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Olfactory cleft evaluation: a predictor for olfactory function in smell-impaired patients?

Sophia C. Poletti[1] · Gustavo Murta[1] · Antje Hähner[1] · Thomas Hummel[1]

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Abstract

Objective In this study, we introduce an extension of previous work by Soler et al. (Int Forum Allergy Rhinol 6(3):293–298, 2016) on a modified endoscopic scoring system of the Lund–Kennedy Score (focusing on the olfactory cleft) to evaluate its correlation with the olfactory function in patients with various smell disorders.

Study design A prospective cohort study.

Methods Two-hundred and eighty-eight participants were included and categorized in five groups according to the cause of their olfactory disorder: (0) control, (1) idiopathic, (2) sino-nasal, (3) postinfectious and (4) post traumatic olfactory loss. Olfaction was evaluated using the “Sniffin’ Sticks” test. The classical Lund–Kennedy scoring and a new olfactory cleft specific Lund–Kennedy scoring (OC–LK) were performed to evaluate mucosal changes.

Results Significantly higher OC–LK scores on both sides were found in smell-impaired patients as compared to normosmic controls. When comparing the 4 groups, a significant difference of the OC–LK score were present between the sino-nasal and all other groups. Most importantly, significant negative correlations with strong effects were shown in the sino-nasal group between the OC–LK score and odor discrimination and odor identification. However, no such correlation emerged between the classical LK score and smell function.

Conclusion Olfactory cleft evaluation using the OC–LK score correlates with the olfactory function in patients with sino-nasal smell disorder. This diagnostic tool may reflect the underlying pathophysiological mechanism of sino-nasal smell loss, and therefore, should complement olfactory diagnostics in patients with sino-nasal smell disorder.

Keywords Lund–Kennedy scoring system · Sino-nasal · Olfactory loss · Olfactory cleft · Endoscopic grading

Introduction

The prevalence of olfactory dysfunction in the general population is a matter of debate and frequently underestimated. In a large population-based German survey of 1277 participants aged 25–75 years, a prevalence of 3.6% functionally anosmic and 18% hyposmic subjects was found [1]. While approximately 75,000 consultations per year at German ENT clinics account for smell impairment, the main reason for olfactory loss is found in sino-nasal diseases followed by postinfectious and idiopathic smell loss [2].

Olfactory loss is highly prevalent in patients with sino-nasal disease such as chronic rhinosinusitis (CRS) [3–5]. However, the underlying pathology is not fully understood and so far no clinical staging system highly correlated with the olfactory function as to be useful in a daily clinical setting. Based on the two pathophysiological mechanisms of olfactory dysfunction suggested in CRS patients—the conductive (swollen or hypertrophic mucosa) and the sensorineural (affecting directly olfactory sensory neurons) loss [6–8]—several studies tried to identify and quantify the inflammation of the sinuses and the olfactory cleft (OC) using different CT scan analysis and to correlate with the olfactory function [9, 10].

Commonly used CT staging systems for CRS like the Lund–Mackay Score focus specifically on the sinuses rather than quantifying the extent of disease in the OC [11]. But recent studies analyzing the OC opacification by means of three-dimensional volumetric measurements show

Sophia C. Poletti and Gustavo Murta equally contributed.

✉ Thomas Hummel
thummel@mail.zih.tu-dresden.de

[1] Department of Otorhinolaryngology, Smell and Taste Clinic, TU Dresden, Fetscherstrasse 74, 01307 Dresden, Germany

correlations between OC opacification and smell tests to some extent [12, 13]. With the sinus-specific scoring systems showing no such promising correlations, olfactory cleft changes seemed more predictive of olfactory function than sinus opacification.

Nasal endoscopy was used to assess patients' response to medical therapy, evaluate surgical need or to predict the need for revision surgery [14]. Reports on the correlation between postoperative Lund–Kennedy scores and quality of life have been conflicting [15–17]. Correlations with the olfactory function in patients with sino-nasal or any other entities of smell disorder has been weakly described in literature and remains mostly unclear. Only recently a paper by Soler et al. focused on the correlation between endoscopic findings in the OC and olfactory function in patients with chronic rhinosinusitis [18]. However, this elegant study failed to look at controls and forms of olfactory loss beyond CRS. Therefore, the goal of this study was to determine whether the Lund–Kennedy score of the olfactory cleft correlates with the olfactory function in smell-impaired patients and whether this correlation is superior to the conventional sinus-specific Lund–Kennedy staging system. Secondary goals are to investigate correlations in relation to the characteristics of smell impairment (i.e., self-ratings of olfaction and nasal breathing, results from questionnaires related to nasal function) and the OC scoring system.

Materials and methods

Study cohort

A prospective study was conducted at the Smell and Taste Clinic (Department of Otolaryngology) of the "Technische Universität" (TU) Dresden. The study was performed according to the Declaration of Helsinki and approved by the Ethics Committee of the Medical Faculty of the TU Dresden (application number: EK122032011). Only participants above the age of 18 were included in the study and all experiments were undertaken with the understanding and written consent of each participant. The following exclusion criteria were applied: pregnancy, neurological diseases and any systemic disease associated with smell disorders like chronic renal failure or untreated thyroid disorders. If—due to superior–anterior septal deviations for example—the assessment of the entire olfactory cleft was not possible, the participant was further excluded from the study. Participants were instructed to only drink water one hour prior to the experiment and further not to wear any scented products on the day of testing.

