WILEY-BLACKWELL

Allergy & Rhinology

An inertial sensor-based system designed to measure and prevent undesired camera rotation during endoscopic sinus surgery

Journal:	*International Forum of Allergy & Rhinology*
Manuscript ID	ALR-19-0684.R2
Wiley - Manuscript type:	Letter to the Editor
Date Submitted by the Author:	n/a
Complete List of Authors:	Viera-Artiles, Jaime; Hospital Universitario Marques de Valdecilla, ENT Valdiande, José; Universidad de Cantabria, Photonics Engineering Group Ospina, Javier; Hospital Universitario de la Fundación Santa Fe de Bogotá, Division of Otolaryngology - Sinus and Skull Base Surgery Costales, María; Hospital Universitario Central de Asturias, ENT, Head and Neck Surgery López-Higuera, José; Universidad de Cantabria, DPTO. TECNOLOGIA ELECTRONICA E INGENIERIA DE SISTEMAS Y AUTOMATICA; Centro de Investigacion Biomedica en red en Bioingenieria Biomateriales y Nanomedicina; IDIVAL
Keywords:	Endoscopic Sinus Surgery, Endoscopy, FESS, Residency Training in Rhinology, Rhinology Workforce, Endoscopic Skull Base Surgery
Abstract:	**Background**: Maintaining a stable visual horizon during endoscopic sinus surgery is essential to preserve spatial orientation. A constant camera movement generates a rotation which tilts the operating field's view, producing a visuomotor incongruence with detrimental effects in surgical performance and safety, especially above 15 o. We aimed to study this phenomenon on endoscopic sinus surgery in order to prevent it. **Methods**: We developed a system that can be attached to any conventional endoscopic camera and can measure camera movement parameters and their variation from a reference position, feeding back this information in real-time as a reference guide overlay over the original image to aid in maintaining a stable visual horizon. A pilot study was conducted to test the utility and feasibility of the system in human cadaveric specimens, comparing similar tasks performed with and without the reference guides. **Results**: Camera roll was prospectively measured in 18 tasks. Globally, there was a 52.2% (± 18.3%) reduction in this parameter when the reference guides were active. Specifically, there was 86.8% reduction in the total amount of time where camera roll was above 15o. The impact of the reference guides, nonetheless, was greater in inexperienced participants. All the comparisons were statistically significant ($p < 0.05$).

	Conclusions: Undesired camera rotation is a latent factor inherent in endoscopic procedures. The designed reference guide strategy effectively reduced camera roll during endoscopic sinus surgery in the laboratory. The potential benefits of this system go beyond sinus surgery and open a new field for researchers and surgical educators.

Jaime Viera-Artiles

TITLE PAGE

Manuscript Title: An inertial sensor-based system designed to measure and prevent undesired camera rotation during endoscopic sinus surgery.

Running Title: System to reduce camera rotation in endoscopy

Key Words: Endoscopy, Nasal Surgical Procedures, Sinusitis, Spatial Orientation.

Funding and Conflict of Interests: This project has been developed thanks to the Innovation Support Program "InnVal" of the Marqués de Valdecilla Research Institute (IDIVAL). The funder had no role in study design, data collection and analysis, decision to publish, or preparation of the manuscript. The authors have declared that no competing interests exist.

Jaime Viera-Artiles

TEXT

To the Editor, we present a prototype of an inertial sensor-based system capable of accurately determining camera roll during and a reference-guide strategy that presumably reduces the surgeon's undesired tilted view during endoscopic sinonasal procedures, a latent factor with negative impact in surgical performance and safety.

Minimally invasive surgery has a steep learning curve due to several drawbacks inherent in the use of an endoscope in contrast to open surgery, such as the indirect view of the operating field and the loss of stereoscopic vision, which alters depth perception[1]. Endoscopic sinus surgery (ESS) and anterior skull base surgery pose an additional challenge due to the complexity and narrowness of the anatomy, necessitating constant movement of the endoscope to navigate from one zone to another, thus increasing the difficulty maintaining a stable visual horizon.

Mastering endoscopic camera operation is essential during the first steps of this learning process and allows surgeons to maintain the visual stability necessary to successfully locate anatomic landmarks while operating[2]. The identification of those landmarks is crucial for spatial orientation and safety in these procedures. During ESS, rigid endoscopic cameras are usually placed inside the nose and held by the surgeon, having rotational freedom in all spatial axes. This freedom and the constant need of camera movement generates an unconscious and often undesired camera rotation that can lead to disorientation. This problem is not solved by surgical intraoperative navigations systems, which are meant to locate the position of the instruments' tips in relation to preoperative imaging and not to visually aid spatial orientation while operating the camera.

