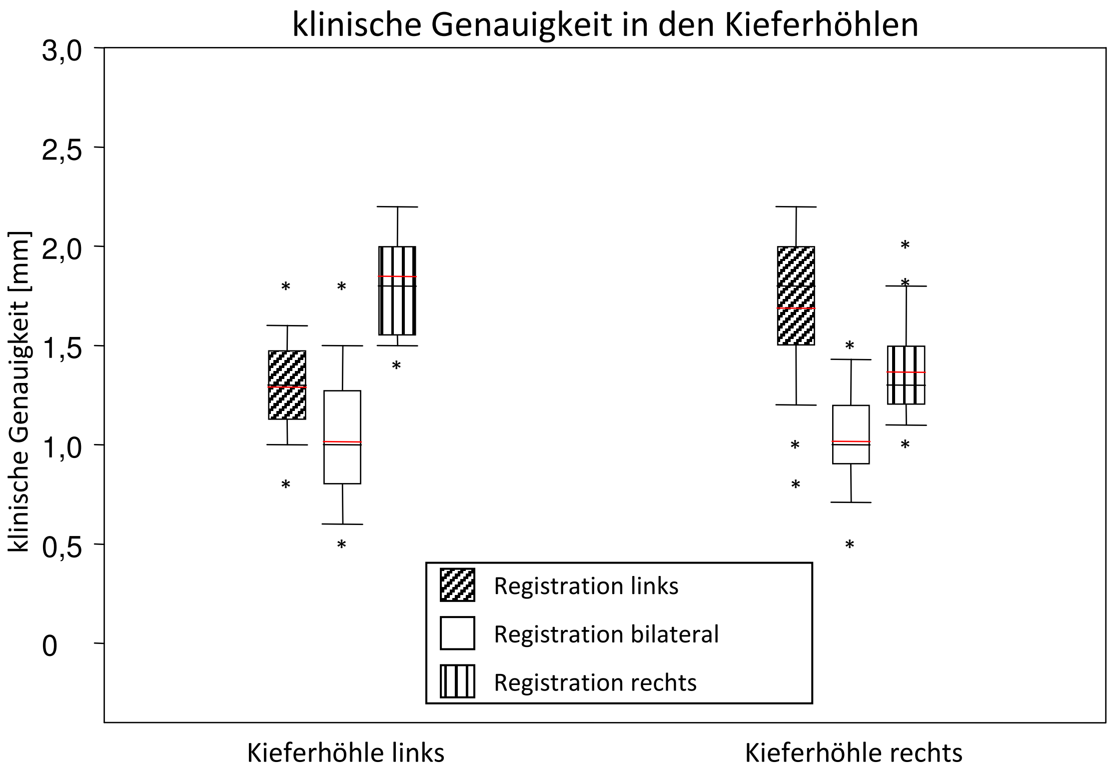
Realität und auf dem Navigationsbildschirm möglich und garantierten so einen möglichst objektiven Messvorgang. Auf diese Weise konnte darauf verzichtet werden, nicht punktgenau definierte Messpunkte wie das Nasion, die Nasenspitze oder den äußeren Gehörgang zu verwenden, wie es in vorhergehenden Studien der Fall war (Raabe 2002; Schlaier 2002; Khan 2003; Grevers 2002). Diese ziemlich ungenauen anatomischen Punkte weisen einen Durchmesser von mehreren Millimetern auf, lassen damit breiten Raum für Interpretationen und erhöhen das Risiko für eine Unter- oder Überschätzung des notwendigerweise subjektiven Untersuchers. Dadurch, dass die Zielschrauben direkt in den Nebenhöhlen plaziert wurden, konnte die klinische Genauigkeit des Navigationssystems direkt und präzise in der Region der Nasennebenhöhlenoperationen ermittelt werden. Dies ist von besonderer Bedeutung, da die Genauigkeit bekanntermaßen mit wachsendem Abstand zum Registrierungsgebiet (z.B. Gesicht) abnimmt (Gunkel 2000; Knott 2004). Dieser Sachverhalt konnte durch unsere Untersuchungen bestätigt werden. Die klinische Genauigkeit im Bereich der Gesichtsoberfläche kann also nicht ohne weiteres auf intrakranielle Regionen übertragen werden. Praktisch bedeutet das, dass der HNO-Chirurg sich bewusst sein muss, dass die im Bereich der Stirnhöhle oder im vorderen Siebbein zufriedenstellende Navigationsgenauigkeit sich im hinteren Siebbeinbereich oder in der Keilbeinhöhle signifikant verschlechtern kann.

Position der Landmarke	**Klinische Genauigkeit [mm]**	**SD [mm]**
frontal, links	1.01	0.56
frontal, rechts	0.89	0.42
temporal links	1.12	0.23
temporal, rechts	1.06	0.40
präaurikulär, rechts	0.98	0.38
präaurikulär, links	1.11	0.39
retroaurikulär, links	1.74	0.44
Sinus maxillaris (links)	1.02	0.34
Sinus maxillaris (rechts)	1.02	0.27
Sinus frontalis (posterior links)	0.91	0.30
Sinus frontalis (posterior central)	0.78	0.37
Sinus frontalis (posterior rechts)	0.77	0.30
Sinus ethmoidalis (Dach)	1.27	0.42
Sinus sphenoidalis	1.25	0.47
Laterale Schädelbasis	1.40	0.64
Felsenbein	1.76	0.45

Klinische Genauigkeit an den einzelnen Landmarken nach symmetrischer Oberflächenregistrierung (Mittelwert (mm) ± Standardabweichung).

Die durchschnittliche Genauigkeit des untersuchten Navigationsgerätes nach laserbasierter Registrierung ist für die Anforderungen der endoskopischen Nebenhöhlenchirurgie ausreichend. Auch die maximale Abweichung von 3,2 mm ist immer noch im Bereich der Genauigkeitswerte, die allgemein als suffizient für klinische Belange eingeschätzt werden (Metson 2003; Roth 1995). Unter den Bedingungen im klinischen Alltag ist es zu erwarten, dass es zu einem Verlust an klinischer Genauigkeit kommt. Die Korrelation zwischen Patientenanatomie und den Bilddaten kann durch Verrutschen des Referenzsterns, die veränderte Haut, Reflexionen nach Desinfektion und vor allem durch Mimikveränderungen zwischen Bildgebung und dem intraoperativ entspannten Gesicht erschwert sein (Bush 1996). Dennoch kann von einer akzeptablen Genauigkeit ausgegangen werden.

Zusätzlich konnte gezeigt werden, dass die Auswahl des Registrierungsgebietes und die Verteilung der gescannten Registierungspunkte einen deutlichen Einfluss auf die Genauigkeit hat. Durch den Vergleich von Messungen nach unterschiedlichen, streng einseitigen Registrierungen konnte der Einfluss auf die Genauigkeit festgestellt werden. Es war zu erwarten, dass eine auf der kontralateral gelegenen Gesichtshälfte durchgeführten Registrierung zur niedrigsten Genauigkeit führte. Interessanterweise war die Zielpunktabweichung auch dann, wenn das Registrierungsareal und die Messungen ipsilateral durchgeführt wurden deutlich größer als nach symmetrischer Registrierung.



Klinische Genauigkeit des Navigationsgerätes in den Kieferhöhlen nach Oberflächenregistrierung (unilateral und bilateral).

Praktisch bedeutet dies, dass bei der Auswahl des Registrierungsgebietes symmetrisch verteilte Punkte ausgewählt werden sollten, die einen möglichst großen Teil des Patientengesichtes abdecken. Dies ist zu berücksichtigen, wenn das Operationsgebiet vorbereitet wird, da es notwendig sein kann, die

Registrierung vor der Lagerung, Desinfektion und sterilen Abdeckung durchzuführen, um eine möglichst hohe Genauigkeit zu erreichen.
In der Studie wurde die klinische Genauigkeit des Navigationssystems nach laserbasierter Oberflächenregistrierung direkt in den Nasennebenhöhlen bestimmt. Diese Region ist von höchster Wichtigkeit für den HNO-Chirurgen und eine hohe Genauigkeit in diesem Bereich unbedingte Voraussetzung für einen verlässlichen Einsatz des Navigationssystems. Die gemessenen Genauigkeitswerte waren zufriedenstellend. Die bewusste, gezielte Auswahl des Registrierungsgebietes und das möglichst symmetrische, beidseitige Scannen der Gesichtsoberfläche ist unerlässlich für optimale Genauigkeitswerte (Ledderose 2007).

Originalarbeit:

Ledderose GJ, Stelter K, Leunig A, Hagedorn H. Surface laser registration in ENT-surgery: accuracy in the paranasal sinuses - a cadaveric study. Rhinology. 2007

Originalarbeiten zu angrenzenden Themengebieten:

Stelter K, **Ledderose G**, Tschiesner U, Matthias C, Spiegl K. Clinical Application of a New Dental Reference System for Computer Assisted Surgery at the Lateral Skull Base. The Open Otorhinolaryngology Journal. 2008

Ledderose GJ, Hagedorn H, Spiegl K, Leunig A, Stelter K. Image guided surgery of the lateral skull base: Testing a new dental splint registration device. Computer Aided Surgery. 2012

Stelter K, **Ledderose G**, Hempel JM, Morhard DFB, Flatz W, Krause E, Müller J. Image guided navigation by intraoperative CT scan for cochlear implantation. Computer Aided Surgery, 2012

2.5.2 Bedeutung der Navigation für den Operateur im klinischen Alltag

Wir untersuchten nun nach den technischen Eigenschaften des Navigationsgerätes (Ledderose 2007; Stelter 2012; Ledderose 2012b) in einer Reihe von prospektiven Studien auch die praktische Bedeutung, die die Verwendung eines Navigationsgerätes während einer Nasennebenhöhlenoperation im klinischen Alltag und in der Ausbildung haben kann.

Im Einzelnen beschäftigten wir uns mit der Beantwortung folgender Fragen:

- Wie verändert sich die endoskopische Nasennebenhöhlenchirurgie durch die Verwendung eines Navigationssystems im klinischen Alltag? Verbessert sich das chirurgische Ergebnis?
- Wurde die präoperativ festgelegte operative Strategie durch die Verwendung des Navigationsgerätes verändert?
- Führt das zu große Vertrauen in die Technik des Navigationsgerätes möglicherweise zu Fehlern oder Komplikationen während der Operation?
- Verliert der Operateur chirurgische Fähigkeiten, weil er zu sehr dem Gerät vertraut?

In einer ersten prospektiven Studie wurden acht Operateure ausgewählt, die insgesamt 32 Patienten mit beidseitigen, entzündlichen Nebenhöhlenerkrankungen operierten. Dabei wurde nach Randomisierung eine Seite mit Navigationssystem, die andere ohne Navigationssystem operiert. Es wurde festgehalten, wie oft und wann der Chirurg das Navigationsgerät verwendete und ob die chirurgische Strategie sich dadurch änderte. Ein standardisiertes und validiertes Interview vor und nach dem Eingriff erfasste die subjektive Einschätzung des jeweiligen Chiurgen und die kognitive Belastung (Human Factors Evaluation Questionnaire for Computer Assisted Surgery Systems, HFEQ-CASS) (Endsley 1999).
Es ergaben sich unter anderem folgende Schlussfolgerungen: Das Navigationsgerät kann während einer Nasennebenhöhlenoperation sehr hilfreich sein. Es erleichtert das Finden von Landmarken, kann aber dabei das anatomische Verständnis und den präzisen chirurgischen Plan nicht ersetzen. Das Navigationsgerät sollte einen festen Platz in der Klinik und der Ausbildung haben. Das Navigationsgerät kann substanziell zur anatomischen Orientierung beitragen. Es ist nicht sinnvoll, diese Technologie nur für spezielle, besonders schwierige Operationen oder nur für besonders erfahrene Chirurgen vorzubehalten. In Notfällen kann das System nur effektiv verwendet werden, wenn der Umgang vorher öfters auch in Standardsituationen trainiert wurde (Neumuth 2009; Stelter 2011).
Zweifellos ist die mentale und körperliche Belastung für den Chirurgen während einer endoskopischen Nasennebenhöhlen- oder Schädelbasisoperation hoch (Alobid 2011). Der Operateur muss viele verschiedene technische Geräte bedienen und muss gleichzeitig verschiedene Informationen von

verschiedenen Informationsquellen verarbeiten. Navigationssysteme stellen zusätzliche anatomische Informationen zur Verfügung, die die intraoperative Orientierung erleichtern sollen (Khan 2003). Besondere der ungeübte Benutzer kann durch die Verwendung eines Navigationssystems aber auch zusätzlich belastet werden (Stelter 2015; Stelter 2011). Im Rahmen einer weiteren Studie wurde versucht, die verschiedenen Anforderungen und Belastungen während einer endoskopischen Nasennebenhöhlenoperation zu identifizieren und zu analysieren.

Es wurden folgende Fragestellungen beantwortet:

- Erhöht die Verwendung des Navigationsgerätes die körperliche und mentale Belastung während einer endoskopischen Nebenhöhlenoperation?
- Bedeuten die zur Verfügung gestellten Informationen des Navigationsgerätes eine zusätzliche Belastung für den Chirurgen?
- In welchen Situationen während einer endoskopischen Nebenhöhlenoperation mit Navigation sind die mentalen Anforderungen an den Chirurgen am höchsten?

Ziel der Studie war es, die mentalen und physischen Anforderungen zu messen, die während einer Nasennebenhöhlen- und Schädelbasisoperation mit und ohne Navigation zu meistern sind. Vierzig endonasale, endoskopisch kontrollierte Operationen wurden durchgeführt, die Hälfte mit Unterstützung durch ein Navigationsgerät. Die Operationen wurden von vier erfahrenen Chirurgen vorgenommen. Als biometrische Daten dienten neben anderen Parametern wie der Atemfrequenz vor allem die Zu- bzw. Abnahme der Herzratenvariabilität.

Es zeigte sich, dass während einer endoskopischen endonasalen Nebenhöhlenoperation hohe mentale Belastungen auch für erfahrene Chirurgen auftreten. Das Stresslevel ist während des Eingriffs deutlich erhöht. Während die Stressreaktion in mental und körperlich belastenden Situationen physiologisch ist und zu einer besseren Konzentration und besseren Leistung befähigt, können eine Überforderung oder auch zusätzliche, vermeidbare Stressoren zu Erschöpfung und Frustration führen.

Die Verwendung des funktionierenden Navigationsgerätes verursachte dabei keine Veränderung. Es ist also keine zusätzliche Belastung durch den Einsatz des Navigationsgerätes zu erwarten.

Allerdings ließen sich andere Stressoren identifizieren, wie beispielsweise Gespräche von Kollegen oder Studenten im Operationssaal, eingeschränkte Sicht durch Blutung oder Bohrungen in der Keilbeinhöhle oder auch das Versagen von medizinischen Geräten wie z.B. dem Navigationsgerät, dem Sinusbohrer, der Koagulationspinzette, dem Sauger oder ähnlichem. Positiv wirkte sich eine ruhige Atmosphäre im Operationssaal und die Anwesenheit eines weiteren, erfahrenen Operateurs (z.B. Neurochirurg) aus.

Nicht die Komplexität der Operation oder die zahlreichen verschiedenen medizinischen Geräte und Informationen, die zum Beispiel durch das Navigationsgerät zur Verfügung gestellt werden, wirken sich negativ auf die mentale Belastung des Chirurgen aus, sondern in erster Linie unqualifiziertes

Personal oder unpassendes Verhalten sowie mangelhaftes Teamwork. Suffizientes Training in der Verwendung der technischen Geräte und angemessenes Verhalten aller beteiligten Mitarbeiter sind deshalb für den möglichst reibungslosen Ablauf der endoskopischen Nasennebenhöhlenoperation und einen möglichst wenig frustrierten Operateur unerlässlich (Stelter 2015; Theodoraki 2015).

Originalarbeiten:

Ledderose GJ, Stelter K, Leunig A, Hagedorn H. Surface laser registration in ENT-surgery: accuracy in the paranasal sinuses - a cadaveric study. Rhinology. 2007

Ledderose GJ, Hagedorn H, Spiegl K, Leunig A, Stelter K. Image guided surgery of the lateral skull base: Testing a new dental splint registration device. Computer Aided Surgery. 2012

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3. Zusammenfassung

Die vorliegende kummulative Habiliationsleistung befasst sich mit ausgewählten Aspekten der endoskopischen Nasennebenhöhlenchirurgie. Sie beruht auf einer Reihe von klinischen und experimentellen Untersuchungen. Zahlreichen Fragestellungen, die für den Nebenhöhlenchirurgen von hohem Interesse und praktischem Nutzen sind, wurde so begegnet. Neben einer Vielzahl weiterer Ergebnisse wurden folgende zentrale Erkenntnisse gewonnen:

Die funktionelle endoskopisch kontrollierte Nasennebenhöhlenoperation eignet sich bei richtiger Indikation als Therapie für entzündliche Nebenhöhlenerkrankungen, da sie komplikationsarm ist, zuverlässig zu einer hohen Patientenzufriedenheit führt und objektiv nachweisbar mit einer deutlichen Zunahme der gesundheitsbezogenen Lebensqualität verbunden ist (Ledderose 2012a).

Endonasale Tumoren stellen eine besondere Herausforderung in der Nasennebenhöhlenchirurgie dar. Technische Fortschritte wie spezielle Mikroinstrumente, gewinkelte Optiken mit hoher Auflösung, die Verwendung eines Navigationssystems, verschieden stark gebogene Bohrer und nicht zuletzt die größere Operationserfahrung führen dazu, dass sich das Indikationsspektrum für die transnasale endoskopische Operationstechnik stark erweitert hat. Gutartige Tumoren in der Stirnhöhle, die für das Endoskop und die Operationsinstrumente grundsätzlich schwer zugänglich sind und damit eine besondere Herausforderung darstellen, können mittlerweile häufig genauso transnasal endoskopisch entfernt werden wie benigne Tumoren, die durch eine starke Durchblutung und ein mitunter lokal destruierendes Wachstum entlang von Orbita und Schädelbasis gekennzeichnet sind. Die endoskopischen Techniken vereinen die Möglichkeit maximaler Radikalität mit minimaler Invasivität. Gleichzeitig profitiert der Patient durch eine geringere Morbidität und eine kürzere Hospitalisation (Ledderose 2011a; Ledderose 2011b; Ledderose 2013).

Die endoskopische Resektion von bösartigen sinonasalen Tumoren wird teilweise kritisch gesehen, da die häufig geforderte en-bloc-Resektion allenfalls in Einzelfällen möglich ist. Entscheidend für den Erfolg der endonasalen, endoskopisch unterstützten Tumorresektion ist in erster Linie die sorgfältige Auswahl von geeigneten Patienten. Dann stellt diese Operationstechnik eine ausgezeichnete Therapiemöglichkeit dar (Ledderose 2014). Auch radikale Tumorentfernungen sind transnasal vergleichsweise schonend möglich. Intraoperativ ist eine exzellente Visualisierung des Malignoms möglich. Die Operationstechnik verursacht weniger Schmerzen, hinterlässt keine äußerlich entstellenden Verstümmelungen und erfordert etwas weniger postoperative Wundpflege als die konventionelle Chiurgie. Bei korrekter Patientenauswahl ist die endonasale Operationstechnik gleichwertig zum extranasalen Vorgehen. Auch palliative Eingriffe zur Symptomkontrolle sind möglich (Ledderose 2015).

Die häufigste traumatische Ursache für eine Rhinobasisverletzung ist die Verletzung der Lamina cribrosa während einer Nasennebenhöhlenoperation. Patienten mit Revisionsoperationen und mit ausgeprägter Polyposis sind besonders gefährdet. Die endoskopisch kontrollierte Duraplastik erwies sich bei intraoperativ verursachten Rhinobasisverletzungen als höchst erfolgreich (Ledderose 2017).

Das Navigationsgerät ist eine zusätzliche Orientierungshilfe für endoskopische Nasennebenhöhlenoperationen und hilft mit, das Indikationsspektrum zu erweitern. Die klinische Genauigkeit des Navigationssystems nach laserbasierter Oberflächenregistrierung ist für den HNO-Chirurgen ausreichend. Die bewusste, gezielte Auswahl des Registrierungsgebietes und das möglichst symmetrische, beidseitige Scannen der Gesichtsoberfläche ist Voraussetzung für optimale Genauigkeitswerte (Ledderose 2007).

Das Navigationsgerät erleichtert die intraoperative Identifikation von Landmarken und trägt damit substantiell zur Orientierung bei. Es kann aber das anatomische Verständnis und den präzisen chirurgischen Plan nicht ersetzen. Das Navigationsgerät sollte einen festen Platz in der Klinik und der Ausbildung haben (Stelter 2011). Der Einsatz des Navigationsgerätes verursacht keine zusätzliche mentale oder physische Belastung für den Chirurgen. Die Komplexität der Operation oder die zahlreichen verschiedenen medizinischen Geräte und Informationen, die unter anderem auch durch das Navigationsgerät zur Verfügung gestellt werden, wirken sich nicht negativ auf die mentale Belastung des Chirurgen aus. Suffizientes Training ist für den reibungslosen Ablauf einer endoskopischen Nasennebenhöhlenoperation mit oder ohne Navigation unerlässlich (Stelter 2015; Theodoraki 2015).

4. Der kumulativen Habilitationsschrift zu Grunde liegende eigene Veröffentlichungen

4.1 Übersicht

1. Ledderose GJ, Braun T, Betz CS, Stelter K, Leunig A. Functional endoscopic surgery of paranasal fungus ball: clinical outcome, patient benefit and health-related quality of life. Eur Arch Otorhinolaryngol. 2011

2. Ledderose GJ, Betz CS, Stelter K, Leunig A. Surgical management of osteomas of the frontal recess and sinus: extending the limits of the endoscopic approach. Eur Arch Otorhinolaryngol. 2010

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8. Ledderose GJ, Stelter K, Leunig A, Hagedorn H. Surface laser registration in ENT-surgery: accuracy in the paranasal sinuses - a cadaveric study. Rhinology. 2007

9. Ledderose GJ, Hagedorn H, Spiegl K, Leunig A, Stelter K. Image guided surgery of the lateral skull base: Testing a new dental splint registration device. Computer Aided Surgery. 2012

10. Stelter K, Theodoraki MN, Becker S, Tsekmistrenko V, Luz M,·Olzowy B, **Ledderose G**. Specific stressors in endonasal skull base surgery with and without navigation. Eur Arch Otorhinolaryngol. 2014

11. Theodoraki MN, **Ledderose GJ**, Becker S, Leunig A, Arpe S, Luz M, Stelter K. Mental distress and effort to engage an image-guided navigation system in the surgical training of endoscopic sinus surgery: a prospective, randomised clinical trial. Eur Arch Otorhinolaryngol. 2014

12. Stelter K, Ertl-Wagner B, Luz M, Muller S, **Ledderose G**, Siedek V, Berghaus A, Arpe S, Leunig A. Evaluation of an image-guided navigation system in the training of functional endoscopic sinus surgeons. A prospective, randomised clinical study. Rhinology. 2011

4.2 Sonderdrucke

Eur Arch Otorhinolaryngol
DOI 10.1007/s00405-012-1925-7

RHINOLOGY

Functional endoscopic surgery of paranasal fungus ball: clinical outcome, patient benefit and health-related quality of life

Georg J. Ledderose · Thomas Braun · Christian S. Betz · Klaus Stelter · Andreas Leunig

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Abstract Paranasal fungus ball can cause chronic rhinosinusitis. Removal via functional endoscopic sinus surgery is usually performed; however objective data on the overall benefit and patient satisfaction are very scarce. The study focuses on the clinical outcome and the quality of life following endoscopic surgery due to fungus ball sinusitis. Forty patients diagnosed with fungus ball sinusitis who underwent functional endoscopic surgery were included. Epidemiologic data, pre-, intra- and postoperative findings were recorded. Surgical success, the detailed benefit and the health-related quality of life were objectively assessed 1 year after the surgery based on a standardized questionnaire (modified SNOT 20) and the Glasgow Benefit Inventory. Health-related quality of life improved significantly in >90% of patients ($p < 0.05$). There were no serious complications or recurrences. As the treatment of choice functional endoscopic sinus surgery of paranasal fungus ball sinusitis is associated with exceptionally high patient satisfaction.

Keywords Paranasal fungus ball sinusitis · Non-invasive mycosis · Health-related quality of life · SNOT-20 · Glasgow Benefit Inventory

Introduction

The fungus ball sinusitis accounts for approximately 4% of surgically treated chronic inflammatory diseases of the paranasal sinuses [1]. It belongs to the chronic non-invasive mycoses showing no fungus infiltration of mucosa or ambient tissue. The compact concrement of hyphae in the paranasal sinus appears as a nearly ball-shaped mass. Aspergillus species are the most common cause of paranasal mycosis in Europe, while other fungi are significantly less frequent [2, 3].

While systemic immunocompetence seems to be less important [4], inadequate ventilation and drainage of the sinuses may play a decisive role in developing a chronic non-invasive mycosis of the nose and paranasal sinuses. Displaced dental material—especially in the maxillary sinus—is often discussed as an assignable cause as well [3–6].

The afflictions caused by the fungus ball sinusitis are non-specific. Common symptoms are pain or a sense of pressure in the paranasal area, a blocked nose, rhinorrhoea, post-nasal drip, foetor ex naso and hyposmia. The unilateral appearance of these symptoms is typical but not obligatory. Kind and intensity of the symptoms depend on the localisation and the extent of the mycosis [2, 7]. Absence of clinical symptoms is also possible, and accordingly, the fungus ball sinusitis sometimes is an incidental finding [4].

The diagnosis is based on the characteristic findings in the endoscopic and intraoperative examination as well as on the pathohistological or microbiological evidence of fungus [7]. Additionally, typical CT or MRI imaging may reveal a mostly unilateral, nearly complete opacity of the affected sinus, possibly surrounded by thickened bone. Often there is a radiopaque area in the centre of the opacity called "iron-like signal", which is caused by crystallization of fungus calcium or possibly by displaced dental fillings [3, 6–9].

The paranasal fungus ball should always be treated surgically to reduce associated clinical symptoms and to

G. J. Ledderose (✉) · T. Braun · C. S. Betz · K. Stelter · A. Leunig
Department of Otorhinolaryngology, Head and Neck Surgery, Ludwig Maximilian University Munich, Marchioninistr. 15, 81377 Munich, Germany
e-mail: johannes_georg.ledderose@med.uni-muenchen.de

rule out other causes of unilateral paranasal disease, such as inverted papilloma or malignant tumours. Functional endoscopic sinus surgery and standard postoperative care are the treatment of choice. The aim is to remove all of the fungus and detritus and ensure the drainage and ventilation of the paranasal sinuses. The mucosa has to be spared. There is no need for medicinal antimycotic therapy [6, 10].

While several recent studies have reported on diagnostic criteria, preoperative symptoms, surgical technique, perioperative management and rate of complications or recurrence in endoscopically treated patients with fungus ball sinusitis [5–8, 10, 11], objective data on the postoperative development of clinical symptoms and overall benefit for the patient are still scarce [11]. It was therefore the aim of our study to specifically focus on the clinical outcome in patients with fungus ball sinusitis after endoscopic surgery and assess the patients' benefit and health-related quality of life using validated tools.

Methods

The ethical approval was given by the university's ethics committee in form of a declaration of ethical no-objection. Additionally, the study was approved by the department's data protection official. All patients diagnosed with fungus ball sinusitis who underwent functional endoscopic surgery at the ENT department of the Ludwig Maximilian University of Munich from 04/2007 to 04/2010 were analyzed. Inclusion criteria were typical intraoperative findings and the histopathological verification of a concretion of fungus hyphae.

Epidemiologic data, the localisation of the fungus ball, the imaging morphology in the CT-scan, the surgical management, the histopathological finding and the microbiologic result were recorded. Follow-up examinations were performed 3 weeks, 4 months and 1 year after the surgery.

After 1 year the change of the specific symptoms and the subjective evaluation of the surgical success were assessed using a standardized questionnaire (modified SNOT 20) [12]. The Sino-nasal outcome test (SNOT-20) is widely used for sinonasal conditions to evaluate the effectiveness of treatment both surgically and medically [13]. Unlike other quality-of-life instruments designed to measure rhinitis symptoms, the SNOT-20 measure is not divided into subscales or domains [13]. Patients can specify their rhinosinusitis-related health status by stating the severity of symptoms [14]. The possible range of scores is 0–5, with a higher score indicating a worse rhinosinusitis-related health condition. The difference between the scores before and after treatment shows the therapeutic success. We used a modified German version that includes additional questions on nasal obstruction, foetor ex naso and loss of smell and taste. The SNOT-20 can be combined with other measures to provide a more complete description of outcome especially regarding health-related quality of life [13].

Therefore, the patients were also asked to fill in the Glasgow Benefit Inventory (GBI), a well validated questionnaire for ENT interventions [15], to determine precisely their detailed benefit and the health-related quality of life after functional endoscopic sinus surgery because of paranasal fungus ball. We chose the GBI as a sensitive tool for assessing changes in health status following an intervention. The GBI defines health status as the general perception of well-being, including psychological, social and physical domains. In contrast to the SNOT-20, it does not compare pre- and postoperative scores but rather directly addresses the change in health status resulting from surgery, as the maximal sensitivity to change is crucial [15, 16]. The GBI consists of 18 questions covering different aspects of health-related quality of life. It is independent of any specific health condition or the context of the intervention. However, to improve sensitivity, the text can be modified to allow focusing on the matter of interest. Thus we altered it according to existing recommendations for nasal surgery.

Answers are selected from a Likert scale ranging from 1 to 5. Raw data are processed into total GBI scores, which range from −100 (maximal adverse effect), through 0 (no effect), to +100 (maximal positive effect). In addition, subscores can be calculated: a general subscore, a social support score, and a physical health score [15–17]. The one sample signed rank test was applied to test if scores differed significantly from 0 (with 0 meaning no effect of the treatment on the health-related quality of life), and a p value < 0.05 was considered to be statistically significant. All collected data were entirely and irreversibly anonymized.

Results

Epidemiology

We included 40 consecutive patients diagnosed with a fungus ball sinusitis who underwent functional endoscopic sinus surgery. The mean age was 56 years (range 22–91 years), with about 50% of the patients being between 61- and 70-years-old. The gender ratio was 62.5% (female)–37.5% (male). The most frequent concomitant diseases were hypertension (65%), type 2 diabetes (15%) and bronchial asthma (10%). 5% of the patients were taking systemic steroids. Dental treatment had been done before in 65% of the patients.

Localisation of disease

In 87.5% the maxillary sinus, in 15% the ethmoidal cells, in 7.5% the sphenoid sinus and in 2.5% the frontal sinus were affected. Two patients had a bilateral involvement of the maxillary sinuses (5%), in 95% the disease was unilateral. More than one sinus was affected in five patients (12.5%).

Endoscopic examination

Endoscopically, a pathologic finding, e.g. purulent secretion, mucosal polyps or fungus components, was found in 25 patients (62.5%) (Fig. 1a, b).

Imaging

In the routinely performed preoperative CT scan a complete opacity of the affected sinus was apparent in 47.5% of the patients. The iron-like signal was seen in 57.5% of all cases, and 67.5%, when the maxillary sinus was involved, respectively (Fig. 2a).

Surgical management

All of the patients underwent functional endoscopic sinus surgery. No transfacial or transvestibular techniques were used. The aim of surgery was to completely remove the bulks of fungus and detritus and to ensure the drainage and ventilation of the affected paranasal sinuses (Fig. 1b). Single mucosal samples were taken for histopathological analysis, but no extensive excision of mucosa was performed. In 7.5%, surgery was performed under the control of a navigation system. No serious complications were recorded.

Histopathology

Histopathologically, a dense concrement of fungal hyphae without mucosal, vessel or osseous infiltration was apparent in all cases. The mucosa showed signs of a slight accompanying infection. No allergic mucus was detected (Fig. 2b).

Microbiology

In only four cases (10%) fungal growth could be verified by microbiologic culture. In all of the positive cultures *Aspergillus fumigatus* was diagnosed. In 55% a superinfection could be assessed, most frequently caused by *Staphylococcus aureus* or a mixed infection of gram negative and positive bacteria.

Follow-up treatment

An antimycotic treatment was not conducted. The usual postoperative treatment was applied including application of topical steroids and nasal saline irrigation. In case of a bacterial superinfection (30% of the patients) a short-term systemic antibiotic therapy was given. No recurrence was observed in the one-year follow-up period. No patient needed further sinus surgery (Fig. 1c).

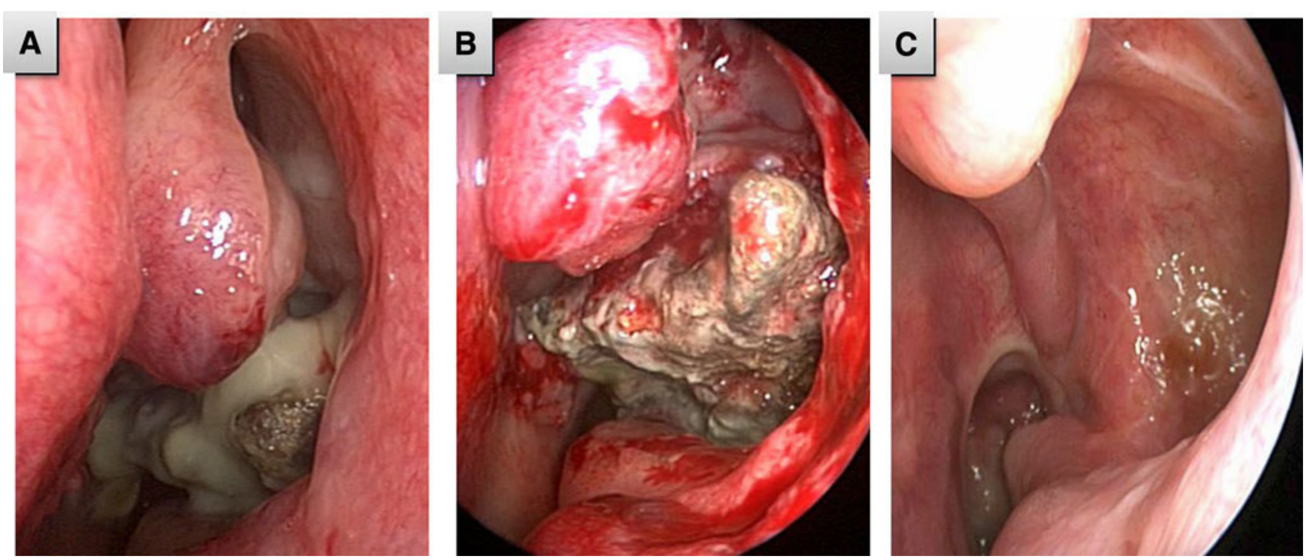

Fig. 1 Endoscopic removal of a paranasal fungus ball in the left maxillary sinus. Purulent secretion in the preoperative endoscopic examination (**a**); intraoperative view of the fungal concrement (**b**). In the endoscopic follow-up neither recurrence of fungus ball nor impaired wound healing were observed (**c**)

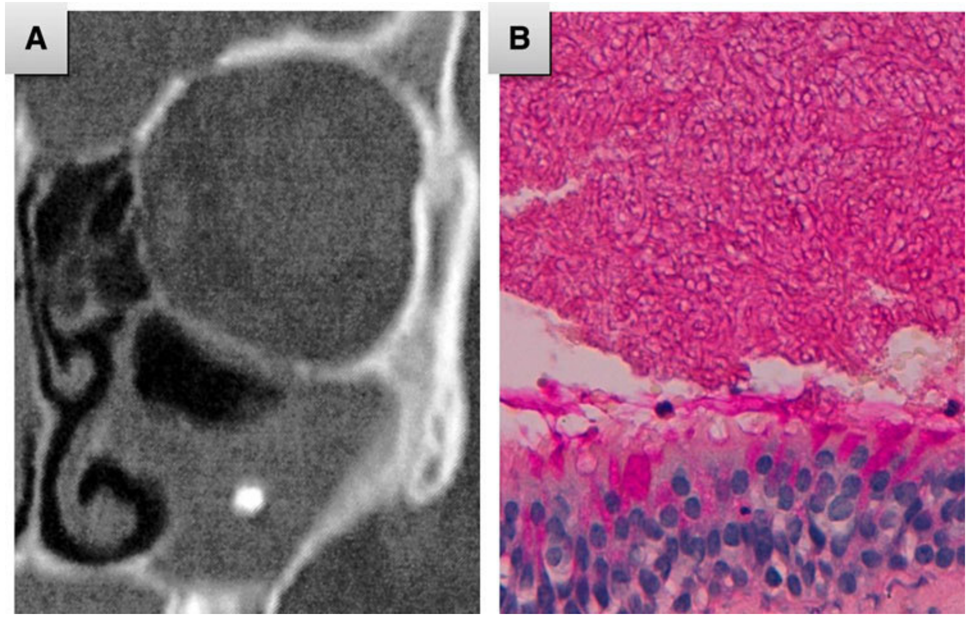

Fig. 2 CT-imaging and histopathology of paranasal fungus ball. Note the characteristic iron like signal in the preoperative CT scan (**a**); the histopathological examination (**b**) shows a dense concrement of fungal hyphae without mucosal, vessel or osseous infiltration. The mucosa shows signs of a slight accompanying infection (×400 magnification, PAS)

Postoperative survey

The survey was done 1 year after surgery by reference to a standardized questionnaire. The most common preoperative symptoms and their change after surgery as recorded with the modified SNOT measure are displayed in Fig. 3a, b.

The subjective evaluation of the surgical success was thereby recorded, too 87.5% of the patients would undergo the surgery again, 82.5% would recommend it. 90% of the patients reported an improvement of their general condition, 82.5% felt an increase in their quality of life.

The change of the health status after the surgical intervention was validated additionally using the GBI. The results are displayed in Fig. 4. The total score was 21.1 (distribution of total scores: 5% < 0; 5% $= 0$; 90% > 0), the general score 18.8 (5% < 0; 5% $= 0$; 90% > 0), the social support score 5.0 (5% < 0; 65% $= 0$; 30% > 0) and the physical health score 46.7 (5% < 0; 5% $= 0$; 90% > 0). All of the mean scores were >0, indicating a positive effect of the treatment on the patients' health-related quality of life. With the exception of the social support score, this effect was statistically significant for all the scores ($p < 0.05$, one sample signed rank test).