According to the cause of smell impairment, participants were categorized in five groups: (0) control, (1) idiopathic, (2) sino-nasal, (3) postinfectious and (4) post traumatic olfactory loss (see position paper on olfactory dysfunction [19]).

While postinfectious olfactory loss was defined as a smell impairment following an upper respiratory tract infection, post traumatic olfactory loss occurs as a result of a head trauma. Sino-nasal olfactory loss, typically fluctuating in nature, arises from inflammatory disease of the nasal mucosa, including smell impairment due to allergic/non-allergic rhinitis and chronic rhinosinusitis with and without nasal polyps. If no underlying pathology for olfactory impairment could be evaluated through well-established diagnostics, participants were diagnosed as having an idiopathic smell loss. And finally, participants with a normal sense of smell, represented in a TDI score (composite threshold–discrimination–identification score) of > 30.5 [20] were classified as the control group.

To evaluate the mucosal conditions with focus on the olfactory cleft, each participant underwent nasal endoscopy through an experienced ear, nose, and throat specialist. Nasal endoscopy exams were scored semi-quantitatively using the Lund–Kennedy staging system. Olfactory function was quantified by means of the extended Sniffin' Sticks test and nasal symptoms were assessed using the sino-nasal outcome test—20 (see below). Further, participants were asked to rate their olfactory ability and nasal airflow on Likert-type visual analogue scales ranging from 1 to 10 (1—no olfaction/nasal airflow to 10—very good olfaction/nasal airflow).

Nasal endoscopy and Lund–Kennedy score

Nasal endoscopy was performed in each participant during consultation at the Smell and Taste Clinic. Initially the internal nose was scored semi-quantitatively using the Lund–Kennedy scoring system (classical Lund–Kennedy Score, c-LK-Score) with subsequent focus on the olfactory cleft. Here, a modified Lund–Kennedy score (olfactory cleft Lund–Kennedy score, OC–LK score) was used to describe the mucosa of the olfactory cleft separately as detailed in Table 1. Each side was evaluated separately with a total possible score of 10 on each side and each region (whole nose/olfactory cleft). The olfactory cleft was regarded as a three-dimensional space consisting of following borders: anteriorly defined through the anterior attachment of the middle turbinate, posteriorly the anterior wall of the sphenoid sinus, medially the nasal septum and laterally through the middle and superior turbinate. The superior boundary was the cribriform plate, whereas the inferior limitation was set around 1 cm below the skull base. In line with the literature in which olfactory cleft opacification was measured using CT images [10], we divided the olfactory cleft in an anterior and a posterior portion separated by the anterior end of the superior turbinate. If the superior turbinate was not present or sufficiently visible, the posterior third of the

Table 1 Lund–Kennedy endoscopic scoring system. Endonasal endoscopy with (A) evaluation of the endonasal mucosa (classical Lund–Kennedy Score, c-LK Score) and (B) evaluation of the olfactory cleft mucosa (olfactory cleft Lund–Kennedy Score, OC–LK Score)

A. Classical Lund–Kennedy scoring systems (c-LK)	
Polyps	0 = no polyps
	1 = polyps in middle meatus only
	2 = beyond middle meatus
Edema	0 = absent
	1 = mild
	2 = severe
Discharge	0 = no discharge
	1 = clear, thin discharge
	2 = thick, purulent discharge
Scarring	0 = absent
	1 = mild
	2 = severe
Crusting	0 = absent
	1 = mild
	2 = severe
B. Olfactory cleft Lund–Kennedy scoring system (OC–LK)	
Polyps	0 = no polyps
	1 = polyps blocking < 50% of the olfactory cleft
	2 = polyps blocking > 50% of the olfactory cleft
Edema	0 = absent
	1 = mild
	2 = severe
Discharge	0 = no discharge
	1 = clear, thin discharge
	2 = thick, purulent discharge
Scarring	0 = absent
	1 = mild
	2 = severe
Crusting	0 = absent
	1 = mild
	2 = severe

middle turbinate was defined as the border between anterior and posterior olfactory cleft. If only one portion was affected by the polyps—either the anterior or posterior—1 point (< 50%) was added to the OC–LK Score. However, if both portions were affected or polyps crossed the defined border, 2 points (> 50%) were added to the score. Figure 1 pictures different mucosal conditions of the olfactory cleft as used in the modified Lund–Kennedy score of the OC (OC–LK Score).

Olfactory testing

Olfactory function was quantified in a total of 288 participants using the Sniffin' Sticks test which consists of three