Rotation along the longitudinal axis (X-axis), also known as camera roll, tilts the horizon of the endoscopic image, generating a misalignment between the displayed image and the actual operative field, creating a visuomotor incongruency that makes tool manipulation and localization of anatomic landmarks more difficult[3].

This undesired camera rotation is a latent factor inherent in the system and has a negative impact on surgical performance by requiring multiple corrections and an extra cognitive effort known as "mental rotation", increasing operating time and fatigue[4]. Moreover, a tilted view of the operative field increases the risk of endoscopic procedures by favouring wrong judgments regarding the anatomical plane, mostly at angles from 15 to 30°. To prevent this increased risk during surgery, a "gravity-line" strategy has been described recently, emphasizing the importance of keeping the camera in the direction of gravity, in accordance with open surgeries[5]. The effects of this phenomenon on ESS have not been studied.

MATERIALS AND METHODS

The system comprises 3 parts: an inertial sensor placed inside a hermetic box, a computer system with a custom-made software and a foot pedal to control the software.

The inertial sensor uses the angular acceleration from a 3-axis accelerometer and the angular velocity from a 3-axis gyroscope to provide the spatial orientation through the roll (rotation along the X-axis) and pitch (rotation along the Y-axis) angles. The sensor is located inside a hermetic box with a total weight of 26 grams and is capable of obtaining and recording 50 measurements per second. The box can be attached to any endoscopic camera using an articulated holder (Figure 1A). It is then connected to the computer system, which receives and processes the information.

The software captures the incoming video from the endoscopic system and shows it unmodified on the screen whilst processing the sensor data and displaying it as overlay graphics by using a circular bar for the roll. The guides are colour-coded by default using green for rotations from 5° to 10°, orange from 10° to 15° and red over 15° (Figure 1 B-D). However, these settings could be customized as the surgeon desires.

To test the feasibility of the prototype, a pilot prospective, randomized and observational study in 2 fresh human cadaveric specimens (4 sides) was conducted in the dissection laboratory. Seven participants were enrolled with different degrees of training and exposure to ESS. To determine the intrasubject impact of the reference guides, different tasks selected among parts of a regular ESS were assigned to each participant. Every participant performed the same assigned task on the same side of both specimens. One task was performed without the reference guides and the other with the guides activated, in a randomized order. Wilcoxon signed-rank sum tests were conducted to compare the roll angles of each task with the reference guides activated against the theoretical mean roll angle of the combined tasks without the guides.

RESULTS

A total of 18 tasks (surgical steps) during 49 minutes and 3 seconds with a mean duration of 3 minutes and 12 seconds per task, were compared. The only parameter used in the comparisons was the variation of the camera roll over time (Table 2).

Globally, the mean rotation was 18º in all tasks without guides and 7.8º with the guides on. This translates to a camera roll reduction of 52.2% ± 18.3%, with a maximum of 84.4% ($p < 0.05$) in an inexperienced surgeon (C-4; Figure 2) and a minimum of 20.8% ($p < 0.05$) in an expert (D-6; Figure 2). The impact of the reference guides was statistically significant in all the comparisons ($p < 0.05$).

The percentage of time during the tasks without the reference guides where the camera roll was above 15º was 59.1% and 11.1% with the guides activated. Thus, we found 86.8% in rotation time reduction above this threshold using the guides.

DISCUSSION

The tasks performed with hidden reference guides showed that camera roll is indeed inherent in camera operation. The intensity of this phenomenon, nonetheless, could be affected by experience in endoscopic procedures.

On the other hand, the strategy of using reference guides seemed to be very effective at reducing this rotation and helped all participants to reduce substantially the amount of time when the rotation was above 15º, aiding experienced surgeons at achieving 100% of the task below this threshold. The mean reduction, as expected, was higher in participants with less exposure to endoscopic sinonasal surgery. Furthermore, a larger potential effect could be expected with further training, as the system has its own learning curve.