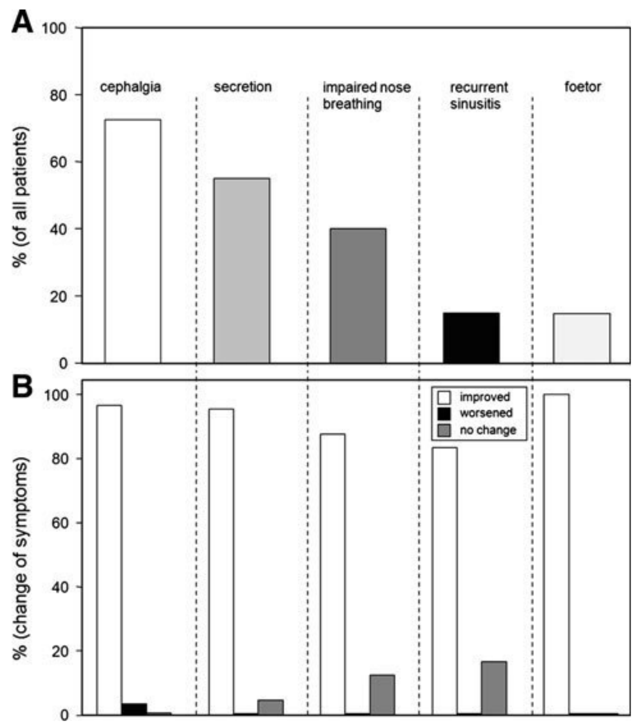

Fig. 3 Clinical symptoms of paranasal fungus ball sinusitis. Shown are the preoperative frequency (**a**) and the subjective change of the symptoms as assessed 1 year after surgical removal of the fungus ball (**b**)

Discussion

The diagnosis of fungus ball sinusitis is based on the typical endoscopic or intraoperative findings and the histopathological examination. In all of our cases these criteria were met. Additionally, the characteristic signs in the CT or MRT imaging were considered. These were unilaterality of the disease (95%), a partial or complete opacity of the affected sinus (100%) and the iron-like signal (57.5 %). Due to the sensitivity of the pathogens and the poor viability of fungal elements in the ball, microbiological cultivation turned out to be impossible in most of the cases, which is in line with previous reports [9, 18]. Therefore the diagnosis of fungus ball sinusitis should not routinely rely on the results of microbiological cultures.

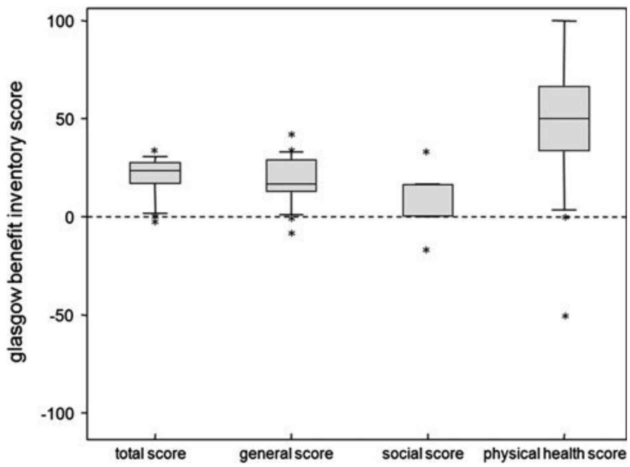

Fig. 4 Change in quality of life after paranasal fungus ball surgery. Effect of treatment was assessed by applying the GBI questionnaire. Scores range from −100 (maximal adverse effect), through 0 (no effect), to +100 (maximal positive effect). Results were tested for statistical significance using the one sample signed rank test, and with the exception of the social support score, the positive effect of the treatment was statistically significant ($p < 0.05$) for all scores. Lines within the boxes display the median values, asterisks indicate outlying points

The aetiology of fungus ball sinusitis remains uncertain. Exclusively dentogenic reasons are quite unlikely as 12.5% of the patients had plain maxillary sinuses, and only 65% of our patients had a dental treatment in their medical history. These numbers match with previous studies, too [3, 7, 9]. Additionally, the iron-like signal—sometimes attributed to represent displaced dental fillings—showed up in the sphenoid sinus as well. The collected epidemiological data are consistent with previously published studies regarding age, gender predominance (female:male 1.67:1) and paranasal localisation. We confirm that the functional endoscopic sinus surgery should be considered as the therapy of choice. In all patients the fungus ball could be completely removed without any severe complications, showing no recurrence within the one-year follow-up period. However, the overall success of any surgical intervention cannot be obtained from measures of technical success alone. The changes in the clinical symptoms and in the quality of life resulting from the intervention must also be considered [19]. Validated questionnaires are important means to assess the subjective outcomes of certain treatments.

Despite the frequency of occurrence, data regarding the change of symptoms and quality of life after surgical therapy of paranasal fungus ball are still very limited [11]. By applying a questionnaire especially designed for a population of people with rhinosinusitis (modified SNOT 20) we were able to assess the change of symptoms as well as the subjective evaluation of the surgical success by the patient. Similar to other studies performed regarding functional endoscopic surgery the vast majority of the patients reported an improvement of symptoms after functional endoscopic surgery [12].

As a validated and well-established instrument for the specific evaluation of the health status and resulting quality of life we used the GBI. It was generated specifically for otorhinolaryngology, and it is characterised by its sensitivity to non-acute disorders, as they are generally seen in otorhinolaryngology. The assessment of the health status following a surgical intervention is based on the general perception of well-being, which includes physical, psychological and social well-being [15, 16]. The GBI is well established in ENT surgery in general, particularly in plastic surgery [17]. There are also several studies using the GBI in rhinosurgery. Konstantinidis reported a total score of 6.3 after septoplasty [20], and Salama a total score of 25.2 for treatment of sinusitis with minimal-invasive sinus-technique [21]. After functional endoscopic sinus surgery, Salhab et al. determined a total score of 22.6 [22]. Another study reports a total score of 25 after FESS due to chronic non-polyposis sinusitis and 30.6 after FESS with polypectomy [23]. However, comparable data for endoscopic paranasal fungus ball surgery has not been published yet.

Overall, the scores we assessed by the GBI were in the range of those reported after FESS performed for different reasons [22, 23]. We detected a considerable increase in the general quality of life (general health score) and a great gain in the health-related quality of life (physical health score). Patients suffering from sinusitis are generally not socially stigmatized. Consistently, no significant change of the social support score was detected. The physical health score of 46.7 was remarkably high compared to the scores reported by the studies mentioned above [21–23]. This might be due to the fact that a paranasal fungus ball is strictly localised and most symptoms result from obstruction, which can be resolved completely and pointedly employing functional sinus surgery. In this respect it is comparable to the resection of obstructive polyps. Correspondingly, Newton obtained a similarly high physical health score of 33.3 after FESS with polypectomy [23].

Conclusion

In conclusion, complete removal of paranasal fungus ball via functional endoscopic sinus surgery should be considered the therapy of choice. There were no serious complications or recurrence. It resulted in high patient satisfaction and was associated with a clear increase in the health-related quality of life.

Conflict of interest The authors declare that they have no conflict of interest.

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RHINOLOGY

Surgical management of osteomas of the frontal recess and sinus: extending the limits of the endoscopic approach

Georg J. Ledderose · Christian S. Betz · Klaus Stelter · Andreas Leunig

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Abstract Osteomas are among the most common benign tumors of the paranasal sinuses. Symptomatic osteomas are most often found in the frontal recess and the frontal sinus. While the extranasal approach is still a part of the treatment concept for removing osteomas at this localization, over the last years the endoscopically controlled endonasal approach has greatly gained in importance due to the improved surgical equipment. We retrospectively analyzed the surgical indication, surgical approach and outcome of the removal of osteomas of the frontal recess and the frontal sinus performed at our hospital between 1996 and 2010. The exact surgical technique, intra- and postoperative complications, the duration of the hospital stay and the follow-up and subjective contentment of the patients were evaluated. With a total of 24 patients being included, the study comprises one of the largest groups of patients with osteomas of the frontal recess and sinus. Over the study period, the frequency of the endoscopic approach clearly increased. Previously suggested guidelines for the endoscopic resection of a frontal sinus osteoma turned out to be superseded. Endoscopically controlled resection even of large, adversely located osteomas of the frontal recess and the frontal sinus is becoming increasingly possible, but is still naturally limited by the individual anatomic conditions and the need for experienced surgeons.

Keywords Osteoma surgery · Frontal sinus · Frontal recess · Endoscopically controlled resection · External approach

G. J. Ledderose (✉) · C. S. Betz · K. Stelter · A. Leunig
Department of Otorhinolaryngology, Head and Neck Surgery, Ludwig-Maximilians-University Munich, Marchioninistr. 15, 81377 Munich, Germany
e-mail: johannes_georg.ledderose@med.uni-muenchen.de

Introduction

Osteomas are among the most common benign tumors of the paranasal sinuses. They are usually located in the frontal sinus or the frontal recess [1–3]. The incidence is approximately 0.5%, with men being affected slightly more often than women [4]. The average age of osteoma patients is around 50 years [5–8]. The etiology of these tumors is still a matter of discussion with various causes having been proposed, such as an embryonic malformation, familial disposition or hereditary transmission, traumatic or inflammatory triggers, calcifying polyposis, metaplastic changes or a calcium metabolism disorder [1, 9]. The tumor grows very slowly, but its size may increase considerably over time [2].

Due to their slow growth only approximately 10% of all osteomas become clinically symptomatic [1, 5, 10], and consequently they are often detected as incidental findings on CT images. Approximately 3% of all CT scans of the paranasal sinuses reveal osteomas [11, 12]. As possible differential diagnosis, particularly fibrous dysplasia and ossifying fibroma have to be considered [3, 7]. The clinical symptoms that may be caused by osteomas are dependent on size and localization. Important anatomic structures can be affected, as can the ventilation and drainage of the affected paranasal sinuses. Most patients with clinically symptomatic osteoma in the paranasal sinus region complain about a particularly frontal sensation of pressure or headaches [4, 6, 8, 13], which most likely arise from an impaired drainage of the sinuses and subsequent chronic rhinosinusitis [4, 14]. Recurrent sinusitic symptoms, a cosmetic impairment, such as a protrusion of the anterior wall of the frontal sinus, and facial pain are also commonly reported [6, 8, 13]. Depending on their position, osteomas may also become symptomatic due to the orbital and the intracranial complications or secondary formation of mucoceles [1, 15].

While it is generally agreed that surgical intervention is not indicated for asymptomatic osteomas [6, 14], symptomatic osteomas are always treated surgically [1]. Traditionally, surgical removal of frontal sinus osteomas, in particular, has been conducted by an extranasal approach with or without frontal sinus obliteration [16]. In recent years, however, endonasal endoscopically controlled removal has been increasingly performed, depending on the osteoma's localization. Endoscopic resection of a frontal sinus osteoma was first reported in 1992 [17]. In the last 10 years, improved surgical instruments (e.g., drills) and endoscopes (e.g., telescopes with 45° and 70° angles of view), and consequent enhancement of endoscopically assisted surgical techniques have led to a continuous increase in the number of cases in which endonasal osteoma resection was possible [4, 8, 11, 18]. Based on the early experiences, guidelines for the endoscopical resection of paranasal sinus osteomas have been proposed [6, 11, 18, 19]. However, since symptomatic osteomas and hence larger series on endonasal removal of frontal osteomas are still comparatively rare, a systematic evaluation of these guidelines in a sufficient number of cases has not been performed yet, which has also been stressed in the recently published European position paper on endoscopic management of tumors of the paranasal sinuses [4].

In the present study, we retrospectively analyzed the patients admitted for surgical removal of osteomas of the frontal sinus and the frontal recess between 1996 and 2010. In addition to the osteoma localization, surgical indication and outcome, special emphasis was placed on the respective surgical method, i.e. whether an extranasal or an endonasal endoscopically controlled approach, or a combination of both, had been chosen.

Methods

All patients who underwent surgery for symptomatic osteomas of the frontal recess and the frontal sinus at the Clinic for Otorhinolaryngology of the LMU in Munich between 1996 and 2010 were retrospectively included into the study. The study reviewed the patient group, the osteoma size and position, the symptoms which led to surgery being indicated in each case, the type of surgical approach and any intraoperative complications. Concerning the surgical approach, the exact operation procedure, the respective instruments and endoscopes and, if applicable, the use of the navigational system were recorded.

For the surgery of the frontal sinus and the frontal recess a number of different surgical procedures are possible. The typical extranasal approaches include the frontal trephine via a browline or a coronary incision. The endoscopically controlled frontal sinus surgery can be done as a Draf type IIA frontal sinusotomy (removal of all ethmoidal cells that could obstruct the frontal sinus drainage), extended by the axillary flap approach when required [20, 21]. Further important procedures are the frontal sinus drainage Draf type IIB (resection of the frontal sinus floor between the lamina papyracea and the nasal septum to provide a maximal opening on one side) and the median drainage Draf type III (Draf type IIA and B on both sides with additional resection of the middle part of the floor of the frontal sinus and the adjacent parts of its septum, also known as the "modified Lothrop procedure") [3, 22].

For all of these different surgical steps, suitable endoscopes (telescopes with 0°, 45° and 70° angles of view) and a whole series of surgical instruments (straight, 40°- and 60°-curved shaver, 15°, 40° and 70° standard and diamond drills with diameters of 3.6 to 4 mm, "Clearvision®"-System, Karl Storz GmbH & Co KG, Tuttlingen, Germany) and a navigational system have been available in the last 8 years of the study period.

The length of hospitalization was determined. The diagnosis was performed in each case by CT imaging in the coronal, axial and sagittal plane to assess the size, position, relation to adjacent structures and the drainage pathway of the affected paranasal sinuses. The osteomas were classified according to the grading system of Chiu et al. [18] (Table 1). Postoperatively, the patients were examined after 2 weeks, 3 months, 6 months and 12 months. Postoperative assessment consisted of a clinical observation and an endoscopic control of the operative situs (Fig. 1e). Only if corresponding symptoms were reported, an additional CT scan of the paranasal sinuses was performed at these postoperative visits

Table 1 Grading system for osteomas of the frontal sinus and frontal recess, according to Chiu et al. [18] and Seiberling et al. [3]

Grade	Characteristics
I	Origin of the osteoma posterior and inferior in the frontal recess; localization of the osteoma medial to a virtual sagittal plane passing through the orbital lamina; anteroposterior diameter of the tumor is <75% of the anteroposterior diameter of the frontal sinus
II	As Grade I; anteroposterior diameter of the tumor >75% of the anteroposterior diameter of the frontal recess
III	Origin of the osteoma anterior and/or superior in the frontal sinus and/or osteoma extending lateral to a virtual sagittal plane passing through the orbital lamina
IV	Osteoma fills the entire frontal sinus

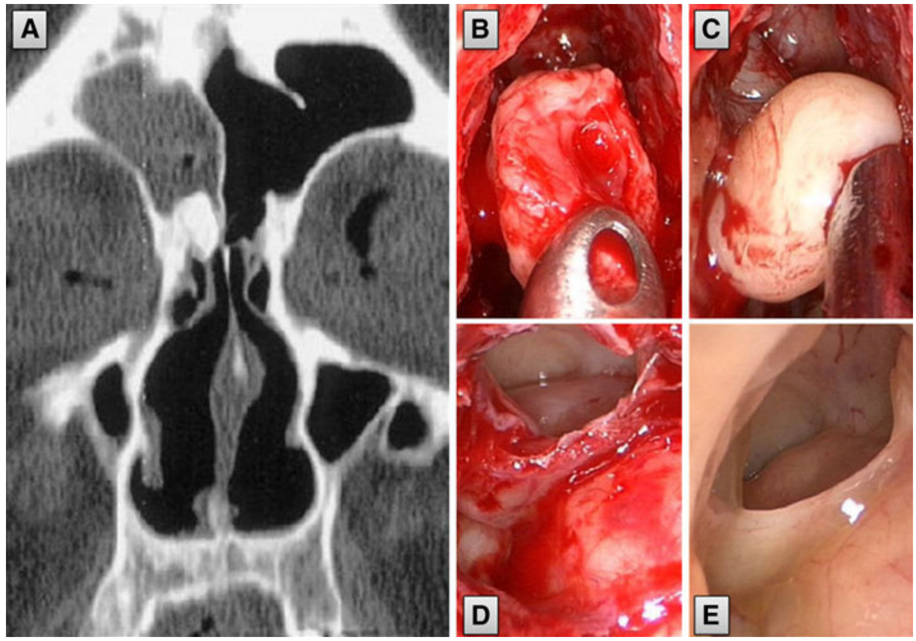

Fig. 1 Endoscopically assisted surgery on an osteoma of the right frontal recess (Grade II according to Chiu et al. [18]). In the coronal CT scan, one can see the secretion retention in the form of an incipient mucocele in the right frontal sinus (**a**). Removal of the osteoma (**b**), drainage of the retained secretion (**c**), view into the frontal sinus (**d**) and normal frontal sinus opening 1 year post surgery (**e**)

(Fig. 2). The patients were surveyed 3 months after surgery using the standardized "SNOT 20" questionnaire. Furthermore, the patients were encouraged to subjectively assess the outcome of the operation by means of additional questions.

Results

Patient group

A total of 24 patients underwent surgery during the period from January 1996 to April 2010. The average age was 43.5 (SD 9.4) years; there were 11 male and 13 female patients. Eight patients had undergone previous sinus surgery without the osteoma being removed.

Osteoma localization

Seventeen osteomas were located in the frontal sinus (71%) and seven osteomas in the frontal recess (29%). The exact size, localization and origin of the osteoma are shown in Table 3.

Symptoms

The most common symptoms leading to indication for surgery were headaches or a sensation of pressure in the region of the paranasal sinuses (83%), symptoms of sinusitis due to the osteoma (87%), often influenced by accompanying polyposis or, less frequently, a cosmetic impairment with deformity, particularly in the region of the anterior wall of the frontal sinus (10%). In 37% of cases, surgery was indicated because of the secretion retention in the form of an incipient or already manifested mucocele with displacing character and thinning of the bone (Fig. 1). No orbital or cerebral complications had occurred in the study population (Table 2).

Surgical approach

Surgery procedure and size, localization and grade of the osteoma are shown in detail in Table 3. In 12 patients (50%), the osteoma was removed via a combined endo- and extranasal approach. In eight cases (33%), exclusively an endonasal operation under endoscopic control was performed, and in four cases (17%), an external approach alone was chosen. In 14 cases (58%), the operation was navigation-assisted.

The extranasal and combined approach

For the extranasal approach (alone or as a part of the combined procedure) a frontal sinus trephine via a brow-line incision was performed on 13 patients. In three patients, the frontal sinus trephine was done via a coronal incision, and in one patient an additional extranasal median drainage type III was conducted. In case of a combined extranasal and endoscopically controlled approach, an endonasal endoscopic Draf type IIA frontal sinusotomy was performed (50%). Often, an additional septoplasty was needed (Table 3).

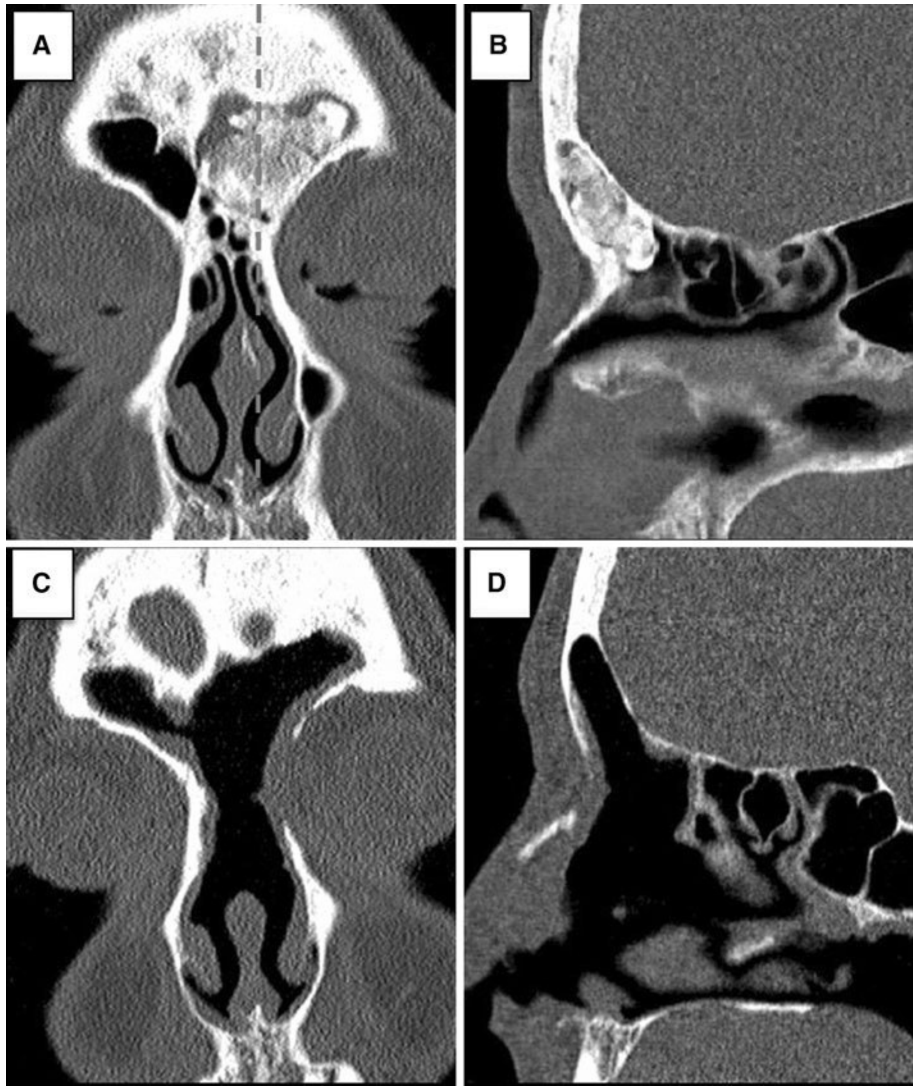

Fig. 2 CT in coronal (**a**) and sagittal (**b**) slices. Approximately 50% of the osteomas are located laterally to the virtual sagittal plane passing through the orbital lamina (**a**); therefore, the tumor fills the frontal sinus almost completely (**a**, **b**). The postoperative CT scan in coronal (**c**) and in sagittal (**d**) slices 5 months after surgery. This Grade IV osteoma of the left frontal sinus was removed via an endonasal approach (modified Lothrop procedure)

Table 2 Preoperative symptoms resulting in surgery being indicated

Symptoms	Number of patients	Percentage (%)
Headache and/or sensation of pressure in the paranasal sinus region	20	83
Secondary sinusitis symptoms	21	87
Polyposis	6	25
Secondary mucocele	9	37
Cosmetic impairment	2	10
Previous sinus surgery	8	33

The endoscopically controlled approach

For the endoscopically controlled removal of the osteomas on four patients, a Draf type IIA frontal sinusotomy was sufficient. Three times a frontal sinus drainage Draf type IIB was performed, and once an endoscopic median drainage Draf type III (“modified Lothrop procedure” or “frontal drill out procedure”) was chosen. The surgery was done via an axillary flap approach if necessary, as described by Wormald [21]. The exact surgical procedure depending on the osteoma size, its localization and its origin is displayed in Table 3.

Complications

During one combined endo- and extranasal operation, relatively heavy intraoperative arterial bleeding occurred, which was controlled by coagulation of the sphenopalatine artery. In one case, bleeding with concurrent orbital hematoma occurred 2 days after an extranasal frontal sinus osteoma operation, which necessitated surgical revision. The source of bleeding was identified as the anterior ethmoidal artery. In another patient, bleeding from the left ethmoid bone occurred 5 days after the combined endo- and extranasal

Table 3 Localization, origin, grading (according to Chiu et al. [18], Table 1) and corresponding surgery for the frontal sinus and frontal recess osteomas

Number	Year of surgery	Localization	Grade (Chiu et al.)	Origin of osteoma	Surgical procedure
1	1996	Frontal sinus left	4	Anterior, inferior, wide base	Coronary incision, median drainage III, Draf type IIA frontal sinusotomy, septoplasty
2	1997	Frontal sinus right	3	Inferior, wide base	Eyebrow incision
3	1999	Frontal recess left	2	Posterior, pediculated	Eyebrow incision, Draf type IIA frontal sinusotomy, septoplasty
4	2000	Frontal sinus left	3	Inferior, wide base	Eyebrow incision, Draf type IIA frontal sinusotomy, septoplasty
5	2000	Frontal sinus left	3	Posterior, wide base	Eyebrow incision, Draf type IIA frontal sinusotomy, septoplasty
6	2000	Frontal recess left	1	Medial, inferior, pediculated	Eyebrow incision
7	2000	Frontal sinus left	3	Inferior, wide base	Eyebrow incision, Draf type IIA frontal sinusotomy, septoplasty
8	2001	Frontal sinus right	3	Pediculated, cranial	Eyebrow incision
9	2002	Frontal sinus right	3	Anterior, wide base	Eyebrow incision, Draf type IIA frontal sinusotomy
10	2002	Frontal sinus right	3	Posterior, wide base	Eyebrow incision, Draf type IIA frontal sinusotomy, septoplasty
11	2003	Frontal recess right	2	Anterior, pediculated	Eyebrow incision, Draf type IIA frontal sinusotomy
12	2003	Frontal sinus left	4	Anterior, wide base	Coronary incision, Draf type IIA frontal sinusotomy
13	2004	Frontal recess right	1	Lateral, pediculated	Draf type IIA frontal sinusotomy
14	2004	Frontal recess left	2	Anterior, pediculated	Draf type IIA frontal sinusotomy
15	2005	Frontal sinus left	4	Posterior, wide base	Eyebrow incision, Draf type IIA frontal sinusotomy
16	2006	Frontal sinus right	3	Inferior, wide base	Eyebrow incision
17	2006	Frontal sinus right	2	Medial, inferior, pediculated	Draf type IIA frontal sinusotomy
18	2007	Frontal recess right	1	Medial, inferior, pediculated	Draf type IIA frontal sinusotomy
19	2007	Frontal sinus left	3	Cranial, pediculated	Draf type IIB frontal sinusotomy, septoplasty
20	2008	Frontal sinus right	4	Cranial, pediculated	Eyebrow incision
21	2009	Frontal sinus left	4	Posterior, contact to skull base, lateral wide base	Mediandrainage III, septoplasty
22	2009	Frontal sinus right	3	Lateral, posterior, pediculated	Draf type IIB frontal sinusotomy, septoplasty
23	2010	Frontal recess left	2	Superior, wide base	Draf type IIB frontal sinusotomy
24	2010	Frontal sinus right	4	Lateral, wide base	Coronary incision, Draf type IIA frontal sinusotomy

osteoma operation; this was successfully treated conservatively by means of temporary nasal tamponade.

Length of hospitalization

Patients in whom an extranasal surgical approach was chosen were hospitalized for an average of 9.2 days post-op (SD 2); for patients who underwent endonasal surgery, the average was 5.3 days (SD 4).

Postoperative survey

The postoperative control took place 2 weeks, 3 months, 6 months and 1 year after surgery. Three months postoperatively, 79% of the patients were surveyed using the "SNOT 20" questionnaire. How symptoms changed following surgery and if a reoperation was necessary was recorded. Furthermore, patients were asked for a subjective assessment of the outcome.

The patients interviewed benefited from the operation. The symptoms leading to the operation being indicated had receded in 89% of the cases. Furthermore, the vast majority of patients (95%) were subjectively very satisfied with the outcome of the operation.

One patient reported an increase in headaches and sensation of pressure in the region of the paranasal sinuses, although the imaging follow-up showed no sign of residual or recurrent osteoma in the paranasal sinus system. Following appropriate neurologic assessment, a neuropathic facial pain was diagnosed. In another patient, another operation (septoplasty) became necessary due to the persisting impairment of nasal respiration (Tables 4, 5).

Discussion

Symptomatic osteomas of the paranasal sinuses are most often located in the frontal sinus and the frontal recess. They are diagnosed by a CT scan of the paranasal sinuses, which is essential for surgical planning and—as a navigation CT—is necessary if image-guided surgery is to be applied.

Symptomatic osteomas should be surgically removed, but careful diagnosis is required. For example, "headaches" or "sensation of pressure", the most commonly reported symptoms of osteomas [4], often also have other causes, and can, therefore, lead to misdiagnosis [23]; nor are sinusitic complaints necessarily attributable to the presence of an osteoma. Osteomas are often discovered incidentally during imaging and remain asymptomatic due to their slow rate of growth. Surgery is not usually indicated for such osteomas. In contrast, surgery is clearly indicated in cases of cosmetic impairment, chronic sinusitis symptoms caused by the bone tumor, secondary formation of mucoceles or orbital and intracranial complications [6, 14]. Removal of a symptomatic osteoma resulted in a regression of symptoms in a large percentage of cases.

Table 4 Postoperative survey using the "SNOT 20" questionnaire: postoperative change in paranasal sinus symptoms

Symptom	Improved	Unchanged	Worsened
Pain	17	1	1
Sensation of pressure	17	1	1
Impairment of nasal respiration	14	4	0
Rhinorrhea	9	4	0

Table 5 Postoperative survey using the "SNOT 20" questionnaire: subjective assessment of outcome

Question	Yes	No
"Would you undergo the operation again?"	17	2
"Would you recommend the operation to others?"	18	1
"Has your general state of health been improved by the operation?"	12	1
"Has your quality of life improved?"	12	1
"Was a repeat operation on your nose/paranasal sinuses necessary?"	1	18

The gold standard for removing frontal sinus osteomas is still considered to be by external osteoplastic surgery, if necessary with frontal sinus obliteration [16, 19]. Nevertheless, endoscopic endonasal resection of paranasal sinus osteomas has now become an important alternative technique in many cases [4, 11, 19]. The endoscopically controlled approach—with the relative reduction in patient trauma it offers—can not only be used for osteomas of the ethmoidal cells and maxillary sinuses, but is increasingly applied to the region of the frontal recess and the frontal sinus. The endonasal approach has been facilitated by the further development of endoscopes (telescopes with various angles of view) and surgical instruments (drills, "Clearvision®", Karl Storz GmbH & Co KG, Tuttlingen, Germany), and refinement of surgical techniques (frontal sinus drainage type IIB, mediandrainage type III, "drill out", "modified Lothrop procedure" [3, 20, 22]). Particularly when using drills, the bimanual technique ("four hands, two nostrils") can possibly reduce both surgery time and complications, thanks to the better overview it provides [24]. The navigation system, having shown to offer satisfactory accuracy [25], supplies a further tool to facilitate orientation during the endoscopic osteoma operations.

This development is reflected in the patient group of the present study: an extranasal or a combined extranasal and endonasal approach for the removal of osteomas of the frontal recess was only chosen before 2002. Thereafter, all osteomas in this localization could be removed endoscopically. Furthermore, since 2002 a navigation system was used intraoperatively as a standard.

The limits of the endoscopic endonasal approach are set by certain anatomic conditions, especially the localization and size of the osteoma in relation to the size of the frontal recess. The decisive factor here is the anteroposterior diameter [6, 11, 16, 18, 19]. Several authors state that the criterion for the indication of endoscopically controlled endonasal surgery is that osteomas of the frontal sinus or frontal recess must be located predominantly medial to a virtual sagittal plane passing through the orbital lamina and must be attached in the lower half of the posterior wall of the frontal sinus [6, 11, 18, 19]. Furthermore, neither the anterior nor the posterior wall of the frontal sinus should be involved over a large area. Castelnuovo et al. [19] additionally preclude osteomas of the ethmoid bone which affect the lateral and inferior wall. Similarly, exclusively the extranasal surgical approach is recommended if the osteoma extends intracranially or if there is pronounced orbital involvement [11]. Chiu et al. [18] developed a new classification system for frontal sinus osteomas (Table 1). They recommend endoscopic resection of Grade I and II osteomas, and extranasal removal of Grade III and IV osteomas.

In the patient group of the present study, however, it was found that, in carefully selected individual cases, it is also possible to remove Grade III and even Grade IV osteomas endonasally (Fig. 2). These are tumors which do not fulfill the stated requirements because they are, e.g., localized more laterally in the frontal sinus (Table 3). In accordance, Seiberling et al. [3] report that it is possible to endonasally remove individual frontal sinus osteomas that are mainly located laterally to the virtual plane through the orbital lamina, as can be osteomas that almost completely fill the frontal sinus.

The advantage of the extranasal surgical technique is a better overview of the osteoma and a possibly shorter operation. Disadvantages are a lower patient compliance, cicatrization and higher morbidity due to longer hospitalization. The endonasal technique enables shorter hospitalization, preserves the natural endonasal drainage pathways, or creates new ones, for example via median drainage, but requires longer surgical training and wide experience on the part of the surgeon in what is a rather rare clinical picture. If the surgeon is not sufficiently experienced, or if the necessary facilities are not available, the patient should be referred to a suitably equipped center. It should be noted that even when an osteoma is removed via an extranasal approach, an endonasal operation may still be helpful for preserving the natural drainage pathways, especially in the frontal sinus region [11, 16]. A final judgment on whether the endonasal surgical technique is less susceptible to complications cannot be made due to the small number of patients in the present study and the scarcity of complications. Since all the documented complications occurred with extranasal operations, a corresponding trend may, however, be discernable.

Conclusion

Removal of a symptomatic osteoma results in a regression of symptoms in a large percentage of cases. Endoscopically assisted surgery is often possible, but is still naturally limited by the individual anatomic conditions. However, technical improvements, such as special instruments and angled endoscopic telescopes have widened the scope of indications for this technique. Previously suggested guidelines for the endoscopical resection of a frontal sinus osteoma turned out to be superseded. The extranasal approach nevertheless remains an important part of frontal sinus osteoma surgery. Successful osteoma surgery requires both the appropriate technical conditions and the comprehensive training in endo- and extranasal surgical techniques.

Conflict of interest The authors declare that they have no conflict of interest.

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RHINOLOGY

Paranasal ossifying fibroma: endoscopic resection or wait and scan?

Georg J. Ledderose · Klaus Stelter · Sven Becker · Andreas Leunig

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Abstract The ossifying fibroma is a fibro-osseous lesion that rarely occurs in the paranasal sinuses. Due to its tendency to behave locally aggressively, complete resection is generally recommended. A subdivision into the aggressive juvenile ossifying fibroma (JOF) and the less aggressive cemento-ossifying fibroma of the adult (COF) is clinically reasonable. The objective of the study was to retrospectively analyze the management and follow-up of the patients diagnosed with ossifying fibroma at our ENT-department from 2006 to 2010. A total of five patients were included, thereby comprising one of the largest case series of paranasal ossifying fibromas. In three patients an exclusively endoscopically controlled resection was performed. Two patients with asymptomatic COF declined surgery. Within the 2-year follow-up, no progression was detected. While the JOF should always be surgically treated, for the asymptomatic paranasal ossifying fibroma of the adult (COF) a wait-and-scan strategy, similar to that recommended for osteomas or fibrous dysplasia, could be an option in selected cases.

Keywords Fibro-osseous lesion · Paranasal ossifying fibroma · Endoscopically controlled endonasal approach · Juvenile ossifying fibroma · Cemento-ossifying fibroma

G. J. Ledderose (✉) · K. Stelter · S. Becker · A. Leunig
Department of Otorhinolaryngology, Head and Neck Surgery, Ludwig-Maximilians University Munich,
Marchioninistr 15, 81377 Munich, Germany
e-mail: johannes_georg.ledderose@med.uni-muenchen.de

Introduction

Fibro-osseous lesions of the paranasal sinuses are benign tumours composed of varying amounts of fibrous stroma or osseous tissue; they comprise the three entities of fibrous dysplasia, ossifying fibroma, and osteoma [1]. With an incidence of about 0.5%, osteoma is the most common among them, while fibrous dysplasia and particularly ossifying fibroma are rare [2]. Unequivocal distinction between fibrous dysplasia and ossifying fibroma, whether based on clinical symptoms, imaging or histopathology, is often difficult [3].

Paranasal fibro-osseous lesions infrequently cause clinical symptoms and are often incidental findings on radiographs or CT images. When symptomatic, headaches or pressure sensations (most likely due to an impairment of the drainage ways and a subsequent sinusitis) are most commonly reported. Depending on the size and position, chronic rhinosinusitis, facial deformity, ocular symptoms, or intracranial complications are also possible [4, 5].

Surgical resection of asymptomatic osteomas is generally not recommended [2, 6]. Similarly, surgical treatment of fibrous dysplasia is only indicated in severe cases for the relief of symptoms caused by, e.g. compression of the optic nerve or chronic rhinosinusitis [2, 7, 8]. On the contrary, radical resection of paranasal ossifying fibromas, particularly fibromas of the juvenile type, is widely considered the treatment of choice due to their locally aggressive behaviour [1, 3, 8–11].

In recent years, the resection of paranasal ossifying fibromas by an endoscopic approach has markedly increased, paralleling an extension of the limits of endoscopic techniques in paranasal sinus surgery as a whole [12]. However, as the ossifying fibroma is a very rare condition, no larger series exist in the literature. Published data are mostly limited to single case reports [2, 4, 8, 9, 13], demonstrating the need for further studies to evaluate the possibilities and limits of the endoscopic resection of paranasal ossifying fibromas. This is especially true as endoscopic surgery in this particular area, in the close neighbourhood to delicate structures such as the orbita, the skull base, the optical nerve or the carotid artery, requires the utmost precision, experience and skill on part of the surgeon.

We report on five patients with the histopathologically verified diagnosis of paranasal ossifying fibroma. Two patients declined surgery after having been informed about possible surgical complications. In the remaining three patients, an exclusively endoscopically controlled resection of the ossifying fibromas was performed. The surgical procedure and outcome as well as the follow-up of both, the surgically treated and non-treated patients, were recorded. It was an important aspect of the study to evaluate whether the resection of the paranasal ossifying fibroma of the adult is always indicated, as generally postulated, or whether a more restrictive approach, as recommended for osteoma or fibrous dysplasia, could be an option in selected cases.

Methods

A retrospective analysis was performed of the medical records for all patients ($n = 5$) diagnosed with an ossifying fibroma of the paranasal sinuses at the Department of Otorhinolaryngology, Head and Neck Surgery, Ludwig-Maximilians-University Munich, Germany, from 2006 to 2010. Demographic information, symptoms and clinical findings, sites of involvement and the result of radiological imaging were recorded. Tissue samples of the lesions were routinely taken and histologically analysed by the Department of Pathology of the Ludwig-Maximilians-University Munich and a pathologic reference centre for bone lesions. Treatment, surgical procedure, intra- and postoperative complications and the results of clinical and imaging follow-up are presented.

