Jure Urbančič[1], Constance Gléron[2], Gregorio Benites[3], Martin Škrlec[4], Domen Vozel[5]

Real-life Time Consumption in Image-guided Endonasal Endoscopic Procedures

Dejanska poraba časa pri navigacijski kirurgiji nosu in obnosnih votlin

ABSTRACT

KEY WORDS: navigation, FESS, image-guidance

BACKGROUNDS. Endoscopic endonasal surgery has evolved from the work of Messerklinger, Draf and Wigand. Its unprecedented development has taken over vast depths of the nose, paranasal sinuses, and skull base. The use of preoperative CT and MRI images allows safer and faster access to complex structures. The study aims to provide adequate information regarding the usage times and the possible correlation between image-guidance systems use and the duration of the surgery for specific procedures. METHODS. We analysed the intraoperative data regarding the use of image-guidance systems, identified problems with its use and different influencing factors, and analysed the added value of its use from the surgeons perspective. RESULTS. We confirmed the relation between the complexity of the process and the prolongation of the surgery. Complex cases will demand an increased number of image-guidance systems position verifications, which will prolong the time of image-guidance systems handling during the procedure. To further explain the data, we propose three timelines representing the three typical surgical scenarios. DISCUSSION. The time used for image guided systems and the absolute difference in operating times at various endoscopic endonasal procedures implies that the main reason for prolonged surgery is probably extensive surgical work and is not always directly related to image guided systems use itself.

IZVLEČEK

KLJUČNE BESEDE: navigacija, FESS, usmerjanje s pomočjo slikovnih preiskav

IZHODIŠČA. Endoskopska kirurgija nosne votline se je razvila iz dela Messerklingerja, Drafa in Wiganda. Njen razvoj je povezan tudi z razvojem kirurške tehnologije, kot je

[1] Asist. Jure Urbančič, dr. med, Katedra za otorinolaringologijo, Medicinska fakulteta, Univerza v Ljubljani, Zaloška cesta 2, 1000 Ljubljana, Univerza v Ljubljani, Vrazov trg 2, 1000 Ljubljana; Klinika za otorinolaringologijo in cervikofacialno kirurgijo, Univerzitetni klinični center Ljubljana, Zaloška cesta 2, 1000 Ljubljana; jure.urbancic@kclj.si

[2] Constance Gléron, štud. med., Klinika za otorinolaringologijo in cervikofacialno kirurgijo, Univerzitetni klinični center Ljubljana, Zaloška cesta 2, 1000 Ljubljana; Université de Lausanne, Faculté de Biologie et de Médecine, Rue du Bugnon 21, 1005 Lausanne

[3] Gregorio Benites, štud. med., Medicinska fakulteta, Univerza v Ljubljani, Vrazov trg 2, 1000 Ljubljana; Faculty of Medicine, National University of Trujillo, Roma Avenue 338, Trujillo

[4] Martin Škrlec, dr. med., Klinika za otorinolaringologijo in cervikofacialno kirurgijo, Univerzitetni klinični center Ljubljana, Zaloška cesta 2, 1000 Ljubljana

[5] Asist. dr. Domen Vozel, dr. med., Medicinska fakulteta, Univerza v Ljubljani, Vrazov trg 2, 1000 Ljubljana; Klinika za otorinolaringologijo in cervikofacialno kirurgijo, Univerzitetni klinični center Ljubljana, Zaloška cesta 2, 1000 Ljubljana

uporaba prej narejenih posnetkov CT ali MRI za orientacijo v operativnem polju. Namen raziskave je prikaz vpliva obsega kirurškega postopka na navigacijo in njuna časovna ocena. METODE. Analizirali smo med posegi zbrane podatke in primerjali dolžino posega za uporabo navigacije. Poiskali smo morebitne težave pri nastavitvah in ustaljeni uporabi navigacije, napovedne dejavnike za podaljšano dolžino posega in ocenili dobrobit uporabe navigacije s stališča kirurga. REZULTATI. Potrdili smo povezavo zapletenosti posega z dolžino posega. Daljši in zapletenejši poseg sicer zahteva večkratno uporabo navigacije, a je zapletenost posega vseeno boljši napovedni dejavnik za njegovo dolžino. Obenem predlagamo tudi tri časovnice, ki ponazarjajo potek uporabe navigacije med samim posegom. RAZPRAVA. Čas uporabe navigacije in razlike v absolutni dolžini posega pri različnih endoskopskih operacijah v nosu nakazuje, da je razlog za dolžino posega pravzaprav količina čistega kirurškega dela in ne sama uporaba navigacijske tehnologije.