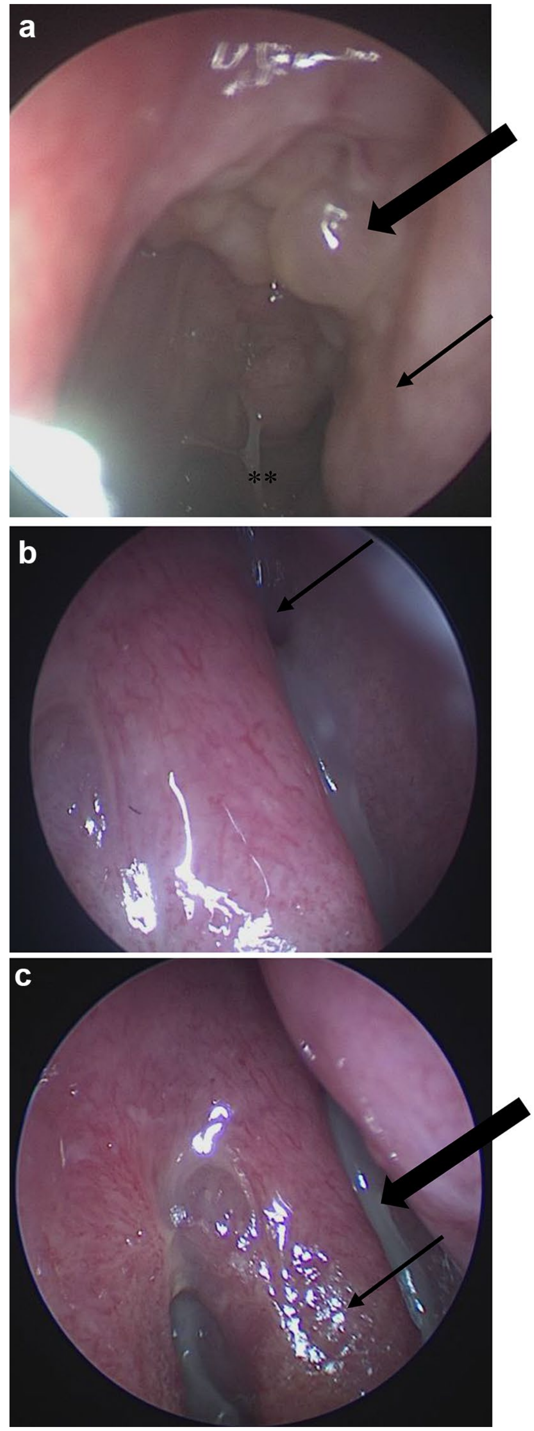

Fig. 1 Pictures different mucosal conditions of the olfactory cleft as used in the modified Lund–Kennedy score of the OC (OC–LK Score). **a** Polyps left nostril with the thin arrow pointing at the middle turbinate and the thick arrow at the polyps within the OC. Polyps can be seen posterior to the middle turbinate (> 50% OC affection, 2 points in OC–LK score respectively). **Discharge. **b** Edema of the right OC (arrow) containing thick discharge. Narrowing of the cleft region due to distinct mucosa swelling of the OC (accounting for 2 points in OC–LK score). **c** Discharge of the right OC. Bulky arrow indicating thick discharge (2 points in OC–LK score respectively) and the slim arrow pointing at the middle turbinate

subtests [21]. During the odor threshold task, subjects had to detect the odorized (phenylethylalcohol, PEA) pen among three samples with the other two pens containing odorless propylene glycol. With the odor discrimination task again a triplet of pens was presented to the subject who had to discriminate one different odor amongst two identical odors. Regarding the odor identification task, subjects had to smell a single odorous pen and choose the correct answer from a list of four descriptors. The sum of the three tests (threshold–discrimination–identification) accounted for the composite TDI-score—demonstrating the final olfactory test result—with a maximum of 48 points (each subtest added a maximum of 16 points) [22]. Normosmia was set at 30.5 points or more in the composite TDI score, whereas hyposmia was diagnosed at scores between 16.5 and 30.5 points and functional anosmia below 16.5 points.

Sino-nasal outcome test-20 (SNOT-20)

Each of the 288 participants completed the SNOT-20 Questionnaire. This questionnaire measures both sino-nasal symptoms and general quality-of-life parameters in a composite fashion poses the sino-nasal outcome test-20 (SNOT-20). It is a modification of the 31-item rhinosinusitis outcome measure and contains 20 questions [23] which are based on a 0–5 scale, where 0 defines no problems and 5 defines maximal problems with the given symptom (Table 2).

Statistical analysis

Using SPSS 23.0 (SPSS Inc. Chicago, Ill., USA) data were statistically analyzed by means of t-tests for independent samples to investigate differences between normosmic controls and smell impaired patients. To evaluate differences by group (control 0, patients 1–4) multivariate analysis of variance (ANOVA) was applied. Pearson's correlation coefficients were used to evaluate correlations between study variables. The level of significance was defined as $p<0.05$.

Results

Study cohort

The overall cohort included 288 participants out of which 48 (29 women, 19 men, ∅ age 55, range 21–85, SD 15.7) were controls with normal Sniffin' Sticks test results and 240 (137 women, 103 men, ∅ age 59, range 18–89, SD 14.5) with an impaired sense of smell. According to the cause of smell impairment patients were categorized in four different groups. Group 1 consisted of 116 patients with an idiopathic smell disorder. Group 2 containing patients with sino-nasal smell impairment included 33 patients and group 3 involved 59 patients with postinfectious olfactory loss. Group 4 comprising patients with post traumatic olfactory loss included 32 patients. Demographics, duration of disease, number of smokers and the occurrence of parosmia within each group are summarized in Table 3.

Table 2 Sino-nasal outcome test (SNOT-20)

1	Need to blow nose	0 1 2 3 4 5
2	Sneezing	0 1 2 3 4 5
3	Runny nose	0 1 2 3 4 5
4	Cough	0 1 2 3 4 5
5	Postnasal discharge (dripping at the back of your throat)	0 1 2 3 4 5
6	Thick nasal discharge (snot)	0 1 2 3 4 5
7	Ear fullness	0 1 2 3 4 5
8	Dizziness	0 1 2 3 4 5
9	Ear pain	0 1 2 3 4 5
10	Facial pain/pressure	0 1 2 3 4 5
11	Difficulty falling asleep	0 1 2 3 4 5
12	Waking up at night	0 1 2 3 4 5
13	Lack of a good night's sleep	0 1 2 3 4 5
14	Waking up tired	0 1 2 3 4 5
15	Fatigue	0 1 2 3 4 5
16	Reduced productivity	0 1 2 3 4 5
17	Reduced concentration	0 1 2 3 4 5
18	Frustrated/restless/irritable	0 1 2 3 4 5
19	Sad	0 1 2 3 4 5
20	Embarrassed	0 1 2 3 4 5