Results

In three patients, the paranasal ossifying fibromas were removed endoscopically. The follow-up revealed neither residuum nor recurrence of the lesions. The remaining two patients declined surgery, despite the histological confirmation of the diagnosis, due to the operative risks. After detailed information, they decided on a wait-and-scan strategy. The clinical and imaging follow-up within 2 years revealed no symptoms and no significant growth of the fibromas.

Case 1 (2005)

In a 45-year-old woman a circumscribed mass in the right anterior and posterior ethmoid cells and the sphenoid sinus was incidentally found when performing an MRI for a different reason. The medial wall of the orbita was slightly repressed (about 5 mm) and the lamina cribrosa of the frontal skull base was involved (Fig. 1a). The CT-scan confirmed this result. The patient did not report any symptoms arising from this lesion. We performed an endoscopically controlled sampling. Intraoperatively a reddish, partly bone-hard, partly soft tumour was discovered. The lesion appeared to be well supplied with blood. The histological analysis confirmed the diagnosis of a cemento-ossifying fibroma. The patient decided against surgery. During the follow-up period the fibroma did not cause any symptoms. The MRI-control 1 year after the diagnosis showed no substantial growth (Fig. 1b).

Case 2 (2006)

A male patient, aged 54, complained about a blocked nose on the right and rhinorrhoea. CT and MRI imaging revealed a tumour with a bony shell in the right ethmoid cells and the main nasal cavity with slight impression of the medial orbital wall. As a secondary finding there was a polyposis nasi (Fig. 2a). The tumour was removed by an endoscopically controlled and navigation system-assisted approach. The fibroma appeared to be hard, bony, easily

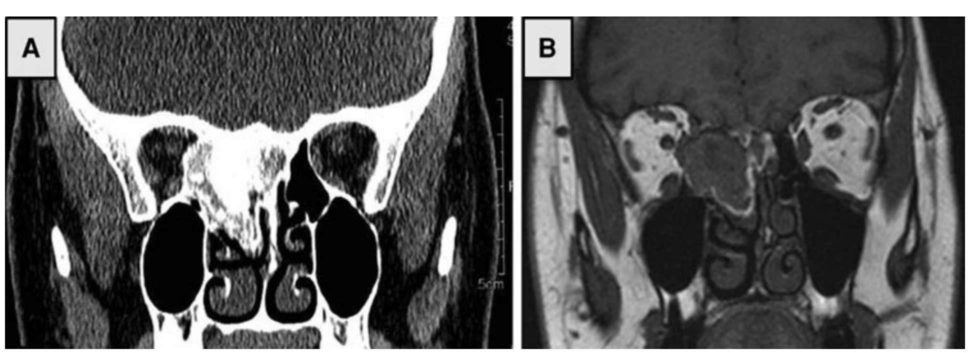


Fig. 1 Case 1: The CT-scan shows a circumscribed mass in the right anterior and posterior ethmoid cells and the sphenoid sinus. The medial wall of the orbita is slightly repressed and the lamina cribrosa of the frontal skull base is involved (**a**). The MRI 2 years after the diagnosis shows no substantial growth (**b**)

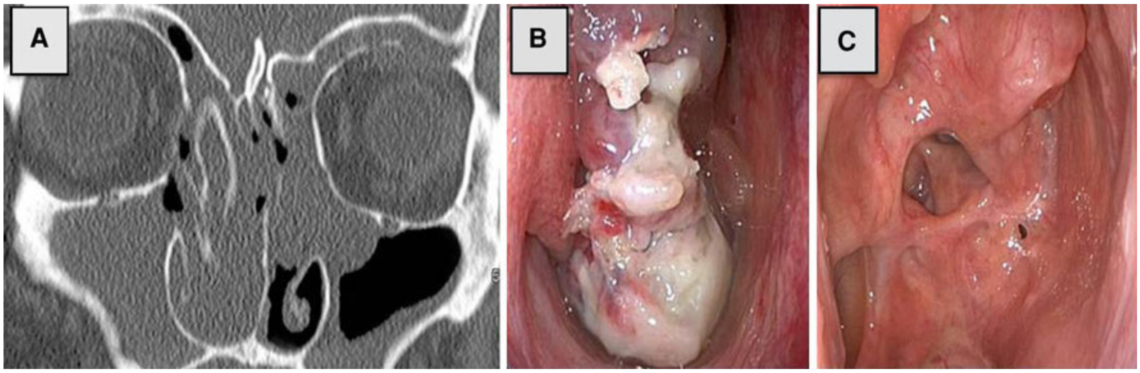


Fig. 2 Case 2: The CT-scan shows a tumour with a bony shell in the right ethmoid cells and the main nasal cavity with slight impression of the medial orbital wall and a polyposis on both sides (**a**). Endoscopically, the fibroma appears bony, partly ulcerative and partly polypoid (**b**). The endoscopic view 2 years after surgery reveals no residuum or recurrence (**c**)

bleeding, partly ulcerative and partly polypoid (Fig. 2b). The histological analysis confirmed the diagnosis of a cemento-ossifying fibroma. The postoperative long-term follow-up showed no residuum or recurrence of the tumour (Fig. 2c).

Case 3 (2007)

The 49-year-old female patient suffered from slight headache. CT and MRI images showed a bony mass in the posterior right ethmoid cells extending to the skull base and the dorsal nasal septum (Fig. 3a). During endoscopy for sampling a whitely, partly bony tumour in the posterior ethmoid was found on the right side. The histological diagnosis was ossifying fibroma. Surgery was not performed. During the follow-up there was no worsening of the headaches. The CT-control 1 year after the diagnosis showed no substantial growth (Fig. 3b).

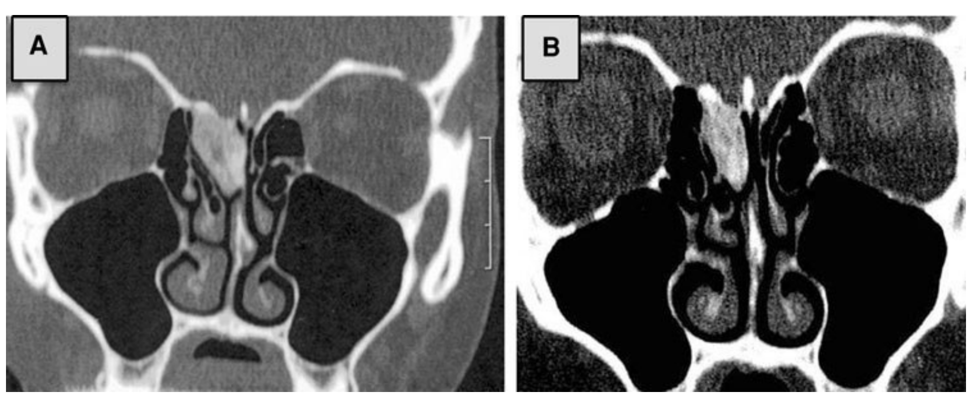
Case 4 (2008)

A female patient, aged 27, presented with a headache projected in the centre of the skull. The imaging (CT and MRI) demonstrated a plain tumour originating from the roof of the sphenoid sinus close to the internal carotid artery and the optic nerve (Fig. 4a). The lesion was completely resected endoscopically under the control of a navigation system using a bimanual technique. The dorsal nasal septum was removed to gain a wide access to the sphenoid sinus. Intraoperatively a hard, plain, whitely tumour originating from the sphenoid roof was found (Fig. 4b). Pathohistologically an ossifying fibroma was diagnosed; a juvenile type could neither be confirmed nor excluded. Two weeks after surgery, a wound infection occurred requiring an in-patient stay of 4 days. The long-term follow-up showed no sign of residuum or recurrence (Fig. 4c).

Case 5 (2010)

A 26-year-old male patient complained about progressive cephalgia and facial pain, a blocked nose on the right side and rhinorrhoea. An extensive, hyperdense and expansive mass in the anterior and posterior ethmoid as well as in the main nasal cavity was found on CT and MRI scans. The medial orbital wall was impressed and the lesion showed an extensive contact to the skull base, which seemed to be partly consumed. The dura appeared to be lifted in some

Fig. 3 Case 3: The CT-scan shows a bony mass in the posterior right ethmoid cells with wide contact to the skull base and the dorsal nasal septum (**a**). The CT-control 2 years after the diagnosis shows no substantial growth (**b**)



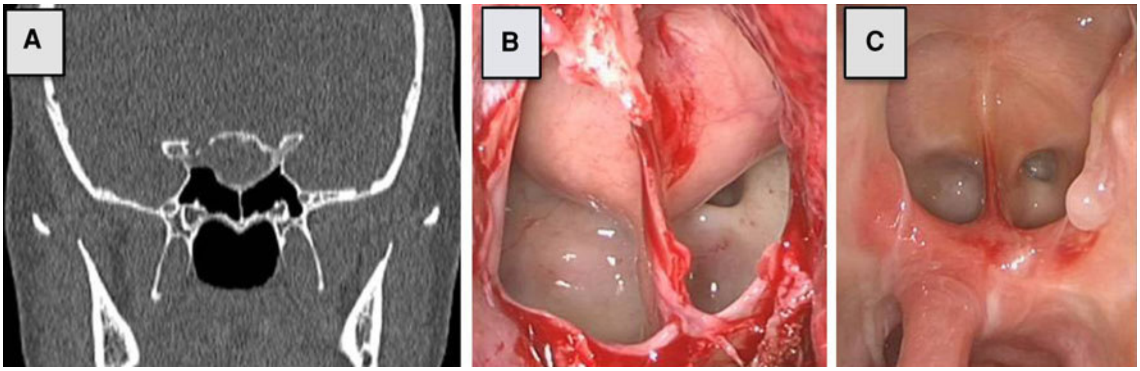


Fig. 4 Case 4: The CT-scan shows a tumour originating from the roof of the sphenoid sinus close to arteria carotis interna and nervus opticus (**a**). Endoscopically, a hard, plain, whitish tumour originating from the sphenoid roof was found after removing the dorsal part of the nasal septum and opening the sphenoid sinus (**b**). The endoscopic view 1 year after surgery revealed no residuum or recurrence (**c**)

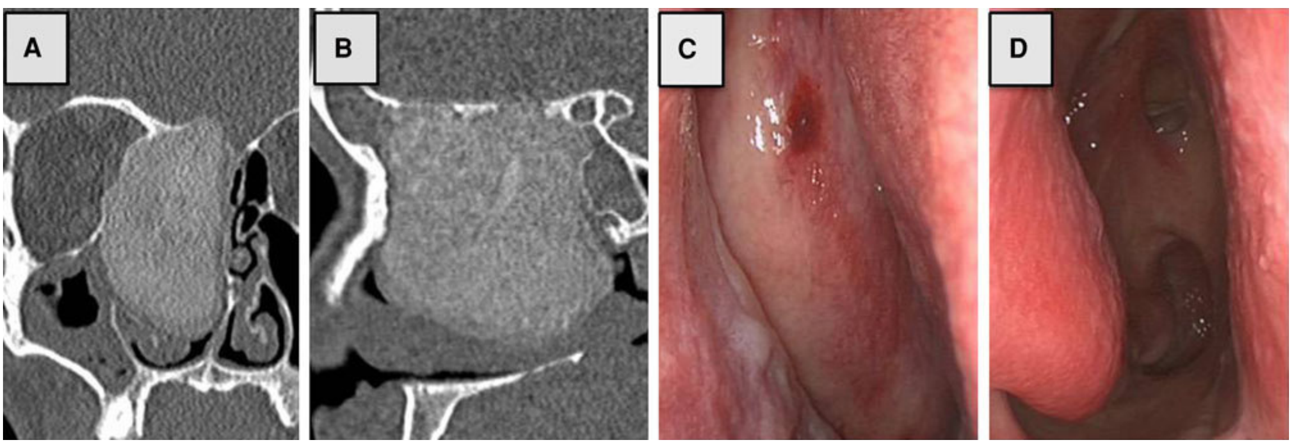


Fig. 5 Case 5: The CT-scan shows an extensive, hyperdense and expansive mass in the anterior and posterior ethmoid and the nasal cavity. The medial orbital wall is impressed and there is a wide contact to the skull base. The dura appears to be lifted in some areas (**a** and **b**, coronar and sagittal slices). Endoscopically, a large whitish to reddish ethmoid tumour was found (**c**). The endoscopic view 7 months after surgery reveals no residuum or recurrence (**d**)

areas (Fig. 5a, b). The fibroma was removed endoscopically controlled and navigationally assisted. The bimanual technique was used. Intraoperatively, we discovered a large whitish to reddish ethmoid tumour (Fig. 5c). The ocular bulb was shifted laterally, the frontal skull base was clearly thinned and the dura slightly lifted. Because of these circumstances a small CSF-leak could not be avoided. It was closed simultaneously. Histologically, a juvenile ossifying fibroma (JOF) was diagnosed. The postoperatively performed follow-up examinations showed no residual or recurrence of the fibroma (Fig. 5d).

Discussion

Benign fibro-osseous lesions of the paranasal sinuses may be divided into osteoma, fibrous dysplasia and ossifying fibroma [1], with osteoma being the most frequently occurring tumour among them [2]. Its aetiology is still not completely understood. Surgical removal should be restricted to symptomatic osteomas [2, 6], which account for only about 10% of paranasal osteomas and are most often found in the frontal recess or the frontal sinus.

Fibrous dysplasia results from a replacement of osseous tissue by fibrous connective tissue during bone growth and is predominantly seen in childhood or early adolescence [7]. However, exacerbation of the disease or even first manifestation can occur in adults, too. Aetiologically, a spontaneous mutation of the GNAS-1 gene, which codes for an intracytoplasmatic embryonic transducer protein responsible for bone maturation, has been suggested [2]. Fibrous dysplasia mainly affects long bones, such as femur and humerus; however, craniofacial bones and the paranasal sinuses can also be involved. During growth surgical interventions should be considered carefully because of the possibility of the spontaneous cessation of the disease after puberty [2, 7]. A complete and possibly extensive resection with the risk of cosmetic deformity is not necessarily indicated. In the case of clinical symptoms, a less invasive surgical procedure for tumour debulking might be sensible [2, 8].

Among the fibro-osseous lesions of the paranasal sinuses, ossifying fibroma is the one with the lowest incidence. Its aetiology is still unresolved, but trauma may be an important factor, particularly in the development of cemento-ossifying fibroma [14]. Presently, the classification of ossifying fibromas is somewhat confusing. Multiple, sometimes overlapping terms are used, including ossifying fibroma, cementifying fibroma, cemento-ossifying fibroma, desmo-osteoblastoma, psammo-osteoid fibroma, psammomatoid ossifying fibroma, juvenile ossifying fibroma, juvenile aggressive ossifying fibroma or juvenile active ossifying fibroma [11]. These terms partly refer to the more or less well-defined subtypes of ossifying fibroma, but some of them might also be used synonymously [1, 11]. From a clinical point of view, division into the *cemento-ossifying fibroma* (COF) and the *juvenile ossifying fibroma* (JOF) seems to be reasonable [10].

The cemento-ossifying fibroma (COF) of the head region affects most often patients between the ages of 20 and 40 years [15]. It is typically found in the mandibulo-dental region, where it shows a slow-growing behaviour with a low recurrence rate after resection [8]. The juvenile ossifying fibroma (JOF) appears mostly in the upper jaw region of children under 15 years. It is characterized by a high recurrence rate after surgical removal [3, 4, 10]. Ossifying fibromas rarely occur in the paranasal sinuses, e.g. the sphenoid, frontal and ethmoid sinuses, where they are believed to behave more aggressively [8]. Especially the JOF can be rapidly growing and locally destructive [1, 2, 4, 8]. For this reason, the complete resection of all subtypes of ossifying fibroma presenting in the paranasal sinuses is widely recommended [1, 3, 4, 8–11]. Radiotherapy is considered as ineffective and might even implicate the risk of malignant transformation [3]. Due to the high recurrence rate, a long-term follow-up is crucial even after complete resection, particularly in the case of JOF [8, 10].

The different therapy concepts for paranasal fibro-osseous lesions—restrictive and often conservative in osteoma and fibrous dysplasia as opposed to mainly surgical in ossifying fibroma—stress the importance of an accurate diagnosis [7], which is based on clinical, endoscopical, radiographic and histopathological findings. The CT-scan is the imaging of choice. An additional magnet resonance tomography is advisable for ruling out a cerebral or orbital invasion. While the diagnosis of osteoma is often straightforward, it is difficult at times to differentiate between ossifying fibroma and fibrous dysplasia, both clinically and radiologically [3]. Endoscopically, the ossifying fibroma appears as a hard, partially ulcerative, reddish or whitish mass. In the CT-scan it presents as a well-circumscribed, expansive mass of varying density with a bony shell [2, 16]. The sharply defined outside margin is the most important radiological sign for distinguishing between fibroma and fibrous dysplasia, in which the immature fibrobone merges with the healthy bone without demarcation [11]. For a definite diagnosis, the histological assessment of a tissue sample is essential [7, 11]. Fibrous dysplasia is a poorly delineated lesion with varying amounts of fibrous or osseous components. It is characterized by trabeculae of fibrous bone and the absence of osteoblasts. In ossifying fibromas metaplastic fibrous bone trabeculae may secondarily turn into lamellar bone. Histologically, ossifying fibromas show osteoblastic rimming of the trabeculae and a relatively monomorphic stroma with high cell density and little forming of collagen fibres [17]. The histopathologic assessment and differentiation of the single subtypes of ossifying fibromas can often be very difficult and sometimes even impossible. However, obtaining the clinically meaningful differentiation between COF and JOF should at least be tried.

Because of its locally aggressive behaviour and comparatively high vascularisation, the complete surgical resection of an ossifying fibroma of the paranasal sinuses can be challenging, particularly when the frontal skull base or the orbita are involved [2, 8]. Consultation of a neurosurgeon or an ophthalmologist might be advisable. Since ossifying fibroma is very rare, larger series on resection, particularly by using an exclusively endonasal approach, are missing [2, 13]. Traditionally, extranasal or microscopical techniques have been used to achieve complete resection [8, 13]. In case reports, the endoscopically controlled removal of ossifying fibromas has been described [11, 13, 14, 16]. Based on improved endoscopes and instruments, the further development of operation techniques (e.g. “four-hand-technique”) [18] and the routine application of precise navigational systems, the limits of the endoscopic approach could be extended over the last decades [12]. In accordance, the three surgically treated paranasal ossifying fibromas presented here could be removed exclusively endoscopically controlled. After resection a close follow-up is necessary since there is a high chance for recurrence. Over the study period (at least 6 months follow-up) none of the patients presented with residual or recurrent tumour.

Two patients with asymptomatic (case 1) or only slightly symptomatic (case 3) paranasal ossifying fibromas declined surgery after detailed information due to possible operative risks. In view of their age (45 and 47 years), the presence of a JOF was unlikely. In case 1, a COF was diagnosed histologically, whereas in case 3 further classification of the ossifying fibroma was not possible. During a 2-year follow-up no progression of the fibromas was detected, either clinically or radiologically, suggesting that not all forms of paranasal ossifying fibromas behave aggressively. Thus, a wait-and-scan strategy—similar to the recommended procedure for other fibro-osseous lesions like osteoma or fibrous dysplasia [2]—might be justified in selected cases of asymptomatic cemento-ossifying fibroma of the adult. Prerequisites are a definite (histological) diagnosis, detailed information of the patient and close clinical and radiological control. By contrast, based on present knowledge the obviously much more aggressive juvenile ossifying fibroma (JOF) should always be totally resected.

Conclusion

The ossifying fibroma of the paranasal sinuses is a rare fibro-osseous lesion. Based on the varying growth behaviour, a subdivision into the aggressive juvenile ossifying fibroma (JOF) and the less aggressive cemento-ossifying fibroma of the adult (COF) seems reasonable. The correct diagnosis of the respective subtype can be demanding and should consider the patient's age, clinical endoscopic findings, localisation, growing behaviour, the imaging results (CT and MRI) and the histopathological diagnosis. Complete removal is considered the therapy of choice. The exclusively endoscopically controlled resection of the fibroma was possible in the presented cases. In two patients with COF, who declined surgery, the long-term follow-up revealed no progression. While the JOF should always be surgically treated because of its potential aggressiveness, for the asymptomatic paranasal ossifying fibroma of the adult (COF) a wait-and-scan strategy might be chosen, as recommended for paranasal osteoma and fibrous dysplasia. Either way, a close long-term follow-up is essential.

Conflict of interest The authors declare that they have no conflict of interest.

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Case Report

Endoscopic Resection of Sinonasal Hemangiopericytoma following Preoperative Embolisation: A Case Report and Literature Review

Georg J. Ledderose,[1] Donata Gellrich,[1] Markus Holtmannspötter,[2,3] and Andreas Leunig[1,4]

[1] *Department of Otorhinolaryngology, Head and Neck Surgery, Ludwig Maximilian University Munich, Marchioninistraße 15, 81377 Munich, Germany*
[2] *Institute for Neuroradiology, Ludwig Maximilian University Munich, Marchioninistraße 15, 81377 Munich, Germany*
[3] *Center for Diagnostic Radiology, Department of Neuroradiology, Rigshospitalet, University of Copenhagen, Denmark*
[4] *Center for Rhinology, Starnberg/Munich, Germany*

Correspondence should be addressed to Georg J. Ledderose; johannes_georg.ledderose@med.uni-muenchen.de

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Objectives. Hemangiopericytoma is a rare tumor entity deriving from pericytes. Less than 5% of hemangiopericytoma occur in the nasal cavity and are characterised by a rather benign nature with low tendency of metastasis. However, as the recurrence rate in the literature ranges from 9.5% to 50%—depending on the length of followup—a radical surgical resection is considered as the gold-standard treatment. Only a few years ago, a wide external approach, usually via lateral rhinotomy or Caldwell-Luc, was performed. Endoscopic techniques were regarded as appropriate for small low-vascularised tumors only. *Methods*. We present the case of a 64-year-old patient with an extended sinonasal hemangiopericytoma, who was successfully treated by an endoscopic controlled endonasal tumor resection after embolisation with Onyx. Further, to support the new treatment option, we review the literature concerning all features of sinonasal hemangiopericytomas and their therapeutical management. *Results/Conclusion*. Onyx, which has not been described in the context of hemangiopericytoma yet, is a very effective embolic agent for a preoperative embolisation of sinonasal hemangiopericytoma allowing a safe endoscopic surgery.

1. Introduction

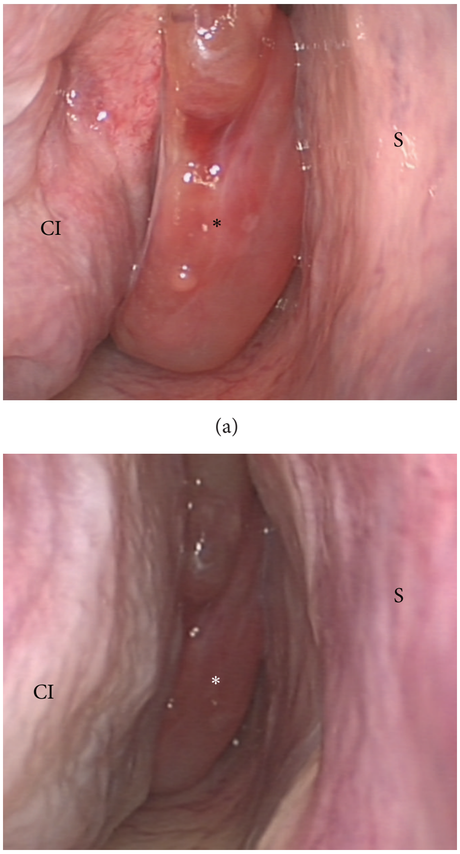
Sinonasal hemangiopericytomas are a rare upper aerodigestive tract tumor deriving from perivascular modified smooth muscle cells. This vascular neoplasm firstly described in 1943 by Stout and Murray [1] may arise in any part of the body [2]; only 15%–30% are located in the head and neck region [3]. Of these, only 5% are found in the nasal cavity and paranasal sinus [4]. Hemangiopericytoma located in the nasal region is frequently characterized by a more benign nature with low tendency of metastasis [5]; however, sinonasal hemangiopericytoma exhibits a recurrence rate of approximately 25% [3].

In the last two decades, less than 250 cases have been published so that sinonasal hemangiopericytoma represents a rather rare tumor entity. A total of 57 patients out of the 250 analysed cases underwent an endoscopic tumor resection, of which 23 patients received a preoperative embolisation of the high vascularised hemangiopericytoma.

Here, we review the relevant literature and report about a 64-year-old patient presenting with sinonasal hemangiopericytoma. We used a liquid embolic agent, consisting of an ethylene vinyl alcohol dissolved in the organic solvent dimethyl sulfoxide (DMSO) and containing tantalum powder for radiopacity (Onyx) and performed an endoscopically controlled resection. To our knowledge, this is the first report about preoperative embolisation of sinonasal hemangiopericytoma using this material.

2. Case Report

A 64-year-old Caucasian man in good general health presented to our institution complaining of nasal obstruction



(a)

(b)

Figure 1: Endoscopic view of the operational field before surgery (a). After embolization, shrinking is clearly seen (b). Nasal septum (S), concha inferior (CI), concha media (CM), sphenoid sinus (SS), and tumor (*).

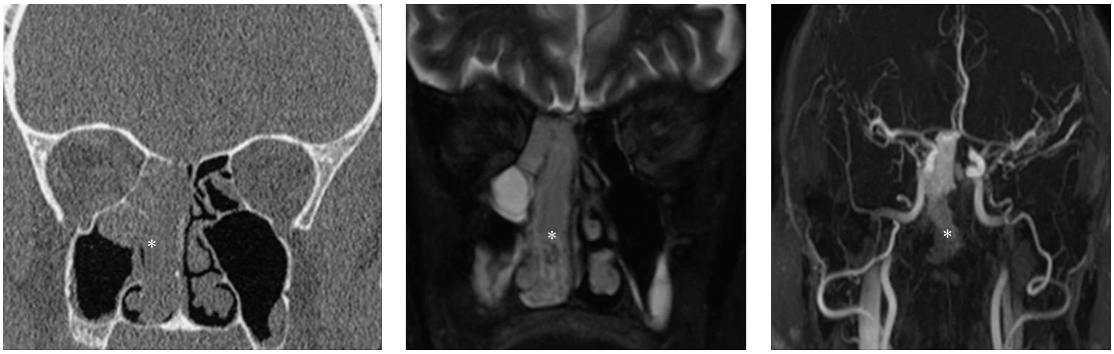
on the right side for 6 weeks. Further, the patient reported a singular episode of epistaxis. Other nasal symptoms such as recurrent epistaxis or sinusitis were absent. Head and neck examination revealed a polypoid mass obstructing the right nasal cavity subtotally (Figure 1(a)). The posterior rhinoscopia showed a partial obstruction of the nasopharynx as well. There was no cervical adenopathy or other disorder in the head and neck. A CT scan of the paranasal sinuses revealed a soft-tissue mass involving the right dorsal nasal cavity, the right ethmoid, and the sphenoid sinus as well the nasopharynx (Figure 2(a)). A strong enhancement was seen after intravenous contrast administration. Further, bone destruction of the right ethmoid structures was demonstrated. In the CT staging, neither local nor distant metastases were visible. The MRI confirmed a circumscribed, submucosal, heterogeneous mass measuring $5 \times 2.4 \times 4.5$ cm, extending from the cribriform plate to the platinum durum, infiltrating the ethmoidal cells and the right maxillary and sphenoid sinus (Figure 2(b)). The cribriform plate also seemed to be infiltrated. The tumor was brightly vascularised with flow signal voids. Conventional digital angiography through the right external iliacal artery revealed a vascular network of the mass, mainly supplied by the right maxillary artery, as also seen in MRI angiography (Figure 2(c)). Additionally, the angiography showed a half-moon shaped blush, in particular of the dorsocranial portion of the tumor, supplied by ethmoidal branches of the right ophthalmic artery. A tumor resection by an endonasal approach was planned upon a biopsy revealing the suspicion of hemangiopericytoma. As the biopsy was followed by a prolonged bleeding and as the radiologic findings confirmed the high vascularisation of the mass, the right maxillary artery as the main vascular feeder was selectively embolised with an ethylene vinyl alcohol dissolved in the organic solvent dimethyl sulfoxide (Onyx) 24 hours before surgery (Figures 1(b) and 3). Following the preoperative embolisation, the endoscopic tumor resection was performed via endonasal approach with a navigation system. Upon resection of the dorsal part of the septum, a pedicled tumor insertion at the rhinobasis was exhibited in four hands technique and resected completely without any complication (Figure 4).

Histologically, the tumor was submucosal, unencapsulated, and showed fascicular pattern. The tumor cells were uniform, spindle-shaped with oval nuclei, accompanied by an inflammatory cell infiltrate including eosinophils. “Stag horn” vessels, as typical for hemangiopericytoma, were focally identified as well as few nuclear atypia. Immunohistochemistry revealed a strong staining pattern to vimentin but no reaction with actin. The cells were immunoreactive for CD 34, slightly for Bcl2 and CD99 but negative for S-100 and epithelial membrane antigen (EMA). The Ki67-proliferation index was slightly increased at <2%. Due to a high recurrence rate of up to 25%, the patient has been followed up regularly by endoscopic surveillance and MRI controls. One year after surgery, there was no sign of locoregional disease recurrence, neither by endoscopy (Figures 5(a) and 5(b)) nor by MRI (Figures 6(a) and 6(b)).

3. Discussion and Literature Review

The term “sinonasal hemangiopericytoma,” formed 60 years ago, covers a wide range of neoplasia, all characterized by their histological appearance consisting of a uniform cell pattern of high cellularity and staghorn vessel formations. As a diversity of tumors meet this criterion, the term “sinonasal hemangiopericytoma” has become disputed. Some authors prefer the term “intranasal hemangiopericytoma-like tumors” [5]; other studies postulate a close relationship with soft tissue hemangiopericytoma justifying the term “sinonasal hemangiopericytoma” [1]. The WHO classification of head and neck tumors proposed in 2005 that sinonasal hemangiopericytoma should be named glomangiopericytoma due to their similarity with glomus tumors [6] especially as there are studies revealing a closer relationship of sinonasal hemangiopericytoma to glomus tumors than to hemangiopericytoma [7].

In the clinical-pathological routine, the practice has become accepted to use the term “hemangiopericytoma” for all tumors with hemangiopericytoma-like histology after exclusion of other tumor entities [8]—as done in this case report.



(a) (b) (c)

Figure 2: Radiologic findings of sinonasal hemangiopericytoma. CT scan (a), MRI scan (b), and MRI angiography (c). A circumscribed, submucosal, heterogeneous soft-tissue mass measuring $5 \times 2.4 \times 4.5$ cm involving the right dorsal nasal cavity, the right ethmoid, and sphenoid sinus as well as the nasopharynx. A strong enhancement was seen after intravenous contrast administration (*tumor).

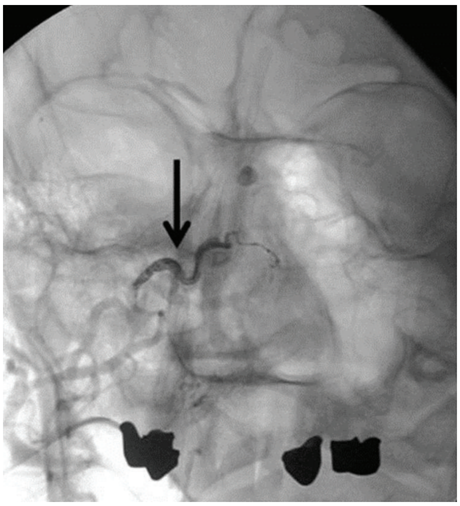


Figure 3: Sinonasal hemangiopericytoma after embolisation with Onyx. Right maxillary artery embolised with Onyx (→).

Sinonasal hemangiopericytoma mainly affects middle-aged patients [9]. Generally, the manifestation of a sinonasal hemangiopericytoma is possible at any age; our collected literature cases revealed the age of 18 years as the earliest age of onset [10]. Some studies report an equal-to-slight female predominance [11]; other authors deny any gender predilection [12]. In our literature review, including the case reports of 206 patients, the gender of patients was mentioned in 65 cases only. This group of 65 patients in total was composed of 32 male and 33 female patients—reflecting an equal gender distribution.

The etiology is still unknown [13]. Former theories that trauma, long-term steroid use, arterial hypertension, and hormone imbalance might be predisposing risk factors for sinonasal hemangiopericytoma [14] are regarded as obsolete in the contemporary literature [15, 16].

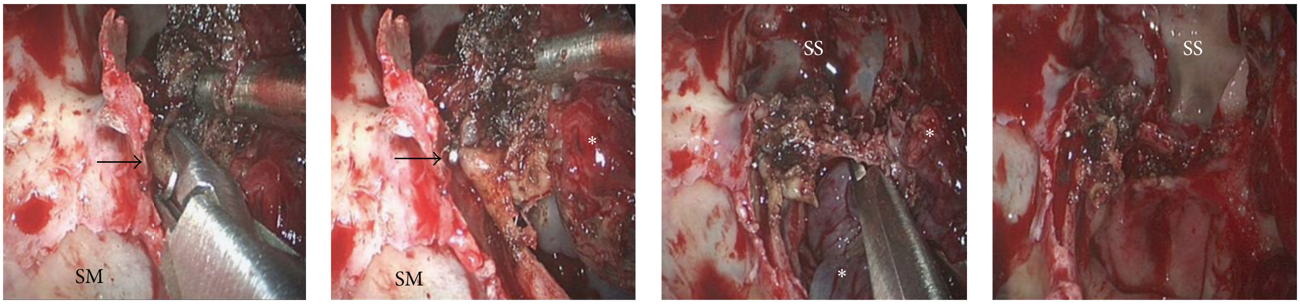
In 1976, Compagno and Hyams provided the first detailed description and characterisation of the histological findings of sinonasal hemangiopericytoma [5]. Thus, sinonasal hemangiopericytoma presents hardly any nuclear polymorphisms with no hemorrhagia, no necrosis, nor any other characteristics found in malign hemangiopericytoma at somatic sites. Due to the typical histological characteristic of the uniform cell pattern of high cellularity with staghorn vessel formations, Compagno and Hyams formed the term "hemangiopericytoma-like" [3, 5]. However, the histological findings firstly described in 1976 by Compagno and Hyams do not allow to make an explicit histopathologic diagnosis.

Large vessels with staghorn configuration, which are also often cited as characteristic for sinonasal hemangiopericytoma, are neither specific nor entirely sensitive findings as they may be seen in many other soft-tissue spindle-cell neoplasia [17].

Since immunochemistry has found its entrance into pathology, several epitopes have been identified to help diagnosing sinonasal hemangiopericytoma. However, vimentin and CD34 are considered as the only antigens to be reliably detected in tumor cells of sinonasal hemangiopericytoma [12], whereas later studies state a lower CD34 expression of 80%–90% [8]. Other epitopes as actin, S-100 or factor XIIIa can be found in a few cases only [18]. Though, the histological detection of vimentin and CD34 does not allow any discrimination from other neoplasms of the entity of solitary fibrous tumors. According to recent studies, the vessels of the sinonasal hemangiopericytoma partially show a positive staining for D2-40 (the so-called podoplanin antibody). In case of positivity for D2-40, a clear discrimination between sinonasal hemangiopericytoma and other entities is possible, as podoplanin is not expressed by any solitary fibrous tumor other than hemangiopericytoma [8, 19].

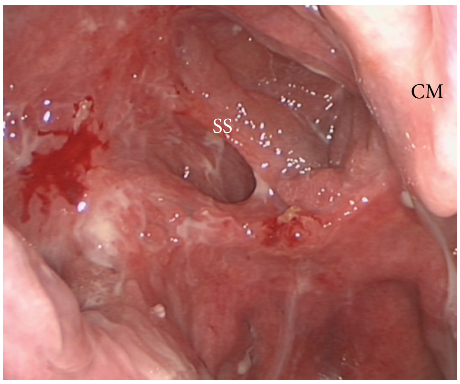
The majority of sinonasal hemangiopericytoma is located in the nasal cavity itself and presents clinically with epistaxis and nasal obstruction [20, 21]. Pain occurs rather rarely and has to be regarded as sign of local infiltration [22]. Vision Impairment, headache, and local swelling are less frequent symptoms as well [23].

In the ENT examination, sinonasal hemangiopericytoma is frequently mistaken for inflammatory polpys [13]. Although only histology can find the final diagnosis [23, 24],

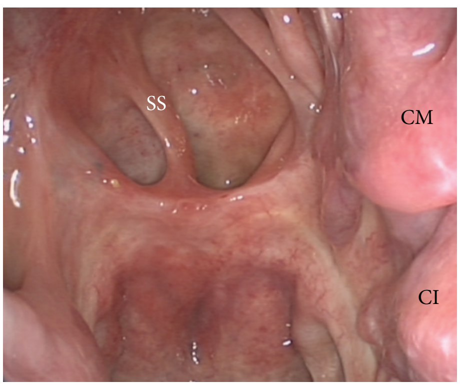


(a) (b) (c) (d)

Figure 4: Endoscopically controlled resection. Operation started as a common functional endoscopic sinus surgery including clearing out the ethmoid cells and identifying the frontal sinus and the maxillary sinus. Upon resection of the dorsal part of the septum, a pedicled tumor insertion at the rhinobasis and the lateral nasal wall was found. The tumor's feeder vessels were exhibited. The vessels originating from the arteria sphenopalatine were specifically identified and clipped ((a), (b); →). The tumor was completely resected using four hands technique ((c), (d)). Maxillary sinus (SM), sphenoid sinus (SS), and tumor (*).

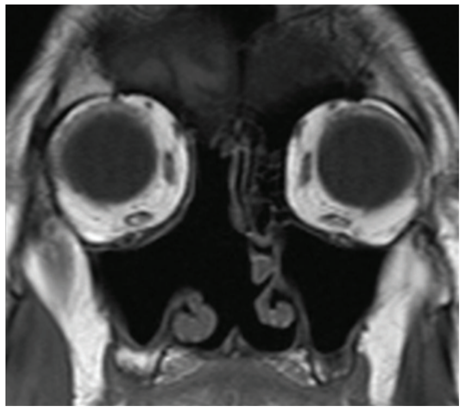


(a)

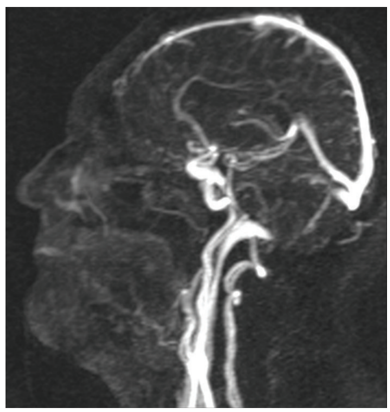


(b)

Figure 5: Endoscopic view of the operation field 3 months after surgery (a). No sign of recurrence. Twelve months after surgery (b), there is no sign of irritation. Concha inferior (CI), concha media (CM), and sphenoid sinus (SS).