BACKGROUNDS

Endoscopic sinus surgery (ESS) has evolved from the work of pioneers like Messerklinger, Draf and Wigand and has become a critical surgical strategy for a growing number of indications *(1–3)*. In the 80s, the need for a radiologic definition of paranasal sinus anatomy arose, and CT was ideal for the purpose *(4)*. Reports of severe intraoperative complications were not rare, even when experienced surgeons were equipped with detailed anatomical knowledge and three-plane CT imaging *(5, 6)*.

Some authors were even advocating using a microscope instead of an endoscope for reasons of obscured view and lack of magnification in life-threatening emergencies *(7)*. But endoscopic surgery was far from finished. New, bold ideas kept emerging, like the radical endoscopic removal of malignant disease *(8)*. When anatomic landmarks were missing, and the orientation in the labyrinth of the nose became increasingly difficult, a new computer-aided surgery (CAS) model seemed a promising though costly advancement *(9)*.

The basic concept was transferred from neurosurgery. Navigational systems with headframes were used to set the coordinates for stereotactic surgery *(10)*. CT images allowed continuous intraoperative axial, coronal and sagittal views of the exact location of the instrument tip *(11–13)*.

Essentially two types of image-guidance systems (IGS) are available, electromagnetic and optical. Both have proven benefits and drawbacks *(14–16)*. Smaller and more compact systems with more straightforward or advanced software solutions were gradually adapted to use in otorhinolaryngology or neurosurgery *(17)*. IGS-guided systems were first regarded as a tool with the potential to help increase postoperative results by reducing the surgeon's workload. A new term for a surgeon's feeling of safety was introduced when it was suddenly realised that IGS is helpful but may not alter the operating strategy *(18)*. The new mindset was nevertheless already in place, and progress from open surgical procedures to endoscopic – morbidity sparing procedures was enormous *(19, 20)*.

Massive development was also made in improved endoscopes, new surgical instruments and visualisation *(21)*. Specifically, the use of IGS may even shorten the surgery time in ESS. Nevertheless, it demands additional expertise and time to prepare to use the devices and instruments *(22)*. Streamlined solutions involving IGS showed the added benefit of lower time consumption and better ergonomics, and a need for additional training *(23)*. The surgical equipment's availability, reliability, and proper function have been given a pivotal role in reducing preventable errors and decreasing complications *(24)*. Nevertheless, some authors may still be reluctant to identify the IGS as a critical component of the endoscopic technique for the most challenging procedures such as sinonasal malignancies *(25, 26)*.

Operating time has been identified as a potential risk factor in skull base surgery *(27)*. The study's main aim was to provide adequate information regarding the usage times and the possible correlation between IGS use and the duration of the surgery for specific procedures. To our knowledge, there is a lack of data regarding the real-life impact of using the IGS in a broad spectrum of endoscopic endonasal procedures. Mainly, since the use of IGS also influences changes in the surgeon's actions *(28)*. We compared the effects through different endonasal endoscopic procedures, taking into consideration the effectiveness of the surgery and identifying specific problems regarding handling during set-up or operational use.

METHODS

The study was designed as a retrospective quality control study of surgical cases where IGS was routinely used for a nose and paranasal sinuses procedure in general anaesthesia performed in a single tertiary referral centre from 1st March 2013 to the 31st December 2016. Cases were stratified into subgroups of malignant disease, frontal disease, inverted papilloma (IP), chronic rhinosinusitis with nasal polyps (CRSwNP), group of guided biopsies, and abscess drainage and isolated sphenoid disease and cerebrospinal fluid (CSF) leak repairs, including gliomas or meningoceles. Type of treatment, the involvement of the skull base and time of surgery was extracted from the institutional database. A control group of patients with CRSwNP was randomly selected from the same database. According to hospital policy, all patients had priorly signed an informed consent to allow the recordings of their procedures for educational, research, and quality control use. The patient's data was anonymised immediately after synchronising the documentation from the hospital information system, while surgical appliances and surgeon's notes were anonymised after the procedure. Perceived precision, orientation, surgical score and surgical confidence were also routinely measured *(29)*.

The data was re-evaluated using the timeline embedded in the recording of the endoscopic procedure. Recordings were done with the Karl Storz AIDA® video system (Karl Storz AG, Tuttlingen, Germany) in 720p25 quality, the Sony HD Recorder (Sony Europe Limited, Weybridge, United Kingdom) in 1080p25 quality or the Elgato Capture HD60 (Corsair Components Inc., Freemont, USA) attached to a personal computer in 1080p60 quality. Brainlab Kolibri optical navigation with Ent 2.1.1 software (Brainlab AG, Munich, Germany) and standard tip registration technique with four points (lateral orbital rims, glabella, and premaxillary area) was used.

We had excluded cases with missing data (time profiles and questionnaires), patients where other surgical factors (malfunction of non-IGS related equipment, use of non-standard techniques or procedures, if a young surgeon was performing under surveillance) or when anesthesiological factors (procedure stopped for vital reasons) may have influenced the length of the procedure. The surgeon uploaded all the patient data, planned the registration points, applied the headband or navigational pole for the head clamp, prepared the instruments and concluded registration.