There were no statistically significant differences in sex distribution (Chi^2 [4] $=7.31$, $p=0.12$) or the proportion of smokers (Chi^2 [4] $=4.65$, $p=0.33$) by group. As expected, significant differences appeared in the occurrence of parosmia between groups (Chi^2 [4] $=29.23$, $p<0.001$). Using univariate analysis of variance (ANOVA), no significant differences emerged in age distribution by group [$F(4, 281)=2.2$, $p=0.74$]. However, significant differences could be found in the duration of disease [$F(3, 230)=3.84$, $p=0.01$]. Regarding the duration, the most relevant difference within the diseased groups was shown between the groups with sino-nasal and postinfectious olfactory loss ($p=0.04$) with a longer duration for the sino-nasal group.

Olfactory testing, self ratings of olfaction and nasal airflow

Olfactory test results from the Sniffin' Sticks test and self ratings of nasal breathing and smell ability by group are shown in Table 4. ANOVA revealed highly significant differences in threshold [$F(4, 282)=24.90$, $p<0.001$], discrimination [$F(4, 282)=16.13$, $p<0.001$], identification [$F(4, 283)=31.47$, $p<0.001$] and TDI scores

[$F(4, 282) = 35.93$, $p < 0.001$] between the groups. As expected, post-hoc analysis presented main differences between control group and each of the smell impairment groups ($p_s < 0.001$). Further, significant differences appeared between group 3 and 4 in threshold ($p = 0.008$), identification ($p < 0.001$) and TDI ($p < 0.001$) score and between group 1 and 4 in identification ($p < 0.001$) and TDI ($p = 0.002$) score. Regarding the self ratings significant differences were demonstrated by group [olfaction: $F(4, 257] = 85.61$, $p < 0.001$; breathing: $F(4,256) = 4.20$, $p = 0.003$). The post-hoc-test showed significant differences between group 0 and group 2 ($p = 0.001$) and between group 2 and 4 ($p = 0.017$) in nasal breathing ratings. In terms of olfactory ratings, significant differences emerged between the control group and each of the other groups 1–4 ($p_s < 0.001$) but also between groups 1 and 4 ($p = 0.013$) and groups 2 and 4 ($p = 0.011$).

Lund–Kennedy score analysis and correlations

Table 5 summarizes the classical Lund–Kennedy scores of each nostril (c-LK score left/right) and the modified LK score of the olfactory cleft (OC–LK score left/right) for each side within each group. Comparing normosmic controls (group 0) with all smell-impaired patients (group 1), a significant difference emerged in the OC–LK score on both sides with higher scores seen in patients (left: $t\,[124.5] = -3.89$, $p < 0.001$, group 0: $M = 0.3$, $SD = 0.6$, group 1: $M = 0.8$, $SD = 1.1$; right: $t\,[144] = -4.01$, $p < 0.001$, group 0: $M = 0.4$, $SD = 0.5$, group (1): $M = 0.8$, $SD = 1.1$). Figure 2 demonstrates the overall OC–LK score of smell-impaired patients compared to normosmic controls. Similarly, a significant difference was shown between normosmic and smell-impaired patients for the left c-LK score with higher scores seen in patients (left: $t\,[89.9] = -2.15$, $p = 0.034$, group 0: $M = 0.6$, $SD = 1.1$, group 1: $M = 1.0$, $SD = 1.6$). A weak but significant

Table 3 Demographics, duration of disease, number of smokers and the occurrence of parosmia by group

Group	Entity of smell loss	Gender		Age			∅ Disease duration (year)	Smoker	Parosmia
		f	m	∅	Range	SD			
0	Control	29	19	55	21–85	15.7	–	7	21
1	Idiopathic	65	51	60	18–89	14.5	3.9	9	87
2	Sino-nasal	13	20	55	28–77	13.8	7.4	6	18
3	Postinfectious	40	19	60	28–83	12.2	2.4	4	50
4	Post traumatic	19	13	55	18–79	18.2	3.0	3	26

Table 4 Sniffin' Sticks test scores and self ratings of nasal breathing and smell by group

Group	Threshold		Discrimination		Identification		TDI		Rating olfaction		Rating airflow	
	∅	SD	∅	SD	∅	SD	∅	SD	∅	SD	∅	SD
0	7.0	2.9	11.3	2.2	12.6	2.4	30.9	5.6	8.3	1.1	7.9	2.2
1	2.8	2.6	8.2	3.2	7.5	3.5	18.5	7.6	3.3	1.9	7.1	2.1
2	3.5	3.0	6.8	3.4	7.0	4.2	17.0	9.1	3.6	2.2	5.8	2.5
3	3.6	3.2	8.3	2.9	8.4	3.5	20.2	7.6	3.0	1.9	7.2	2.1
4	1.6	1.5	6.8	2.3	4.7	3.0	13.0	8.9	2.0	1.9	7.7	2.0

Table 5 Classical Lund–Kennedy scores (c-LK score left/right) and modified LK score of the olfactory cleft (OC–LK score left/right) by nostril and group