(a)



(b)

Figure 6: MRI (a) and MRI angiography (b) 12 months after surgery. The right nasal cavity appears to be free without any signs of tumor recurrence or residual.

biopsy is not recommended as it may lead to severe bleeding [20, 25]. Therefore, radiological examination by CT and/or MRI should preferentially be performed. A CT scan of the paranasal sinuses reveals a soft-tissue mass with strong enhancement after contrast administration and can clearly demonstrate bone destruction [26]. However, the CT scan does not allow a clear differentiation between tumor mass and inflammatory fluid in obstructed paranasal sinuses. Hence, it is highly recommended to perform an MRI scan as well. On T1-weighted MRI, sinonasal hemangiopericytoma appears as solid isointense masses with strong enhancement after intravenous contrast administration; on T2-weighted imaging, the tumor mass is isointense to low intense in contrast to inflammatory fluid reflecting high-intense signals [27]. The intravenous contrast administration during CT and MRI scan allows estimating the tumor vascularisation. The best visualisation of the vessel supply of the sinonasal hemangiopericytoma can be achieved by conventional digital angiography, which helps at the same time to plan a preoperative embolisation [23].

In order to estimate the risk of an aggressive clinical course, several criteria for malignance have been established. A large tumor size of >6.5 cm and the histological finding of necrosis, nuclear atypia, and a high number of mitosis are associated with a poorer prognosis [9]. However, the presence of one of these features does not predict an aggressive clinical course; it is rather the sum of several criteria for malignancy to be considered as prognostically unfavorable [1, 17]. Though, there are sinonasal hemangiopericytoma without any of the mentioned criteria which nevertheless develop malignancy. Hence, a certain potential of malignancy should always be taken into account [8].

In the meantime—concerning meningeal hemangiopericytoma—it has become apparent that metastases are the only proven sign of a poor outcome, whereas histological features fail to show any prognostic value [16, 28].

In contrast to hemangiopericytoma located at somatic sites, sinonasal hemangiopericytoma has a very low tendency for metastasis. The metastasis rate is approximately 5% [3]. However, lymphogenous and hematogenous metastases are described in the literature [14]. Regional lymph nodes as well as lungs, liver, and bone are the most common site of metastasis [11, 20].

Thus, the lethality of sinonasal hemangiopericytoma is less than 5%, in opposition to somatic hemangiopericytoma exhibiting a lethality of 25%–60% [3, 16].

In sinonasal hemangiopericytoma, the therapy of choice is indisputably the wide-field excision with negative margins [14, 29]. Only a few years ago, an external surgical approach, usually via lateral rhinotomy, was considered as the standard treatment regimen [22, 24] and was even regarded as obligatory when the tumor breached the cribriform plate [30] or spread beyond the sinonasal region [24]. An elective neck dissection is not indicated as lymphogenous metastases occur rarely [29].

Recently, the tumor resection via endonasal approach became more important in the treatment of sinonasal hemangiopericytoma. Out of 206 cases published in the last two decades and collected in this literature review, 57 patients received an endoscopic endonasal resection, of which 23 patients underwent a preoperative embolisation.

The endoscopic controlled endonasal approach offers many advantages compared to the external approach—particularly, a better overview for accurate assessment of the tumor insertion, the margins and the surrounding tissue. Obtaining a comparable view with an external approach would only be possible by a surgically extensive exposition, which appears less appropriate for a usually localized tumor [20]. Further, an external approach is associated with an increased amount of blood loss during the surgical exposure [31]. Other added benefits of an endonasal approach are the preservation of the natural physiology of the nose and the reduced risk of damaging the lacrimal structures. The avoidance of outer incision with consecutive scars is another advantage of the endoscopic controlled endonasal approach [20].

In very few cases only, an endoscopic controlled endonasal approach may be limited by certain factors, for example, a large tumor size with invasion in the fossa pterygopalatina, orbital involvement, or a highly vascularised tumor [20]. However, a high vascularisation of the tumor does not generally exclude an endoscopic resection provided that embolisation may be successfully performed before surgery. A preoperative embolisation helps to avoid intraoperative hemorrhagia and affects positively the tumor size and the area of resection [9].

Our personal experience let us to recommend an endoscopic controlled endonasal resection even in case of a large and highly vascularised tumor, preferably by using four hands technique in cooperation with a neurosurgeon. As condition precedent to an endonasal approach, we consider—apart from the surgeon's technical expertise—a successful embolisation before surgery. During endonasal endoscopic tumor resection, a proper hemostasis is crucial to avoid excessive bleeding necessitating a conversion to an external approach [24]. Twenty-three patients out of 206 collected literature cases of sinonasal hemangiopericytoma underwent an embolisation before surgery. However, no data are available concerning the embolisation with Onyx as successfully performed in the case hereby described.

Onyx is a liquid embolic agent, consisting of an ethylene vinyl alcohol dissolved in the organic solvent dimethyl sulfoxide (DMSO) with added tantalum powder for radiopacity. In the early 1990s, the use of a similar substance as an endovascular embolic agent for intracranial arteriovenous malformations was described by Taki et al. [32].

The polymerisation commences quickly upon the intra-arterial injection of Onyx. When placed in aqueous solutions or suspensions as blood, the DMSO diffuses out and causes the precipitation of the copolymer. Consequently, a spongy embolus which does not adhere at the delivery catheter is formed allowing a slow, controlled embolisation [33]. The depth of the distal vascular penetration by Onyx depends on the concentration of the copolymer providing a good handling of the embolic material [34].

The Onyx copolymer precipitates radially from the outer layer inwards over minutes to hours giving an excellent control throughout the embolisation with Onyx. Further, the Onyx embolus does not adhere to the delivery catheter. Therefore, the catheter does not have to be withdrawn as quickly as when using other liquid embolic agents, allowing a controlled and safe embolisation [35].

In the hereby described case of preoperative embolisation with Onyx, there were no adverse effects apart from a garlic similar smell during the first 36 hours after surgery, which is based on the expiration of the DMSO. Hence, Onyx is a safe and effective liquid embolic agent for the preoperative embolisation of sinonasal hemangiopericytoma.

To our knowledge, there are no prospective studies concerning the effectivity of other therapy modalities as radiotherapy or chemotherapy; all available data are based on retrospective studies with a rather small number of cases [20].

Chemotherapy shows a limited effectivity and is indicated as palliative treatment in the event of inoperable tumors or metastases [36]. Methotrexate, cyclophosphamide, vincristine and adriamycin may lead to a partial remission [37].

Radiotherapy as primary therapy of hemangiopericytoma of all sites has met with very limited success and is associated with a recurrence rate of 87.6% during the first five years [38] compared to a recurrence rate of 47% after tumor resection as primary therapy [15]. Hence, the radiotherapy is recommended for unresectable tumors and should be combined with chemotherapy [24].

In the event of recurrence of which the incidence is according to the literature from 9.5% to 50%, depending on the length of the followup, a reresection is considered as the treatment of first choice [39]. Although an adjuvant radiation may reduce the risk of recurrence, it is controversially dis-cussed due to the good outcome after the reresection and the side effects of radiation of the head and neck [20].

The prognosis of hemangiopericytoma is not definitively predictable, neither by the clinical appearance nor by the histological findings. Recurrence may occur after a prolonged disease-free interval and has been even reported 26 years after tumor resection so that a regular, life-long surveillance of patients with hemangiopericytoma is mandatory [12, 15]. Further, recurrence frequently precedes the development of metastases after tumor resection [29].

4. Conclusion

In sinonasal hemangiopericytoma, an endoscopically controlled, endonasal tumor resection after preoperative embolisation proved to be an excellent treatment method. Together with the surgeon's technical expertise, the embolisation with Onyx allows a well-controlled endoscopically endonasal resection of even extended sinonasal hemangiopericytoma.

Conflict of Interests

The authors declare that they have no conflict of interests. There was no financial support provided by the companies.

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RHINOLOGY

Endonasal resection of early stage squamous cell carcinoma of the nasal vestibule

Georg J. Ledderose · Simone Reu · Anna S. Englhard · Eike Krause

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Abstract The squamous cell carcinoma of the nasal vestibule (SCCNV) is a comparatively rare malignant disease. It occurs in the transition zone at the limen nasi. The choice of treatment for small tumors is a matter of controversy. Due to better cosmetic results, radiation therapy is usually recommended, however some recent reports have suggested that early stage tumors are equally or even more effectively managed by surgery. There was no standardized surgical procedure applied in these studies, though. The goal of our investigation was the retrospective evaluation of patients with a T1 or T2 carcinoma of the nasal vestibule who were treated surgically with an endonasal, endoscope-controlled approach at our ENT clinic between 2008 and 2010. Given the rarity of SCCNV, the 10 included cases represent the largest group of patients with early stage SCCNV treated primarily surgically by an endonasal approach so far. Our study shows that the endonasal resection of an early stage vestibular carcinoma seems adequate as a possible therapy. In the follow-up observation period no local or loco-regional recurrence was observed. The external cosmetic damage and endonasal scarring do not appear to be pronounced even following cartilage resection and were regarded as not seriously disadvantageous.

G. J. Ledderose (✉) · A. S. Englhard · E. Krause
Department of Otorhinolaryngology, Head and Neck Surgery, Ludwig Maximilian University, Marchioninistr. 15, 81377 Munich, Germany
e-mail: johannes_georg.ledderose@med.uni-muenchen.de

S. Reu
Department of Pathology, Ludwig-Maximilian University, Munich, Germany

Keywords Squamous cell carcinoma of the nasal vestibule · Endonasal resection · Endoscopic control · Cosmetic result · Radiation

Introduction

The nasal vestibule is the anterior part of the nasal cavity, extending from the nares to the limen nasi, a mucosal fold formed by the upper margin of the alar cartilage and the lower margin of the lateral cartilage. The medial wall of the nasal vestibule is built of the nasal septum, the columella, and the medial section of the alar cartilage. The anterior part of the nasal vestibule is lined with squamous epithelium containing sebaceous glands and hair follicles [1]. At the limen nasi, the squamous epithelium becomes the typical ciliated epithelium of the nasal mucosa. The transition zone is called the muco-cutaneousjunction and is covered with transitional epithelial cells [2, 3].

In this area squamous cell carcinoma of the nasal vestibule (SCCNV), a comparatively rare malignant disease occurs. The incidence is given as 2–4 per million [4, 5]. SCCNV therefore represents less than 1 % of all head and neck tumors [3]. It causes nonspecific symptoms, such as itching, nasal respiratory obstruction, hemorrhaging and ulceration. Initially it can be easily mistaken for an inflammation, which is why often several months pass between the first symptoms and the definitive histological diagnosis [1].

In most cases SCCNV is histologically well or moderately differentiated (Fig. 1). Its 5-year survival rate ranges between 40 and 92 % [2–6]. It depends strongly on tumor size and local extension [4]. For example, Agger et al. reported in their study cancer-specific survival rates of 83, 63 and 39 %, for tumors classified as T1, T2 or T3

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according to Wang, respectively [3]. The staging system established by Wang is commonly used to assess the tumor spreading. This system has only three stages, is clinically orientated and describes the size of the tumor according to the adjacent structures [7]. It is widely viewed as simpler and more useful than the staging system of the UICC [1–3].

Another decisive prognostic criterion is the existence of lymph node metastases [3–5]. Lymphatic drainage takes place primarily through the submental and submandibular lymph nodes. Lymph node metastases are found in 8–15 % of all diagnosed SCCNV [1, 5]. Distant metastasis in the lung, brain, bones and skin is rare, but may occur during the further course of the disease [2].

The choice of treatment for small tumors (stage 1 or 2) is a matter of controversy. In principle, surgery or radiation therapy is possible. Due to the better cosmetic results, radiation therapy (66–75 Gy) is usually the therapeutical method of choice [3, 5–12]. However, individual investigations have shown that with regard to local tumor control, the outcome of surgical therapy is comparable to or better than that of primary radiation therapy, even in small tumors; the surgical procedures were not exactly described [3, 6]. Endonasal surgical treatment of SCCNV offers the possible advantage of a similar scale of tumor resection as conventional surgical approaches while morbidity is reduced. The goal of our investigation was the retrospective evaluation of cases in which patients were surgically treated for a T1 or T2 carcinoma of the nasal vestibule at our ENT clinic with an endonasal, endoscope-controlled access.

Methods

Ethical approval was given by the university's ethics committee in the form of a declaration of ethical no-objection. Additionally, the study was accepted by the department's data protection official.

A retrospective analysis was performed on all patients ($n = 10$) undergoing surgery for an early staged SCCNV (stage T1 or T2 according to Wang and UICC) at our ENT department between 2008 and 2010. Larger tumors with deeper infiltration as well as lesions with an unidentifiable site of origin were excluded (Figs. 2, 3; Table 1).

Preoperative CT staging included paranasal sinuses, neck, thorax and abdomen. The primary therapy was surgical resection via an endonasal, endoscope-controlled access (Fig. 3).

Patient history, symptoms and clinical findings, the extension of the lesion, sites of involvement, the surgical procedure, results of radiological and histopathological examination, complications, the duration of the in-patient stay and a possible adjuvant therapy were recorded. Histological analysis was done by the Department of Pathology of the Ludwig-Maximilians-University Munich.

The follow-up survey was done routinely every 6 weeks the first year, every 3 months the second year and every 6 months as of the third year. It comprised a clinical and endoscopic examination, an ultrasound scan of the neck and photo documentation.

Results

Ten patients diagnosed with an early staged SCCNV at the Department of Otorhinolaryngology, Head and Neck Surgery, Ludwig-Maximilians-University Munich, Germany, were included between 2008 and 2010.

The mean age was 50.4 years (range 32–65), the gender ratio was 4/6 (m/f). Five patients were smokers or former smokers. According to Wang's staging system eight tumors were classified as T1 and two as T2 carcinoma showing infiltration of the upper septum (Figs. 2, 3; Table 1). A CT scan proved absence of deeper infiltration. In two cases suspect cervical lymph nodes were detected. There was no sign of distant metastasis.

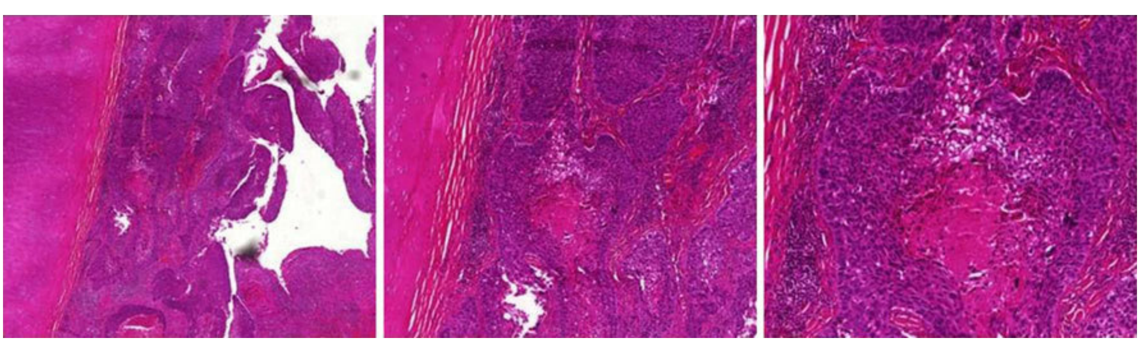

Fig. 1 Histological image (HE stain, magnification ×20, ×50 and ×100) of a moderately differentiated SCCNV. It shows stromal infiltration, necrosis, focally keratinizing and already touching the cartilage

Fig. 2 Clinical appearance of a SCCNV originating from the mucocutaneousjunction (stage 1)

An endonasal surgical approach was chosen in all patients. Endoscopical control proved beneficial especially in the deeper regions of the main nasal cavity. In each case, the tumor was resected en bloc, followed by an additional circular resection to assure safe margins. In five patients, parts of the alar cartilage had to be resected, in three of them including parts of the lateral cartilage. In three patients parts of the septal perichondrium and the septal cartilage had to be removed as well. Complete resection was confirmed histopathologically in all patients. In one case, close margins were detected.

Due to suspect lymph nodes a selective neck dissection of levels 1 and 2 was performed in two cases. One patient showed a lymph node metastasis (regio 1b). No serious intra- or postoperative complications were observed.

The postoperative treatment was similar to the care of patients who undergo rhino- or septoplasty. The average in-patient stay was 4.9 days (range 2–10 days). After interdisciplinary discussion adjuvant radiation was performed in two cases with lymph node metastasis or close margins, respectively (Table 1).

The average follow-up time was 37.6 months (range 25–55 months). Follow-up examinations revealed neither local nor loco-regional recurrence in any of the patients (Table 1). Two patients showed long-term enlargement of cervical lymph nodes. The performed selective neck dissections revealed no metastasis. External retractions and internal nasal scarring occurred up to 12 months postoperatively and depended mostly on the extent of cartilage resection (Figs. 3, 4). A one-sided obstruction of nasal

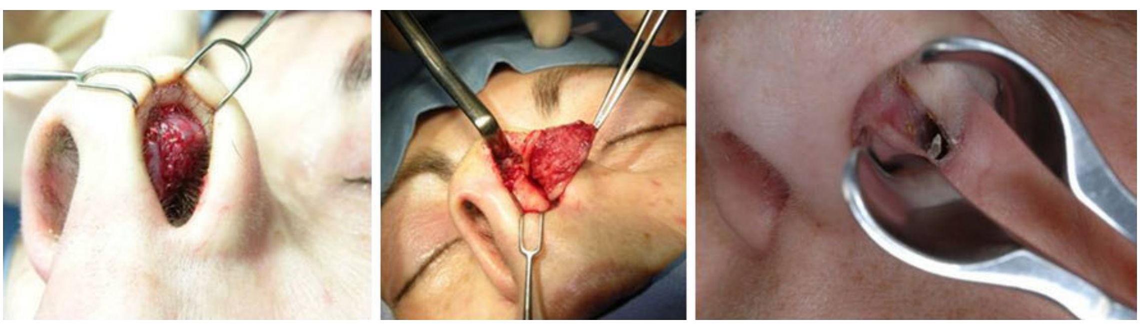

Fig. 3 Endonasal resection of a SCCNV (stage 2). After about 12 months the endonasal photo documentation showed only minor scarring despite resection of parts of the septal perichondrium and the medial crus of the alar cartilage

Table 1 Table of all patients ($n = 10$) undergoing endonasal surgery for an early staged SCCNV

No.	Staging (UICC)	Staging (Wang)	*N*	In-patient stay (days)	Adjuvant therapy	Follow-up period (months)	Recurrence
1	T1	T1	cN0	4	–	55	–
2	T2	T1	cN0	5	–	50	–
3	T2	T1	pN1	10	Radiotherapy	45	–
4	T2	T1	cN0	4	–	40	–
5	T1	T1	cN0	3	–	38	–
6	T1	T1	cN0	2	–	36	–
7	T2	T2	pN0	9	–	30	–
8	T1	T1	cN0	5	–	29	–
9	T2	T2	cN0	4	–	28	–
10	T2	T1	cN0	3	Radiotherapy	25	–
				Mean 4.9		Mean 37.6	

Fig. 4 Cosmetic result 12 months postoperatively after endonasal resection of a T2 SCCNV with resection of parts of the septal, the alar and the lateral cartilage. Up to now the patient has rejected a cosmetic or functional correction

respiration was considered the main complication. Within the observation period none of the patients decided to undergo cosmetic or functional correction.

Discussion

The optimal therapy for early stage carcinoma of the nasal vestibule is subject to some controversy. Radiation is the most common recommended therapy. The ostensibly better cosmetic result is offered as an argument for radiation [5–12]. Surgery is recommended for larger tumors and for salvage operations when the patient does not respond to radiation. In these cases radical resection in combination with postoperative radiation is superior to primary radiation therapy, since larger tumors subjected to primary radiation tend to recur [4]. Wallace et al. declare more than 4 cm as the limiting size for treating tumors by primary radiation therapy [6].

In retrospective studies Agger et al. and Dowley, for example, proved that even in small tumors (T1 and T2) surgery shows comparable results with regard to loco-regional absence of tumor and survival rate [3, 4]. The advantages of surgical therapy are evident: The patient is no longer subjected to the direct and indirect consequences of radiation therapy, such as soft tissue necrosis and stress of prolonged treatment [6]. The cosmetic result following an operation is viewed as disadvantageous, though. However, it is necessary to consider that especially for T1 and some T2 stage tumors endonasal resection is often possible. This intervention entails negligible morbidity, shows a good tendency to heal and has only mild cosmetic deficits. In addition, Dowley et al. found in their retrospective investigation of cases over a period of 20 years that only around 65 % of patients had good cosmetic results following radiation therapy [4].

The patients included in our study exclusively underwent endonasal operations. The support of an endoscope proved beneficial especially in deeper lying regions of the main nasal cavity. In this way regions such as the inner resection margin and the posterior nasal septum, which various authors consider to be especially critical [1, 5], could be optimally assessed intraoperatively. The surgical technique proved to be largely stressfree for the patient and produced no scarring from skin incisions. Naturally, depending on the extent of resection of the morphogenetic cartilage, external retractions and internal nasal scarring resulted. However, even following cartilage resection these were generally discreet and were not perceived as serious by the patients. A one-sided obstruction of nasal respiration was considered the main problem. Up to now all patients have rejected cosmetic or functional correction. No serious intra- or postoperative complications were observed. Follow-up examinations showed no local or locoregional recurrence in any of the patients.

Since SCCNV is a comparatively rare disease it was not the aim of our study to compare different treatment options, which would have required a much larger study group. However the excellent loco-regional control that we observed in our study is in accordance with the results that Agger et al. found in their subgroup of 19 surgically treated patients with T1 tumors (94 % loco-regional control). The even slightly better outcome in our group of 10 patients may be explained by the lower number of patients and the shorter follow-up period of three years. This observation period, however, seems adequate for initial assessment in view of the fact that early relapse is most frequent. In their retrospective study including 174 patients Agger et al. found that all recurrences occurred within the first 3 years following diagnosis. This is also confirmed by other studies [3, 5, 8].

Due to highly rare lymph node metastases in the early tumor stage the standard neck dissection is indicated only if suspicious lymph nodes are found by imaging [1, 7]. Naturally, the prerequisite is a thorough initial staging examination and a regular follow-up, which must include at least a cervical ultrasound. Up to 11 % of the patients develop a lymph node recurrence, mostly in the first years following diagnosis [1, 5, 11, 12]. Therefore, a targeted imaging control is indispensable during the follow-up observation period. This recommended procedure proved also useful in the patients that we examined. In two patients with conspicuous morphological imaging findings a selective neck dissection of regions 1 and 2 was performed. In one case a submandibular lymph node metastasis was confirmed (regio 1b). In the follow-up observation period lymph nodes were conspicuous in another two patients. For this reason a selective neck dissection was performed, too. However, this showed no tumor infiltration.

Jeannon et al. recommend postoperative radiation for lymph node metastasis or resection with close margins [2]. These criteria applied to two patients, who therefore were treated with adjuvant radiation therapy.

A relationship between the formation of the tumor and nicotine abuse, as repeatedly postulated, could not be confirmed in our study, which might be explained by the small study group. As in other studies, a possible HPV association of the vestibular carcinoma was investigated histologically via the p16 method, but could not be proven [3].

Decisive for the success of endonasal tumor resection is the careful selection of patients, as well as a thorough preoperative diagnosis with the aid of a CT scan or MRI to correctly assess the extent of the tumor spreading and the structures affected [4]. In our opinion, deep infiltration represents a contraindication for endonasal access. This must be evaluated as a poor prognostic sign and demands a radical surgical intervention and possibly postoperative radiation therapy [2].

Our results strongly indicate that endonasal surgery is an effective treatment option for early stage SCCNV tumors. Moreover, by applying the comparatively gentle endonasal surgical approach cosmetic side effects were mostly negligible in our patients. Given the rarity of SCCNV, however, a prospective multicenter study would be desirable to compare the different therapeutic options and develop definite therapeutic recommendations.

Conclusion

Our study shows that endonasal resection is an adequate therapy for T1 or T2 vestibular carcinoma. Using an endoscope may be helpful, especially in the deeper nasal regions. This approach eliminates the side effects of radiation to the patient. In the follow-up observation period no local or loco-regional recurrence was observed. No external scarring due to skin incisions resulted. External cosmetic damage and endonasal scarring do not appear to be pronounced even following cartilage resection and were regarded by the patients as not seriously disadvantageous.

Conflict of interest The authors declare that they have no conflict of interest.

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RHINOLOGY

Surgical management of recurrent sinonasal mucosal melanoma: endoscopic or transfacial resection

G. J. Ledderose · A. Leunig

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Abstract Sinonasal mucosal melanoma (SNMM) is associated with poor prognosis. Local recurrence is common and represents a major problem in the therapy. Wide resection surgery is usually applied. However, given the almost futile prognosis, optimal symptom control may be preferable to wide resection at all costs. The aim of our study was to analyze the outcome in patients with recurrent SNMM treated by transfacial radical surgery or by a less invasive endoscopically controlled approach. Patients with recurrent grade III or IV staged SNMM who presented to our ENT department between 2000 and 2010 were either treated by transfacial ($n = 10$) or endoscopically controlled surgery ($n = 12$). The patients' charts were reviewed for clinical symptoms, relapse-free time and survival time. Clinical symptoms improved after surgery. The morbidity after endoscopic surgery was significantly lower than after transfacial surgery. The chosen surgical technique did neither affect relapse-free nor survival time. When treating recurrent SNMM, the comparatively gentle and less mutilating endoscopic approach proved to be a sufficient surgical procedure, being not inferior to aggressive surgery with respect to recurrence and survival rate.

First results of the study were presented at the 5th World Congress for Endoscopic Surgery of the Brain, Skull Base and Spine and the First Global Update on FESS, the Sinuses and the Nose in Vienna, March 2012.

G. J. Ledderose (✉) · A. Leunig
Department of Otorhinolaryngology, Head and Neck Surgery, Ludwig Maximilian University Munich, Marchioninistr. 15, 81377 Munich, Germany
e-mail: johannes_georg.ledderose@med.uni-muenchen.de

A. Leunig
Rhinology Center, ENT-Clinic Munich Bogenhausen, Dr. Gaertner GmbH, Munich, Germany

Keywords Sinonasal mucosal melanoma · SNMM · Local recurrence · Survival · Relapse-free time · Endonasal · Extranasal

Introduction

The sinonasal mucosal melanoma (SNMM) is a very rare tumor entity with an estimated incidence of 1 per 500.000 per year [1–3]. It bears a particularly poor prognosis even if compared with other malignomas of the paranasal sinuses. A high risk of hematogenous metastasis and often late diagnosis are responsible for reported 5 year survival rates of only 15–45 % [4–10]. Due to its low radiosensitivity [5, 6, 8, 9, 11, 12] radical surgery with wide margins is considered the therapy of choice [3, 4, 6, 9, 13]. The high incidence of local recurrence often within a few months after surgery substantially contributes to the almost futile prognosis [7]. The complex anatomy of the paranasal sinuses and incomplete resection, submucosal lymphatic spread and possibly implantation during surgery all favor local relapse [3, 6, 9, 14, 15]. Recurrent SNMM is characterized by its increased local aggressiveness. In contrast to the mostly expansive growth of the primary tumor, the growing behavior becomes infiltrative and often multilocular. Complete resection is frequently impossible, and the prognosis deteriorates dramatically [7, 9, 14, 16]. It is important to take this into account when planning surgical treatment of local recurrent SNMM. Currently, radical resection applying transfacial or transcranial approaches is still widely considered as the "gold standard" [3]. This often implicates mutilating procedures such as (partial) resection of the nose or enucleation of the eye. However, given the poor prognosis it must be questioned whether radical surgical treatment is always justified [3]. Alternatively, endoscopically

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controlled removal of visible tumor tissue is often possible [8], which reliably controls clinical symptoms (particularly epistaxis and blocked nasal breathing) [8, 9, 11, 17, 18].

Only few published studies have focused on recurrent SNMM. In our study we retrospectively analyzed the outcome in patients treated for recurrent SNMM at our ENT department applying either conventional radical or endoscopic surgery. We found no significant difference between these surgical approaches with regard to relapse rate or survival time.

Methods

The study was approved by the institutional ethics committee and the department's data protection official.

Patients ($n = 22$) presenting to our ENT department between 2000 and 2010 with recurrent SNMM classified as T3, T4a or T4b (UICC 2009) who underwent surgery were included in the study. There was no or only localized infiltration of the skull base or periorbita (Table 1). Hospital stay and postoperative pain were recorded. The postoperative pain was monitored using a visual analogue scale ranging from 0 (no pain) to 10 (severe pain). Results were registered 6 h after surgery (i.e. day 1) and subsequently every day in the morning until discharge from hospital.

Staging (UICC 2009), histopathology, verification of clear margins, local and distant metastasis, relapse-free time, and survival time were recorded and analyzed with regard to the respective surgical approach.

All patients were treated with curative intent. To assure an unambiguous histopathological and immunohistochemical diagnoses, we only included patients as of 2000. Only first recurrent tumors of comparable size and infiltration were included to avoid possible bias, e.g. from the more likely use of the endoscopical approach with small, locally restricted tumors. Therefore neither very small nor very large or inoperable tumors were included (Table 1). Likewise, patients were excluded if the macroscopically visible tumor could not be removed completely. Furthermore, patients who had previously undergone radiotherapy, immunomodulatory therapy or chemotherapy were excluded.

As our study group consisted of patients with recurrent melanoma only, all of the patients underwent adjuvant radiotherapy after surgery. Chemo or immunomodulatory therapy was inconsistently applied in later stages of the disease.

Statistical analyses

The reference point for survival analyses was the day of surgery of recurrent SNMM. The primary endpoint was relapse-free survival, and overall survival was a secondary endpoint. Survival data were analyzed using Kaplan–Meier's method and compared with the log-rank test. Student's *t* test was applied to test for significance of differences in the recorded parameters and $p < 0.05$ was considered statistically significant.

Results

Of the 22 patients included, 10 patients underwent a transfacial procedure and 12 patients were treated endoscopically. As tumor staging was similar in all cases, the choice of the surgical approach was mainly based on the surgeon's preference (Table 1a, b). All patients in our study group underwent a curative intent R0 resection, regardless of the surgical approach. All patients were treated by postoperative radiotherapy and obtained intermittent chemotherapy at a later time point.

The main preoperative symptoms were a blocked nose and nose bleeding. These symptoms improved similarly irrespective of the surgical procedure applied.

Postoperative pain was significantly lower in the endoscopically treated group (Fig. 1), and hospitalization was significantly shorter than in patients undergoing a transfacial procedure (4.2 [2–7] vs. 11.2 [3–21] days, $p < 0.05$).

Histopathological verification of clear margins was difficult in both treatment groups, leaving it basically to the clinical judgment of the surgeon to define complete resection [6]. Even though clear margins were histopathologically verified in 40 % of patients undergoing a transfacial procedure (Table 1a) compared to 16.6 % in the endoscopically treated group (Table 1b), this did not influence the course of the disease. Distal metastasis and local recurrence occurred in 60–70 % regulation of whether clear margins were stated. Furthermore, the surgical approach had no significant impact on second recurrence or survival rate. The mean disease free interval was 24.6 ± 4.6 months and 19.5 ± 4.0 months after an endoscopical or transfacial approach, respectively (Fig. 2a). The mean survival time in endoscopically treated patients was 39.9 ± 7.4 months compared to 47.7 ± 11.5 months in patients who underwent transfacial surgery (Fig. 2b).

Selective neck dissection was limited to cases with radiologically suspicious cervical lymph nodes (e.g. in PET–CT scan). Three patients were neck dissected, and one of the patients was found positive for cervical lymph node metastasis in level 2B (Table 1b).

Distant metastasis was seen in 50 % of the patients treated by transfacial surgery and 67 % of endoscopically controlled treated patients in the follow-up (Table 1).

Table 1 Tumor characteristics and follow-up in patients undergoing **a** extranasal surgery and **b** endonasal surgery for local recurrent sinonasal mucosal melanoma

Year of surgery	Histology	Surgical technique	TNM UICC 2009	Infiltration of periorbita (E) or dura (D)	Verified clear margins	Distant metastases	Follow-up
(a) Extranasal surgery							
2002	Amelanotic	Transfacial (Weber–Ferguson)	T3N0	–	No	Pulmonary	Death with local recurrence and distant metastases
2003	Amelanotic	Transfacial (midface degloving) and additional subcranial approach	T4bN0	D	No	None	Death with local recurrence
2003	Amelanotic	Transfacial (lateral rhinotomia, ablatio nasi)	T3N0	–	Yes	Cerebral, osseous	Death with local recurrence and distant metastases
2003	Amelanotic	Transfacial (Weber–Ferguson, enucleation of the eye)	T4bN0	D, E	No	Pulmonary	Death with local recurrence and distant metastases after one additional surgery
2004	Amelanotic	Transfacial (Weber–Ferguson), enucleation of the eye	T4aN0	E	Yes	Pulmonary	Death with local recurrence and distant metastases
2004	Melanotic	Transfacial (midface degloving, enucleation of the eye)	T4aN0	E	Yes	Cerebral	Death with local recurrence and distant metastases
2005	Melanotic	Transfacial (Weber–Ferguson, enucleation of the eye)	T4bN0	D, E	No	None	Death with local recurrence
2006	Amelanotic	Transfacial (lateral rhinotomia)	T3N0	–	No	None	Two further operations, relapse-free at end of study
2009	Melanotic	Transfacial (lateral rhinotomia)	T3N0	–	Yes	None	Relapse-free
2010	Amelanotic	Transfacial (Weber–Ferguson)	T4bN0	D	No	None	Relapse-free
(b) Endonasal surgery							
2002	Amelanotic	Endoscopic resection	T3N0	–	Yes	Cerebral, hepatic, osseous	Death with local recurrence and distant metastases
2004	Amelanotic	Endoscopic resection	T3N0	–	No	Pulmonary	Death with local recurrence and distant metastases
2007	Melanotic	Endoscopic resection	T4aN0	–	No	Hepatic	Death with local recurrence and distant metastases
2007	Amelanotic	Endoscopic resection	T4aN0	–	No	Pulmonary	Death with local recurrence and distant metastases
2008	Amelanotic	Endoscopic resection	T3N0	D	No	Pulmonary	Death with local recurrence and distant metastases
2008	Amelanotic	Endoscopic resection	T3N0	D	No	None	One further operation, relapse-free at the moment
2008	Amelanotic	Endoscopic resection	T4aN0	E	No	Pulmonary	Death with local recurrence and distant metastases

Table 1 continued

Year of surgery	Histology	Surgical technique	TNM UICC 2009	Infiltration of periorbita (E) or dura (D)	Verified clear margins	Distant metastases	Follow-up
2008	Melanotic	Endoscopic resection	T4bN1[a]	D, E	No	Pulmonary, cerebral	Locally relapse-free after one further operation; death with distant metastases
2010	Amelanotic	Endoscopic resection	T3N0	–	Yes	None	Relapse-free
2010	Melanotic	Endoscopic resection	T4bN0	D	No	None	Relapse-free
2010	Melanotic	Endoscopic resection	T3N0	–	No	None	Relapse-free
2010	Melanotic	Endoscopic resection	T4aN0	D	No	Cerebral	Death with local recurrence and distant metastases

[a] Level 2a

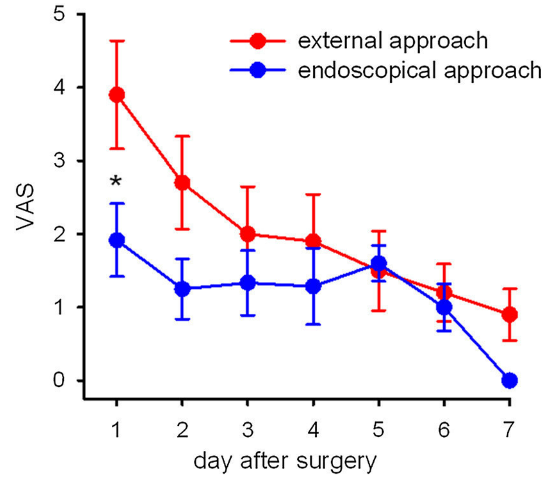

Fig. 1 Postoperative pain in patients treated by transfascial or endoscopical techniques. Pain was estimated using a visual analogue scale (VAS) ranging from 0 (no pain) to 10 (severe pain); $*p < 0.05$

Discussion

A common problem in the course of treatment of SNMM is the high rate of local recurrence, bearing an almost futile prognosis [3, 7, 14, 16, 19]. Confronted with a distinct destructive and often multilocular growing behavior of the relapse [9], curative surgery has to be more extensive, often mutilating. This inevitably has a severe impact on the quality of life [16]. Transfacial techniques are often favored as they best enable clear margins [4]. An alternative is the transnasal endoscopic procedure [8].

The comparison and evaluation of the different therapeutic strategies are hampered by the low incidence of SNMM [3]. Some studies performed a combined analysis of melanoma and other tumor entities of the paranasal sinuses and skull base [17, 18], which significantly complicates the extraction of specific data [11]. Furthermore, studies comprising higher case numbers mainly have to rely on retrospective analyses covering long periods of patient enrollment [8, 20]. Earlier publications need to be interpreted cautiously in the light of recent advances in histochemical, immunohistochemical and ultrastructural diagnostics, particularly as the histopathological diagnosis is often not straightforward [10]. Furthermore, some authors do not differentiate with respect to tumor stage, primary or recurrent tumor, inoperability, metastasis, or localization [9, 11, 14, 15, 17]. In addition, the inconsistent use of various adjuvant therapies complicates any comparative analysis [8].