The guides seem to benefit novice surgeons by making them aware of a rotation that otherwise would occur unnoticed. This could facilitate the localization of anatomic landmarks necessary for spatial orientation that would be more challenging in tilted fields and serve as a valuable camera operation learning tool. Conversely, senior surgeons with enough experience to stay oriented even with a certain degree of angular rotation (as a result of mental compensation), can benefit from the guides in procedures where no references are available and surgical orientation may be limited, for instance, in patients with distorted anatomy or previous operations.

Different systems have been published that attempt to maintain a stable horizon by automatically rotating the image in flexible endoscopes[6]. This problem, to a lesser extent, also occurs with rigid scopes, but it seems to have only aroused interest among laparoscopists. There is an immense knowledge gap in the literature regarding this issue in the field of rhinology, which reflects a low interest that might also indicate an underestimation of the possible negative effects of this phenomenon.

Intraoperative orientation has been a matter of concern since endoscopic approaches were first utilized. In the past few years, new strategies based in augmented reality have been developed, fusing computer-generated images of the patient's imaging data with a real-time endoscopic view of the surgical field, providing three-dimensional visual cues to aid spatial orientation[7]. This promising technology has not yet seen widespread implementation, probably due to its recentness and elevated prices. Our new proposed system is not meant to be a substitute for any of the previously mentioned devices but an addition designed to tackle a different aspect of the disorientation problem that can work in conjunction with them.

Despite all this technological advancement, orientation is still a complicated subject to assess due to its subjective nature, which makes it difficult to describe, measure and quantify. The implications and effects of disorientation concerning surgery are poorly understood and often related to contributing factors of systematic error that could lead to intraoperative complications[8]. The proposed system gives researchers a new measuring tool to try to understand camera operational dynamics as contributing factors in disorientation.

To summarize, we have developed a device that can accurately recognize camera roll and a reference-guide system to reduce it during ESS. Unnoticed camera roll and the consequent image misalignment are inherent in camera operation. This latent factor can combine with others in a chain of errors leading to complications in ESS and probably in endoscopic skull base surgery as well. Therefore, a system dedicated to studying and preventing this factor would probably increase the safety of endoscopic procedures. Further studies are needed to probe the clinical benefits in a larger scale of this new accessory to the conventional scopes.

Jaime Viera-Artiles

Authors: Jaime Viera-Artiles MD[1], José J. Valdiande BEng[2], Javier Ospina MD[3], María Costales PhD[4], José M. López-Higuera PhD[2,5].

Institutions:

1. ENT department, Hospital Universitario Marqués de Valdecilla, Santander, Spain.
2. Photonics Engineering Group, Universidad de Cantabria, Santander, Spain.
3. Division of Otolaryngology - Sinus and Skull Base Surgery, Fundación Santa Fe de Bogotá, Bogotá, Colombia.
4. ENT department, Hospital Universitario Central de Asturias, Oviedo, Spain.
5. CIBER-BBN and IDIVAL, Santander, Spain.

Corresponding Author: Jaime Viera-Artiles, Departamento de Otorrinolaringología, Hospital Universitario Marqués de Valdecilla. Av. Valdecilla, 25, 39008 Santander, Cantabria. Spain. jaimevieraartiles@gmail.com ; Tel: +34 691 485 966

Jaime Viera-Artiles

REFERENCES

1. J. Wade N. Frames of reference in vision. *Minim Invasive Ther Allied Technol*. 2009;5:435-439. doi:10.3109/13645709609153705

2. Sodergren MH, Orihuela-Espina F, Froghi F, et al. Value of orientation training in laparoscopic cholecystectomy. *Br J Surg*. 2011;98(10):1437-1445. doi:10.1002/bjs.7546

3. Gallagher AG, Al-Akash M, Seymour NE, Satava RM. An ergonomic analysis of the effects of camera rotation on laparoscopic performance. *Surg Endosc*. 2009;23(12):2684-2691. doi:10.1007/s00464-008-0261-x

4. Conrad J, Shah AH, Divino CM, et al. The role of mental rotation and memory scanning on the performance of laparoscopic skills: A study on the effect of camera rotational angle. *Surg Endosc Other Interv Tech*. 2006;20(3):504-510. doi:10.1007/s00464-005-0363-7

5. Zhu A, Yuan C, Piao D, Jiang T, Jiang H. Gravity line strategy may reduce risks of intraoperative injury during laparoscopic surgery. *Surg Endosc*. 2013;27(12):4478-4484. doi:10.1007/s00464-013-3093-2

6. Lee HC, Jung CW, Kim HC. Real-time endoscopic image orientation correction system using an accelerometer and gyrosensor. *PLoS One*. 2017;12(11):1-12. doi:10.1371/journal.pone.0186691

7. Citardi MJ, Agbetoba A, Bigcas J-L, Luong A. Augmented reality for endoscopic sinus surgery with surgical navigation: a cadaver study. *Int Forum Allergy Rhinol*. 2016;6(5):523-528. doi:10.1002/alr.21702

8. Sodergren M, Yang G, Darzi A. Perception and orientation in minimally invasive surgery. *Arch Surg*. 2012;147(3):210-211.