Preoperative planning was performed immediately after uploading the patient data. It consisted of defining different points or trajectories through the proposed surgical path. Precision was checked with a navigational tooltip, first running over the external nose and second by touching the inferior and middle turbinate under endoscopic control. The result was successful when the precision was confirmed by touching anatomical points on the IGS and observing the real-time endoscopic picture. To acquire the correct type of data, navigation was always used to verify the position and not for continuously navigating the approach (navigated drill or similar instrument).

The intraoperative performance of the IGS, the preoperative planning, registration, calibration of various IGS instruments problems, systemic problems with the IGS, surgical orientation, precision and confidence regarding the use were collected via a surgical questionnaire. A well-defined scale is mandatory to show a significant percentage of surgical strategy changes and their magnitude. The moment when a surgeon confirms a catastrophic situation would understandably present the most highly scaled strategy change (table 1).

Data preparation was done using Microsoft Excel 2016 and Microsoft Office Timeline (Microsoft, Redmond, USA). All statistical analysis was performed using SPSS v. 20.0. (IBM, Armonk, USA). Since no patient data was used after the initial identification of cases, no national ethics committee opinion was needed according to the institutional ethics board opinion.

Statistics

We calculated the mean time used for registration, mean time of the procedure and mean time of intraoperative use. We compared the values regarding specific procedures and the involvement of the skull base using the Mann-Whitney U test, Kruskal--Wallis test, and analysis of variance (ANOVA). Statistical significance was assumed at $p<0.05$. For non-normally distributed data, weused the non-parametric test. The homogeneity of variance was tested with Levene's test of equality. Groups were compared with a univariate analysis of variance, and the difference was determined by one-way ANOVA using the Bonferroni adjustment. We checked the linear relationship of elapsed time (mean time to the end of registration vs mean duration of the procedure and mean time of intraoperative use vs mean duration of the procedure). We created a linear regression model including selected variables. The probable cor-

Table 1. Definition of categories in the surgeons' questionnaire. IGS – image-guidance systems, VAS – visual analogue scale.

Registration, calibration and orientation issues	0. None
	1. Minor, not an issue
	2. Minor, but issue on time and performance
	3. Major issue, with limited usage of device
	4. IGS usage impossible
Precision and orientation score (self-assessed VAS)	0. Unsatisfactory ... 10 – Excellent
Same procedure as without use of IGS (self-assessed VAS)	0. Not ... 10 – Certainly, by all means
Was the strategy changed during use of IGS (self-assessed VAS)	VAS > 5 positive

relation of the number and duration of intraoperative image-guidance use with the total surgical time was assessed. A mean number of calibration attempts, boot time, a mean number of intraoperative applications, mean precision of the IGS as perceived by the surgeon, mean intraoperative orientation score and mean response, and whether the surgeon would perform the same surgery without IGS were calculated. Group means were compared by one-way ANOVA using the same criteria for homogeneity of variance. Multiple comparisons using Bonferroni adjustment were made to identify statistically significant pairs. Scaled answers were reflected, log10 values were used in the ANOVA test.

RESULTS

Out of 117 cases, 51 met the defined criteria for the study. All were operated by one experienced surgeon. Detailed group characteristics are presented in table 2.

Most of the procedures (74.5%) did not involve the skull base. In 82.4% of the cases, CT of the nose and paranasal sinuses was used as a source of navigational data. The extension of the procedures (CRSwNP with IGS and without IGS) was the same (p=0.056). Detailed times in stratified subgroups are presented in table 3, pairwise comparison in table 4 and cumulative IGS usage data in table 5.

The mean procedure time in malignant disease is statistically different from all other

Table 2. Group characteristics. N – number of patients, SD – standard deviation, CRSwNP – chronic rhinosinusitis with nasal polyps, CSF – cerebrospinal fluid, IGS – image-guidance systems.

Patient's data	**N (%)**
Sex	
Female	22 (43.2)
Male	29 (56.9)
Age (years)	51.1 (0.1–81.5, SD 19.2)
Procedure	
Malignant disease	12 (23.5)
Frontal disease	13 (25.5)
Inverted papilloma	9 (17.6)
CRSwNP	5 (9.8)
Guided biopsies and abscess drainage	8 (15.7)
CSF leak repairs (glioma, menigoceles)	4 (7.8)
Skull base procedures	
Yes	13 (25.5)
No	38 (74.5)
Source of IGS data	
CT of the nose and paranasal sinuses	42 (82.4)
CT and MR of the nose and paranasal sinuses	6 (11.8)
Other (CT of the head, orbit)	3 (6.0)

Table 3. Time consumption for registration of the image-guided systems (IGS) and procedure time for subgroups. SD – standard deviation, CRSwNP – chronic rhinosinusitis with nasal polyps, CSF – cerebrospinal fluid.