Preliminary data indicate that endoscopically controlled resection of first manifestation of SNMM may have a similar outcome as conventional surgical techniques regarding recurrence rate and survival time [8, 9, 11, 17, 18], as long as complete resection of the tumor, the most important

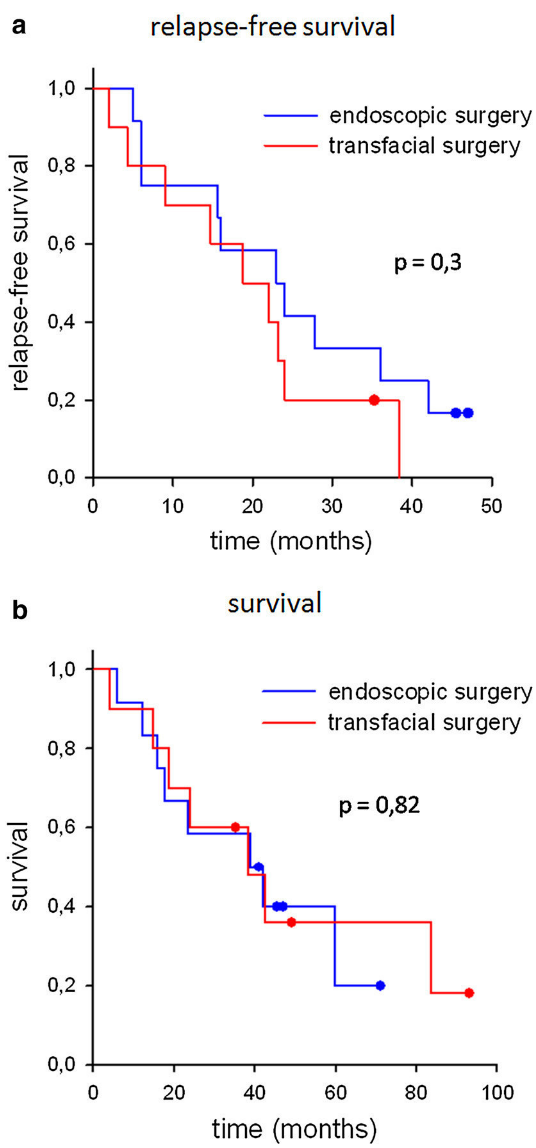

Fig. 2 Kaplan–Meier estimates of 22 patients treated for recurrent sinonasal mucosal melanoma. Disease-free (**a**) and survival time (**b**) stratified by the surgical technique (external approach, $n = 10$; endoscopical approach, $n = 12$)

prognostic criterion, is guaranteed [6, 11]. Our data suggest that this is also true for recurrent SNMM. Whereas the average survival time observed in both groups confirmed previous reports [4–10], we found no significant differences in survival time between the treatment groups. Importantly, the quality of life was less affected by the endoscopic approach. Patients treated endoscopically reported overall less pain, benefitted from less visible cicatrization and a shorter period of hospitalization than patients who underwent conventional surgery. While the surgical approach did not significantly impact survival time and overall outcome, we found that distant metastasis, particularly cerebral metastasis, is often the determining lethal factor. There was no significant difference in the occurrence of metastasis between the two treatment groups, though.

Resection of locally advanced or recurrent tumors is frequently followed by postoperative radiotherapy to improve local tumor control [5, 9, 21, 22] and the overall outcome [4]. As our patients suffered from recurrent tumors, all of them were given postoperative radiation therapy. It should be noted, however, that radiosensitivity of SNMM appears to be generally low [3]. Several studies could not find an increased survival rate [10, 23] or improved local control [8, 24, 25] in patients undergoing postoperative radiotherapy. Similarly, the evidence for any positive effect of systemic cytostatic or immunomodulatory chemotherapy has not been conclusive [6, 11]. Chemotherapy is infrequently applied and usually reserved for late tumor stages with or without distant metastasis [9, 11]. In our patient group, cytostatic or immunomodulatory therapies were applied inconsistently and mostly in the stage of distant metastasis. Nonetheless, new biological treatments are emerging and might hold promise for the future [14].

In summary, while complete resection certainly remains the primary therapeutic goal, the local recurrent melanoma can often be treated by the use of comparatively gentle endoscopic controlled surgical techniques, which provide an excellent visualization, cause less pain, leave no mutilating visible scars and require less postoperative care than conventional surgery. It should be carefully considered whether to choose endoscopical surgical techniques as this will most likely not affect the prognosis but contribute to an improved quality of life in the terminally ill.

Conclusion

SNMM is a rare tumor with a short median survival. It has a high rate of distant metastasis and relapse. The prognosis for recurrent local SNMM is even worse. Our study is the first to analyze specifically different surgical strategies for the therapy of local recurrent SNMM. The comparatively gentle and less mutilating endoscopic approach proved to be a sufficient surgical procedure, being not inferior to wide resection surgery with respect to recurrence and survival rate. Further verification of these results should be performed in future studies.

Conflict of interest The authors declare that they have no conflict of interest.

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CORRESPONDENCE: OUR EXPERIENCE

WILEY

Cerebrospinal fluid leaks during endoscopic sinus surgery in thirty-two patients

1 | INTRODUCTION

The incidence of cerebrospinal fluid (CSF) leaks occurring during functional endoscopic sinus surgery (FESS) ranges from 0.2% to 0.8%.[1] Accurate repair is crucial as an undetected dural defect poses a significant risk to the patient. Endonasal endoscopic closure of CSF leaks has replaced open surgical techniques.[2,3] Therapeutic success depends on the location of the CSF leak, the surgical procedure and the postoperative treatment.[3-5] In order to prevent iatrogenic damage to the anterior skull base and dura, the surgeon must be familiar with possible predisposing conditions. Here, we reviewed the 32 cases of iatrogenic CSF leaks occurring during FESS at our ENT department between 2000 and 2015. Our aim was to identify potential risk factors and define predilection sites for CSF leaks in the anterior skull base during FESS. In addition, we evaluated the method of repair with respect to the location of the leak.

2 | MATERIAL AND METHODS

2.1 | Institutional review board approval

This study is a retrospective review of anonymised clinical records. Approval for this study was obtained from the ethics committee of the Ludwig Maximilians University of Munich and the department's data protection official.

2.2 | Study design, setting and participants

A total of 32 patients who experienced an iatrogenic dural lesion while undergoing endoscopic sinus surgery for the treatment of inflammatory paranasal sinus disease at the Department of Otorhinolaryngology, Head and Neck surgery of the Ludwig Maximilians University Munich between 1/2000 and 1/2015 were included. CSF leaks due to other causes were excluded. We recorded the indication for FESS and, if applicable, for previous sinus surgeries, the patients' skull base anatomy according to Keros' classification, the surgeons' experience, the exact location of the CSF leak, the surgical procedure performed, the grafts used to cover the defect, the application of intrathecal fluorescein and of lumbar drainage, the rate of success and the follow-up period.

3 | RESULTS

3.1 | Study population

Thirty two cases were included in this study. 17 patients were male, and 15 were female; the mean age was 43.2 years. All individuals underwent endoscopic sinus surgery for the treatment of chronic inflammatory paranasal sinus disease. 14 patients presented with chronic rhinosinusitis with polyps. 18 subjects had a history of previous paranasal sinus surgery. In 18 patients, the defect was discovered intraoperatively and closed in the same session.

There was no significant difference between the study population and the general population with regard to skull base anatomy using Keros' classification criteria[6]:

Keros type	General population (%)[6]	Study population (n)	Study population (%)
1 (depth of 1-3 mm)	26.3	10	31
2 (depth of 4-7 mm)	73.3	21	66
3 (depth of 8-16 mm)	0.5	1	3

Approximately 7000 endonasal sinus surgeries were performed at our hospital over the study period of 15 years. CSF leaks occurred in 32 cases (0.4%). 29 (90.6%) of these leaks occurred in the hands of comparatively inexperienced surgeons who had performed less than 100 FESS.

3.2 | Diagnosis and symptoms

In 18 patients, no further diagnostic procedures were needed as the defect was discovered intraoperatively and was closed immediately. The other 14 patients showed symptoms such as watery rhinorrhea (in 12 cases, 86%), headache (6 cases, 43%) and vertigo with nausea (1 case, 7%). One patient (7%) presented with meningitis as the first symptom. In all 14 patients, rhinoliquorrhoea was verified by a positive beta-2 transferrin test (100%). First symptoms occurred on average 2.3 months (1 day to 9 months) after sinus surgery.

3.3 | Surgical procedure of CSF leak closure

All CSF leaks were closed via an endonasal endoscopically controlled approach. The endonasal repair was performed by four different experienced surgeons (>500 of FESS).

Keypoints

- The inadvertent CSF leak is a very rare but potentially hazardous complication in endoscopic sinus surgery.
- We performed a systematic review of a series of 32 cases of CSF leaks occurring during sinus surgery.
- We identified surgical inexperience and impaired orientation in the surgical field as the main risk factors for iatrogenic CSF leaks.
- The lateral lamella of the cribriform plate and the anterior ethmoid roof are predilection sites for CSF leaks in the anterior skull base.
- We determined suitable methods of repair based on the location of the leak and found high success rates after endoscopic leak closure.

3.4 | Intrathecal application of fluorescein and lumbar drain

Sodium fluorescein was applied intrathecally in 12 patients (86% of postoperatively diagnosed CFS leaks). The perforation could be identified in 11 cases (92%). In one patient, liquor staining failed to expose the leak, most likely due to insufficient head tilting or waiting time between dye application and surgery. The perforation was obvious in the CT scan in this case and could be identified easily and repaired during endoscopic surgery. No adverse effects were recorded. A lumbar drain was routinely placed in eight patients only during the first 5 years of the study period and did not show any benefit with respect to the surgical outcome.

3.5 | Location of the skull base defect and surgical closure

Location of CFS leaks and details about the surgical technique and the materials used for closure are summarised in Table 1.

3.6 | Surgical outcome, complications and follow-up

There were no intraoperative complications. One individual (3%), who had been treated with a lumbar drain, complained of severe headaches and suffered from a pneumocephalus. Three patients (9%) experienced a relapse of the CSF leak resulting in a success rate of 91% (Table 1). Revision surgery was performed 1, 5 or 32 days after the unsuccessful first closure. The success rate of the secondary repair procedure was 100%. The follow-up period was at least 16 months.

4 | DISCUSSION

4.1 | Synopsis of key findings

Our study reveals potential risk factors for an inadvertent CSF leak during FESS. These include the lack of surgical experience and impaired orientation in the surgical field due to excessive inflammatory disease or previous surgeries. The majority of CSF leaks were located in the lateral lamella of the cribriform plate and the anterior ethmoid roof. Intrathecal application of sodium fluorescein can reliably help in localising the leak intraoperatively. The choice of the graft material was not critical. In general, we recommend the combination of an underlay-onlay technique for leak repair. However, defects in the lateral lamella of the cribriform plate can often be only approached by an onlay technique.

4.2 | Strengths of the study

Although several studies exist on the endoscopic repair of skull base defects, the number of studies that focus on iatrogenic CSF leaks occurring during sinus surgery is surprisingly small. Results are partly contradictory and often do not distinguish between different causes of CSF leaks.[7] To the best of our knowledge, there is no study

TABLE 1 Localisation of the skull base defect and surgical technique and material of dura repair, cases of failure

Localisation of CSF leak		Surgical technique: Overlay	Underlay	Combination	Material used for dura repair: TachoSil© (Fibrinogen/ Thrombin)	Fibrin sealant	Autologous or allogenic fascia	Mucous membrane flap pedunculated/ free	Nasoseptal flap	Failure of primary closure
Lateral lamella of cribriform plate	17 (53%)	15 (47%)	-	2 (6%)	16 (50%)	9 (28%)	1 (3%)	2 (6%)	-	3 (9%)
Anterior ethmoid roof	9 (28%)	2 (6%)	-	7 (22%)	8 (25%)	5 (16%)	1 (3%)	-	-	-
Posterior ethmoid roof	3 (9%)	1 (3%)	-	2 (6%)	2 (6%)	1 (3%)	1 (3%)	-	-	-
Sphenoidal sinus	2 (6%)	-	1 (3%)	1 (3%)	1 (3%)	-	-	-	1 (3%)	-
Posterior wall of frontal sinus	1 (3%)	1 (3%)		-	1 (3%)	-	-	-	-	-
Overall	32 (100%)	19 (59%)	1 (3%)	12 (38%)	28 (88%)	15 (47%)	3 (9%)	2 (6%)	1 (3%)	3 (9%)

comprising a comparably high number of cases and focusing specifically on this patient cohort.

4.3 | Comparisons with other studies and clinical applicability of the study

4.3.1 | Predisposing conditions

Our data suggest that surgical inexperience is a main risk factor for inadvertent CSF leak during FESS.

Difficult orientation in the surgical field is another important risk factor. Orientation can be impaired due to excessive inflammatory disease resulting in an increased risk of bleeding or due to the loss of anatomical landmarks after previous surgeries. Consistently, the percentage of patients with a history of previous surgeries or chronic rhinosinusitis with polyps was comparatively high in our study group. Several reports confirm this finding.[2,3]

Anatomical variations, such as a low, asymmetric ethmoid roof ('dangerous ethmoid'), a lower cribriform height relative to the height of the ethmoid roof, and a greater slope of the skull base in the sagittal plane, may increase the risk for CSF leaks. However, we did not find any differences in the Keros type between our study group and the average population that would support this assumption.[6]

4.3.2 | Location of CSF leaks

Reports about the predilection sites of iatrogenic skull base injuries during sinus surgery are contradictory, and supporting data are often missing. In our study group, most defects (81%) were located in the lateral lamella of the cribriform plate and in the anterior ethmoid roof. These areas are, unlike the sphenoid sinus, for example, almost always in or in close proximity to the surgical field. In addition, the lateral lamella of the cribriform plate is the thinnest part of the rhinobasis.

4.4 | Surgical procedure of CSF leak closure

4.4.1 | Intrathecal use of fluorescein and lumbar drain

Fluorescein may be administered intrathecally to trace the leakage and to control the surgical success.[3,5] In our study, the defect could be demonstrated in 92% of the cases. Post-surgical lumbar drainage did not show any benefit but caused a significant pneumocephalus in one case. In accordance, most authors agree that lumbar drainage is not routinely indicated.[8]

4.4.2 | Choice of graft material

The type of occlusion material depends on the location and size of the defect. In addition, personal preferences of the surgeon play an important role.[3] A great variety of materials have been proposed, including homo- or autologous fascia, free or pedunculated mucous membrane grafts, fibrin glue and fibrinogen/thrombin preparations.[1-3,5,7] According to our results, the choice of the material does not have a major impact on the surgical success.

4.4.3 | Closure of the CSF leak

It is crucial to carefully expose the defect by completely removing the mucosa from the bone edges.[9,10] We found that a combination of onlay and underlay technique is suited for repairing defects in the ethmoid roof or sphenoid sinus. In the lateral cribriform plate, occlusion by onlay technique only is the method of choice as the lesions are usually small, the connection between dura and the thin bone is very close, and manipulation easily increases the defect. However, our data suggest that this could increase the risk for an unsuccessful closure. Major reconstructive procedures, for example by use of a nasoseptal flap, are rarely indicated.

4.4.4 | Rate of success

Reports indicate high overall success rates of endoscopic CSF leak repair between 90% and 97%.[3,9,10] In our patient cohort, 91% of primary and 100% of secondary repairs were successful. Our results suggest that leaks in the lateral lamella of the cribriform plate are the most difficult to repair. All insufficient dura closures happened in this area, most likely due to the local anatomy that makes surgical procedures more challenging.

CONFLICT OF INTEREST

The authors declare that they have no conflict of interest.

G.J. Ledderose[1]
K. Stelter[1,2]
C.S. Betz[1]
A.S. Englhard[1]
C. Ledderose[3]
A. Leunig[1,4]

[1]*Department of Otorhinolaryngology, Head and Neck Surgery, Ludwig Maximilians University Munich, Germany*
[2]*ENT-Center Mangfall-Inn, Rosenheim, Germany*
[3]*Department of Surgery, Beth Israel Deaconess Medical Center, Harvard Medical School, Boston, MA, USA*
[4]*Rhinology Center, ENT-Clinic Munich Bogenhausen, Dr. Gaertner GmbH, Munich, Germany*

Correspondence
G.J. Ledderose, Department of Otorhinolaryngology, Head and Neck Surgery, Ludwig-Maximilians-University Munich, Munich, Germany.
Email: *johannes_georg.ledderose@med.uni-muenchen.de*

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Surface laser registration in ENT-surgery: accuracy in the paranasal sinuses – a cadaveric study*

Georg J. Ledderose, Klaus Stelter, Andreas Leunig, Hjalmar Hagedorn

Department of Otorhinolaryngology, Head and Neck Surgery, Ludwig-Maximilians-University, Munich, Germany

SUMMARY

Over the past decade, surgical navigation systems have found widespread use in ENT-surgery. Navigational accuracy highly depends on the registration process. The objective of this study was to assess the accuracy in the paranasal sinuses and lateral skull base after surface laser registration using the navigation system VectorVisionCompact® (BrainLab, Heimstetten, Germany). Repeated measurements were performed on two cadaver heads. Sixteen titanium screw fiducials per head were placed in facial bones, the paranasal sinuses and the lateral skull base, thereby serving as exactly identifiable measurement points. The respective influence on measurement accuracy depending on the localization and conformation of the registration area was evaluated by performing symmetrically bilateral as well as strictly unilateral registrations. The resulting overall accuracy for a symmetrically bilateral surface laser registration was 1.13 ± 0.53 mm, ranging from 0.77 (sinus frontalis) to 1.76 (petrous bone) mm, and thus proved to be clinically sufficient. Increasing distance between target point and registration area went along with a decline in accuracy. Navigational accuracy was significantly influenced by the choice of the registration area. Best accuracy was detected after symmetrically bilateral registration.

Key words: accuracy, image-guided surgery, laser registration, paranasal sinuses

INTRODUCTION

Surgery of the paranasal sinuses and the frontolateral skull base, in close proximity to vital structures such as brain, carotid artery or optic nerve, is potentially hazardous and requires the utmost precesion. Over the past decade, surgical navigation systems have found widespread use in ENT-surgery [(1)]. They are appreciated as useful tools for clarifying complex anatomy and assisting in the exact positioning of surgical instruments, especially if intraoperative orientation is further complicated by the loss of surgical landmarks from previous surgeries or tumor destruction [(2-4)]. The clinical efficiency of navigation systems is influenced by human factors, for example requirements for specific skills, as well as surgical system properties [(5)]. Technical reliability of image-guided surgery (IGS) highly depends on successful registration, which is the process of establishing a correlation between a preoperative image data set (e.g. CT scan) and the intraoperative anatomy. Many registration methods are based on external markers, e.g. adhesive skin markers, bone screw markers or markers fixed on a headband or a Mayfield clamp [(4,6)]. Contour-based registration (e.g. surface laser registration), which aligns the unique contours of the face instead of external fiducial markers, is an attractive alternative to these methods in ENT-surgery because of its considerably higher practical convenience. It eliminates the need for the time-consuming application of external markers, which have to be fixed in the identical position at the time of the CT scanning prior to registration and at the time of surgery. Navigational accuracy has been reported to be slightly lower after surface registration as compared to fixed-marker based registration protocols, though [(7-9)]. As the registration process of calculating a mapping relationship between the image and the surgical anatomy can never be accomplished perfectly, inaccuracy is an inherent limitation of IGS systems. Surgical navigational accuracy, also referred to as target registration error (TRE), is defined as the distance between the real position of a surgical target or instrument and its indicated position in the CT scan [(10)].

So far, data about the actual surgical accuracy in the paranasal sinuses are only sparse [(8,11)]. In an experimental study using headset-based registration, theoretical TRE values as low as 0.3-0.4 mm were reported for vaguely defined anatomic land-

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marks in sinus cavities and skull base. Clinical relevance of these data has been questioned, though, as clinically observed navigational accuracy is generally substantially higher (11). For systems relying on laser-based registration, e.g. the VectorVision® system (BrainLab, Heimstetten, Germany), no studies determining navigational accuracy specifically in the sinuses or skull base, i.e. in the area of interest for sinus surgery, have been published. Results of previous studies using skin-affixed fiducials for accuracy measurements (7,9) cannot be easily applied to the situation in the paranasal sinuses as there is evidence that accuracy is influenced not only by the registration method but also by the position of the target point relative to the registration area (8,12).

The purpose of the present study was to assess the accuracy in the paranasal sinuses after surface laser registration using the navigation system VectorVisionCompact® (BrainLab). Objective and standardized measurement conditions should be guaranteed by the use of cadaver heads, which are superior to other experimental models such as skulls or plastic heads when doing surface scanning. Furthermore, the respective influence on measurement accuracy depending on the configuration and symmetry of the registration area was to be evaluated in this study.

MATERIALS AND METHODS

Navigation system execution

The experiments were performed on two cadaver heads (Institute of Anatomy, Munich University). Titanium screws fixed in facial bones, the paranasal sinuses and the frontobasal region served as exactly defined target fiducials. The exact landmark locations are listed in Table 1 and Table 2. Axial spiral computed tomography scans (slice thickness 1 mm) were obtained and transferred to the passive optical navigation system VectorVisionCompact® (BrainLab, Heimstetten, Germany).

Contour-based registration was performed with a handheld laser scanner device (z-touch®). No external markers are needed for this registration method. The system automatically correlates the position of the scanned area to the reference star and calculates each coordinate link with the corresponding point from the CT data set. Fixing the reference star to the skull by a bone screw ensured its constant position during the whole measuring procedure. Points for the surface laser scanning were distributed along the nasion, the forehead and the orbita rim. These parts are hairless and the skin covers the bones tightly, thus forming an individual spatial relief. Tissue shifting between CT scanning and registration is neglectable in these areas (6). The laser reflections detected by the infrared cameras of the navigation system represent the localization data, which is transferred to the system. Having detected a sufficient number of points (approximately 100), this three-dimensional information is matched with the image data set of the tomographies.

In order to determine whether the navigational accuracy is affected by the configuration and location of the registration area relative to the surgical field, in addition to symmetrically bilateral registration, strictly unilateral registration was performed by exclusively scanning areas located on the left or the right half of the face, respectively.

Navigational accuracy was assessed as previously described (7,9,13,14). The pointer was aimed at the clearly defined central depression of the target fiducials, which can be easily identified both in reality and on the navigation screen. In the paranasal sinuses the correct positioning was guaranteed by endoscopic control. The distance between the target point and the tip of the pointer was measured separately for the three planes (axial, coronar, sagittal) using the scale on the navigation screen. The highest value from these three measurements, i.e. the maximum deviation, represents a reasonable approximation to the navigational accuracy.

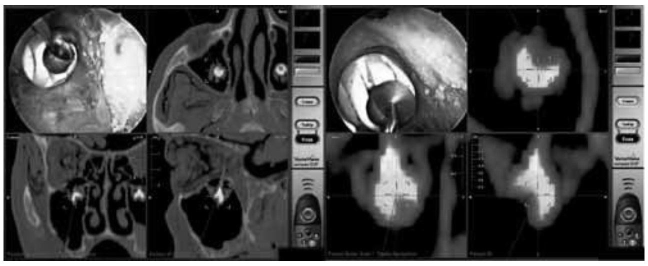

Figure 1. Screenshots during cadaver accuracy measurements (overview and zoom mode). The fiducial landmark of the left maxillary sinus is shown. The positional deviation was determined by use of the metric scale in 600% zoom mode (right).

Within each of the three tested conditions (unilateral left, unilateral right and symmetrically bilateral registration) 10 replicate measurements were performed for each of the two cadaver heads amounting to a total of 20 replicates per registration method for each landmark. Each replicate measurement consisted of shutting down and restarting the computer, reregistration by surface laser scanning and relocalization of the target fiducials.

Statistics

Data are expressed as mean values (mm) ± standard deviation. Differences in mean accuracy values depending on the registration area were tested for statistical significance by the Kruskal-Wallis-test.

RESULTS

The mean accuracy values for each landmark after symmetrical bilateral registration are shown in Table 1 and Table 2, resulting in an overall accuracy of 1.13 ± 0.53 mm. Single accuracy measurements ranged from 0 mm to a maximum value of 3.2 mm.

Accuracy values obtained for the superficial landmarks revealed the following trend: increasing distance between tar-

Table 1. Each of the two cadaver heads was registrated 10 times choosing a symmetrical target area (n=20 for each landmark). Data are expressed as mean values (mm) ± standard deviation.

Position of superficial landmarks	Accuracy (SD) [mm]
frontal, left	1.01 (0.56)
frontal, right	0.89 (0.42)
temporal, left	1.12 (0.23)
temporal, right	1.06 (0.40)
preauricular, right	0.98 (0.38)
preauricular, left	1.11 (0.39)
retroauricular, left	1.74 (0.44)

Table 2. Each of the two cadaver heads was registrated 10 times choosing a symmetrical target area (n=20 for each landmark). Data are expressed as mean values (mm) ± standard deviation.

Position	Accuracy (SD) [mm]
Sinus maxillaris (left)	1.02 (0.34)
Sinus maxillaris (right)	1.02 (0.27)
Sinus frontalis (posterior left)	0.91 (0.30)
Sinus frontalis (posterior central)	0.78 (0.37)
Sinus frontalis (posterior right)	0.77 (0.30)
Sinus ethmoidalis (top)	1.27 (0.42)
Sinus sphenoidalis	1.25 (0.47)
Lateral skull base	1.40 (0.64)
Petrous bone	1.76 (0.45)

get point and registration area went along with a decline in accuracy. Accordingly, accuracy was comparatively high at the frontal landmarks (1.01 ± 0.56 and 0.89 ± 0.42 mm), which are directly neighbouring on points used for registration, while the maximum deviation of 1.74 ± 0.44 mm was detected at the fiducial placed in the retroauricular area, i.e. in considerable distance to the registration area (Table 1).

This observation also applies to the accuracy determined for the fiducials inside the paranasal sinuses and the lateral skull base. Likewise, accuracy was highest next to the registration area in the frontal sinuses (0.91 ± 0.30 mm, 0.78 ± 0.37 mm and 0.77 ± 0.30 mm), while a loss of accuracy could be stated for the further distant landmarks in the sphenoid sinuses (1.25 ± 0.47 mm), the lateral skull base (1.40 ± 0.64 mm) and the petrous bone (1.76 ± 0.45 mm) (Table 2).

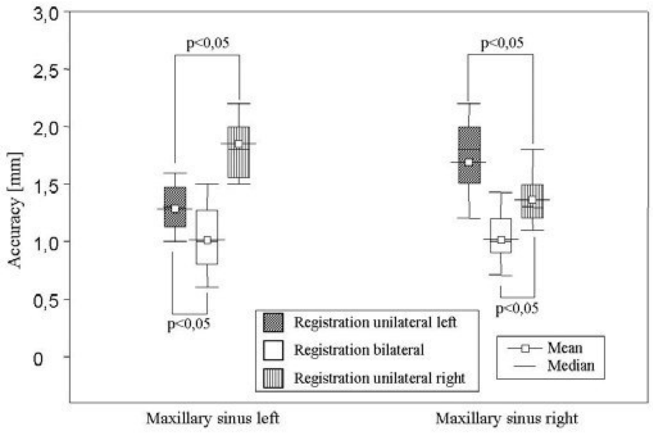

Figure 2. Accuracy at landmarks in the maxillary sinuses. Accuracy, measured in the maxillary sinuses after unilateral left, unilateral right and symmetrically bilateral registration.

Measurement accuracy was significantly influenced by the choice of the registration area. Registration restricted to one half of the face resulted in higher accuracy at ipsilateral landmarks compared to contralateral ones ($p<0,05$) (Table 3). Highest accuracy values were detected after symmetrically bilateral registration. In Figure 2 accuracy values following left-sided, right-sided or bilateral registration are exemplarily shown for the landmarks located in the maxillary sinuses. Similar results were achieved for the superficial landmarks.

Table 3. Each of the two cadaver heads was registrated choosing 10 times strictly the left and 10 times strictly the right half of the face as target area (n=20 for each landmark). Data are expressed as mean values (mm) ± standard deviation.

Position	Accuracy after unilateral registration (SD) [mm]	
	Registration left	Registration right
frontal, left	1.50 (0.40)	1.89 (0.39)
frontal, right	1.68 (0.52)	1.26 (0.48)
temporal, left	1.34 (0.31)	1.73 (0.25)
temporal, right	1.58 (0.49)	1.26 (0.58)
preauricular, right	1.61 (0.44)	1.26 (0.46)
preauricular, left	1.41 (0.44)	1.85 (0.40)
retroauricular, left	1.98 (0.44)	2.49 (0.42)
Sinus maxillaris (left)	1.29 (0.24)	1.85 (0.26)
Sinus maxillaris (right)	1.69 (0.38)	1.37 (0.26)
Sinus frontalis (posterior left)	1.17 (0.28)	1.11 (0.27)
Sinus frontalis (posterior central)	1.09 (0.37)	1.03 (0.28)
Sinus frontalis (posterior right)	1.16 (0.29)	1.10 (0.30)
Sinus ethmoidalis (top)	1.54 (0.21)	1.41 (0.34)
Sinus sphenoidalis	1.73 (0.49)	1.78 (0.46)
Lateral skull base	1.81 (0.48)	1.94 **(0.56)**
Petrous bone	1.90 (0.48)	2.20 (0.54)

DISCUSSION

Confident use of image-guided surgery requires exact knowledge about the accuracy that can be expected under the chosen conditions. Accuracy may, for example, vary with respect to the navigation system, the registration protocol, or the spatial relationship between surgical and registration area. Therefore, differences in the setting must be considered when interpreting the results from the numerous studies addressing navigational accuracy. The accuracy values obtained by surface laser registration in this study are comparable to those reported by Khan et al. (1.9 mm) (13) or Schlaier et al. (1.31 mm) [9], who, however, used fixed landmarks for registration. On contrast, the deviations described here are markedly lower than those of former surface-based registration studies (2.77 mm [9]; 2.4 – 2.8 mm (7)) performed with the VectorVision® system (BrainLab, Heimstetten, Germany). The higher average accuracy of 1.13 ± 0.53 mm, ranging from 0.77 (sinus frontalis) to 1.76 (petrous bone) mm, can be explained by the optimized measuring conditions in our study: potential changes in the position of the target fiducials between CT scanning and accuracy measurement could be prevented by the use of cadaver heads, which not only provided an ideal model of in vivo skin porperties for the registration process but also allowed the application of bone-anchored target fiducials. Furthermore, these specifically designed fiducials made it possible to exactly define the measurement points both in reality and on the screen, thereby warranting a highly objective measuring procedure. This way we did not have to rely on anatomic structures such as the nasion, the nose tip or the external auditory canal as previously reported [7,9,13,15]. The use of these rather vaguely defined anatomic points with a diameter of several millimetres leaves room for interpretation and increases the risk for under- or overestimating the navigational accuracy.

By placing fiducials in the paranasal sinuses and the lateral skull base, the accuracy could be assessed directly in areas of ENT-surgical procedures themselves. This is of some importance since accuracy decreases with growing distance to the scanned area as has been shown previously [6,11]) and could be confirmed by our results as well. Therefore, accuracy values obtained for superficial landmarks cannot be easily transferred to intracranial regions.

So far, only few studies have investigated the surgical accuracy that can actually be achieved in the paranasal sinuses. High navigational accuracy has been suggested in an experimental study reporting very low target registration errors (TRE) between 0.3 and 0.4 mm measured for anatomic landmarks in the sinus cavities and skull base [11]. The slightly higher values noted by us might be explained by the differences in the respective registration method (headset-based vs. surface laser registration) and the choice of measurement targets (less exactly defined anatomic landmarks instead of titanium screws). More recently, Knott et al. [8] determined navigational accuracy using touch-based, contour-aligning registration. TRE was reported as 1.5 mm at screw targets at the anterior ethmoid and the sphenoid [8], which is in good agreement with our results based on surface laser registration.

The mean accuracy as determined in this study meets clinical requirements. More importantly, even the maximum deviation of 3.2 mm is still in the range of accuracy values that are generally considered sufficient for clinical purposes (1 – 3 mm [3,16]). In contrast to the optimized conditions of our study, the real conditions of surgery are likely to lead to a certain loss of accuracy. The matching precision between the CT-image data and the actual patient anatomy may be impaired by the dislocation of the headband carrying the reference star, the altered skin reflexions after disinfection, and particularly the changes of the mimic occurring between the CT imaging and the intraoperatively relaxed face [17]. Nevertheless, accuracy can be expected to be still acceptable.

While there is good evidence that the accuracy varies with the distance between surgical target and registration area [6,8,11], it has not been explored conclusively to what degree navigational accuracy is influenced by the conformation of the registration area and the distribution of the registration points. From a practical point of view, this is of some importance since it could occasionally be desirable to restrict the registration area to only part of the face, depending on the intended surgical procedure and related positioning.

Performing the measurements on cadaver heads allowed the comparison of different target areas for the laser scan with respect to their influence on measurement accuracy. As expected, registration restricted to the contralateral half of the face led to the lowest accuracy. Interestingly, even if target measure point and registration area were ipsilateral, accuracy was still significantly lower compared with the accuracy values obtained after symmetrical, bilateral scanning. Therefore care should be taken when choosing the registration area to use points for scanning that are symmetrically distributed and cover as much of the patient's face as possible. It is important to consider this when preparing the operation site, as it may be necessary for best results to do the registration before positioning, disinfection or sterile covering.

CONCLUSION

In this study, navigational accuracy was assessed directly in the paranasal sinuses and the lateral skull base. This region is of eminent importance for the ENT surgeon. The accuracy of the navigation system after surface laser registration proved acceptable. A sensible choice of the registration area and thorough symmetrically bilateral scanning are inevitable for optimal results.

DECLARATION

The authors declare that no conflicts of interest exist.

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Dr. Georg J. Ledderose, MD
Klinikum Großhadern
Marchioninistr. 15
81377 Munich
Germany

Tel.: +49-89-7095 3888
Fax: +49-89-7095 6869
E-mail: johannes_georg.ledderose@med.uni-muenchen.de

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BIOMEDICAL PAPER

Image guided surgery of the lateral skull base: Testing a new dental splint registration device

GEORG J. LEDDEROSE[1], HJALMAR HAGEDORN[2], KATHRIN SPIEGL[3], ANDREAS LEUNIG[1], & KLAUS STELTER[1]

[1]*Department of Otorhinolaryngology, Head and Neck Surgery, Ludwig-Maximilians-University Munich, Munich, Germany;* [2]*Department of Otorhinolaryngology, Head and Neck Surgery, Klinikum Dachau, Dachau, Germany; and* [3]*Department of Prosthetic Dentistry, Ludwig-Maximilians-University Munich, Germany*

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Abstract

Objective: The widespread use of image guided surgery in the frontolateral skull base region has been limited by the need for a reliable and non-invasive registration procedure that provides sub-millimetric accuracy. We developed and validated preclinically a non-invasive, easy-to-use registration device based on a dental splint with a laterally mounted fiducial carrier.

Methods: Repeated accuracy measurements were performed on six titanium target fiducials which were screwed into the lateral skull base region of a cadaver head and could be unequivocally identified both on the CT image and in reality. The system accuracy was evaluated by determining the deviation of the real target position from the position indicated in the CT scan. The accuracy of the dental splint-based registration was compared to that of two standard registration procedures: contour-based laser surface registration and fixed marker registration.

Results: The mean accuracy of 0.55 ± 0.28 mm obtained when using the maxillary splint device was similar to that obtained with the "gold standard" registration using bone-implanted markers (0.33 ± 0.26 mm), while being clearly superior to that obtained with contour-based laser surface registration (1.91 ± 0.74 mm).

Conclusions: Registration using the non-invasively fixed maxillary fiducial platform can provide sub-millimetric accuracy in the lateral skull base region. *In vivo* validation may prove dental splint-based registration to be an accurate and non-invasive alternative option for image guided surgery of the lateral skull base, and may facilitate the application of navigation systems in this delicate region.

Keywords: *Image guided surgery, lateral skull base, dental splint registration, laser surface registration, fixed marker registration, navigational accuracy*

Introduction

In ENT surgery, particularly sinus surgery, surgical navigation systems have been successfully used for some years. They are widely accepted as useful tools for intraoperatively identifying important anatomical structures and assisting in the exact positioning of surgical instruments, especially when conditions are complex because of the loss of surgical landmarks as a result of previous surgeries or tumor destruction [1-3].

A prerequisite for the reliable use of image guided surgery (IGS) is a successful and accurate registration process, i.e., the matching of the patient's preoperatively acquired image data set (e.g., a CT scan) with the intraoperative reality. The quality of the registration process directly affects the accuracy

Correspondence: Georg J. Ledderose, Department of Otorhinolaryngology, Head and Neck Surgery, Ludwig-Maximilians-University Munich, Marchioninistr. 15, 81377 Munich, Germany. Tel: +49-89-7095 3888. Fax: +49-89-7095 6869. E-mail: johannes_georg.ledderose@med.uni-muenchen.de

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of the navigation system, which is defined as the deviation of the real position of a surgical target or instrument from its position as indicated in the CT scan [4]. Accuracy is highly dependent on the chosen registration method, and tends to increase with the distance between the registration area and surgical target [5-7]. In ENT surgery, non-invasive registration methods are commonly used, such as laser surface scanning [8-11] or tracking of external fiducial markers that are self-adhesive or fixed on headbands [10, 11]. In most cases, these registration methods provide sufficient clinical accuracy for paranasal sinus surgery [12, 13].

Lateral skull base surgery, performed in close proximity to vital structures such as the brain, the middle and inner ear, the vestibular organ, the carotid artery, or the venous sinus, carries considerable risks and requires sub-millimetric precision. IGS can facilitate orientation, especially in complex surgeries such as those for recurrent cholesteatoma, paraganglioma, or CSF leaks. However, as the currently available registration methods are either highly invasive or demonstrate low reliability when applied to targets in the lateral skull base [14, 15], IGS has not yet been established as a standard surgical procedure in this region.

To facilitate and improve the application of IGS in frontolateral skull base surgery, a new registration method providing both high clinical accuracy and minimal invasiveness is desirable. For this purpose, we developed a new registration device consisting of a dental splint with a lightweight laterally mounted fiducial platform. The splint can be reversibly fixed to the maxillary dentition, and no invasively applied markers are needed. For intraoral interventions, such as the navigated placement of dental implants, the use of dental splint registration has already proven its applicability [16, 17]. However, standard dental registration splints are not suitable for IGS of the lateral skull base as the considerable distance between the registration area (the oral cavity) and surgical area results in a high target registration error [4, 5, 18]. We hypothesized that the use of our modified dental splint with immovable, non-invasively fixed registration markers in close proximity to the region of interest would improve navigational accuracy when compared the registration methods commonly applied in ENT surgery. In the present study, we evaluated the navigational accuracy in the lateral skull base region when using this new registration device on a cadaver head, and compared it to two standard registration procedures: the widely used (particularly in ENT surgery) contour-based laser surface registration method and registration via implanted bone screws.