Group	c-LK score left		c-LK score right		OC–LK score left		OC–LK score right	
	∅	SD	∅	SD	∅	SD	∅	SD
0	0.6	1.1	0.7	1.1	0.4	0.6	0.4	0.5
1	0.7	1.0	0.8	1.0	0.6	0.8	0.6	0.8
2	3.7	2.0	3.7	2.0	2.5	1.6	2.5	1.5
3	0.5	1.1	0.5	0.9	0.4	0.6	0.4	0.6
4	0.5	0.9	0.5	1.0	0.4	0.7	0.4	0.7
1–4[a]	1.0	1.6	1.1	1.6	0.8	1.1	0.8	1.1

[a] All patients taken together

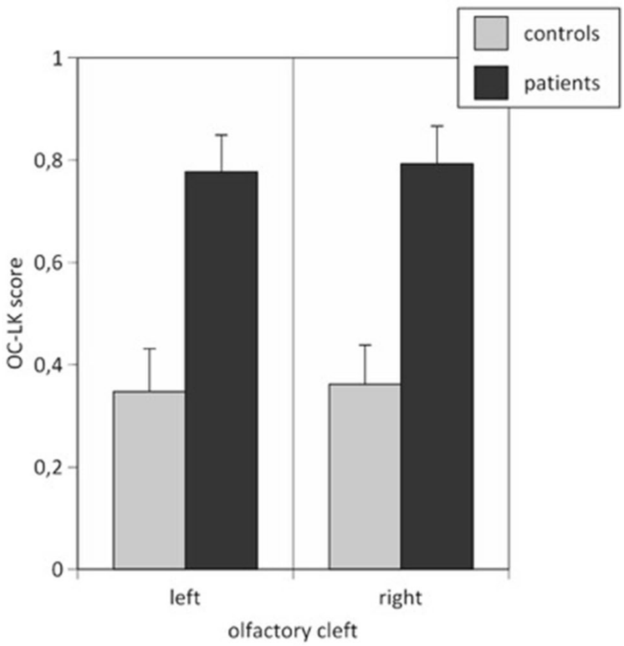

Fig. 2 Olfactory cleft scores of smell impaired patients compared to normosmic controls

negative correlation was shown between the OC–LK scores on both sides and the discrimination score (OC–LK left: $r = -0.15$, $p = 0.01$, OC–LK right: $r = -0.2$, $p = 0.001$), and also between the right OC–LK and the total TDI score ($r = -0.13$, $p = 0.034$). Similar negative correlations could be demonstrated between the c-LK score on both sides and the discrimination score (c-LK left: $r = -0.16$, $p = 0.07$, c-LK right: $r = -0.15$, $p = 0.010$) but not with the total TDI score ($p_s > 0.05$). Similar to the correlations of the c-LK score with the SNOT 20 score (left: $r = 0.21$, $p = 0.001$; right: $r = 0.18$, $p = 0.002$) a weak but significant positive correlation was found with the OC–LK score of both sides (left: $r = 0.14$, $p = 0.024$; right: $r = 0.16$, $p = 0.006$). However, significant negative correlations with a moderate effect emerged between the OC–LK scores of both sides and the nasal airflow rating (left: $r = -0.28$, $p < 0.001$; right: $r = -0.33$, $p < 0.001$). Similarly, OC–LK scores of both sides demonstrated a weak but significant correlation with the subjective rating of olfaction (left: $r = -0.15$, $p = 0.02$; right: r = 0.14, p = 0.028). The self ratings of olfaction showed significant correlations with the TDI ($r = 0.61$, $p < 0.001$), the threshold ($r = 0.54$, $p < 0.001$), discrimination ($r = 0.46$, $p < 0.001$) and identification ($r = 0.55$, $p < 0.001$).

Assessing the results by group using the analysis of variance (ANOVA), significant differences between the groups emerged for the c-LK scores (left: $F(4, 281) = 49.52$, $p < 0.001$; right: $F(4, 283) = 50.64$, $p < 0.001$) and the OC–LK scores (left: $F(4, 279) = 44.67$, $p < 0.001$; right: $F(4, 279) = 46.76$, $p < 0.001$). The post hoc analysis revealed significant differences between group 2 (sino-nasal) and all other groups in the c-LK scores and OC–LK scores of both sides ($p < 0.001$). When analyzing correlations separately by group, the following correlations emerged in group 2: negative correlations could be demonstrated between the right OC–LK score and the discrimination score ($r = -0.50$, $p = 0.019$), the identification score ($r = -0.47$, $p = 0.027$) and the TDI score ($r = -0.50$, $p = 0.019$). OC–LK score of the left side showed significant negative correlations with the identification score ($r = -0.47$, $p = 0.028$) and the TDI score ($r = -0.43$, $p = 0.047$) and a tendency with the discrimination score ($r = -0.40$, $p = 0.068$). Figure 3 shows the negative correlations between the TDI score and the left/right OC–LK scores. Even though a significant positive correlation with a strong effect could be demonstrated between the OC–LK score and c-LK score (right: $r = 0.52$, $p = 0.013$; left: $r = 0.51$, $p = 0.016$), correlations with quantitative smell function (Sniffin' Sticks) could only be shown with the OC–LK score as reported above. A moderate but negative correlation appeared between the right OC–LK score and the nasal airflow rating ($r = -0.46$, $p = 0.030$) and the left OC–LK score with the olfactory function rating ($r = -0.44$, $p = 0.042$).