	Mean time to the end of registration in minutes (SD)	Mean time of procedure in minutes (SD)	p-value[a]	Mean time of the intraoperative use minutes (SD)	Intraoperative use vs. time of procedure p-value[a]
Complete group	15.2 (6.5)	161.4 (142.1)	<0.000	6.7 (6.9)	<0.000
p-value	0.003[b]	<0.000[c]	/	<0.000[b]	/
Procedure					
Malignant disease	21 (7.1)	307.9 (182.1)	0.009	11.8 (10.5)	<0.000
Frontal disease	15.9 (6.4)	112.2 (32.6)	0.1	8.6 (3.4)	0.6
Inverted papilloma	12.2 (3.7)	142.7 (28.7)	0.04	3.1 (2.6)	0.008
CRSwNP	8.6 (0.9)	43 (9.7)	0.5	3.4 (1.3)	0.92
Guided biopsies and abscess drainage	12.2 (4.2)	65 (36.7)	0.46	2.2 (0.9)	0.1
CSF leak repairs (glioma, menigoceles)	16 (6.2)	165 (133.6)	0.7	3.4 (1.5)	0.52
Skull base (p-value)	0.48[d]	<0.000[d]	/	0.04[d]	/
No	13.1 (5.2)	118.7 (91.3)	<0.000	5.6 (4.9)	<0.000
Yes	20.9 (7.2)	286.2 (189.2)	0.007	10.2 (10.1)	0.001

[a] linear regression
[b] Kruskal-Wallis test
[c] ANOVA (log10 of Mean time of procedure)
[d] Mann-Whitney U test

Table 4. Pairwise comparisons of the logarithm of mean duration of surgery (upper row) and mean times of use of the image-guided systems (IGS) (bottom row) by type of surgery using the Bonferroni adjustment. Analysis of variance (ANOVA) ($F(5,45)=17.890$, $p<0.000$); ANOVA ($F(5,45)=18.161$, $p<0.000$). CRSwNP – chronic rhinosinusitis with nasal polyps, CSF – cerebrospinal fluid, IP – isolated papilloma.

	Malignant disease	**CRSwNP**	**Frontal sinus & osteoma**	**Glioma & CSF leak**	**IP**	**Biopsies & abscesses & isolated sphenoid disease**
Guided biopsies and abscess drainage	<0.000 <0.000	non sig. non sig.	0.002 <0.000	0.03 non sig.	0.001 non sig.	/ /
Malignant disease	/ /	<0.000 <0.000	0.003 non sig.	non sig. <0.000	0.04 <0.000	<0.000 <0.000
CRSwNP	<0.000 <0.000	/ /	<0.000 0.001	0.007 non sig.	<0.000 non sig.	non sig. non sig.
Frontal disease	0.003 <0.000	<0.000 non sig.	/ /	non sig. 0.005	non sig. <0.000	0.002 <0.000
CSF leak repairs (glioma, menigoceles)	non sig. <0.000	0.007 non sig.	non sig. 0.005	/ /	non sig. non sig.	0.03 non sig.
IP	0.04 <0.000	<0.000 non sig.	non sig. <0.000	non sig. non sig.	/ /	0.001 non sig.

procedures ($p<0.001$). The time taken for the registration of the IGS is linearly correlated to the duration of the surgery in malignant disease ($r^2=0.51$, $p=0.009$) as well as IP ($r^2=0.50$, $p=0.04$) (see also table 5). In regression analysis, we have also found a linear correlation between the number of separate IGS uses in malignant diseases ($r^2=0.60$, $p=0.005$) and the amount of total intraoperative IGS usage and total duration of the procedures (malignant diseases, $r^2=0.73$, $p<0.001$ and IP, $r^2=0.73$, $p=0.03$). Scaled answers for the precision of the IGS, the intraoperative orientation score, and the estimate of the probability of the same procedure without the IGS are presented in figures 1–3. The percentage of strategy changes is illustrated in figure 4.

Table 5. Cumulative data (N=51) about the usage of the image-guided systems (IGS). N – number of patients, SD – standard deviation, CRSwNP – chronic rhinosinusitis with nasal polyps, CSF – cerebrospinal fluid.