Methods

CT scan and navigation system

The measurements were performed on a cadaver head (obtained from the Institute of Anatomy at the LMU Munich). Axial spiral CT scans were obtained (SOMATOM Sensation 64® CT scanner; Siemens, Germany) (slice thickness 1 mm, continous scan with overlapping slices, 0.5 mm reconstruction increment) and transferred to a VectorVision Compact® passive optical navigation system with the ENT 7.8 software update (BrainLAB, Feldkirchen, Germany).

Methods of registration

Dental splint registration: We developed a new registration device by modifying a common dental registration splint. The key feature was to apply the fiducial carrier unilaterally, in contrast to the large bilateral extraoral reference frames commonly used. The fiducial carrier was attached to an individually adjusted dental splint to bring the registration area as close as possible to the target area, i.e., the lateral skull base. After taking impressions of the upper jaw and determining the maximal intercuspidation, an individually formed dental splint was created from polymethylmethacrylate (PMMA, Ortocryl®; Dentaurum J. P. Winkelstroeter KG, Ispringen, Germany) in the Department of Prosthodontics at the LMU Munich, and adjusted to the maxilla of the cadaver head. The precise fit with the contours of the maxillary teeth held the splint in place and ensured its stable position; adhesive or metal fastening was not required, nor was it necessary for the upper and lower teeth to be closed on the splint. The three-dimensional polyethylene reference body, carrying six fiducial markers for localization in the registration process and three passive reflecting balls for tracking during surgery, was attached with a screw thread to the individually formed PMMA pedicule on the left side of the splint (Figure 1), as the measurements were to be performed on the left lateral skull base. The reference body can be easily removed and is fully sterilizable, while the individual dental splint is discarded after use. CT scanning was performed with the registration splint fitted onto the dentition of the maxilla and the fiducial platform fixed in place. For registration, each fiducial screw was selected with the referenced pointer and detected by the cameras of the navigation system as a defined registration landmark (Figure 1a). This was then matched exactly with the previously saved image data set.

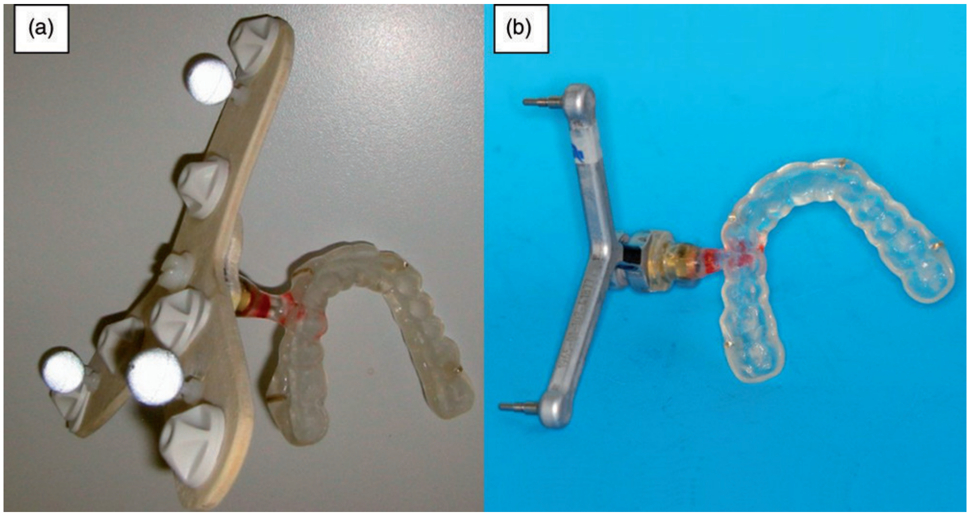


Figure 1. Dental splint (a) attached with a screw thread to a 3D polyethylene body carrying six fiducial markers for registration close to the lateral skull base, and (b) attached, again with a screw-thread, to the reference array intended to carry passive reflecting balls for referencing during navigation.

Fixed marker registration: The highest accuracy values are generally obtained with registration methods that use implanted bone screw fiducials [19, 20]. This minimizes the risk of registration markers being displaced between the CT imaging session and the registration process [21], which can easily occur with soft tissue-mounted adhesive fiducials [22]. At present, fixed marker registration is still considered the "gold standard" for IGS at the lateral skull base [19].

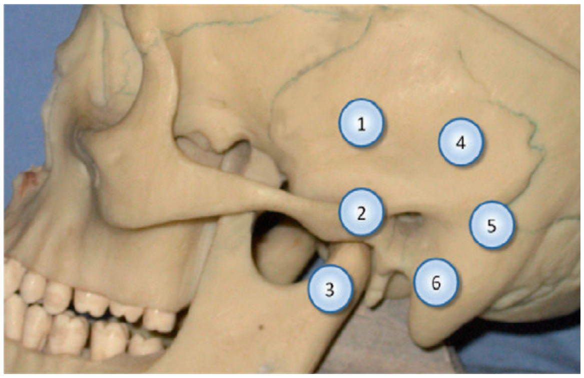
Four screws were drilled into the bone in the area of the left lateral skull base prior to performing the CT scan. Following scanning, the locations of all these registration fiducials were obtained as described above to register the physical space to the image data set.

Contour-based laser surface registration: Contour-based laser surface scanning is commonly chosen in (endoscopically controlled) sinus surgery as a convenient, non-invasive and touchless registration method. The individual contours of the patient's face are aligned with the image data set, thus making the application of external markers unnecessary [8, 10].

Laser scanning was performed with a handheld laser scanner device (z-touch®; BrainLAB, Heimstetten, Germany). The laser reflections detected by the infrared cameras of the navigation system provide the localization data. The system automatically correlates the position of this data to the reference star and calculates each coordinate link with the corresponding point from the CT data set. For effective matching, an adequate number of points (approximately 100) must be detected [8]. The choice of the area to be scanned is crucial to the accuracy of the registration procedure. The scanned regions should be hairless, and the skin should cover the bones tightly so that tissue shift during the interval between CT scanning and registration is negligible [5]. To keep the registration area as close as possible to our measurement points in the frontolateral skull base region, we chose points for scanning that were distributed along the aurical. As the suitable surfaces in the lateral area did not yield a sufficient number of points, it was necessary to expand the registration area along the forehead and orbital rim.

Determination of navigational accuracy

The navigational accuracy was determined as previously described [8, 10, 11, 23, 24]. Six titanium screws fixed in the lateral skull base (Figure 2) served as precisely defined target points. Each was pointed to by an infrared pointer tracked by the navigation system. The distance between the target point and the tip of the pointer was measured separately for the three planes (axial, coronal, sagittal) using the scale on the navigation screen (Figure 3). The highest value among these three measurements, i.e., the maximum deviation, represents a reasonable approximation to the accuracy of the navigation system. Twenty replicate measurements were performed per registration method. Each measurement process consisted of shutting down and restarting the system, registration using the respective method, and localization of



Target point	Location
1	Preauricular cranial
2	Preauricular middle
3	Preauricular caudal
4	Retroauricular cranial
5	Retroauricular middle
6	Retroauricular caudal

Figure 2. The locations of the six precisely defined bone-implanted target fiducials demonstrated on an anatomical model.

the target fiducials. When using the dental splint for registration, the splint was removed and newly adjusted every time. To avoid inter-operator variation, all measurements were performed by the same person.

Statistics

Data are expressed as mean values (in mm) ± standard deviation. Differences between groups were tested for statistical significance using the Kruskal-Wallis test and Tukey's test. A P-value of < 0.05 was considered statistically significant.

Results

Measurements were performed on the left lateral skull base at six target points, three located preauricularly and three postauricularly (Figure 2). Mean accuracy values ($n = 20$) are shown in Table I. The highest accuracy was obtained following fixed marker registration (overall accuracy: 0.33 ± 0.26 mm; range: 0.00–1.50 mm). Accuracy measured following dental splint registration was highly reproducible and was only slightly higher than after fixed marker registration (0.55 ± 0.28 mm; range: 0.00–1.20 mm). Following laser surface registration the accuracy was significantly lower at every measuring point compared to that with fixed marker or dental splint registration ($p < 0.05$; overall accuracy 1.91 ± 0.74 mm; range: 0.40–3.30 mm) (Figure 4).

Following fixed marker registration, no differences in accuracy between the single target points could be detected. In contrast, when registration was performed by laser surface scanning or with the use of the dental splint device, the increasing distance between the registration area and target points corresponded with a significant decline in accuracy (pre- versus retroauricular; $p < 0.001$) which was particularly pronounced for the postauricularly located target points after laser surface registration.

Discussion

The reliability of image guided surgery is highly dependent on accurate matching of the patient's preoperative image data to the intraoperative anatomy. In IGS of the lateral skull base, rigid fixed marker registration with bone screws is still considered the gold-standard registration method [19]. In our study, we confirmed the high accuracy (0.33 ± 0.26 mm) of this registration method; however, its high invasiveness has prevented IGS from becoming a routine procedure in skull base surgery.

In oral and cranio-maxillofacial surgery, registration is often performed using intraoral fiducial markers mounted on an intraoral dental splint device [16, 21]. However, the great distance from the registered region (the oral cavity) prevents the use of such intraoral templates for operations in the lateral skull base area [25]. In fact, in a recent *in vitro* study published by Luebbers and coworkers, adequate precision in regions beyond the mid-face could only be achieved by combining the occlusal splint with two bone-implanted markers on the lateral orbital rim [18]. In the present study, we developed a modified dental splint device with a unilateral reference frame carrying the registration fiducials. Thus, a close spatial relationship between the registration area and the target fiducials was assured. The splint integrates easily into common navigation systems such as the BrainLAB VectorVision, and does not require any additional software. The high accuracy and reliability of this novel registration device was proven by the measurement of values in the submillimetric range for target fiducials located in the lateral skull base region, which almost matched the accuracy of fixed bone-implanted marker registration. Although the more distant targets yielded slightly larger values,

Table I. Navigational accuracy (NA) for different registration methods (target points as outlined in Figure 2). Data represent the mean of $n = 20$ measurements.

	Method of registration					
	Fixed marker		Laser surface scan		Dental splint	
Target point	NA (mm)	SD (mm)	NA (mm)	SD (mm)	NA (mm)	SD (mm)
1	0.30	0.16	1.01	0.48	0.30	0.18
2	0.40	0.24	1.4	0.40	0.40	0.16
3	0.40	0.37	1.8	0.47	0.50	0.23
4	0.30	0.20	2.3	0.49	0.70	0.30
5	0.40	0.28	2.50	0.53	0.70	0.24
6	0.30	0.24	2.40	0.53	0.70	0.29
Mean value ($n = 20$)	0.33	0.26	1.90	0.74	0.55	0.28

SD: standard deviation.

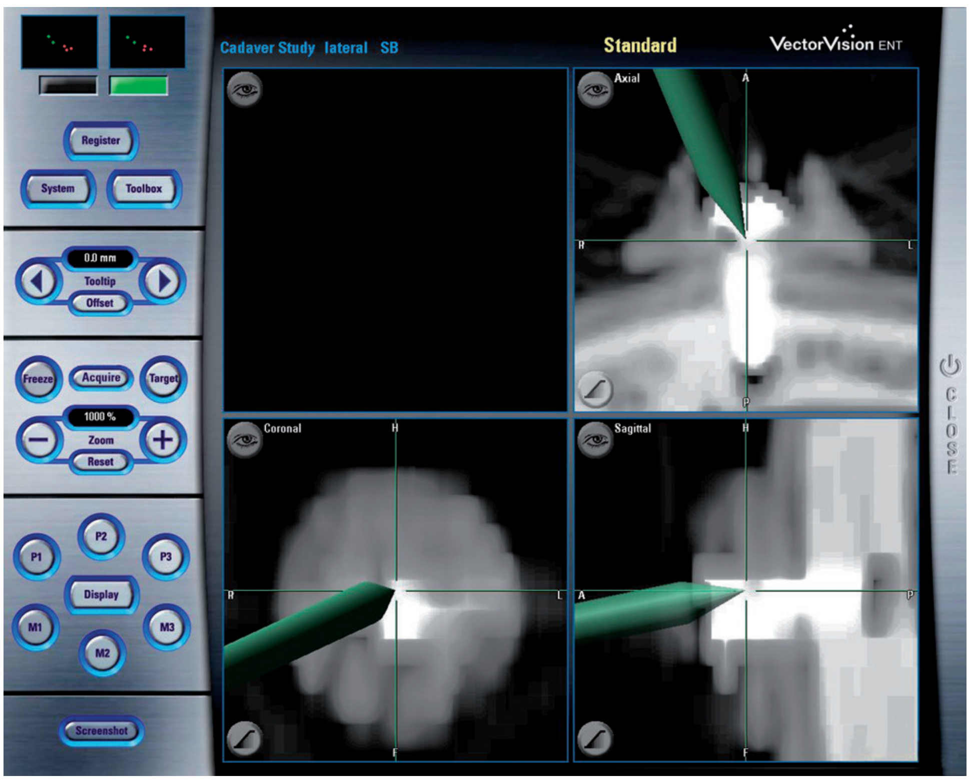


Figure 3. Navigational screenshot. Titanium screws served as target points and were aimed at by the referenced infrared pointer of the navigation system. The distance between the target point and the tip of the pointer was measured separately for each of the three planes (axial, coronal, sagittal) using the scale on the navigation screen.

confirming the significant impact of the distance between the registration and target points on the accuracy [7, 8, 21], even the maximum deviation of 1.2 mm is still within the range (1 to 2 mm) that is often considered "clinically acceptable" for navigation system accuracy [1, 21, 25, 26].

Maxillary splint-based systems with extraoral extensions for reference markers have been used previously with sufficient navigational accuracy in neurosurgery (0.29-0.86 mm [17], 0.0-2.0 mm [27]), in sinus surgery (1.56 ± 0.76 mm [28]), and in the temporal region (0.73 ± 0.25 mm [17, 29]); however, only a few of these systems have been tested for targets in the lateral skull base region [15, 29, 30, 31]. Bale et al. used a mouthpiece-based registration template held in place by a vacuum system to successfully cannulate the foramen ovale [30], but did not test its applicability for

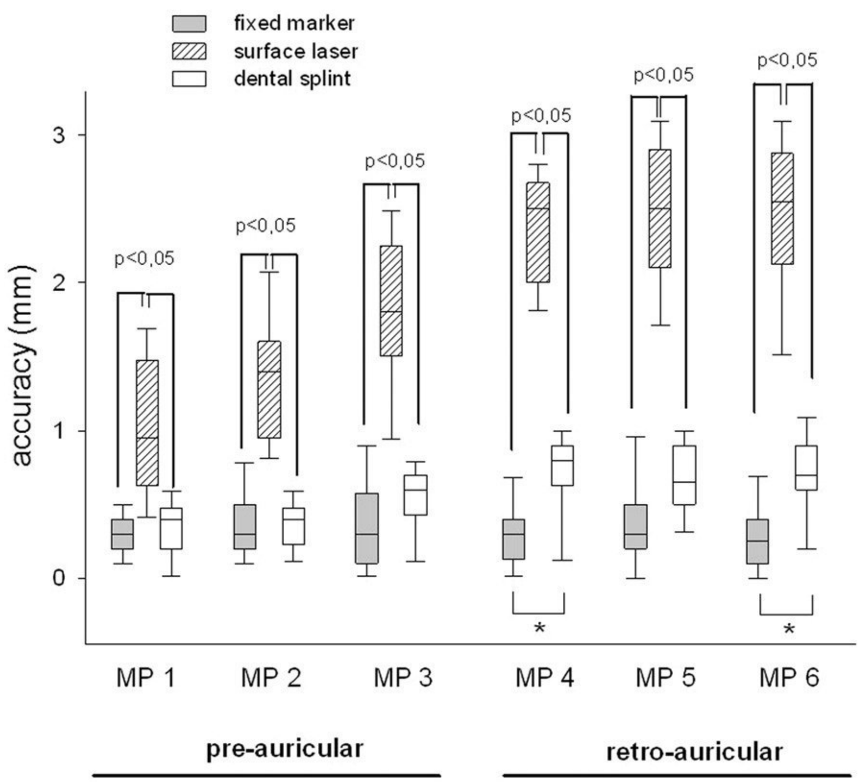


Figure 4. Target registration error for fixed marker registration, laser surface registration and dental splint registration at the six measuring points (MP) located pre- or postauricularly, as indicated in Table I. Results are expressed as box-plots of $n = 20$ independent measurements. $^{*}p < 0.05$ versus fixed marker registration.

other locations in the lateral skull base. In contrast, insufficient accuracy was reported in an *in vitro* model of mastoidectomy when using a navigation bow with integrated registration markers fixed to the upper jaw [15]. A major problem with the existing devices is the large bilateral extraoral reference frame [17, 29, 31], which does not allow the patient's head to be positioned on one side for surgery – a prerequisite for surgery at the lateral skull base. Furthermore, depending on the size and weight of the extensions, the extraoral parts might act as a lever, leading to dislocation of the maxillary splint and poor registration accuracy. Additionally, extraoral support of the reference frame by the nasion or external auditory canal [28] is not advisable, as the attachment of reference structures to soft tissue tends to increase inaccuracy because of soft tissue deformity, a problem also known from non-rigidly mounted registration devices like headbands or headsets [32]. In an attempt to solve this problem, we took special care to make our dental splint device as lightweight and as small as possible. This smaller splint-mounted reference system should not interfere with surgical access in common skull base procedures, such as surgery of the middle ear or paraganglioma.

As the reference array is held in place solely by the close fit with the teeth, a proper dental status is a prerequisite for a rigid attachment of the splint to the maxilla to guarantee high navigational accuracy.

As a non-invasive alternative registration method, laser surface contour scanning has found widespread use in paranasal sinus surgery, and there have been preliminary studies to assess its usefulness in lateral skull base surgery as well [11, 33]. However, common laser-based registration systems could not match the accuracy of bone-implanted fiducial marker registration [11]. The lack of an appropriate registration surface in close proximity to the lateral skull base most likely accounts for the rather poor navigational accuracy reported. The hairy skin, the soft auricle, and the lack of bony anatomical landmarks prevent a reliable registration. On the other hand, scanning of the facial skull, while providing sufficient accuracy in the frontal or paranasal sinuses [8, 12], has been found to be an unsuitable method of registration for targets located in the lateral skull base due to the considerable distance between the reference points and the surgical area [11]. Accordingly, the deviation measured in our study of accuracy after laser surface scanning was more than three times that measured after fixed marker or dental splint registration. With maximum values of 3.3 mm, laser surface registration did not meet clinical requirements for interventions in the lateral skull base, even though the measurements were performed under ideal experimental conditions on a cadaver head, thereby excluding factors that might compromise accuracy *in vivo*, such as soft tissue shifting or altered skin reflection following disinfection. Still, it is possible that future laser scanning devices will overcome the difficulties of marker-less registration in the skull base area. Promising in this respect are preliminary results by Marmulla et al., who used a special laser scanner system that was able to record far more surface points than are recorded by common laser scanners [33]. To minimize the distance between the target and the registration area, they used the auricle as a spatial reference area and assumed an acceptable navigational accuracy in the lateral skull base. One problem with this approach is the possibility of auricular deformation during CT acquisition.

Prior to testing a new registration method *in vivo*, it is important to know the system-immanent (in)accuracy. For an exact evaluation of the system accuracy, it is necessary to exclude any unrelated factors which might additionally influence accuracy in a patient. We therefore conducted the evaluation of the respective registration methods under optimized experimental conditions. According to our measurements, the easy-to-use and non-invasive dental splint registration device provided sufficient accuracy, comparable to that obtained with fixed marker registration and much better than that obtained with ordinary contour-based laser registration. Although it is possible that the accuracy will decrease slightly when tested *in vivo*, the initial results give reason to expect clinical applicability of the device.

Conclusion

The results show that submillimetric accuracy is achievable in the lateral skull base region with a modified, non-invasive maxillary fiducial carrier. This new dental splint device has been proven to provide navigational accuracy similar to that obtained with standard registration methods based on bone-implanted markers, while being clearly superior to standard laser surface registration in this area. The study emphasizes the importance of a close spatial relationship between the registration and target areas. Ongoing clinical studies to evaluate the applicability of this approach *in vivo* may reveal the dental splint-based registration method to be an accurate and non-invasive alternative option for image guided surgery of the lateral skull base.

Conflict of interest: The authors declare that they have no conflict of interest.

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RHINOLOGY

Specific stressors in endonasal skull base surgery with and without navigation

K. Stelter · M. N. Theodoraki · S. Becker · V. Tsekmistrenko · M. Luz · B. Olzowy · G. Ledderose

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Abstract The goal of modern organizational psychology is to recognize, anticipate and finally avoid stress situations. The aim of this study was to measure objectively the mental and physical demands during transnasal surgery with and without the aid of a navigation system. Forty endonasal surgeries (20 with and 20 without navigation, not blinded and not randomized) done by four different experienced rhinosurgeons (>250 FESS procedures done) were included. The heart rate, the heart rate variability, the respiratory frequency and the masseter tone were monitored as biometrical parameters by the surgeons during the whole surgery for the quantification of mental demand. Stress situations could be identified during the procedures by an increase in the heart rate and a decrease in the heart rate variability. Stress level in procedures with navigation did not significantly differ from procedures without navigation. Interestingly, in 10 % of the cases a navigation system would have been helpful, although the surgeon stated before the procedure that such a system would not be necessary. Other stressors could be identified like time pressure, students or colleagues speaking with the surgeon or chatting in the OR and system failure of medical devices, i.e. navigation, sinus drill, electrocautery or shaver. Surgical stressors blurred vision due to diffuse bleeding and drill out procedures in the sphenoid sinus. Calming situations were a quiet atmosphere in the OR (i.e. closed doors) and the participation of another experienced colleague, especially a neurosurgeon. Stress situations occur when complex medical devices like the navigation do not work. For their proper function it is important that the whole OR-team is trained with it. Unqualified or unmotivated OR personnel create stress for the surgeon and disharmony in the team, which then ends in inadequate behaviour.

Keywords Heart rate variability · Navigation · FESS · Skull base surgery · Mental workload · Stress

K. Stelter · S. Becker · V. Tsekmistrenko · G. Ledderose
Department of Otorhinolaryngology, Ludwig Maximilians University, Munich, Germany

K. Stelter (✉)
Private Practice, ENT-Centre Mangfall-Inn, Rosenheim 83022, Germany
e-mail: klaus.stelter@med.uni-muenchen.de

M. N. Theodoraki
Department of Otorhinolaryngology, University of Ulm, Ulm, Germany

M. Luz
Industrial, Engineering and Organisational Psychology of the Technical University, Berlin, Germany

B. Olzowy
Department of Otorhinolaryngology, Otto Körner, University of Rostock, Rostock, Germany

Introduction

Without a doubt, the mental and physical demands of surgeons during functional endoscopic sinus surgery (FESS) and transnasal skull base surgery are high [1]. During every surgery there are more or less stressful situations, which arrest a higher or lower level of attention from the individual surgeon. Depending on the operational experience, age, stage of the clinical hierarchy and ultimately from the individual habituation different stressors take effect on the surgeon and the surgical team [2]. To recognize, anticipate and finally avoid these stress situations is the goal of modern organizational psychology.

In FESS, like in other surgeries, the surgeon has to handle different devices and has to collect information from different sources on the fly and at any time. Surgical navigation systems provide a mass of information and can improve the surgeon´s intraoperative orientation and situation awareness [3]. However, the correct usage of these devices is subject to proper and regular training. Otherwise, these systems create more stress than real help for the surgeons [2]. The specific stressors during FESS and transnasal skull base surgery and while using navigation systems were hardly been evaluated and rarely determined.

The aim of this study is to measure the mental and physical demand of four different rhinosurgeons during transnasal surgery with and without the aid of a navigation system. Afterwards, the following questions should be answered:

– In which situations are the mental demand for the surgeons at the highest level?
– Can a navigation system reduce the cognitive and physical demand?
– How does the surgeon deal with the additional information from the system mentally?

To answer these questions we monitored 40 endonasal surgeries and analyzed stress showing biometrical parameters for the quantification of mental demand: the heart rate, heart rate variability, respiration frequency and masseter tone.

The heart rate is a frequently used parameter for the objective detection of mental effort because of the easy acquisition through the electrocardiogram. It shows that the heart rate increases with an increase in mental effort [4].

A major bias is the influence on the heart rate through external factors like muscle work, respiration or emotions. Although the muscle work during surgery is minimal, because the surgeon cannot move, run or jump in the OR, the psychological effect on the heart rate is not clearly definable [5]. Nevertheless the heart rate is used in several studies as a parameter of mental effort, although the quantity cannot precisely be determined [6, 7]. In addition, the heart rate variability (HRV) describes the variability between the heart beats of a person in a specific situation. In other words the variability of the R–R intervals in the ECG is the interbeat interval (IBI). Since the first studies of Kalsbeek and Ettema, the HRV is used as a parameter and a characteristic variable for the measurement of mental effort [8, 9]. They proved in their studies that the HRV decreases while acting out a binary cognitive task. In other words the heart beats more regularly in situations with high mental workload [10]. The HRV is an established parameter for the quantification of situations with mental effort. It is used for example by pilots and space shuttle operations to register the difficulties of air manoeuvres, the efficiency of the training and the stress level during flights [6, 11].

Materials and methods

After approval by the local ethics committee this prospective clinical field study was conducted at the Department of Otorhinolaryngology, Head and Neck Surgery at Ludwig Maximilians University of Munich in accordance with the ethical standards laid down in the 1964 Declaration of Helsinki. All subjects gave their informed consent prior to their inclusion in the study. Four experienced (more than 250 FESS and transnasal procedures done) rhinosurgeons performed transnasal surgery on ten patients each. Five of these patients were operated with the aid of a navigation system (Vector vision compact, BrainLab, Feldkirchen, Germany) and five patients without. The surgeons of this study were very familiar with this system through prior studies [2, 3, 12]. The study groups were not randomized to meet the ethics committee criteria. The allocation to the groups was determined by the surgeon preoperatively. This was because, first, the patient has a right to know whether a navigation system is used in his particular case or not and, second in difficult cases it is not justifiable not to use such a system which is known to decrease complication rate in certain cases [3]. In summary 40 patients participated. The whole operation was recorded with STORZ AIDA video system. During and 5 min before and after the operation the surgeons were connected to a biofeedback device (Nexus 10, Mindmedia, NL), to monitor the breathing frequency, heart frequency (and variability) and the masseter tonus continuously. Surgical sections of each operation and critical events, i.e. stronger bleeding or if other colleagues were entering the theatre, were marked by a manual trigger of the biofeedback device during the procedure to see whether they had an influence on the stress level.

For a proper heart rate variability analysis, the recorded endoscopic videostream was saved and synchronized with the biometrical data from the biofeedback device postoperatively (Figs. 1, 2).

In the spectral analysis of the HRV three frequency bands are important:

Very low frequency: 0.02−0.06 Hz
Low frequency: 0.07−0.14 Hz
High frequency: 0.15−0.40 Hz

A temperature component is included in the low frequency band, the blood pressure and adrenaline component are included in the 0.1 Hz frequency (low frequency band). The respiratory frequency is a common source of artifacts and was, therefore, monitored in this study for the correct interpretation of the low and high frequency band [13].

In exhausting mental activity the heart beat becomes more regular to ensure a continuous oxygen supply of the brain [9]. The same procedure can be observed by physical effort. The higher the mental or physical effort of the test person is, the lower is the variability of the heartbeat, which

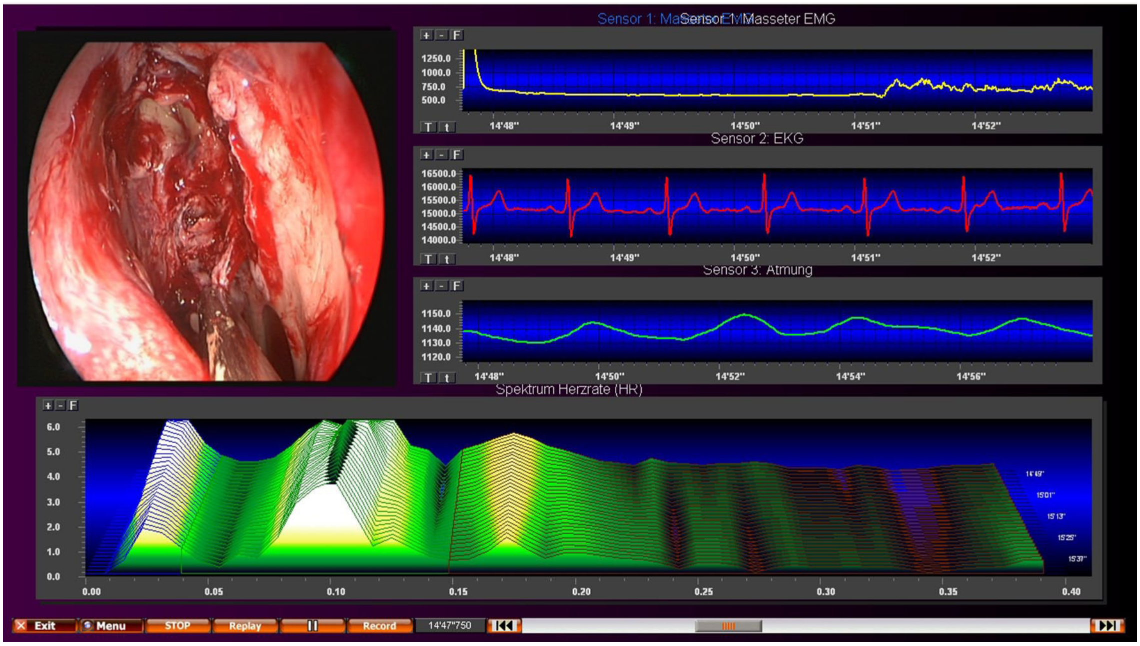

Fig. 1 Screenshot of the intraoperative biofeedback measurements with MindMedia's BioTrace+Software. The experienced surgeon opens the ethmoid and is very calm

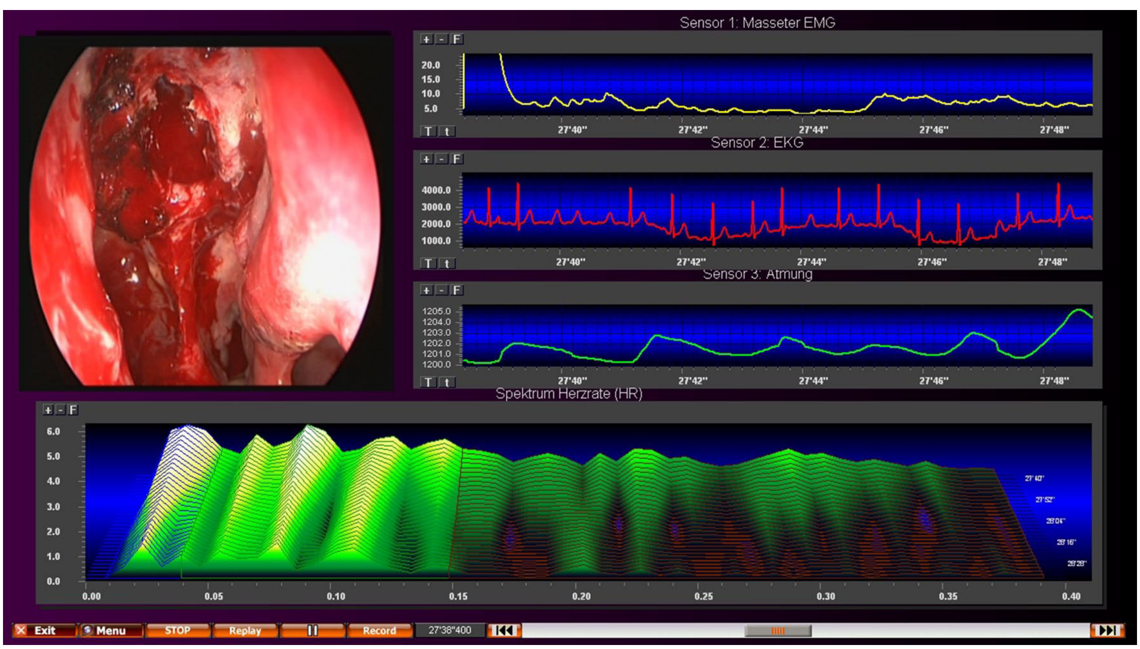

Fig. 2 Screenshot of the intraoperative biofeedback measurements with MindMedia's BioTrace+Software. 15 min later, the posterior ethmoid artery was damaged by accident and the surgeon is stressed

means Querythe more regular beats the heart. This way it can be measured how exhausting (mentally and physically) an activity for an organism is.

All three frequencies show a suppression of the HRV by exertion and concentration [11] but the biggest difference is seen in the low frequency band, especially in the 0.1 Hz component [13].

The HRV was monitored during the whole operation and 5 min before and 5 min after, in the operation theatre, continuously. This way a calibration with a rest situation but in the same surrounding (i.e. temperature, O^2-saturation) was given [7].

The spectral analysis of the interbeat intervals have been implemented with the programme CARSPAN (developed by B. Mulder, Groningen) [14] and the support of the professional group for Organisational Psychology in Berlin. With this spectral analysis it is possible to make a differentiation of the three frequency bands listed above and to quantify them. CARSPAN uses the discrete Fourier analysis to split the time series into spectra.

As an additional indicator of physical and mental effort the masseter tonus was measured, too [15]. In situations of high tension a significantly higher tone of the masticatory muscles is measurable through the unconscious contraction of the muscles by biting the jaws [16].

At the end of every surgery, the surgeon had to answer the question, how much he had benefitted from the additional information of the navigation system on a visual analogue scale. In case the surgeon had not used a navigation system, the question was how much a navigation system could have helped in the particular surgery.

Statistics

In the statistical analysis of this study a team of the professional group for work psychology in Berlin was involved. The following objective parameters were statistically evaluated:

1. Heart rate variability
2. Heart frequency

The statistical evaluation was performed with an analysis of variance (ANOVA) for repeated measurements and *t* test (paired design). The programme used was SPSS 15.0. A significance was considered if $p < 0.05$. The effect size η^2 was also calculated. A pretest power analysis was performed using "Power and sample size calculation Vers. 3.0". Prior studies indicated that the difference of HRV in response to matched pairs is normally distributed with standard deviation 0.6. If the true difference in the mean response of matched pairs is 0.4, we would need to study 20 pairs of subjects to be able to reject the null hypothesis that this response difference is zero with probability (power) 0.8. The type I error probability associated with this test of this null hypothesis is 0.05. Therefore, we included $n = 40$ patients (=20 pairs) and operated on half of them with navigation and half without.

Masseter tone and respiratory rate gave additional information and hints about possible artifacts (speaking, moving and physical work) and situations with special tension (masticatory tense) but were not quantified statistically.

Results

The four subjects (surgeons) were all male, one left-hander and three right-handers. The average age was 39 years (between 36 years and 41 years). All 40 patients were included. The average age of the patients was 47 (SD 9.8) years. Indications for transnasal surgery were:

Chronic sinusitis with/without polyps $n = 26$.
Mucoceles of the frontal sinus $n = 5$.
Inverted papilloma of the paranasal sinus $n = 2$.
Skull base tumours (aesthesioneuroblastoma, intracranial polyps, squamous cell carcinoma, pseudotumor) $n = 4$.
CSF-leaks $n = 3$.
23 (57 %) patients had prior surgery to the paranasal sinus (revision cases).

To classify the grade of difficulty of the endonasal surgery, patients were sorted in four different subgroups: (Fig. 3).

Drop outs

All four surgeons participated in this study performed ten operations each. The included patients participated without drop outs, too. Two operations had to be removed from the heart rate analysis because of an intraoperative system failure of the biofeedback device (no proper ECG was recorded) (Fig. 4).

Heart rate variability analysis and masseter tone analysis

All four surgeons had slightly different individual stressors, which could be identified by the HRV, masseter tone and asking the surgeon to the particular intraoperative situation after the surgery. According to the objective (HRV, HR and masseter tone) and the subjective (questioning) data the following ranking of intraoperative stress situations could be determined:

1. Time pressure.
2. Students or colleagues chatting in the OR.
3. System failure of medical devices: navigation, sinus-drill, electrocautery, storz AIDA recording device, shaver.
4. Diffuse bleeding with blurred vision.
5. Drill out procedures, especially in the sphenoid sinus.