FIGURE/VIDEO LEGENDS

Figure 1A: Example of the location of the hermetic box with the inertial sensor (black arrow) in a regular endoscopic camera. **B-D**: Appearance of the reference system at different stages. B: green colour for rotations from 5º to 10º. C: orange for rotations from 10º to 15º. D: red colour for rotations over 15º.

Figure 2: Mean rotation in every task-participant pair with and without the reference guides.

Video 1: Reference guides' appearance after selecting a reference position.

Video 2: Differences in camera roll during a posterior ethmoidectomy (0 º scope) and frontal sinusotomy (30º scope) performed by an expert rhinologist.

Jaime Viera-Artiles

TITLE PAGE

Manuscript Title: An inertial sensor-based system designed to measure and prevent undesired camera rotation during endoscopic sinus surgery.

Running Title: System to reduce camera rotation in endoscopy

Key Words: Endoscopy, Nasal Surgical Procedures, Sinusitis, Spatial Orientation.

Funding and Conflict of Interests: This project has been developed thanks to the Innovation Support Program "InnVal" of the Marqués de Valdecilla Research Institute (IDIVAL). The funder had no role in study design, data collection and analysis, decision to publish, or preparation of the manuscript. The authors have declared that no competing interests exist.

Jaime Viera-Artiles

TEXT

To the Editor, we present a prototype of an inertial sensor-based system capable of accurately determining camera roll during ~~capable of accurately determine camera roll during endoscopic surgeries~~ and a reference-guide strategy that presumably reduces the surgeon's undesired tilted view during endoscopic sinonasal procedures, a latent factor with negative impact in surgical performance and safety.

Minimally invasive surgery has a steep learning curve due to several drawbacks inherent in the use of an endoscope in contrast to open surgery, such as the indirect view of the operating field and the loss of stereoscopic vision, which alters depth perception[1]. Endoscopic sinus surgery (ESS) and anterior skull base surgery pose~~s~~ an additional challenge due to the complexity and narrowness of the anatomy, necessitating constant movement of the endoscope to navigate from one zone to another, thus increasing the difficulty maintaining a stable visual horizon.

Mastering endoscopic camera operation is essential during the first steps of this learning process and allows surgeons to maintain the visual stability necessary to successfully locate anatomic landmarks while operating[2]. The identification of those landmarks is crucial for spatial orientation and safety in these procedures. During ESS, rigid endoscopic cameras are usually placed inside the nose and held by the surgeon, having rotational freedom in all spatial axes. This freedom and the constant need of camera movement generates an unconscious and often undesired camera rotation that can lead to disorientation. This problem is not solved by surgical intraoperative navigations systems, which are meant to locate the position of the instruments' tips in relation to preoperative imaging and not to visually aid spatial orientation while operating the camera.

Rotation along the longitudinal axis (X-axis), also known as camera roll, tilts the horizon of the endoscopic image, generating a misalignment between the displayed image and the actual operative field, creating a visuomotor incongruency that makes tool manipulation and localization of anatomic landmarks more difficult[3].

This undesired camera rotation is a latent factor inherent in the system and has a negative impact on surgical performance by requiring multiple corrections and an extra cognitive effort known as "mental rotation", increasing operating time and fatigue[4]. Moreover, a tilted view of the operative field increases the risk of endoscopic procedures by favouring wrong judgments regarding the anatomical plane, mostly at angles from 15 to 30°. To prevent this increased risk during surgery, a "gravity-line" strategy has been described recently, emphasizing the importance of keeping the camera in the direction of gravity, in accordance with open surgeries[5]. The effects of this phenomenon on ESS have not been studied.

MATERIALS AND METHODS

The system comprises 3 parts: an inertial sensor placed inside a hermetic box, a computer system with a custom-made software and a foot pedal to control the software.