Cumulative data	**N (or otherwise indicated)**
Boot time (s)	128 (SD 8.9)
Loading problems	0 (0.0%)
Navigational planning	
No planning	24 (47.1%)
Up to two points	13 (25.5%)
Multiple points	10 (19.6%)
Complex planning (points & trajectories)	4 (7.8%)
Registration points	
Minor problems (not an issue of time and performance)	1 (2.0%)
No problems	50 (98.0%)
Number of registration attempts	1.14 (SD 0.5)
Navigational precision estimate	
Green	8 (15.7%)
Yellow	43 (84.3%)
Red	0 (0.0%)
Orientation issues during procedure	
None	47 (92.2%)
Minor, not an issue of time and performance	1 (2.0%)
Minor issue on time and performance	2 (3.9%)
Major issue with limited usage of device	1 (2.0%)
Number of intraoperative uses (mean for group – SD)	6.1 (SD 3.8)
Malignant disease	10 (SD 4.2)
Frontal disease	8.7 (SD 2.2)
CSF leak repairs (glioma, menigoceles)	3.5 (SD 1.3)
CRSwNP	3.4 (SD 1.3)
Inverted papilloma	3.3 (SD 1.6)
Guided biopsies and abscess drainage	3 (SD 0.9)

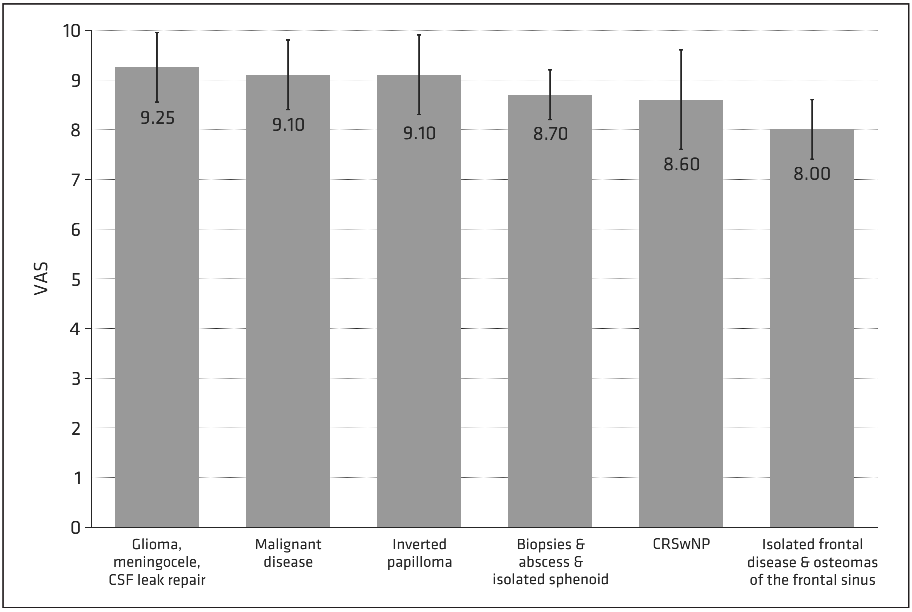

Figure 1. The mean precision of the image-guided systems (IGS) as perceived by the surgeon (visual analogue scale (VAS) of 0 to 10 with standard deviation (SD)). Malignant vs isolated frontal disease and osteomas of the frontal sinus p=0.01, inverted papilloma vs isolated frontal disease and osteomas of the frontal sinus p=0.02, analysis of variance (ANOVA) (F(5,45)=3.885, p=0.005). VAS – visual analogue scale, CSF – cerebrospinal fluid, CRSwNP – chronic rhinosinusitis with nasal polyps.