Discussion

The current study provides the following major results: (1) significantly higher OC–LK scores on both sides in smell-impaired patients as compared to normosmic controls. (2) A significant negative correlation between the OC–LK scores on both sides and the discrimination score and (3) between the right OC–LK score and the TDI. Similar results could be shown for the c-LK score with (4) significantly higher c-LK scores in olfactory loss patients and (5) a significant negative correlation with the discrimination score. Analyzing smell-impaired patients by group, (6) significant differences of the OC–LK and the c-LK score could be demonstrated between the sino-nasal and all other groups. (7) Significant negative correlations with strong effects were shown in the sino-nasal group between the right OC–LK score and the discrimination, identification and the TDI score and also between the left OC–LK score and the identification and TDI score. However, (8) no such correlation of the c-LK score with the smell function was shown by groups in our study.

Chang and colleagues already demonstrated the importance of an olfactory cleft-specific grading system by showing that olfactory cleft CT scores (Lund–Mackay score of the OC) correlated better with the olfactory function than the sinus specific scoring [9]. Likewise, Saito et al. showed strong correlations of the olfactory cleft CT score of CRS patients and the T&T recognition threshold [24]. Soler et al. who used a quantitative volumetric method to determine OC

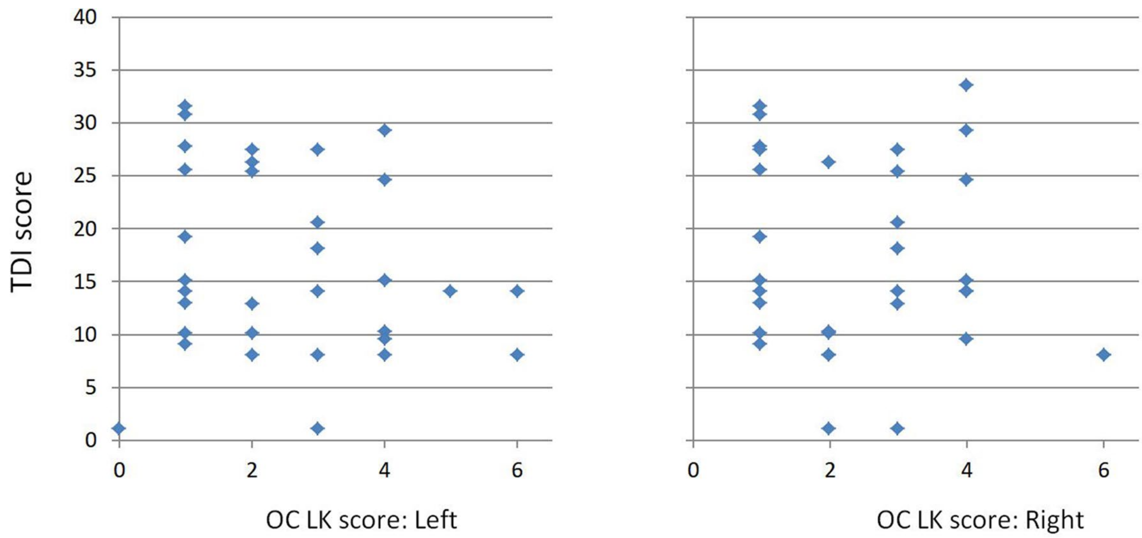

Fig. 3 Correlations between the TDI score and the OC–LK score of both sides

opacification, similarly illustrated correlations between OC opacification and olfactory function in CRS patients with nasal polyps [12].

The role of an endoscopic scoring system of the nasal cavity in evaluating olfactory function was shown in a few studies [4, 25, 26]. But as with the sinus-specific CT scoring no consistent correlations of the classical Lund–Kennedy score with the olfactory function was described. A modified LK scoring (eliminating scarring and crusting score) was shown to correlate with patient-reported outcome measure in CRS patients, however, olfactory function was not investigated [17]. Our data did not show any correlations of the c-LK with the olfactory function when analyzed by group. Hence, we introduced a modified Lund–Kennedy scoring system to evaluate the morphological changes at the OC in smell-impaired patients and to assess any predictability of the olfactory function from this grading system. Studies showing an improvement of olfaction in patients with nasal polyps after functional endoscopic sinus surgery (FESS) [3, 27–29]—and especially in those with olfactory cleft surgery [30, 31]—but also a study from Vandenhende-Szymanski et al. demonstrating the predictability of postoperative smell function from preoperative OC opacification (CT score) [32] further demonstrated the importance of evaluating the olfactory cleft separately. In line with this demand, we could show a significant negative correlation with strong effect between OC–LK score and the olfactory function in the sino-nasal group, indicting the 'worse' the mucosal changes in the olfactory cleft the lower the smell performance. This finding highlights the association of a morphological correlate (i.e., structural changes of OC) with the smell function indicating smell impairment in sino-nasal olfactory loss to originate from OC mucosa changes. The validity of this correlation is further underlined by the fact that in no other group—such as the post traumatic, postinfectious or idiopathic smell loss group—correlations between OC–LK score and smell function emerged, as in these groups smell loss is known to originate from other than OC changes.

Interestingly, besides correlations with olfactory function, a moderate but significant negative correlation appeared between the right OC–LK score and the subjective nasal airflow rating. As olfactory dysfunction and nasal obstruction [33] pose the most commonly reported and apparently most bothersome symptom in CRS patients leading to surgical interventions such as FESS, OC–LK scores could further be helpful in preoperative evaluation of CRS patients refractory to medical treatment.