The inertial sensor uses the angular acceleration from a 3-axis accelerometer and the angular velocity from a 3-axis gyroscope to provide the spatial orientation through the roll (rotation along the X-axis) and pitch (rotation along the Y-axis) angles. The sensor is located inside a hermetic box with a total weight of 26 grams and is capable of obtaining and recording 50 measurements per second. The box can be attached to any endoscopic camera using an articulated holder (Figure 1A). It is then connected to the computer system, which receives and processes the information.

The software captures the incoming video from the endoscopic system and shows it unmodified on the screen whilst processing the sensor data and displaying it as overlay graphics by using a circular bar for the roll. The guides are colour-coded by default using green for rotations from 5° to 10°, orange from 10° to 15° and red over 15° (Figure 1 B-D). However, these settings could be customized as the surgeon desires.

To test the feasibility of the prototype, a pilot prospective, randomized and observational study in 2 fresh human cadaveric specimens (4 sides) was conducted in the dissection laboratory. Seven participants were enrolled with different degrees of training and exposure to ESS. To determine the intrasubject impact of the reference guides, different tasks selected among parts of a regular ESS were assigned to each participant. Every participant performed the same assigned task on the same side of both specimens. One task was performed without the reference guides and the other with the guides activated, in a randomized order. Wilcoxon signed-rank sum tests were conducted to compare the roll angles of each task with the reference guides activated against the theoretical mean roll angle of the combined tasks without the guides.

RESULTS

A total of 18 tasks (surgical steps) during 49 minutes and 3 seconds with a mean duration of 3 minutes and 12 seconds per task, were compared. The only parameter used in the comparisons was the variation of the camera roll over time (Table 2).

Globally, the mean rotation was 18º in all tasks without guides and 7.8º with the guides on. This translates to a camera roll reduction of 52.2% ± 18.3%, with a maximum of 84.4% ($p < 0.05$) in an inexperienced surgeon (C-4; Figure 2) and a minimum of 20.8% ($p < 0.05$) in an expert (D-6; Figure 2). The impact of the reference guides was statistically significant in all the comparisons ($p < 0.05$).

The percentage of time during the tasks without the reference guides where the camera roll was above 15º was 59.1% and 11.1% with the guides activated. Thus, we found 86.8% in rotation time reduction above this threshold using the guides.

Jaime Viera-Artiles

DISCUSSION

The tasks performed with hidden reference guides showed that camera roll is indeed inherent in camera operation. The intensity of this phenomenon, nonetheless, could be affected by experience in endoscopic procedures.

On the other hand, the strategy of using reference guides seemed to be very effective at reducing this rotation and helped all participants to reduce substantially the amount of time when the rotation was above 15º, aiding experienced surgeons at achieving 100% of the task below this threshold. The mean reduction, as expected, was higher in participants with less exposure to endoscopic sinonasal surgery. Furthermore, a larger potential effect could be expected with further training, as the system has its own learning curve.

The guides seem to benefit novice surgeons by making them aware of a rotation that otherwise would occur unnoticed. This could facilitate the localization of anatomic landmarks necessary for spatial orientation that would be more challenging in tilted fields and serve as a valuable camera operation learning tool. Conversely, senior surgeons with enough experience to stay oriented even with a certain degree of angular rotation (as a result of mental compensation), can benefit from the guides in procedures where no references are available and surgical orientation may be limited, for instance, in patients with distorted anatomy or previous operations.

Different systems have been published that attempt to maintain a stable horizon by automatically rotating the image in flexible endoscopes[6]. This problem, to a lesser extent, also occurs with rigid scopes, but it seems to have only aroused interest among laparoscopists. There is an immense knowledge gap in the literature regarding this issue in the field of rhinology, which reflects a low interest that might also indicate an underestimation of the possible negative effects of this phenomenon.

Intraoperative orientation has been a matter of concern since endoscopic approaches were first utilized. In the past few years, new strategies based in augmented reality have been developed, fusing computer-generated images of the patient's imaging data with a real-time endoscopic view of the surgical field, providing three-dimensional visual cues to aid spatial orientation[7]. This promising technology has not yet seen widespread implementation, probably due to its recentness and elevated prices. Our new proposed system is not meant to be a substitute for any of the previously mentioned devices but an addition designed to tackle a different aspect of the disorientation problem that can work in conjunction with them.

Despite all this technological advancement, orientation is still a complicated subject to assess due to its subjective nature, which makes it difficult to describe, measure and quantify. The implications and effects of disorientation concerning surgery are poorly understood and often related to contributing factors of systematic error that could lead to intraoperative complications[8]. The proposed system gives researchers a new measuring tool to try to understand camera operational dynamics as contributing factors in disorientation.