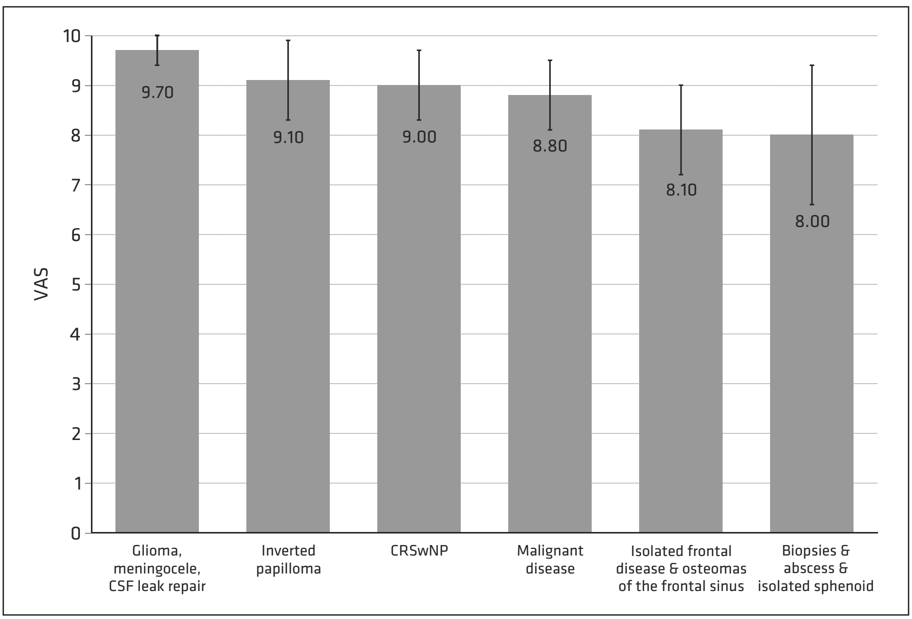

Figure 2. The mean intraoperative orientation score as perceived by the surgeon (visual analogue scale (VAS) of 0 to 10 with standard deviation (SD)). Glioma, menigocele, cerebrospinal fluid (CSF) leak repair vs. biopsies and abscess and isolated sphenoid p=0.04, analysis of variance (ANOVA) (F(5.45)=3.487, p=0.01). VAS – visual analogue scale, CSF – cerebrospinal fluid, CRSwNP – chronic rhinosinusitis with nasal polyps.

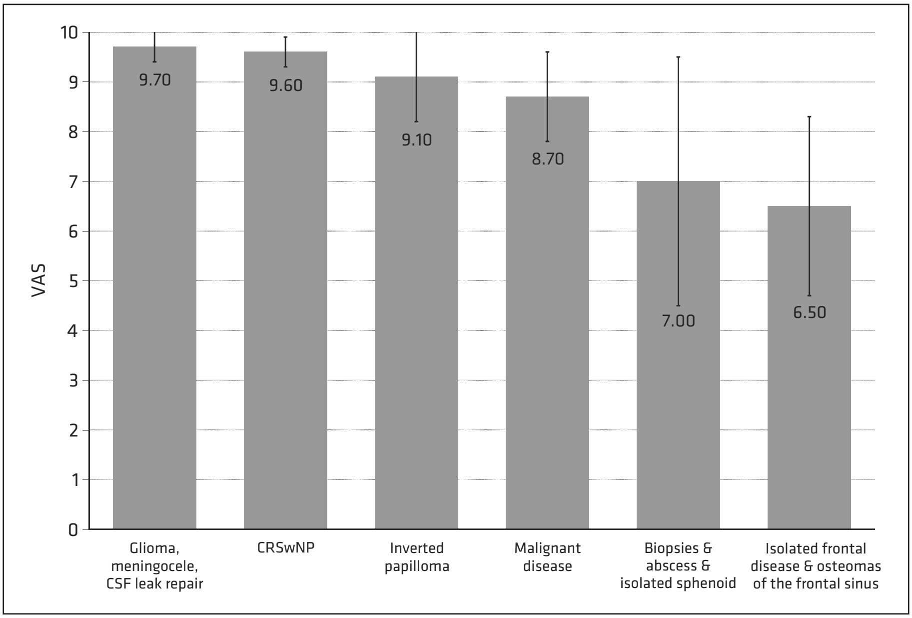

Figure 3. Scaled answer whether the surgeon would perform same surgery without intraoperative IGS (visual analogue scale (VAS) 0 to 10 with standard deviation (SD); 0 – no, 10 – yes, certainly). Isolated frontal disease & osteomas of the frontal sinus vs. malignant disease p=0.02, isolated frontal disease & osteomas of the frontal sinus vs. CRSwNP p=0.001, isolated frontal disease & osteomas of the frontal sinus vs. glioma, meningocele, cerebrospinal (CSF) leak repair p=0.001, isolated frontal disease and osteomas of the frontal sinus vs. inverted papilloma p=0.002, analysis of variance (ANOVA) (F(5,45)=7.380, p<0.000). VAS – visual analogue scale, CSF – cerebrospinal fluid, CRSwNP – chronic rhinosinusitis with nasal polyps.