Furthermore, the addition of an innocuous and easily available morphological criterion (nasal endoscopy in an outpatients setting, no radiation) to the psychophysical test results meets a desire in olfactory diagnostics. The classical Lund–Kennedy Score, meaning the overall mucosal condition of the nasal cavity so far did not allow us to reliably predict olfactory function. However, the degree of disease of the OC, reflected in a reliable OC endoscopic scoring system, may reasonably complement the functional tests in olfactory diagnosis of patients with sino-nasal smell disorder. Whether the modified endoscopic scoring system (OC–LK score) could be used as a predictor of olfactory improvement in patients receiving FESS remains an interesting question and should be subject to further investigations.

As mentioned above, we demonstrated correlations of the OC–LK score with odor discrimination, identification and the TDI score but not with the threshold score as one might have expected indirect evidence for threshold scores to represent peripheral olfaction (OSN) [34]. As the threshold test is a subthreshold test and scores especially in smell-impaired patients are rather low (and vary less) as compared to the other two subtests, correlations with the rather gross Lund–Kennedy scoring system are presumably less frequently found.

Conclusion

Quantitative evaluation of olfactory cleft opacification using a modified Lund–Kennedy score correlates with the olfactory function in patients with sino-nasal smell disorder. This finding could reflect the underlying pathophysiological mechanism of smell loss in sino-nasal disease. Therefore, the endoscopic scoring system of the olfactory cleft may complement olfactory diagnostics in patients with sino-nasal smell disorder.

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Compliance with ethical standards

Conflict of interest TH, GM, AH, SCP declare that they have no conflict of interest.

Ethical approval All procedures performed in studies involving human participants were in accordance with the ethical standards of the institutional and/or national research committee and with the 1964 Helsinki declaration and its later amendments or comparable ethical standards.

Informed consent Informed consent was obtained from all individual participants included in the study.

References

1. Vennemann MM, Hummel T, Berger K (2008) The association between smoking and smell and taste impairment in the general population. J Neurol 255(8):1121–1126. https://doi.org/10.1007/s00415-008-0807-9
2. Damm M, Temmel A, Welge-Lüssen A et al (2004) Olfactory dysfunctions. Epidemiology and therapy in Germany, Austria and Switzerland. HNO 52(2):112–120. https://doi.org/10.1007/s00106-003-0877-z
3. Litvack JR, Fong K, Mace J, James KE, Smith TL (2008) Predictors of olfactory dysfunction in patients with chronic rhinosinusitis. Laryngoscope 118(12):2225–2230. https://doi.org/10.1097/MLG.0b013e318184e216
4. Litvack JR, Mace JC, Smith TL (2009) Olfactory function and disease severity in chronic rhinosinusitis. Am J Rhinol Allergy 23(2):139–144. https://doi.org/10.2500/ajra.2009.23.3286
5. Fokkens WJ, Lund VJ, Mullol J et al (2012) European position paper on rhinosinusitis and nasal polyps 2012. Rhinol Suppl (23):3 p preceding table of contents, 1–298. http://www.ncbi.nlm.nih.gov/pubmed/22764607
6. Lane AP, Turner J, May L, Reed R (2010) A genetic model of chronic rhinosinusitis-associated olfactory inflammation reveals reversible functional impairment and dramatic neuroepithelial reorganization. J Neurosci 30(6):2324–2329. https://doi.org/10.1523/JNEUROSCI.4507-09.2010
7. Yee KK, Pribitkin EA, Cowart BJ et al (2010) Neuropathology of the olfactory mucosa in chronic rhinosinusitis. Am J Rhinol Allergy 24(2):110–120. https://doi.org/10.2500/ajra.2010.24.3435
8. Konstantinidis I, Witt M, Kaidoglou K, Constantinidis J, Gudziol V (2010) Olfactory mucosa in nasal polyposis: implications for FESS outcome. Rhinology 48(1):47–53. https://doi.org/10.4193/Rhin09.102
9. Chang H, Lee HJ, Mo J-H, Lee CH, Kim J-W (2009) Clinical Implication of the Olfactory Cleft in Patients With Chronic Rhinosinusitis and Olfactory loss. Arch Otolaryngol Head Neck Surg 135(10):988–992. https://doi.org/10.1001/archoto.2009.140
10. Kim DW, Kim JY, Jeon SY (2011) The status of the olfactory cleft may predict postoperative olfactory function in chronic rhinosinusitis with nasal polyposis. Am J Rhinol Allergy 25(2):90–94. https://doi.org/10.2500/ajra.2011.25.3617
11. Lund VJ, Mackay IS (1993) Staging in rhinosinusitis. Rhinology 31(4):183–184. http://www.ncbi.nlm.nih.gov/pubmed/8140385
12. Soler ZM, Pallanch JF, Sansoni ER et al (2015) Volumetric computed tomography analysis of the olfactory cleft in patients with chronic rhinosinusitis. Int Forum Allergy Rhinol 5(9):846–854. https://doi.org/10.1002/alr.21552
13. Kohli P, Schlosser RJ, Storck K, Soler ZM (2016) Olfactory cleft computed tomography analysis and olfaction in chronic rhinosinusitis. Am J Rhinol Allergy 30(6):402–406. https://doi.org/10.2500/ajra.2016.30.4365
14. Senior BA, Kennedy DW, Tanabodee J, Kroger H, Hassab M, Lanza D (1998) Long-term results of functional endoscopic sinus surgery. Laryngoscope 108(2):151–157. http://www.ncbi.nlm.nih.gov/pubmed/9473061
15. Ryan WR, Ramachandra T, Hwang PH (2011) Correlations between symptoms, nasal endoscopy, and in-office computed tomography in post-surgical chronic rhinosinusitis patients. Laryngoscope 121(3):674–678. https://doi.org/10.1002/lary.21394
16. Mace JC, Michael YL, Carlson NE, Litvack JR, Smith TL (2010) Correlations between endoscopy score and quality of life changes after sinus surgery. Arch Otolaryngol Head Neck Surg 136(4):340–346. https://doi.org/10.1001/archoto.2010.34
17. Psaltis AJ, Li G, Vaezeafshar R, Cho KS, Hwang PH (2014) Modification of the Lund-Kennedy endoscopic scoring system improves its reliability and correlation with patient-reported outcome measures. Laryngoscope 124(10):2216–2223. https://doi.org/10.1002/lary.24654
18. Soler ZM, Hyer JM, Karnezis TT, Schlosser RJ (2016) The olfactory cleft endoscopy scale correlates with olfactory metrics in patients with chronic rhinosinusitis. Int Forum Allergy Rhinol 6(3):293–298. https://doi.org/10.1002/alr.21655
19. Hummel T, Whitcroft KL, Andrews P et al (2017) Position paper on olfactory dysfunction. Rhinology. https://doi.org/10.4193/Rhin16.248
20. Hummel T, Kobal G, Gudziol H, Mackay-Sim A (2007) Normative data for the "Sniffin' Sticks" including tests of odor identification, odor discrimination, and olfactory thresholds: an upgrade based on a group of more than 3,000 subjects. Eur Arch Oto Rhino Laryngol 264(3):237–243. https://doi.org/10.1007/s00405-006-0173-0
21. Hummel T, Sekinger B, Wolf SR, Pauli E, Kobal G (1997) "Sniffin" sticks': olfactory performance assessed by the combined testing of odor identification, odor discrimination and olfactory threshold. Chem Senses 22(1):39–52. http://www.ncbi.nlm.nih.gov/pubmed/9056084