To summarize, we have developed a device that can accurately recognize camera roll and a reference-guide system to reduce it during ESS. Unnoticed camera roll and the consequent image misalignment are inherent in camera operation. This latent factor can combine with others in a chain of errors leading to complications in ESS and probably in endoscopic skull base surgery as well. Therefore, a system dedicated to studying and preventing this factor would probably increase the safety of endoscopic procedures. Further studies are needed to probe the clinical benefits in a larger scale of this new accessory to the conventional scopes.

Jaime Viera-Artiles

Authors: Jaime Viera-Artiles MD[1], José J. Valdiande BEng[2], Javier Ospina MD[3], María Costales PhD[4], José M. López-Higuera PhD[2,5].

Institutions:
1. ENT department, Hospital Universitario Marqués de Valdecilla, Santander, Spain.
2. Photonics Engineering Group, Universidad de Cantabria, Santander, Spain.
3. Division of Otolaryngology - Sinus and Skull Base Surgery, Fundación Santa Fe de Bogotá, Bogotá, Colombia.
4. ENT department, Hospital Universitario Central de Asturias, Oviedo, Spain.
5. CIBER-BBN and IDIVAL, Santander, Spain.

Corresponding Author: Jaime Viera-Artiles, Departamento de Otorrinolaringología, Hospital Universitario Marqués de Valdecilla. Av. Valdecilla, 25, 39008 Santander, Cantabria. Spain. jaimevieraartiles@gmail.com ; Tel: +34 691 485 966

REFERENCES

1. J. Wade N. Frames of reference in vision. *Minim Invasive Ther Allied Technol*. 2009;5:435-439. doi:10.3109/13645709609153705
2. Sodergren MH, Orihuela-Espina F, Froghi F, et al. Value of orientation training in laparoscopic cholecystectomy. *Br J Surg*. 2011;98(10):1437-1445. doi:10.1002/bjs.7546
3. Gallagher AG, Al-Akash M, Seymour NE, Satava RM. An ergonomic analysis of the effects of camera rotation on laparoscopic performance. *Surg Endosc*. 2009;23(12):2684-2691. doi:10.1007/s00464-008-0261-x
4. Conrad J, Shah AH, Divino CM, et al. The role of mental rotation and memory scanning on the performance of laparoscopic skills: A study on the effect of camera rotational angle. *Surg Endosc Other Interv Tech*. 2006;20(3):504-510. doi:10.1007/s00464-005-0363-7
5. Zhu A, Yuan C, Piao D, Jiang T, Jiang H. Gravity line strategy may reduce risks of intraoperative injury during laparoscopic surgery. *Surg Endosc*. 2013;27(12):4478-4484. doi:10.1007/s00464-013-3093-2
6. Lee HC, Jung CW, Kim HC. Real-time endoscopic image orientation correction system using an accelerometer and gyrosensor. *PLoS One*. 2017;12(11):1-12. doi:10.1371/journal.pone.0186691
7. Citardi MJ, Agbetoba A, Bigcas J-L, Luong A. Augmented reality for endoscopic sinus surgery with surgical navigation: a cadaver study. *Int Forum Allergy Rhinol*. 2016;6(5):523-528. doi:10.1002/alr.21702
8. Sodergren M, Yang G, Darzi A. Perception and orientation in minimally invasive surgery. *Arch Surg*. 2012;147(3):210-211.

Jaime Viera-Artiles

FIGURE/VIDEO LEGENDS

Figure 1A: Example of the location of the hermetic box with the inertial sensor (black arrow) in a regular endoscopic camera. **B-D**: Appearance of the reference system at different stages. B: green colour for rotations from 5º to 10º. C: orange for rotations from 10º to 15º. D: red colour for rotations over 15º.

Figure 2: Mean rotation in every task-participant pair with and without the reference guides.

Video 1: Reference guides' appearance after selecting a reference position.

Video 2: Differences in camera roll during a posterior ethmoidectomy (0 º scope) and frontal sinusotomy (30º scope) performed by an expert rhinologist.