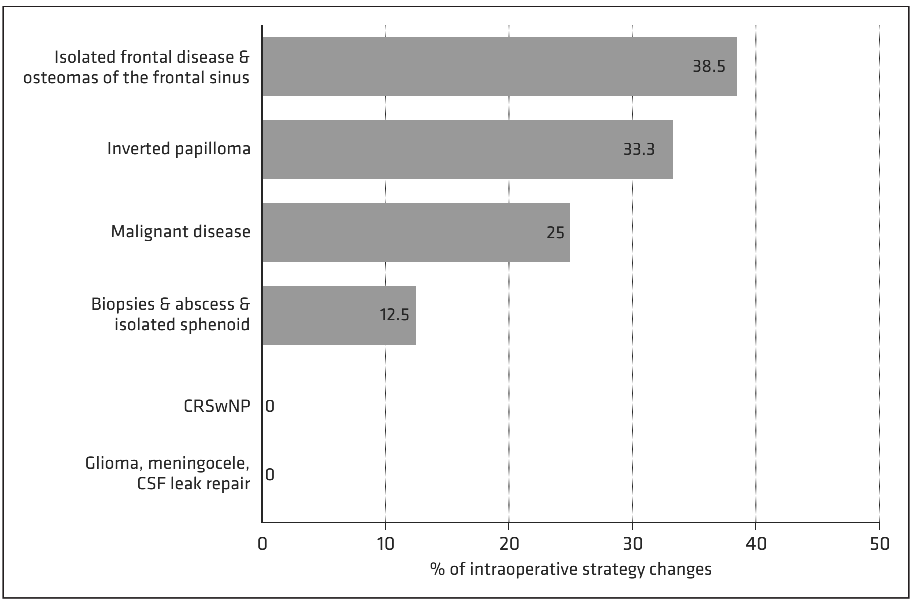

Figure 4. The percentage of strategy changes with IGS use. CRSwNP – chronic rhinosinusitis with nasal polyps, CSF – cerebrospinal fluid.

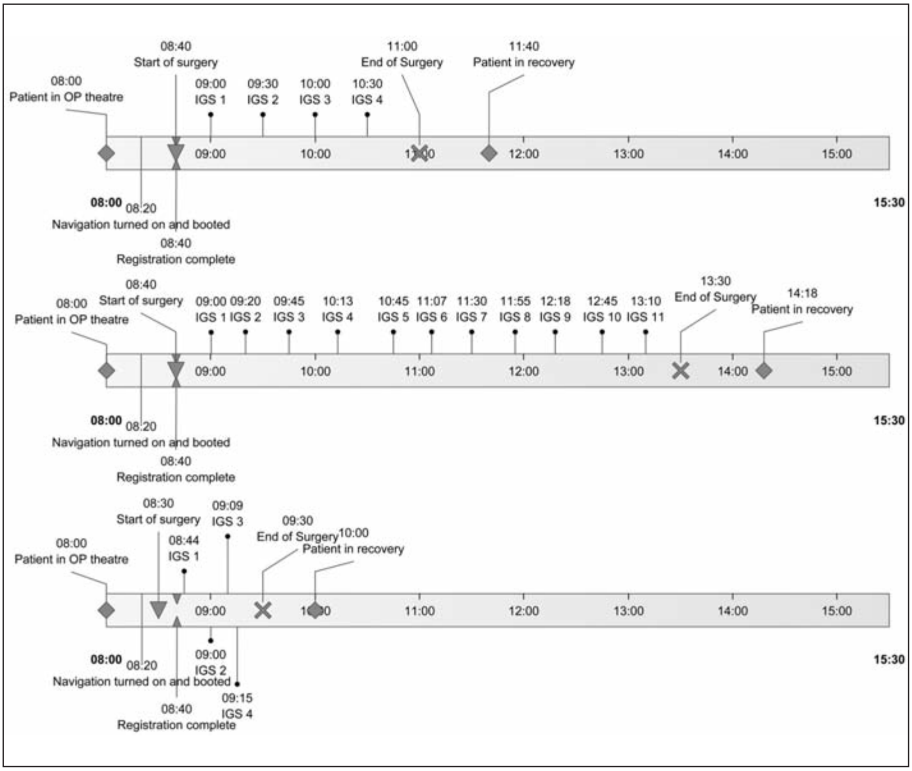

Figure 5. Proposed timeline scenarios for inverted papilloma (IP), malignant disease and chronic rhinosinusitis with nasal polyps (CRSwNP). OP – operative, IGS – image-guided systems.

DISCUSSION

The anatomic complexity that requires the surgeon to use all knowledge, spatial orientation, and surgical intuition to solve the problem emphasises the importance of the IGS. Even more so when surgeons deal with increasingly difficult procedures involving the frontal sinus, CSF leak repair, or oncologic procedures *(15)*.

Observing the meantime of registration shows the understandable tendency to take longer to register when performing a more complicated procedure. In linear regression, for every minute of increase in registration time, the duration of surgery increases by 18.1 minutes in malignant disease and 5.3 minutes in patients with IP. But not all of the groups show a statistically significant difference in the pairwise comparison of mean values. Empowered with the analysis results, three different groups can be eluded, one with malignant pathology being the most time-consuming (duration of the procedure and IGS involvement), following the complex frontal sinus procedures, CSF leak repair, and IP. A correlation between the time of registration and the duration of the surgery was found in malignant cases and inverted papilloma. It can be explained by the similarities in endoscopic approach, instrumentation, and surgical thinking *(30, 31)*.