22. Kobal G, Klimek L, Wolfensberger M et al (2000) Multicenter investigation of 1036 subjects using a standardized method for the assessment of olfactory function combining tests of odor identification, odor discrimination, and olfactory thresholds. Eur Arch Otorhinolaryngol 257(4):205–211. http://www.ncbi.nlm.nih.gov/pubmed/10867835
23. Piccirillo JF, Merritt MG, Richards ML (2002) Psychometric and clinimetric validity of the 20-Item sino-nasal outcome test (SNOT-20). Otolaryngol Head Neck Surg 126(1):41–47. https://doi.org/10.1067/mhn.2002.121022
24. Saito T, Tsuzuki K, Yukitatsu Y, Sakagami M (2016) Correlation between olfactory acuity and sinonasal radiological findings in adult patients with chronic rhinosinusitis. Auris Nasus Larynx 43(4):422–428. https://doi.org/10.1016/j.anl.2015.12.007
25. Gupta D, Gulati A, Singh I, Tekur U (2014) Endoscopic, radiological, and symptom correlation of olfactory dysfunction in pre- and postsurgical patients of chronic rhinosinusitis. Chem Senses 39(8):705–710. https://doi.org/10.1093/chemse/bju042
26. Philpott CM (2011) Olfactory dysfunction in allergic fungal rhinosinusitis. Arch Otolaryngol Neck Surg 137(7):694. https://doi.org/10.1001/archoto.2011.105
27. Pade J, Hummel T (2008) Olfactory function following nasal surgery. Laryngoscope 118(7):1260–1264. https://doi.org/10.1097/MLG.0b013e318170b5cb
28. Rudmik L, Smith TL (2012) Olfactory improvement after endoscopic sinus surgery. Curr Opin Otolaryngol Head Neck Surg 20(1):29–32. https://doi.org/10.1097/MOO.0b013e32834dfb3d
29. Hsu C-Y, Wang Y-P, Shen P-H, Weitzel EK, Lai J-T, Wormald P-J (2013) Objective olfactory outcomes after revision endoscopic sinus surgery. Am J Rhinol Allergy 27(4):96–100. https://doi.org/10.2500/ajra.2013.27.3939
30. Kuperan AB, Lieberman SM, Jourdy DN, Al-Bar MH, Goldstein BJ, Casiano RR (2015) The effect of endoscopic olfactory cleft polyp removal on olfaction. Am J Rhinol Allergy 29(4):309–313. https://doi.org/10.2500/ajra.2015.29.4191
31. Nguyen DT, Gauchotte G, Nguyen-Thi P-L, Jankowski R (2013) Does surgery of the olfactory clefts modify the sense of smell? Am J Rhinol Allergy 27(4):317–321. https://doi.org/10.2500/ajra.2013.27.3907
32. Vandenhende-Szymanski C, Hochet B, Chevalier D, Mortuaire G (2015) Olfactory cleft opacity and CT score are predictive factors of smell recovery after surgery in nasal polyposis. Rhinology 53(1):29–34. https://doi.org/10.4193/Rhin14.160
33. Damm M, Quante G, Jungehuelsing M, Stennert E (2002) Impact of functional endoscopic sinus surgery on symptoms and quality of life in chronic rhinosinusitis. Laryngoscope 112(2):310–315. https://doi.org/10.1097/00005537-200202000-00020
34. Whitcroft KL, Cuevas M, Haehner A, Hummel T (2017) Patterns of olfactory impairment reflect underlying disease etiology. Laryngoscope 127(2):291–295. https://doi.org/10.1002/lary.26229