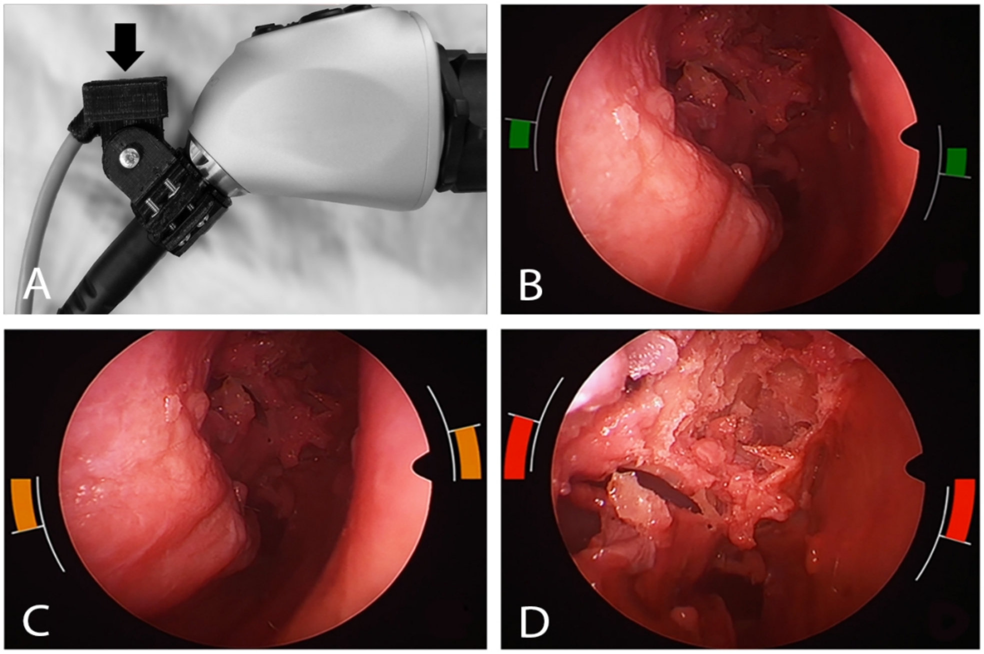

Figure 1A: Example of the location of the hermetic box with the inertial sensor (black arrow) in a regular endoscopic camera.
B-D: Appearance of the reference system at different stages. B: green colour for rotations from 5º to 10º. C: orange for rotations from 10º to 15º. D: red colour for rotations over 15º.

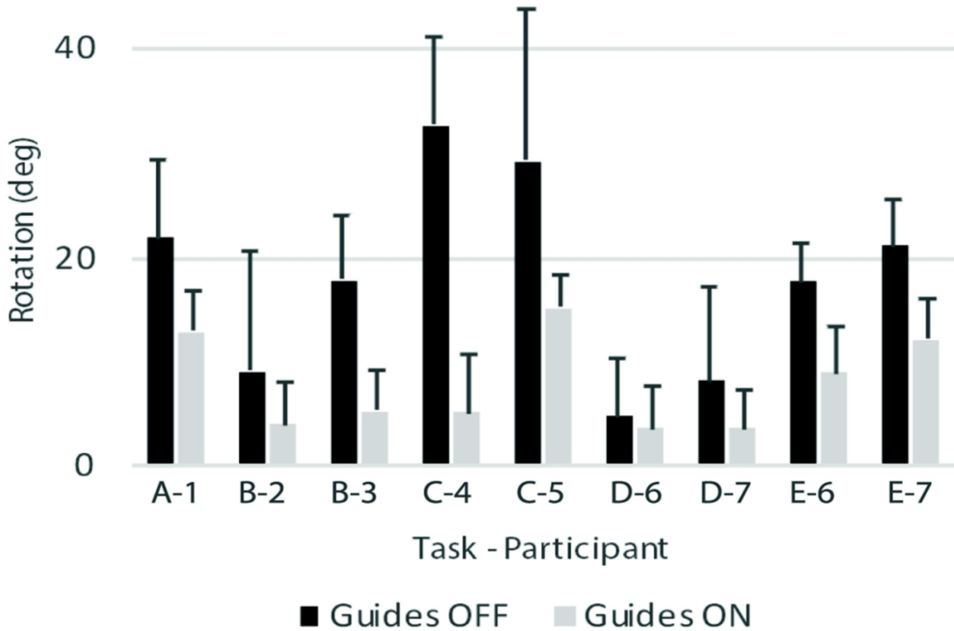

Figure 2: Mean rotation in every task-participant pair with and without the reference guides.

114x76mm (600 x 600 DPI)