Difficult manoeuvres during the operation or the use of the 45° or 70° endoscope did not lead to a higher masseter tone or a lower HRV in the surgeons. In fact, the following circumstances lead to a higher HRV and a depression of the heart rate, which means these were calming down the surgeon:

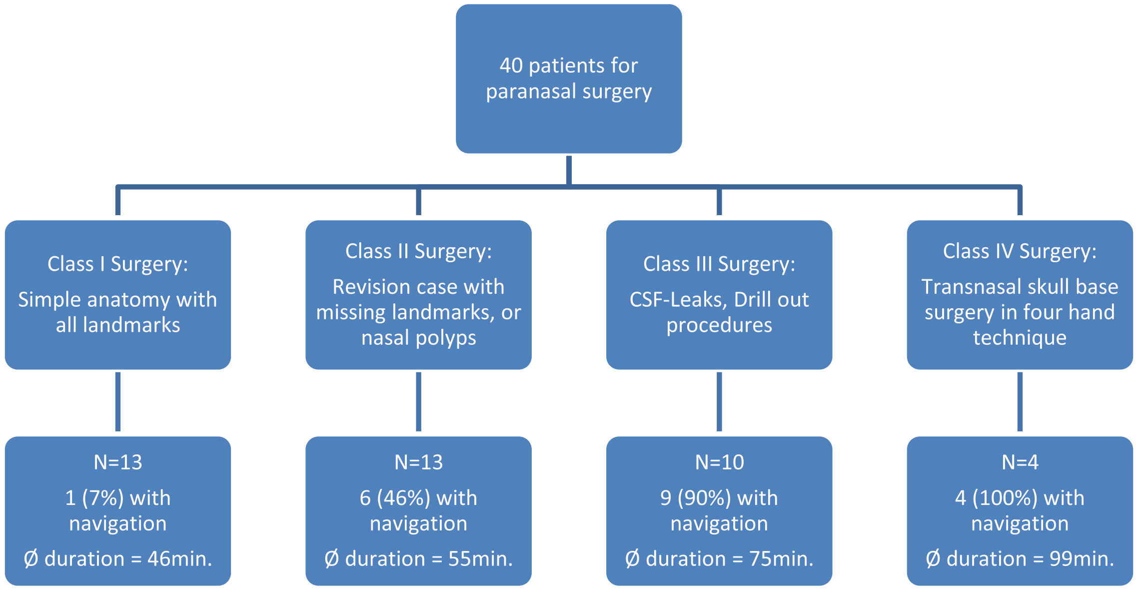

Fig. 3 Allocation of the study subjects to different surgical subgroups in dependence of the difficulty of the endonasal surgery

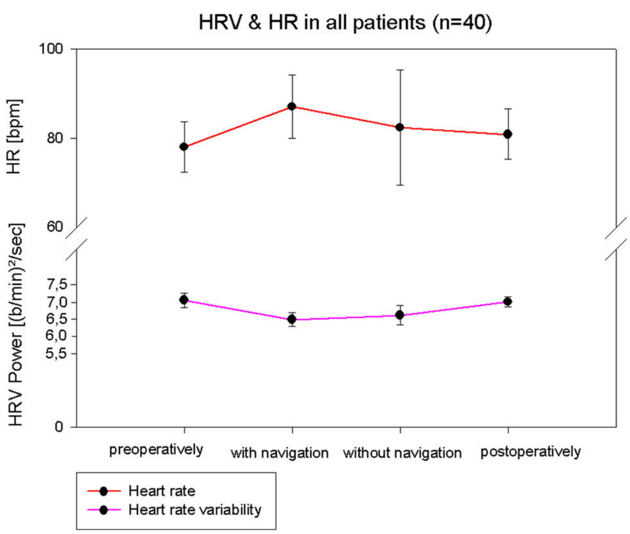

Fig. 4 Heart rate (HR) and heart rate variability (HRV) of the surgeon before and after the surgery and in the two study groups

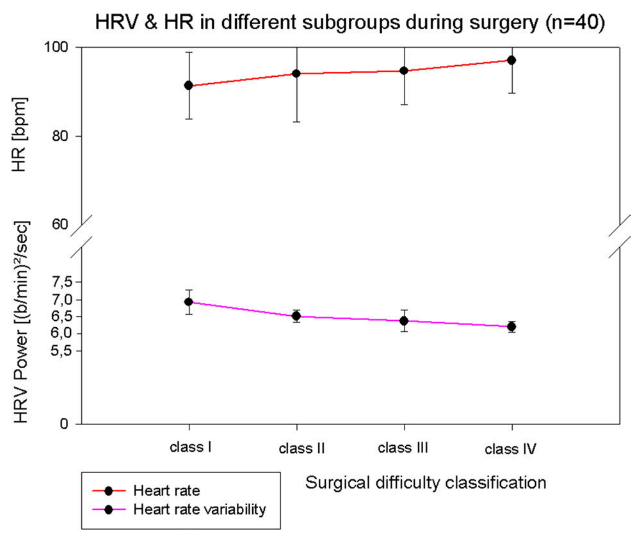

Fig. 5 Heart rate (HR) and heart rate variability (HRV) of the surgeon during the surgery in different complex procedures. Class I is a non-complex procedure, whereas class IV is a highly complex endonasal procedure

1. Quiet atmosphere in the OR (i.e. closed doors).
2. The participation of another experienced colleague, especially a neurosurgeon.

The heart rate was significantly higher during the surgery, compared to the HR before and after the surgery. The HRV showed a corresponding inverse graph. It was higher in the preoperative section in comparison to the intraoperative HRV, which was low. After the operation some minutes were required to reach the preoperative HRV level (rest level). During the operation with navigation the exertion was a bit higher (lower power at the middle frequency band). However, the result was not significant, that means there was no significant difference in HR or HRV between the operations with navigation and without ($p = 0.157$, $\eta^2 = 0.203$). An additional mental load with the use of the navigation system could not be observed.

According to the HRV graphs in Fig. 5 the mental workload increased significantly with the higher complexity of the surgery. The data shows that the average stress level in complex (class IV) endonasal surgery is significantly higher than in "simple" (class I) endoscopic sinus surgery ($p = 0.037$, $\eta^2 = 0.46$).

At the end of the surgery and after the baseline measurement all participating surgeons in the navigation group should answer the question whether the additional information of the navigation system was crucial for the operation. After the surgery without navigation, the question whether a navigation system would have been useful for the particular operation should be answered. The results are in Fig. 6.

Discussion

Cardiovascular indicators of mental load

The heart rates, as well as the HRV, are cardiovascular parameters with a high importance for the detection of psychical and mental effort in surgery [17–19]. With the development of high definition spectral analysis methods the HRV can be split into three different frequency bands during the acquisition "on the fly". Although the suppression of the HRV in situations of mental effort is visible in all three frequency bands, in the middle frequency band it is most obvious [13]. Another reason why this band is to be preferred is the fact that in studies with short acquisition times, like this study, the 0.1 Hz band reacts most sensitively [13] and can be read out in real time.

Nevertheless doubts from several scientists exist for this method [11, 20, 21]. Many studies use the HRV as an indicator for mental effort but the evaluations of the results vary a lot. There exist no standard guidelines for the evaluation of the HRV and there are many activities which cause mental load. However, there is no better objective and reliable method for the measurement of the mental load and effort currently available [14].

Stress factors, cognitive and psychical load

The results of this study underline the state that high mental load dominates in surgical interventions like FESS. During every procedure, the stress levels were significantly higher, than before or after the operations. Preoperatively the HRV is high, during the operation the HRV decreases and is suppressed by adrenaline, which causes the heart to beat more regularly and faster. After the operation the HRV increases again.

During and after the usage of the navigational pointer no suppression in the 0.1 Hz component was visible. On one hand, this means that the application of the navigation system did not cause a higher mental load. On the other hand, the stress level of the surgeon in an operation with similar complexity and without the aid of a navigation system

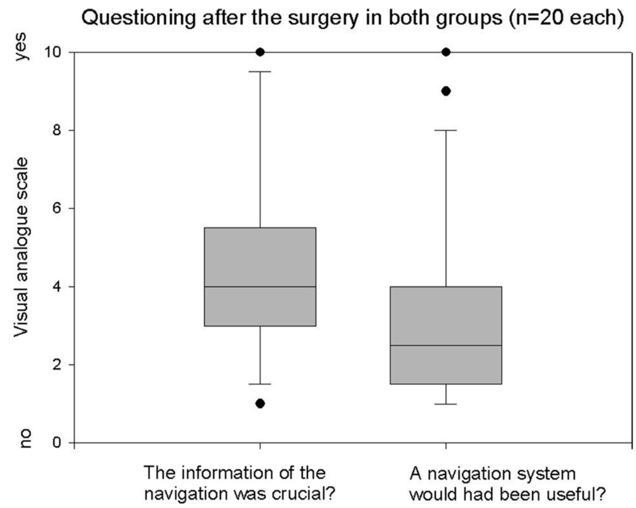

Fig. 6 After every surgery the surgeon had to answer a question on a visual analogue scale about the effort to engage a navigation system for the occurred surgery

remains unclear and could be much higher. To answer this question a proper randomization would be necessary, which is for ethical reasons impossible to achieve in complex skull base operations.

There was no significant difference in the overall HRV in operations with navigation compared to operations without navigation, which means that the stress level was almost equal in these operations. Regarding this equality of the stress levels, it has to be mentioned that, according to Fig. 3 the navigation system was used in more complex operations, like skull base surgery, and it was expected that this kind of surgery should demand more mental effort from the surgeons. No faithful surgeon would deny the fact that a higher mental workload is needed in complex surgery like transnasal skull base surgery.

A reverse picture to the HRV can be observed with the analysis of the HR. The heart rate is significantly increased during the operation compared to the baselines. However, there was no significant difference in the mental workload between the interventions with navigation and without.

Another point was the question about the effort to engage a navigation system after the surgery [19]. Fortunately, in the non-navigation group in most cases (18/20) a navigation system would have been unnecessary. But in two cases (10 %), the surgeon admitted after the surgery that a navigation system could have been useful, although the surgeon thought that such a system would be unnecessary preoperatively. That means that about 10 % of the apparent "easy" FESS turns out into more complicated procedures where a navigation system would be useful. This is a rather high rate for which further investigations should be done. On the opposite, in more than 50 % of the cases where a navigation system was installed, the additional information was not used or crucial for the operation. This seems a rather normal rate and should be even lower in more experienced and cautious surgeons.

Through the objective measurement of the mental workload some other stressors could be identified and attracted attention independently from the usage of the navigation. A significant depression of the HRV could be monitored when students or colleagues were chatting in the OR. The other way round, a quiet and professional atmosphere in the OR inducted a lower mental workload and stress level.

Partly avoidable stressors are system failures of surgical devices like the navigation, the electrocautery, the shaver or the sinus-drill. A complete system failure never occurred during the study, but electrocautery often not functioned because the cable was not plugged in or the shaver blade was not properly fixed to the handpiece. Although these system failures could be fixed easily, it took time and these unprofessional circumstances stressed our surgeons in the study. Postoperatively the surgeons stated, that stress was created by these situations because of unpredictable time loss and the helpless feeling of "nothing to do, but to wait for someone else to fix the problem".

Classic endoscopic surgery specific stressors like blurred visions due to diffuse bleeding or manipulation at high risk structures in the sphenoid sinus caused a higher stress level. Interestingly, this specific kind of stress exhausted the surgeon physically but felt comfortable and physiological. This raises the question, whether the stress level and the additional mental load have negative consequences for the long-term health of the surgeons and the outcome of the surgery. During an operation a certain degree of tension and stress is desirable because it goes with increased concentration and situational awareness. This particular type of stress is called eustress [6], and is not like the harmful and unphysiological distress [22]. Distress can typically lead to overload and burn out syndromes [23]. Unfortunately, the line between eustress and distress is not clearly definable and hardly measureable.

Therefore, avoidable stressors like simultaneous teaching of students in the operating theatre should be eradicated as much as possible. Because of these findings we changed the student´s bedside teaching. The teaching of students in the theatres is not performed any more by the operating surgeon but by an uninvolved supervisor.

Unfortunately, after every surgery the surgeons claimed that the biggest stressor is the time pressure. Although this specific stressor is poorly defined and could not be monitored objectively with this setting, it seems to play a certain role in the OR in University clinics in Germany. Time pressure can be avoided, in a certain way avoidable through better planning and realistic anticipation of the needed surgical time. In any case, time pressure can never be an excuse for an unfortunate event which might have medical or legal consequences.

Conclusion

Endoscopic sinus surgery and endoscopic skull base surgery are heavy mental workload even for advanced surgeons. In situations with heavy workload stress reactions are physiological and natural to get better situation awareness (eustress). Too much workload and the powerless feeling of losing control is unphysiological and can exhaust and frustrate the surgeon (distress), therefore, additional and avoidable stressors have to be identified and then avoided. It could be shown that stress factors are measureable objectively. Further investigations should aim at this to increase the quality of life and efficiency of rhinosurgeons in the future. Unhealthy stress had to be identified and should be communicated in the team without shame. An open discussion among the current and next generation of surgeons about mental demand, stress and rough atmosphere is the chance to improve the OR situation and to make surgery more attractive to female surgeons especially.

In our study, all four surgeons stated the time pressure as the utmost stressor. Unfortunately, especially this particular stressor seems difficult to avoid at first sight. However, realistic adverbial of time by the surgeon pre- and intraoperatively and conservative OR-scheduling can take away a lot of time pressure.

Other stressors like loud chatting in the OR, open doors or malfunction of medical devices can relatively easily be avoided. Correct function of medical devices, like navigation systems, can only be guaranteed by proper maintenance and if these devices are operated by qualified and trained personal. Video endoscopy and navigation systems are complex devices, which need regular training. Failure or malfunction of these devices create distress and can be dangerous for the patient, surgeon and OR team. Nowadays advanced rhinosurgeons have to deal with a lot of different medical devices and a lot of important and unimportant information from these devices. For a good result the surgeon has to extract the important and right information from the medical devices on the fly during every surgery. This is hard mental work. Training and high situation awareness is needed for this. Manufactures of medical devices exactly know this and try to create their devices easier to handle, self explaining and intuitive in operation [24]. But in the end the crucial information can only be extracted if the medical devices and the operating team work correctly, otherwise distress is waiting to happen. For proper operation of complex medical devices it is important that the whole OR-team is trained with it. In most cases malfunction of a medical device is due to false operation by an untrained user. Experienced surgeons know this, that is why they are not stressed or get angry with the medical device itself, but with the operating team Every surgery is teamwork. One last ultimate stressor for everybody in the OR is disharmony in the team, which is in most cases due to inadequate training (which then ends in inadequate behaviour) [25]. The experienced senior surgeon, who plays the biggest role and stays in the centre of the team, can contribute most to harmony and adequate behaviour. The senior surgeon is the one who must always take the blame and the one who must reply to any questions if complications occur. The correct and calm behaviour of the surgeon is not only a matter of legal affairs but even of an ethic point of view. The (senior) surgeon has to be aware of this role and has to train this with his or her team in the OR and outside the OR. Guided simulation trainings, team building actions and professional group and single conversations can contribute to a better team work and more professional atmosphere in the team.

In this study it is shown for experienced surgeons that it is not the complexity of the surgery or the multiple different medical devices with a mass of medical information that creates distress but the inadequate teamwork of the contributing persons in the OR. This is completely different in surgical training situations, where the trainee is stressed by the behaviour of the supervisor and the handling of different medical devices. In addition to this interesting topic of stressors during surgical training will be published (from our workgroup) in the near future. Last but not least it remains unclear whether the reduction of stress leads to a better surgical outcome. Further investigations in this difficult field of organizational psychology are needed.

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Conflict of interest All authors state that there is no conflict of interest.

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ORIGINAL CONTRIBUTION

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Evaluation of an image-guided navigation system in the training of functional endoscopic sinus surgeons. A prospective, randomised clinical study*

K. Stelter[1], B. Ertl-Wagner[2], M. Luz[3], S. Müller[4], G. Ledderose[1], V. Siedek[1], A. Berghaus[1], S. Arpe[1], A. Leunig[1]

[1] Department of Otorhinolaryngology at the Ludwig Maximilian University, Munich, Germany
[2] Institute for Clinical Radiology, University of Munich, Germany
[3] Specialist group for Industrial, Engineering and Organisational Psychology of the Technical University, Berlin, Germany
[4] Innovation Centre Computer Assisted Surgery (ICCAS), Leipzig, Germany

SUMMARY

Introduction: *Many sinus surgeons report improved spatial orientation after using a navigation system. This study investigates the surgical, ergonomic and economic aspects of using a navigation system in training and teaching.*

Materials and methods: *Eight rhino-surgeons in training and 32 patients with bilateral diseases of the paranasal sinus system were included. After randomisation, one patient's side was operated on with a navigation system while the other side was operated on without navigation. It was monitored how often the surgeon used the navigation pointer and then changed the procedures. A standardised and validated interview recorded the cognitive load when using the navigation system and the application efficiency.*

Results: *The operations lasted on average 16 minutes longer with the navigation. Five paranasal sinuses could not be found in the control group without navigation. In only 10-13% of cases did the surgical procedure change after the use of the pointer. Most of the surgeons admitted that particular steps of the operation were more reliable and safer to carry out with the navigation system. The general trust in the system rose in proportion to intraoperative accuracy and repeated use.*

Conclusion: *Overall, there was an overwhelming level of trust in the navigation system. Trainee sinus surgeons seeing their more experienced colleagues using a navigation device tend to overestimate the possibilities of the system and to underestimate the risks. The assistance system was used particularly effectively in the group of slightly more experienced surgeons. In this group, the additional expenditure of time was less and the navigation substantially contributed to reinforcing the anatomical sense of direction.*

Key words: *navigation, FESS, surgical training, perceived risk, workload*

INTRODUCTION

The use of a navigation system in surgical training is currently controversial (1-3). A survey by the University of Leipzig and Berlin found out that approximately 30% of all ear, nose and throat clinics in Germany have access to navigation systems, which are used in 90% of FESS (4). Use of the systems in clinics varies considerably. Sometimes only highly complicated operations are navigation-supported, whereas in other cases the systems are used nearly daily, even for simple procedures.

The consequences of instrument navigation with experienced surgeons is assessed in overwhelmingly positive terms in the literature (4). Most ear, nose and throat surgeons report improved spatial orientation, 45% better situation awareness and over 2/3 assume better surgical results after using a navigation system on FESS (4). At the same time, it is feared that using a navigation device in surgical training could be rather dangerous and lead to a loss of important anatomical knowledge and surgical expertise. Surgeons that use the device agree that instrument navigation should be used as often as possible and hence also with simple operations. Only in this way can

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familiarity with the system be achieved. In established centres, a navigation system enables up to 10% of OR time to be saved [4,7]. A complete evaluation of a navigation system should principally include technical, surgical, ergonomic and economic characteristics [1]: the technical characteristics (accuracy and precision) of several navigation systems have been adequately studied by our working group [8-10].
But surgical, ergonomic and economic features have until now not been researched in routine operations in surgical training. Specifically, the following questions should be answered:

Surgical characteristics:
- Does the trainee surgeon improve the postoperative outcome with the navigation (has he drained all the diseased paranasal sinuses)?
- Did the trainee surgeon change surgical procedures in routine operations because of the navigation (change of strategy)?
- Does the supervisor have to intervene in the operation process less frequently?
- Does the surgeon take more risks (risk homeostasis)?
- Does the trainee over-rely on the device or can the navigation lead to misdirection (excessive trust)?
- Did the surgeon perhaps lose skills because he allowed the system to do the work (surgical skill loss)?

Ergonomic characteristics:
- What are the system's controllability, expectation conformity and self-description capabilities?
- Does it affect the situation awareness?
- Is there a reasonable ratio between the cost of the device and its utility (effort to engage)?
- Can the tasks of the surgeon be appropriately carried out with the system (skill set requirements)?
- Does the system reduce cognitive and physical demands and how does the surgeon handle the increasing workload with the pictorial information offered (workload shift)?

Economic characteristics:
- How high is the additional expenditure of OR time in using the device in standard situations?
- What is the cost of using the navigation device in training?

MATERIALS AND METHODS

The randomised, single blinded clinical study was planned and carried out in accordance with the GCP guidelines and CONSORT (Consolidated Standards of Reporting Trials) Statement [11] of 2008.
Thirty-two patients with bilateral diseases of the paranasal sinus system (chronic sinusitis with or without polyposis nasi) were included between June 2009 and May 2010. In all operations, a navigation system was primarily not required, i.e. all landmarks could be detected without navigation by an experienced surgeon. Complicated anatomy and revision cases were excluded. The operations were carried out with 8 different operating surgeons in training under the supervision of 2 experienced rhinosurgeons. After a block randomisation, one patient´s side was operated with the help of a navigation system (VectorVision compact® with laser registration, BrainLAB, Feldkirchen, Germany), the other patient´s side was operated without navigation (intra-individual design). At the end of the operation, an evaluation was made with the navigation device and the supervising senior physician as to whether the operating surgeon had correctly operated on all the defined regions of the paranasal sinuses (Figure 1).
During the surgery, it was monitored how often the surgeon used the navigation pointer, on which part of the anatomy and how often he changed his surgical strategy. After the first and fourth (last) FESS, each surgeon filled out a standardised and validated questionnaire: the 'Human Factors Evaluation Questionnaire for Computer Assisted Surgery Systems (HFEQ-CASS).'

Intraoperatively, the following objective data were ascertained:
- Operation duration (beginning and end) of both sides separated from each other
- Required time for data transfer and referencing (surface matching by laser)
- Use of the pointer on different anatomical sides (Lamina Papyracea, skull base, sphenoidal sinus and the frontal sinus)
- Change of surgical strategy based on information from the navigation device
- Postoperative drained paranasal sinuses right and left (outcome)

The HFEQ-CASS contains 38 items in two categories. The first question block (12 questions) consisted of
- Mental demands and work load (5 questions)
- Surgical results of the operation (1 question)
- Situation awareness (3 questions)
- Speed (1 question)
- Readiness to take risks (2 questions)

The first five questions were obtained from the *Nasa Task Load Index* [12]. The concept and questions on situation awareness were developed by Endsley [13].

The second question block covered surgical and ergonomic characteristics with 26 questions:
- Cross-checks before use of relevant structures (3 questions)
- Discovering malfunctions (1 question)
- Reduction of surgical sense of direction = skill loss (2 questions)
- Application error = automation bias (1 question)
- Expectation conformity = usability (12 questions)
- Cost-benefit ratio (effort to engage) (1 question)
- Reliability (2 questions)
- Patient safety (2 questions)
- Trust (2 questions)

Statistics

In the planning and analysis of this study a statistician of the institute of biometry, epidemiology and information processing was involved. Every participating surgeon had to do exactly four operations to cover all possibilities with the navigation system and sides:

- begin with the right side with the navigation system
- begin with the left side with the navigation system
- begin with the right side without the navigation system
- begin with the left side without the navigation system.

To test if the use of the navigation system had significant impact on the surgeons' perceived workload and performance as compared to unsupported surgery, ratings on the scales of the first part of the questionnaire were tested for significant deviations from the midpoint of the scale, 3, by the one-sample *t*-tests. A significant deviation from the neutral midpoint meant a benefit with > 3 or a disadvantage with < 3 in use of the navigation system compared to the other patient´s side without the navigation system.

For the second part of the HFEQ-CASS (questions 13-38), the same test (double-sided t-test compared with 3) was basically used. We decided to apply the Bonferroni [14] correction in the present study only to tests including items or scales focusing on aspects of the same human factors. This corresponds to a familywise approach to statistical testing in other settings. For example, changes of workload were analysed by six dependent *t*-tests (one test each for the overall workload score and the five single dimensions of workload considered). In this case, an effect of a single *t*-test was only considered to be significant if $\alpha \leq 0.05/6 = 0.008$. In accordance with this procedure, effects will only be reported as significant of the given α-level if their probabilities are equal to or smaller than the Bonferroni adjusted α.

The results were evaluated with SPSS 14 (Chicago, IL, USA). The graphic treatment was done with SigmaPlot 2000. A prospective power analysis was not carried out since there was no data from preliminary investigations, which could relate to possible differences and mean variations.

RESULTS

Patient collective

In accordance with the study design, all 32 patients were operated on by 8 operating surgeons. After information was provided on participation in the study with an explanation of the functioning of the navigation device, 18 (56%) patients opted to be operated on with a navigation device, 14 (44%) patients said it did not matter whether they were operated with or without a navigation device. The average age of the patients was 46 years (SD = 16 years). All 32 patients suffered from chronic sinusitis on both sides, 17 patients had nasal polyps on both sides, 16 patients also had septal deviation, 5 patients suffered from Samter's Triad.

In total there were 157 diseased paranasal sinuses (right and left): 60 anterior ethmoid cells and maxillary sinuses (= 92% of the patients), 54 posterior ethmoid cells (= 52% of the patients), 25 frontal sinuses (= 30% of the patients), 18 sphenoidal sinuses (= 22% of the patients).

Drop outs

In this study, all 8 subjects (surgeons) completed the prescribed number of operations. There were no dropouts among the patients after inclusion and signed patient information. Accuracy and precision were measured intraoperatively by target registration error (TRE) before each application of the navigation system and after patient registration. Only if the TRE was acceptable, the referencing was accepted. In two cases, registration was impossible, because the data record was too roughly layered. In two other cases, the data record could not be transmitted to the navigation system, because the CT data in DICOM format was carried by an external radiologist to the CD-ROM without the file ending dcm.

Postoperative Outcome

The 157 diseased paranasal sinuses were equally distributed on both sides. During the operation, 80 paranasal sinuses were operated with the help of the navigation and 77 without. The supervisor had to intervene during the operation as often in the study group as in the control group.

At the end of surgery, the supervisor found with the aid of the navigation a total of 5 paranasal sinuses, which had not been opened without the navigation, and 2 sphenoidal sinuses, which had not been opened even with the use of the navigation (Table 1). The supervisor opened the infected sinuses by himself to complete the operation.

Frequency of pointer use and change of strategy

The pointer usage varied a lot between individuals. Not only the operating surgeon, but also the actual situation and the patient played a decisive role.

The change of surgical strategy is the most important aspect in the use of surgical assistance systems. In only 10-13% of cases, the surgical procedure was changed. (Table 2). In these cases, it could not be differentiated whether the operating surgeon used the navigation to verify or correct his previously assumed instrument position.

At the end of each operation, the surgeon had to state on a visual analogue scale (VAS) whether he operated with the navigation on structures, which he would not have operated on without the navigation. With a mean value of 55mm (SD = 34mm), most surgeons believed that they would have done the same steps of the operation with the navigation as without the navigation.

Expanding the indication spectrum

The HFEQ_CASS had three questions indirectly relating the readiness to expand the indication spectrum by using the navigation. The answers showed highly significantly ($p = 0.00000093$) that the trainee surgeons thought that particular steps of the operations were taken more reliably and safely with the navigation system and therefore they were more likely to try them.

Figure 1. Setting in the OR. The operating surgeon carries out the FESS guided by the 19" monitor. To the left side is the VectorVision compact® placed. All objective data was recorded by a third person 'on the fly' with the study notebook (centre).

Risk management and complications

Intraoperative complications included bleeding, which obscured the surgical view (n = 4) and injury to the lamina papyracea and periorbita (n = 2). All complications were distributed equally in the study group (with navigation) and the control group (without navigation). There were no major complications (CSF-leaks, heavy arterial bleeding, injury to the N. opticus or orbital cavity muscles). However, the questionnaire revealed a significantly increased willingness to take risks when using the navigation system.

Over-reliance and over-trust

Both, after the first operation with the navigation system and after the fourth operation with the system, all surgeons thought that paranasal sinus operations could be more safely carried out, and all surgeons trusted the system. On the other hand, many surgeons didn't share the opinion that the system provides greater protection from faulty treatment.

The important issue of trust in the system was additionally raised after each operation based on a VAS. In this way, the operating surgeon had to indicate whether he trusted the navigation system or not. Depending on the intraoperative accuracy of the system this produced extremely varied values. Overall, in 32 operations all operating surgeons trusted the navigation system in over 90% of cases (Figure 2).

The high trust and feeling of safety must be compared with the probability of an operating error due to the navigation system. The HQEF-CASS asked how often the surgeon checked accuracy (cross check) and whether he/she blindly trusted the device's information. The beginner surgeons believed that they would quickly notice a malfunction of the system in critical situations. At the same time, many admitted that the system was not regularly checked for accuracy especially after the 4th operation. Even when the trust in the system was very high, most surgeons indicated that they trusted their own impressions rather than the system's information.

Surgical skill loss

No trainee surgeon thought of a loss of surgical skills when using the navigation system. On the contrary, almost all surgeons reported a better anatomical understanding with the additional information of the image-guided navigation.

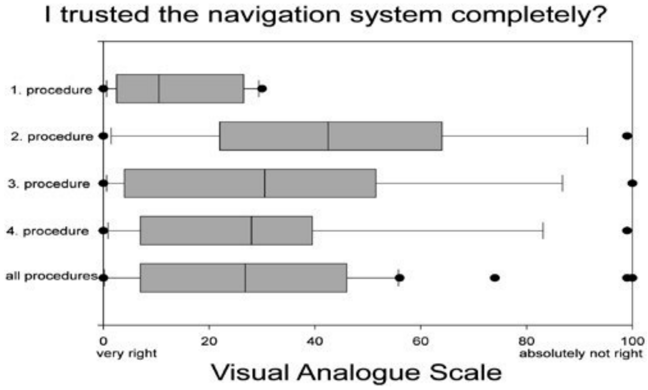

Figure 2. Box plots filled out by beginner surgeons with median, 65% and 95% percentile and exceptions to total trust in the system. 0 mm = maximum trust, 100 mm = no trust.

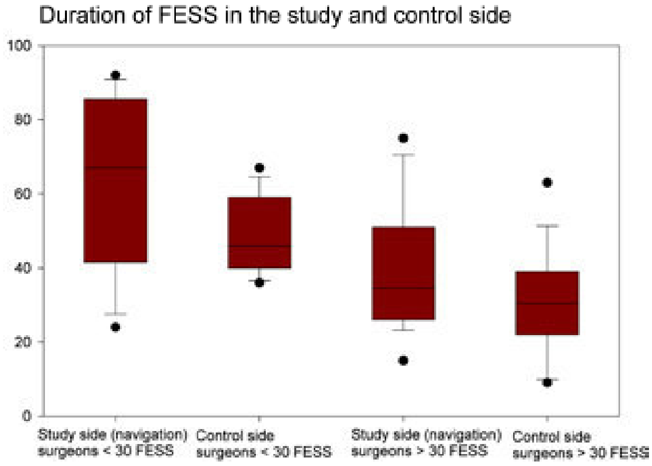

Figure 3. Box plots of the navigated side compared to the control side distributed to less experienced operating surgeons (< 30 FESS operations; n = 4) and more experienced FESS surgeons (> 30 FESS operations, n = 4).

However, three experienced operating surgeons admitted that beginner surgeons would possibly develop less of a surgical sense of direction if they worked with the navigation from the beginning.

Ergonomic characteristics

Workload shift

No significant difference between the control and study group was indicated thereby. This means that the surgeons felt no higher workload when using the navigation system.

Usability

Usability was perceived as positive. Results after the first operation were an average of 2.17 (SD: 0.77) [Scale: 1 = very good usability, 5 = very poor usability] and after the fourth operation even better with an average of 1.95 (SD: 0.82). The values indicated highly significantly a positive usability

Situation awareness

Situation awareness was recorded by 3 questions and was significantly better when using the navigation. The answer patterns after the first and fourth operations did not significantly differ from each other (p = 0.39).

Effort to engage

All surgeons thought that the operational cost of the device was in proportion to the use; after the fourth operation even more than after the first operation.

Economic characteristics

The extent of additional operating room time with the use of a navigation device in standard situations is shown in Figure 3. Although the duration of the study side was 16 minutes longer on average, there were no significant differences either inter-individually (patient to patient) or intra-individually (right against left patient´s side) because of the wide variations in individual OR times. Particularly among the beginners (< 30 FESS operations), there was a trend (p = 0.06) to extend OR time with the navigation (Figure 3).

Cost of a navigation device

The following prices are the individual list prices of the navigation device with the accessory used from BrainLAB in February 2010 in Euro:

Vector VisionII	€ 74.000,-
Softouch and Z-touch registration packet	€ 29.400,-
I-Plan ear, nose and throat planning software	€ 15.500,-
Pointer, headband, instrument adapter, ICM, Steribox	€ 18.830,-
20 reference headbands with markers	€ 550,-
On-site installation and maintenance contract	€ 8.450,-
Total:	€ 146.730,-

Added to this is the extended OR time when using the system for training from 16 minutes per group plus 17 minutes registration and boot up.

DISCUSSION

Since it is unclear what *psychic demand* actually is and this phenomenon also cannot be quantified with scientific methods, it seems reasonable to simply ask people how they subjectively evaluate the demand in a given work situation with informational content. The HFEQ-CASS was designed by the technical group for Industrial, Engineering and Organisational Psychology at the TU Berlin and the Innovation Centre Computer Assisted Surgery (ICCAS) Leipzig especially for evaluating cognitive load in using navigation systems in ORs. A check of internal consistency (Cronbach's α) was possible based on the redundant method of enquiry and produced conclusions on the reliability of the questionnaire.

In preliminary investigations of 213 surgeons, Cronbach´s α produced a number between 0.69 and 0.83 (whereby > 0.7 values are considered very reliable) [4].

Filling out the HFEQ-CASS after each operation was not feasible in view of the scope. Hence, after each operation, the operating surgeons were only asked three specific questions, which were filled out based on a visual analogue scale (VAS). The three questions covered change in surgical strategy, perceived risk and trust in the system.

Change in surgical strategy

Relatively the navigation was used most often for finding the frontal sinus. Frequent use on the frontal sinus corresponds to expectations, since there are the greatest uncertainties and anatomic variations and even experienced paranasal sinus surgeons described finding the frontal sinus as the most demanding part of a FESS [17].

A change in surgical strategy in only 10% of the cases is substantially lower than indicated in the literature [1]. The surgeons were prompted by the supervisor to use the pointer regularly to practice handling the navigation device. Therefore, the navigation was used very often to verify already known landmarks and only rarely contradicted the a priori information of the operating surgeon. In 10% - 13% of cases, however, the pointer position did not correspond to expectations and led to a change in surgical procedure. It was most often suspected that the frontal sinus was opened while, after checking, the navigation showed that the operating surgeon was only looking into an agger nasi cell. A change in surgical strategy on the skull base was mostly indicated after the skull base was confused with cells from the posterior ethmoid bone, just as posterior ethmoidal cells were often confused with the sphenoid sinus. Whether the operating surgeon would have trusted the information from the navigation system to the extent of independently changing his surgical strategy even without the feedback from the supervisor remains a matter for speculation. Very interesting are the two sphenoid sinuses that were not opened/found despite using the navigation (see Table 1). In both cases, the operating surgeons did not trust the navigation and did not open the sphenoid sinus so as not to harm the patient in any way. In both cases, the sphenoid sinus was then opened by the supervisor. On the other hand, in one case navigation was so helpful that the operating surgeon opened the frontal recess wide although this was not assessed as necessary by the supervisor. In doing this, the training surgeon was overestimating his expertise and the possibilities of the navigation and after the operation he recognised that his trust in the system may have been exaggerated.

Trust in the system

General trust in the navigation system was very high among most subjects from the beginning. After the first operation, all surgeons were ready to operate with the navigation system themselves. However, it was already clear to three surgeons

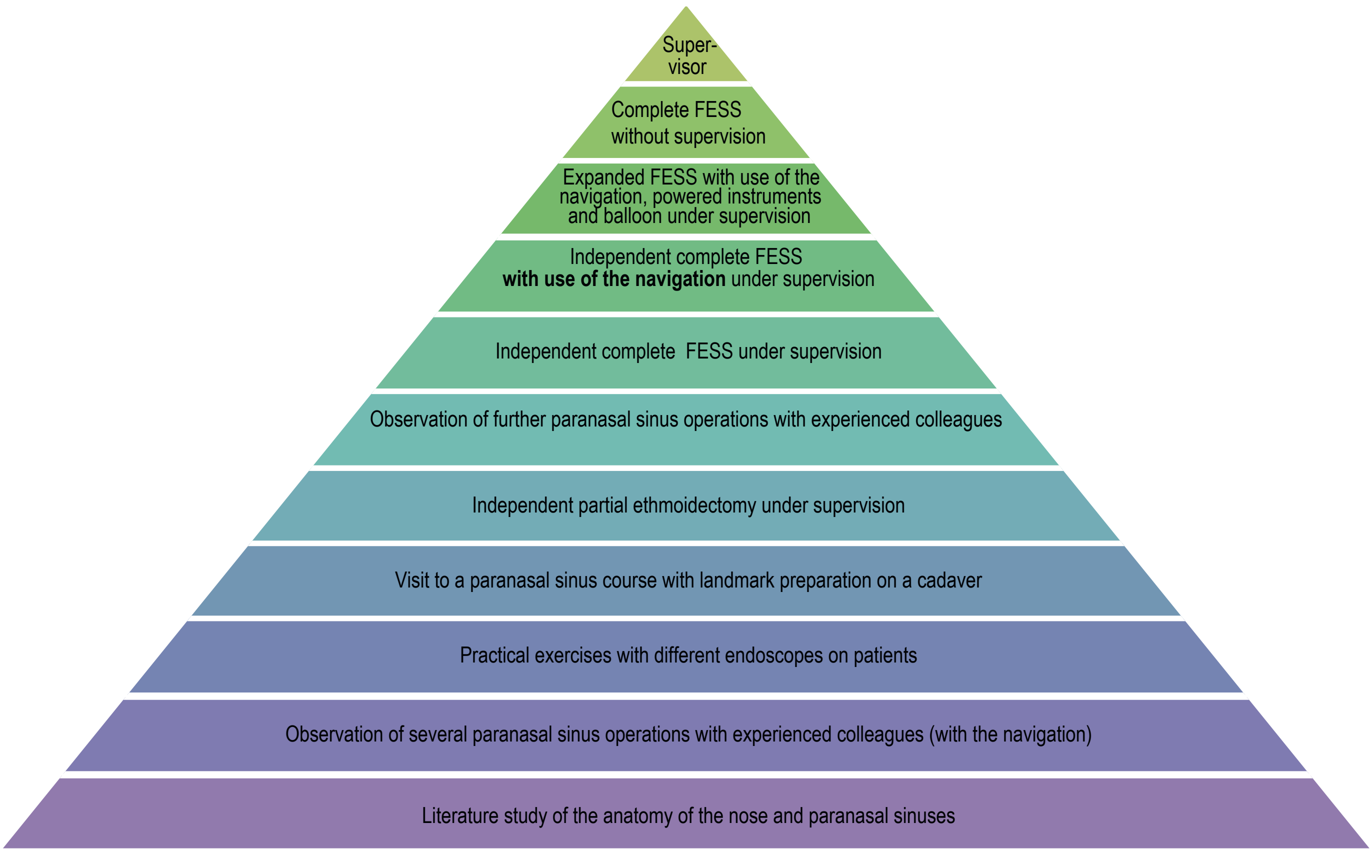

Figure 4. The Munich model of structured FESS training.

after the fourth operation that a navigation system offers no protection against treatment failure but instead could lead to over-trust and mislead.

There was a direct relation between clinical accuracy and trust in the system. In this connection, it is interesting that, when specifically asked if they completely trusted the system during the operation, many surgeons did not trust the system because the deviation was too high. At some distance from the operation and in another context (by the HFEQ_CASS), all surgeons suddenly thought that operations could be done more safely and that there was greater protection from treatment failure. A special problem is the statement of four surgeons after the fourth operation that they no longer did regular cross checks. This is dangerous regarding the increased readiness to take risks with the perceived security provided by the navigation.

Experienced FESS surgeons only trust the system with increased frequency of use[4]. Whereas beginner surgeons who had already seen a navigation device used by experienced colleagues tended to overestimate the possibilities of the system and to underestimate the risks.

Cognitive and physical workload

Most operating surgeons indicated that they did not feel any additional workload from the navigation. This was partly because no surgeon (although anonymised) likes to admit that he/she is negatively affected by high technology in the OR. Another important aspect is that the navigation system was used without any time pressure and after systematic instruction under supervision in the context of this clinical study. Hence, most surgeons even found the navigation to be a mental relief and handling the technology as motivating instead of frustrating.