Registration time and total IGS usage were quite distinctively lower for all other procedures, including those requiring comparably long operating times (CSF leak repair, IP, frontal disease). Frontal sinus surgery is also the pathology where authors

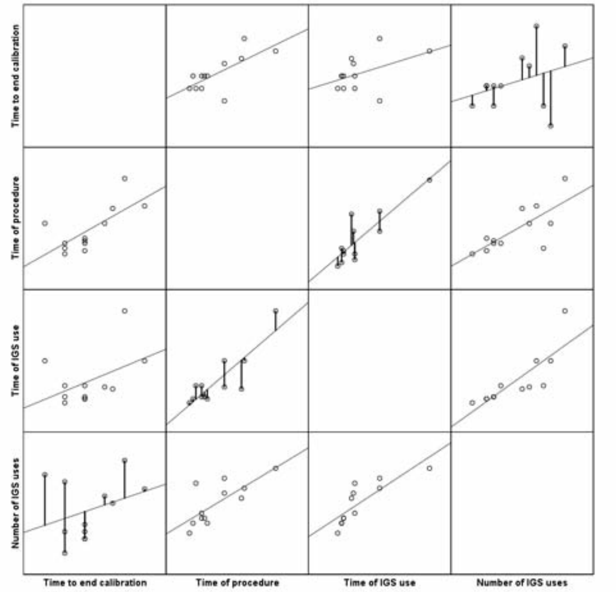

Figure 6. The relationship of parameters affecting the time of procedure for malignant disease. IGS – image guided systems.

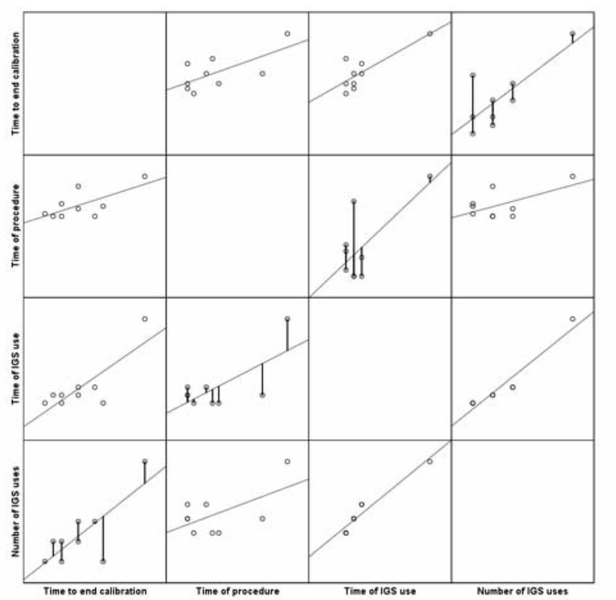

Figure 7. The relationship of parameters affecting the time of procedure for inverted papilloma. IGS – image-guided systems.

were most inclined to trust the IGS during surgery. Reasonable conduct of the endoscopic procedure requires a degree of familiarity with the anatomy and pathology of the patient. The surgeon usually does not blindly follow the advice of the IGS but uses the device as an additional confirmation of known or unknown (*ad-hoc*) anatomical landmarks or simply as a validation tool *(32, 33)*. High rates of perceived precision and high orientation scores during the use of IGS are consistent with other published research data *(9, 15, 17, 22, 32, 34)*. High dependence on IGS in virtually blinded procedures without orientation points is also expected *(15, 35, 36)*.

Other authors have shown that the intraoperative time reduction in conventional functional endoscopic surgery (FESS) was about ten minutes per case *(22)*. We haven't found a significant difference when comparing the duration and the sheer extent of the surgery (CRSwNP). But in more difficult cases, we have found that the time consumption at registration, and the total duration of surgery is higher (table 3).

We have shown that every single use of the IGS should prolong the surgery time in malignant cases by 32.5 minutes (mean number of uses 10). With every minute of IGS use, the intraoperative time increases by 14.93 minutes (malignant diseases, mean time of use of 11.8 minutes) or 7.6 minutes (inverted papilloma, mean time of use of 3.1 minutes).

To explain the data further, we propose a timeline representing the three typical surgical scenarios (figure 5). The time between pins is defined as IGS use and purely surgical work. The relationship between both may not be the same in all the procedures. The first scenario reflects the IGS usage in IP, the second in malignant disease, and the third in CRSwNP. The robustness of proposed scenarios also relies on identifying any aberrantly long usage of IGS. They were specially produced by factors not separately identified upfront. The need to correct the optical pathway for IGS or even for recalibration arises when accuracy falls below acceptable. The added real-time contributes to the IGS use and the surgeon's response to the new information.

Prolongation of the surgery may well be an attribute of a complicated surgical procedure, added difficult anatomy, and raw extension of the disease. The surgical work between individual IGS verifications may be shorter in less complex situations (figures 6 and 7), however, the most demanding endoscopic surgery without IGS may not be a viable option anymore.

Complex cases will demand an increased number of IGS position verifications, which will prolong IGS handling time during the procedure. Comparing the time used for IGS and the absolute difference in operating times at various endoscopic endonasal procedures implies that the main reason for prolonged surgery is probably extensive surgical work and is not always directly related to IGS use itself.

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