Surgical skill loss

In this study, the surgeons were forced to carry out a particularly precise operation plan on behalf of the CT findings preoperatively. These skills could be lost by using the navigation since it is possible to 'simply' operate and consult the navigation in critical situations without a detailed preoperative plan. However, no surgeon saw this as a risk to his own knowledge and skills, but some surgeons admitted that this could happen to younger colleagues in particular and estimated that use of the navigation could be critical for these colleagues.

Time effort and costs

Beginners need more time for operations than experienced surgeons, especially when using additional technology like the navigation. The period per group particularly depends on the level of experience of the surgeon and the difficulty of the anatomy. Hence, wide variations from 9 minutes to 90 minutes per group and side were not surprising. The extended operating time in using the system compared to the opposing group was on average 16 minutes plus 17 minutes registration and boot up. Assuming € 10,-/min OR time [(1)] additional training costs came to € 390,- per use of the navigation system. However, some steps (system boot up, data transfer and CT check up) are carried out by the scrub nurse or the surgeon before the start of the operation, which then does not extend incision to closure time. A considerable extension of OR time should be expected, especially when the navigation is used for the first time. By the second application, a lot of time was already being saved. In addition, during the first four applications pointer use was more rare, but also more effective. If this trend is to be continued, time saved when using the navigation should be expected [(18)]. This study unambiguously shows that effectiveness and time saved by regular use of the assistance system can be increased.

Next steps

An interesting question would be how often a supposedly simple paranasal sinus operation became so complicated that the operating surgeon would be thankful to have a navigation device on board. Most surgeons with access to a navigation device either use the technology very often and for many indications, or use it very rarely and only in extreme cases. To increase or reduce the frequency of use of such assistance systems to a reasonable level, further investigations are essential.

CONCLUSION

The navigation should have an assured place in training and teaching for paranasal sinus operations. Even if this new technology means extra costs, it was welcomed by all study participants (surgeons and patients). Good surgical training is initially expensive, but having a well-trained surgeon in the house is invaluable. The assistance system was used particularly effectively in the group of somewhat experienced operating surgeons (> 30 paranasal sinus operations). Additional expenditure of time was less and the navigation contributed substantially to enhancing anatomical sense of direction. Handling the device must be practiced in familiar environments, without pressure and under supervision. So it makes no sense to reserve this technology only for particular paranasal sinus surgeons for particularly difficult situations. In emergencies, the system can only be used effectively if it had previously been often used. Depending on their attitude to technology and level of training, operating surgeons are prejudiced in favour of or against this technology. These prejudices can be broken down by targeted use of the device in standard situations.

The Munich model of structured FESS training has scheduled regular use of the navigation since the results of this study. This is based on the training sequence in Figure 4.

The Munich training curriculum places particular emphasis on structured landmark preparation. The navigation can be helpful, particularly in finding the corresponding landmarks. Using this technology is, however, pointless without anatomical knowledge and an accurate idea of the course of the operation. The human supervisor can also not be replaced by a navigation device. As long as the above points are adhered to, it should not be feared that surgical skills will be lost because of using the navigation.

Table 1. Missed paranasal sinuses with and without navigation. Additionally opened paranasal sinuses were paranasal sinuses, which should not have been opened according to the preoperative CT scan but which were opened anyway.

	With navigation	Without navigation
Missed paranasal sinuses	2 sphenoid sinuses	1 frontal sinus 3 sphenoid sinuses 1 posterior ethmoid sinus
Additionally opened sinuses	1 frontal sinus	1 posterior ethmoid sinus

Table 2. Absolute values of the paranasal sinuses opened with the navigation in relation to pointer usage and change of surgical strategy.

	Lam. papyracea + maxillary sinus	Posterior ethmoidal cells	Frontal sinus	Sphenoidal sinus
Operated sinus	60	54	25	18
With navigation	30	27	14	9
Pointer-usage	67	68	46	25
Change of strategy	7	9	6	3
Ratio	0.10	0.13	0.13	0.12

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CONFLICT OF INTEREST

None.

AUTHORSHIP CONTRIBUTION

KS, AL are the principal investigators of this study. They had the idea and wrote the paper. BEW prepared all the DICOM Files for navigation and contributed with her radiological point of view. ML, SM prepared and interpreted the HFEQ_CASS. GL, VS included the patients, checked the informed consents and did all the postoperative nasal care. AB is the head of the department and was therefore responsible for the whole study. SA did her doctoral thesis with the results of the study. She collected and sorted all data (intraoperatively and the HFEQ_CASS) and did all statistical calculations.

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Klaus Stelter, MD
Dept. of Otorhinolaryngology, Head and Neck Surgery
Grosshadern Medical Centre of Ludwig-Maximilians-University
Marchioninistr. 15
81377 Munich
Germany

Tel: +49-89-7095 0
Fax: +49-89-7095 6869
E-mail: Klaus.stelter@med.uni-muenchen.de

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RHINOLOGY

Mental distress and effort to engage an image-guided navigation system in the surgical training of endoscopic sinus surgery: a prospective, randomised clinical trial

M. N. Theodoraki · G. J. Ledderose · S. Becker · A. Leunig · S. Arpe · M. Luz · K. Stelter

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Abstract The use of image-guided navigation systems in the training of FESS is discussed controversy. Many experienced sinus surgeons report a better spatial orientation and an improved situational awareness intraoperatively. But many fear that the navigation system could be a disadvantage in the surgical training because of a higher mental demand and a possible loss of surgical skills. This clinical field study investigates mental and physical demands during transnasal surgery with and without the aid of a navigation system at an early stage in FESS training. Thirty-two endonasal sinus surgeries done by eight different trainee surgeons were included. After randomization, one side of each patient was operated by use of a navigation system, the other side without. During the whole surgery, the surgeons were connected to a biofeedback device measuring the heart rate, the heart rate variability, the respiratory frequency and the masticator EMG. Stress situations could be identified by an increase of the heart rate frequency and a decrease of the heart rate variability. The mental workload during a FESS procedure is high compared to the baseline before and after surgery. The mental workload level when using the navigation did not significantly differ from the side without using the navigation. Residents with more than 30 FESS procedures already done, showed a slightly decreased mental workload when using the navigation. An additional workload shift toward the navigation system could not be observed in any surgeon. Remarkable other stressors could be identified during this study: the behavior of the supervisor or the use of the 45° endoscope, other colleagues or students entering the theatre, poor vision due to bleeding and the preoperative waiting when measuring the baseline. The mental load of young surgeons in FESS surgery is tremendous. The application of a navigation system did not cause a higher mental workload or distress. The device showed a positive effort to engage for the trainees with more than 30 FESS procedures done. In this subgroup it even leads to decreased mental workload.

Keywords Heart rate variability · Navigation · FESS · Surgical training · Mental workload

M. N. Theodoraki (✉)
Department of Otorhinolaryngology Head and Neck Surgery, University of Ulm, University Clinic of Ulm, Ulm, Germany
e-mail: marie-nicole.theodoraki@uniklinik-ulm.de

G. J. Ledderose · S. Becker · S. Arpe · K. Stelter
Department of Otorhinolaryngology Head and Neck Surgery, Ludwig Maximilians University, Munich, Germany

A. Leunig
Clinics and Private Practice Dr. Gärtner, Munich, Germany

M. Luz
Industrial, Engineering and Organisational Psychology of the Technical University, Berlin, Germany

Introduction

The clinical use of the navigation system in functional endoscopic sinus surgery (FESS) procedures varies strongly among hospitals. In some institutions the system is only used under complicated conditions, whereas in other hospitals the navigation system is part of the daily routine [1].

Experienced surgeons report a better intraoperative orientation, an improved situational awareness and a decreased surgical risk with the use of the navigation system [2]. Although experts fear that the usage of the navigation system during training would lead to a loss of surgical skills and anatomical knowledge [3], those who use the navigation system, support its usage also for simple procedures on a daily basis. This is because a familiarity with the system has to be achieved for the best performance and the best patient results. However, the correct usage of these devices needs proper and regular training. Otherwise, these systems lead to more stress than real help for the surgeon. The usage and the evaluation of the navigation system in the surgical training have been rarely evaluated.

In this context, the present study examines three cardiovascular parameters during the FESS surgery: the heart rate (HR), the respiratory frequency and the heart rate variability (HRV). Additionally, the left masticator tone was monitored to measure a certain teeth clenching. Actually, this study is the first field study in literature, which measures the heart rate variability in FESS surgery continuously. These well-established biometrical parameters are frequently used in research of mental and physical workload [4–10].

The heart rate is frequently used for the detection of mental workload because of the easy determination through the electrocardiogram. The heart rate increases with an increase of mental effort [11].

Unfortunately, the heart rate is influenced by external factors like emotions and muscle work [7]. Nevertheless, the heart rate is used in many studies as a parameter of mental effort, although the quantity of physical or emotional factors cannot precisely be identified [10, 12].

The HRV describes the variability of the single heart beats to each other. The physiological condition in rest situations shows a high heart rate variability because of the high influence of the parasympathetic nerve system. A relaxed and healthy heart does not beat regularly but slightly irregularly. In other words, the distance between two heart beats (two R-waves) is varying. The HRV can be calculated by these interbeat intervals. Kalsbeek and Ettema proved in their studies that the HRV decreases by doing binary cognitive tasks. In other words, the heart beats more regularly in situations with high mental workload [13–15]. Meanwhile, the HRV is an often used parameter for quantification of mental load. It is used for example by pilots to quantificate the efficiency of training and stress levels during flights [4]. However, heart rate variability is a complex biosignal influenced by many factors beyond the mental distress and the psychical demand [16]. For its proper evaluation, a spectral analysis is needed to divide this parameter in its different elements.

The physical and mental stress during functional endoscopic sinus surgery (FESS) is without doubt high [17]. Thus, the aim of this study is to objectively record the mental workload and distress of surgeons in training during a standard FESS procedure with and without the use of a navigation system.

The following questions should be answered:

- Which situations create the highest stress levels for the trainee surgeons?
- Does a navigation system cause an increase in mental effort and distress compared to the classic FESS?
- Is the navigation system suitable for the surgical training or is the effort to engage too high?

Materials and methods

In this randomized prospective clinical study, eight trainee surgeons performed FESS surgery under supervision of two experienced rhinosurgeons on four patients each. In summary 32 patients participated. The participating surgeons had different level of experience in the FESS surgery. Half of the surgeons had already done more than 30 conventional FESS in the past and belong, in this way, to the more experienced group. The other 4 surgeons with less than 30 FESS form the less experienced group. The cut off was set by 30 FESS procedures (median). In all operations a navigation system was actually not necessary. No complicated anatomical or revision cases were included. During the operation, as well as 5 min before and after, the surgeons were connected to the biofeedback device (NeXus 10, Mindmedia, NL). The heart frequency, the respiratory frequency and the masseter tone were measured continuously. The different parts of the surgery (e.g. opening the different sinuses, changing the angled endoscopes) and critical events (e.g. stronger bleeding or overtaking the surgery by the supervisor) were marked by a manual trigger of the biofeedback device.

The allocation to the study groups was determined through a block randomization. One side of the patient was operated with the aid of a navigation system, the other side without.

Navigation

In this study two identical navigation systems were used: The VectorVision compact® with laser registration (BrainLAB, Feldkirchen, Germany). The OR-team (except for the trainee) was very familiar with this system through prior studies [18–20].

Heart rate variability analysis

In the spectral analysis of the HRV three frequency bands are important:

Very low frequency: 0.02–0.06 Hz
Low frequency: 0.07–0.14 Hz
High frequency: 0.15–0.40 Hz

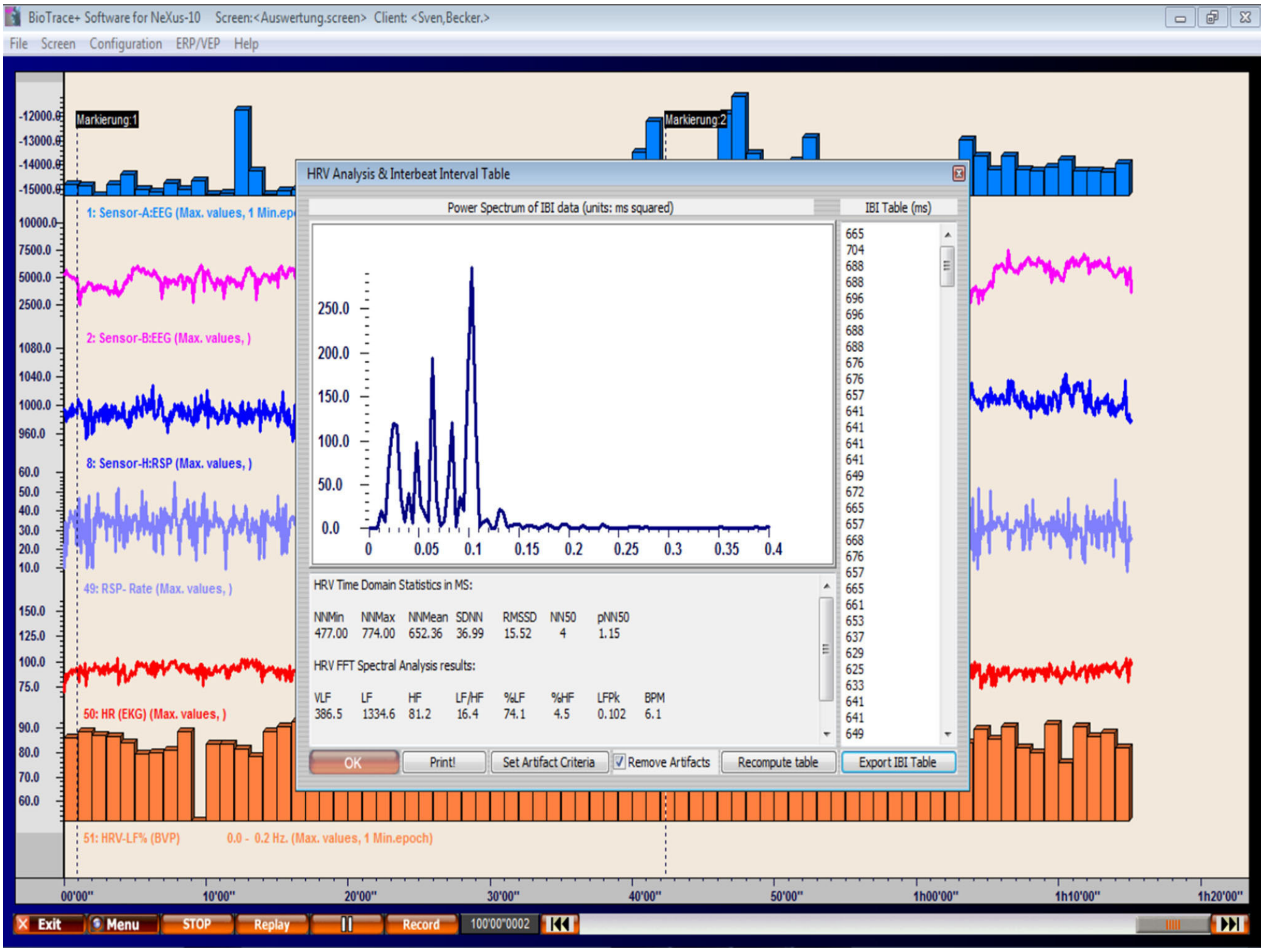


Fig. 1 Screenshot of the intraoperative biofeedback measurements with MindMediás BioTrace+ Software. The spectral analysis shows high values in the 0.1 Hz frequency as a sign of mental relaxation before surgery

In the very low frequency band the temperature changes are dominating. In the low frequency band the blood pressure and adrenaline uptake are involved, and in the high frequency band the respiration frequency. The respiration frequency is a possible source of artifacts (speaking, moving). It was measured in this study for the right interpretation of the low and high frequency band [21.]

All three frequencies show a suppression of the HRV by physical and mental effort [15]. The strongest difference is seen in the low frequency band, especially in the 0.1 Hz component [22]. The 0.1 Hz component is the main parameter for the registration of mental effort in this clinical trial.

The identification of the R-waves in the ECG was carried out by Biotrace software of the biofeedback device (Fig. 1). The resulting time series were analyzed by CARSPAN software (developed by B. Mulder, Groningen). The spectral analysis allows a quantification of the HRV. CARSPAN uses the fast Fourier analysis to split the time series into spectra. CARSPAN splits the deviations of the mean in several frequencies. During mental or physical effort the heartbeat becomes more regular to ensure a continuous oxygen supply of the brain. Thereby, the deviations of the mean become smaller, because they are more regular. The lower the power of the HRV, the more demanding the task is.

Masseter tone and heart rate analysis

During each operation, the masseter tone and the heart rate were measured as additional indicators of physical [23] and mental [8] effort. In situations of high mental effort a higher heart rate and a significantly higher masseter tone were measurable [24].

Statistics

In the statistical analysis of this study a team of the institute for biometry was involved.

Each surgeon performed four operations to cover all four of the following possibilities:

- Begin with the right side, without navigation
- Begin with the left side, without navigation
- Begin with the right side, with navigation
- Begin with the left side, with navigation

For the statistical evaluation an analysis of variance (ANOVA) for repeated measurements (within-design) was performed. The program used was SPSS 15.0. A significance was considered if $p < 0.05$. The effect size η^2 was also calculated.

Results

Patient's collective

Four subjects (surgeons in training) were male, four female and all were right-handed. The average age of the surgeons was 31 years (between 27 and 33). All 32 patients were included. The average age of the patients was 46 (SD 9.5) years.

The indications for the paranasal sinus operations in this study were:

Bilateral chronical sinusitis $n = 32$
Bilateral polyposis of the ehtmoid bone $n = 17$
Additional septum deviation $n = 16$
Polyposis nasi, asthma and aspirin intolerance (sampter trias) $n = 3$

In all patients all landmarks were visible with preoperative endoscopy and CT scan.

Dropouts

All surgeons participated in this study performed all their operations. The included patients also participated without dropouts. Two operations had to be removed from the analysis because of an intraoperative system failure of the navigation device. The whole operation was then performed without navigation.

Analysis of cardiovacular parameters (heart rate, heart rate variability, masseter tonus)

The heart rate was significantly higher during surgery, compared to the HR before and after the surgery (baselines). Preoperatively, the heart rate of the subjects was at physiological resting levels (in average 92 beats/min). During the surgery, the heart rate increased significantly (in average 98 beats/min) and decreased after the surgery again. These findings correlated with the surgeons' concentration level and mental distress situation: Before the procedure the surgeons were relaxed. To fulfill the surgery a higher mental effort was necessary. No significant difference of mental effort was visible with the use of the navigation system ($p = 0.569$, $\eta^2 = 0.048$). Both parts of the operation—the navigation-supported part as well as the non-supported part showed the same heart rate levels (Fig. 2).

A corresponding mirror-inverted result was visible in the heart rate analysis. The HRV was higher in the preoperative section in comparison to the intraoperative HRV, which was low, suitable to the higher mental effort, the physical demand and the distress level. No significant difference was registered between the two parts of the surgery (with and without navigation system). On the contrary, in the non-supported part of the procedure a slightly lower HRV was seen compared to the navigation-supported side (Fig. 3). This result may not be significant with $p = 0.131$ but the effect size of 27.3 % is very high, and speaks for a certain validity.

After the operation some time is required to reach the preoperative HRV level (resting level). An additional mental load with the use of the navigation system could not be observed.

However, a more detailed inspection of the data revealed a difference in psychical distress situation among the eight participating surgeons. In both subgroups (with >30 FESS procedures done, as well as <30 FESS procedures) high heart rate levels and low HRV levels during FESS surgery are visible. However, as it becomes evident from Fig. 4 the HRV of the more experienced group was higher in both parts of the surgery. The HR was accordingly lower in comparison to the less experienced subgroup with less than 30 FESS procedures (Fig. 5). In other words

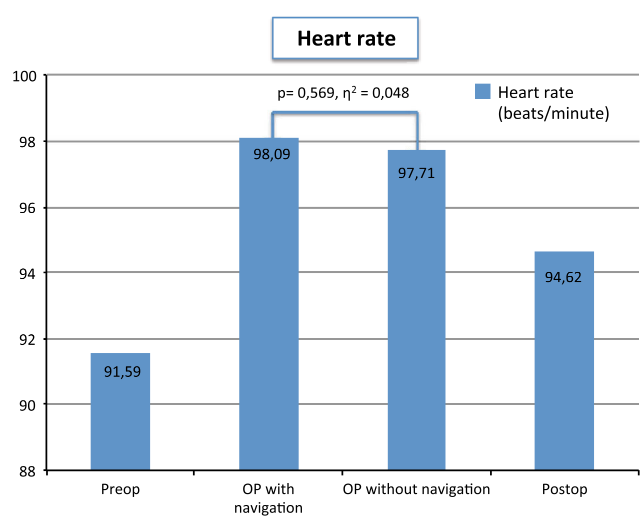


Fig. 2 Heart rate (HR) of the surgeon before and after the surgery and in the two study groups

in the "experienced" subgroup a decreased stress level compared to the "beginner" group could be observed.

None of the two groups showed a difference in the mental workload and the distress level between the navigation-supported part and the non-supported part.

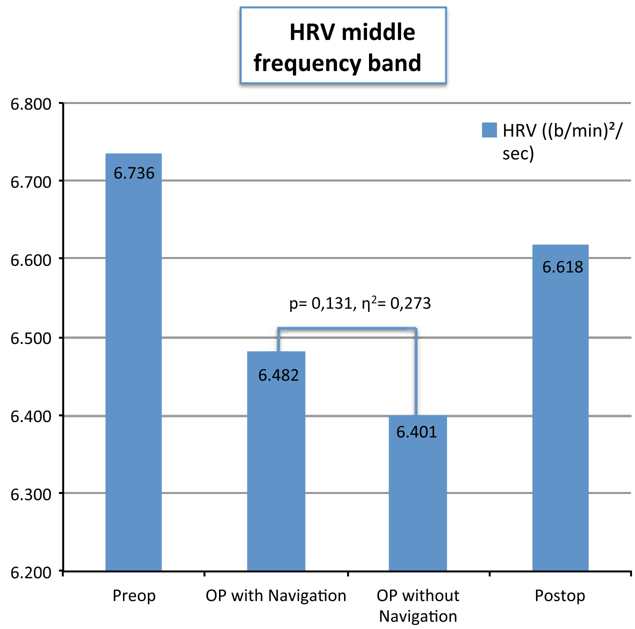


Fig. 3 Heart rate variability (HRV) of the surgeon before and after the surgery and in the two study groups

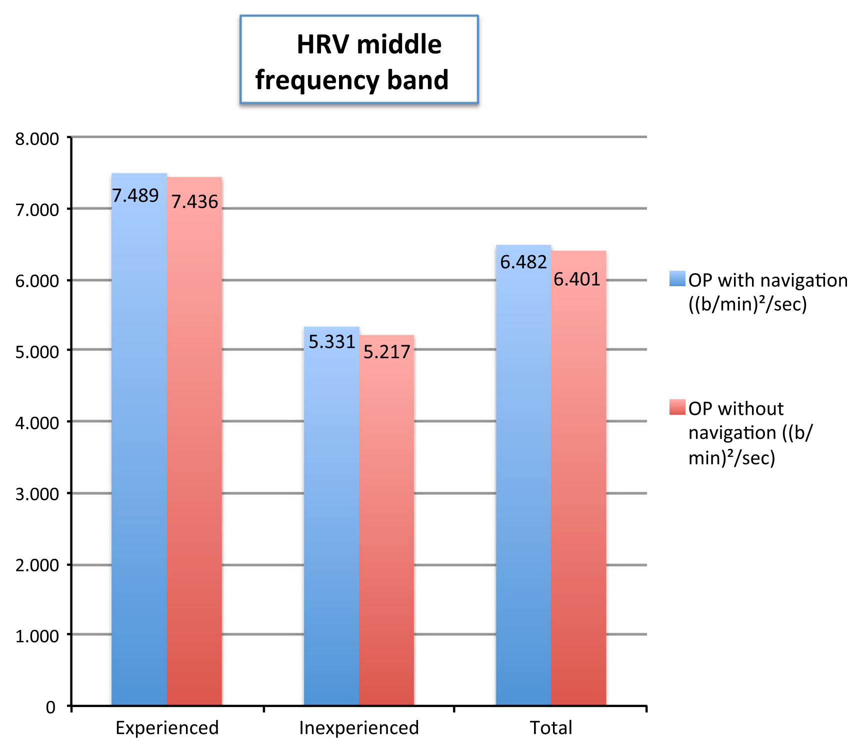
According to the objective (HRV, HR and Masseter tone) data the following intraoperative stress situations could be identified:

The less experienced surgeons (<30 FESS) got distressed by a short absence or diversion of the supervisor, the procedure of septoplasty and the switch to the 45° angled endoscope. No higher stress levels were monitored by operating near risk structures like the skull base or poor vision in this group. The more experienced surgeons (>30 FESS) got distressed by other colleagues or students entering the theatre as well as by operating near the skull base. They also got distressed during the preoperative waiting for the measurement of the baseline due to the permanent time pressure in the hospital as well as poor vision due to insufficient bleeding control (Fig. 6). Difficult maneuvers during the operation or the use of the 45° endoscope did not lead to a higher masseter tonus or a lower HRV in this group.

Discussion

This clinical trial provides insights into the trainee surgeons' mental distress situation and effort during a FESS procedure with and without navigation support. The heart rate and the HRV are cardiovascular parameters with a high significance for the detection of psychic and mental effort [5, 16, 25, 26].

Fig. 4 The difference in the middle frequency band between the less (<30 FESS) and the more experienced (>30 FES) surgeons in training. The surgery with and without navigation is compared



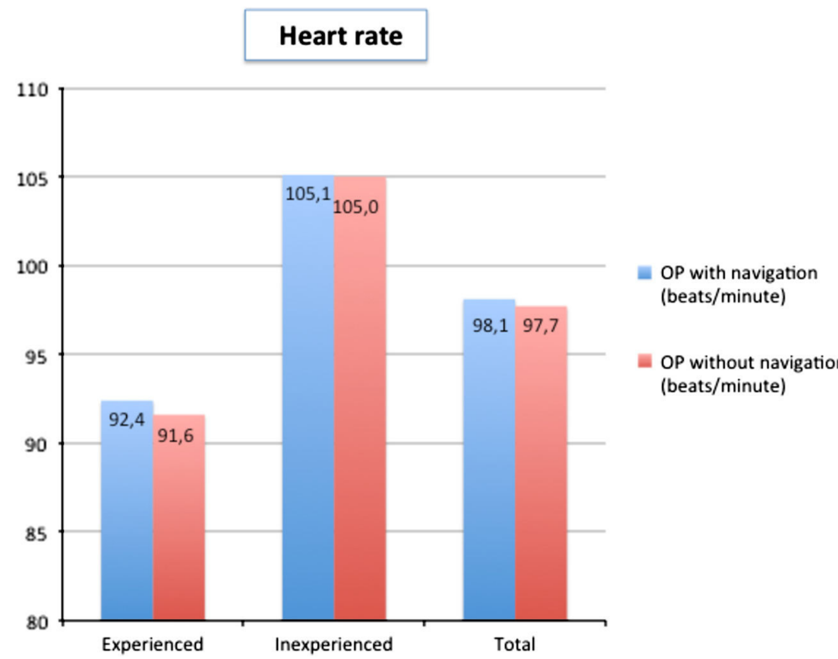


Fig. 5 The difference of heart rate between the more experienced (>30 FESS) and the less experienced (<30 FESS) surgeons in training. The surgery with and without navigation is compared

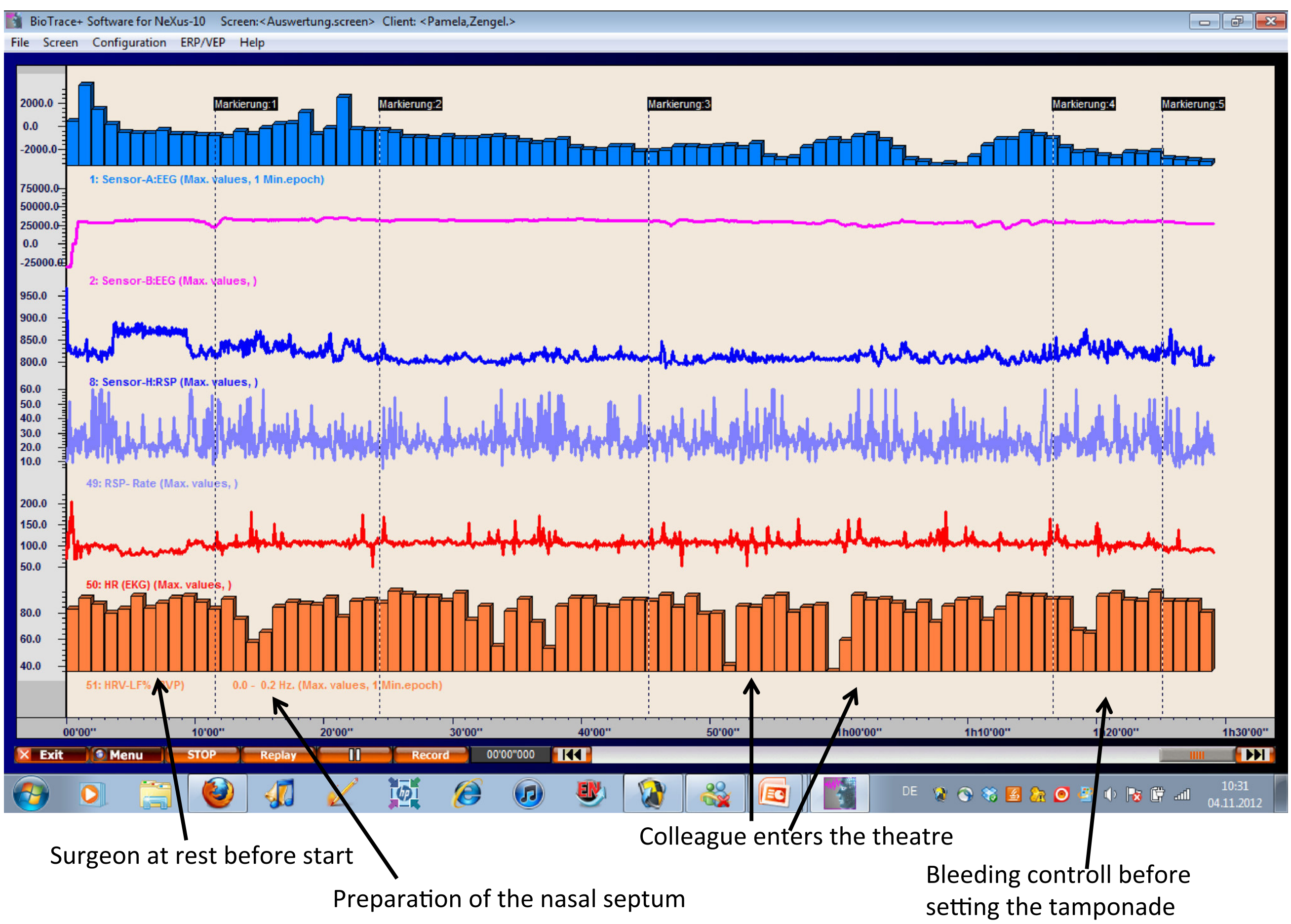


Fig. 6 Screenshot of the intraoperative biofeedback measurements. The masseter tone (*blue bars*) is decreasing during surgery. The *second* and *third line* constitutes the raw data of the ECG and the respiration. The *red line* represents the heart rate in beats per min. The *last row* demonstrates the fluctuations of the middle frequency band, which is calculated through the intervals between the R-hulls in the ECG (interpeak values). The *arrows* point to certain situations where the power of the middle frequency band decreases (high mental effort)

The spectral analysis can separate the HRV into the three components mentioned before, which can be analyzed and be considered separately [4]. The suppression of the HRV in situations of mental effort is visible in all three frequency bands. But the biggest difference is seen in the low frequency band [21]. Another reason why this band is to be preferred, is that in studies with short acquisition times, like this study, the 0.1 Hz band is the most sensitive one [21]. Respiratory rate changes too slow for a real time acquisition. Nevertheless, the difficulty is that many different activities and situations can lead to an increase of psychic demand and there is no better scientific method for an objective evaluation yet. Neither is there currently an objective method for the quantitative measurement of the psychic demand. The only way is to indirectly evaluate this phenomenon from some parameters such as the HR, HRV or masseter tonus, as we did in this study.

Two different aspects were considered: (1) A comparison of the mental workload and psychic demand during a navigation-supported and a non-supported FESS procedure. (2) Evaluation of other factors, which lead to a surgeon's increased psychic distress level.

The HRV was measured continuously during the whole operation, and 5 min before and afterwards for baseline measurements. Our baseline is defined as a situation at rest but in the same environment. The baseline is chosen consciously as the time before and after surgery in the operating theatre and not on a free day without operating procedures like in other studies [17]. The intention is to create similar circumstances as during the surgery (i.e. oxygen-saturation, temperature, daytime) [10]. The results of this study emphasize that high mental load dominates in surgical interventions like FESS procedures. During both procedures, with and without navigation device, the stress levels were significantly higher, than before or after the operations. Preoperatively, the HRV is high, during the operation the HRV is suppressed by the influence of the sympathic nerval system. After the operation the HRV increases again.

There was no significant difference detectable in the HRV levels with the application of the navigation system compared to the non-supported classical FESS side, which means the stress level was almost equal on both sides. Nevertheless, the HRV was slightly higher in the navigation-supported part of the procedure. This result is with $p = 0.131$ not significant but the effect size of 27.3 % is very high. We can suppose that in a study with a bigger number of cases, a significant result could be achieved. In other words, with a bigger case number maybe significant lower stress levels with the usage of navigation system can be shown.

A mirror-inverted picture to the HRV is visible with the HR analysis.

After categorizing the surgeons to their level of experience, a different picture emerged: The more experienced group (>30 FESS procedures) showed in both parts of the surgery (with the use of the navigation system and without) a higher HRV and lower heart rate levels. That means a lower mental workload and distress level than the colleagues with less than 30 FESS procedures done. Therefore, we can suppose that the mental workload and psychic demand decrease by the increasing level of experience. In both groups no difference in stress levels between the navigation-supported part and the non-supported part was measurable.

However, we have to consider that the distribution of the single distress factors during the surgery could have changed without changing the overall mental workload, meaning a "workload shift". Manzey et al. describe that the effort and the distress level benefit clearly from the usage of a navigation system in experienced rhinosurgeons. However, the mental demand can increase because of handling an additional integrated technical device.

In this trial a very important aspect was to fulfill this procedure without any time pressure, in an environment familiar to the surgeons and after a systematic supervised instruction. The surgeons reported even a mental relief with the use of the navigation system and the new technology as motivating and not frustrating [13]. Hence, we cannot observe a workload shift toward the navigation.

Furthermore, some other distress factors attracted attention independently from the usage of the navigation system. A significant depression of the HRV of the younger surgeons in training could be monitored by a short absence of the supervisor, the procedure of septoplasty and the switch to the 45° endoscope. The more experienced surgeons in training were distressed by bleeding situations with poor vision. A reason for the higher distress by the presence of other colleagues and students in the theatre could be the developing concurrence between the trainees and the psychosocial pressure in an university clinic.

To our surprise, risk structures like the skull base or bleeding and poor vision did not increase the mental workload of the less experienced surgeons as much as expected. This could be explained by the fact that the surgeons knew they were under supervision, and in a risk situation the supervisor would support them and would take over the procedure. This result is compatible with the findings of the subjective questionnaire of the first part of this study [13].

A question to be discussed is whether the higher workload and psychic demand during the surgeries have negative consequences on the patient's outcome and the long-term health of the participating surgeons. During an operation, a certain degree of psychic distress is desirable because it goes with increased concentration and situation awareness. Especially, for risk structures and the usage of angled endoscopes an increased level of concentration is necessary. Therefore, in the surgical training an increased mental workload is to be rated as physiological "eustress" [26], and is not a harmful "distress" [27]. "Distress" can typically lead to overload and burn out syndromes. The line between "eustress" and "distress" is not clearly definable. Therefore, avoidable stressors like the presence of colleagues in the operating theatre or the simultaneous teaching of students should be eradicated. Because of these findings student teaching in the theatres of our department is not performed any more by the operating surgeon but by an uninvolved supervisor.

Further investigations

An interesting question for further investigations would be the detection of mental effort and distress level of experienced surgeons during supervision of surgeons in training doing a FESS procedure. An aircraft study showed corresponding high distress level of the captain during a flight of a pilot in training [4]. The pilot in training as well as the captain had similar distress levels in the same situations (e.g. gear down). Because of the high responsibility and the continuous preparation for intervention the high mental effort is comprehensible. The powerless feeling of being dependent from the correct reaction of another individual can be a factor of great distress. This situation could lead in the future to an overload even to a burn out syndrome. The same situation is likely to exist for supervisors in FESS surgeries. An open talk about confidence, team work and limits can help here.

Conclusion

Endoscopic sinus surgery comes along with high mental workload for surgeons in training. In such situation some stress reactions are physiological, natural and necessary to achieve a better situation awareness. However, too much stress and on a permanent basis, is unphysiological and can tire out and frustrate the surgeon. Therefore, avoidable stressors have to be identified and then try to be avoided.

The navigation surgery is connected with a higher organizational effort, but the trainee surgeons are thankful for this opportunity. The additional information of the system is seen by the surgeons as a support and do not lead to a higher mental distress level in comparison to the standard FESS. The handling of a new device and the additional software do not lead to a higher mental demand or worse outcome.

However, handling the navigation system has to be practiced. The right usage of the device, the software, as well as the registration and the reasonable application has to be learned. Training and high situation awareness is needed. The handling of a navigation system does not lead to a higher stress level during FESS. There are more external factors, which create disturbances. Therefore, surgical training should take place in a familiar environment, and without time pressure. Only this way it can be ensured that the surgeon is concentrated and can work without additional pressure and mental distress. In this study, the participants could process and correctly classify the presented information most of the time. However, this would not be possible without a correct and sufficient training in the anatomy of the paranasal sinuses.

In situations where the navigation is mandatory (e.g. missing landmarks) it can only be used effectively and correctly by regular training and a sufficient experience with the device.

Conflict of interest All authors state that there is no conflict of interest.

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