SCONA 2018

Society for Computational Fluid Dynamics of the Nose & Airway

Sunday April 22, 2018 | London, UK

CONFERENCE PROGRAM

WELCOME

Welcome to the first world congress of the Society for Computational Fluid Dynamics (CFD) of the Nose and Airway.

In recent years there has been an explosion in interest in the field of CFD of the Nose and Airway. The time has come for researchers in Engineering and Healthcare to convene and explore the frontiers of this exciting new field.

In our packed one-day program, we will discuss the Engineering/ technical aspects of CFD simulation, along with practical clinical applications of the results. Our Faculty consists of leading innovators from across the globe, whose knowledge and insights will appeal to experienced researchers, novices entering the field, and interested observers alike.

The conference will be held in conjunction with the Eurpean Rhinological Society Meeting, in the spectacular city of London, against the stunning backdrop of the Thames river, London Bridge, Tower Bridge and The Shard.

We look forward to the pleasure of your company in London on Sunday April 22nd, 2018.

ABOUT SCONA

Computational Fluid Dynamics (CFD) uses highly sophisticated computer algorithms to simulate the flow of air and particles through complex 3D structures in an accurate, reproducible and scientific manner.

In recent years, researchers have begun to explore the use of CFD in the nose and airway, firstly by modelling airflow patterns, calculating changes in temperature and pressure, and measuring wall shear stress. Next, researchers studied common abnormalities, such as septal deviation, septal perforations and inferior turbinate hypertrophy. Recently, CFD has been used to model and predict the effects of surgery and therapeutic interventions.

It has become clear that CFD is a disruptive technology that is fundamentally changing our understanding of airflow in the human respiratory system and our approach to surgical procedures.

The Society for CFD of the Nose and Airway (SCONA – www.scona.org) was formed to foster knowledge, collaboration and collegiality between researchers in this exciting new field.

PROGRAM

8:00: REGISTRATION

SESSION 1: ENGINEERING FUNDAMENTALS

No.	TIME	TITLE	SPEAKER
1.1	8:30	Welcome	Narinder Singh
1.2	8:35	Introduction and historical overview	Dennis Doorly
1.3	8:45	Acquisition of imaging data	Raul Cetto
1.4	8:55	Constructing the model	Dennis Doorly
1.5	9:15	Physiological considerations - flow, surface, deformity, temperature, mucosal interface, nasal cycle	Jinxiang Xi
1.6	9:35	Models of flow (turbulence, steadiness, compressibility)	Kiao Inthavong
1.7	9:55	Interpreting simulation results	Guilherme Garcia
1.8	10:15	Software considerations - current and future	Manuel Burgos

10:35: MORNING TEA

SESSION 2: SIMULATION & CLINICAL IMPLICATIONS

No.	TIME	TITLE	SPEAKER
2.1	11:00	Controversies, challenges and future directions in simulation	Jinxiang Xi
2.2	11:25	Correlating CFD with objective clinical testing and physical models	Guilherme Garcia
2.3	11:45	CFD results for airflow in the normal nose	Dennis Frank-Ito
2.4	12:05	CFD results for airflow in the normal airway	David Wootton
2.5	12:25	Temperature, humidity and olfaction	Fabian Sommer
2.6	12:45	Ethnic variation	De Yun Wang

13:05: LUNCH

SESSION 3: CLINICAL

No.	TIME	TITLE	SPEAKER
3.1	13:50	Drug delivery and particle deposition	Kiao Inthavong
3.2	14:02	Septal deviation	Catherine Rennie
3.3	14:14	Septal perforation	Joerg Lindemann
3.4	14:26	Inferior turbinate surgery and The Empty Nose Syndrome/ Atrophic rhinitis	De Yun Wang
3.5	14:38	The nasal valve	Neil Tolley
3.6	14:50	Virtual surgery - modifying the model	Manuel Burgos
3.7	15:02	Sinus surgery	Seung-Kyu Chung
3.8	15:14	The upper airway - pathology and surgery	David Wootton
3.9	15:31	CFD modelling: under CPAP and during nasal and oral breathing	Masaaki Suzuki

15:43: AFTERNOON TEA

PROGRAM CONTINUED

SESSION 4: FRONTIERS & NEW RESEARCH

No.	TIME	TITLE	SPEAKER
4.1	16:00	Physical Parameters determining Clinical Indications for CFD Simulations: The New Agreement of the International RIGA Consensus Conference on Nasal Airway Function Tests	Klaus Vogt
4.2	16:10	Predicting Patient-Reported Improvement Scores After Nasal Airway Obstruction Surgery Using Computational Fluid Dynamics Modeling	Dennis Frank-Ito
4.3	16:20	Airflow and particle deposition in large airways under sniff condition	Hadrien Calmet
4.4	16:30	The role of CFD in the pathogenesis of chronic rhinosinusitis	Seung-Kyu Chung
4.5	16:40	Ventilation of the Anterior Ethmoid, the Maxillary and Frontal Sinus with Special Consideration of the Ethmoid Infundibulum with Computational Fluid Dynamics (CFD)	Jochen Schachenreiter
4.6	16:50	Nasal-Geom, a free software program for nasal cavity reconstruction	Jose Luis Cercos-Pita
4.7	17:00	Nasal-flow: an automatised web service for airflow analysis of the human upper airways	Ismael Rodriguez
4.8	17:10	Segmentation of the Nasal Cavities and Paranasal Sinuses Using Artificial Intelligence	Walter Koch
4.9	17:20	Analyses of nasal cavity flows based on highly-resolved CFD computations	Andreas Lintermann
4.10	17:30	Dimensionless Parameters to distinguish health from disease	Enrique Rojas
4.11	17:40	Custom CFD software for Rhinologists (MeComLand, NoseLand)	Manuel Burgos
4.12	17:50	A prospective CFD study assessing Retrosternal Goitres	Charlotte McIntyre
4.13	18:00	Study of Sensitivity and Specificity of Fully Automated CFD Solution in Patients Affected by Nasal Airway Obstruction (NAO)	Guillermo Sanjuan

18:20: CONFERENCE CLOSE

SPEAKERS

PROF. DENIS DOORLY

Professor Denis Doorly is a Professor of fluid mechanics based at the Imperial College London's Faculty of Engineering and Aeronautics.

1.2 Introduction and historical overview

1.4 Constructing the model

DR. RAUL CETTO

Dr. Raul Cetto is an honorary researcher and visiting lecturer at Imperial College London.

1.3 Acquisition of imaging data

PROF. JINXIANG XI

Professor Jinxiang Xi is a Professor in mechanical engineering with a special interest in computational fluid dynamics, bio-fluids, respiratory aerosol dynamics and inhalational drug delivery.

1.5 Physiological considerations - flow, surface, deformity, temperature, mucosal interface, nasal cycle

2.1 Controversies, challenges and future directions in simulation

DR. KIAO INTHAVONG

Dr. Kiao Inthavong received his PhD from RMIT in 2008, and since then has been an ARCPost-Doc Fellow, before taking up a Senior Lecturer position at the School of Engineering. His research is in fluid-particle dynamics with applications in the fields of respiratory health, and air-quality in the indoor built environment. He has strong collaborations with many institutions worldwide including partners from Clarkson University, Duke University, Kyushu University, Purdue University, FH Burgenland, and CSIRO. He has over 100-peer reviewed publications including two scholarly books with Springer (incl. "Computational Fluid Particle Dynamics in the Respiratory System") and has an h-index of 21. He has received over $875k in research funds including 2 ARC Discovery Grants, and 1 LinkageGrant.

1.6 Models of flow (turbulence, steadiness, compressibility)

The nasal cavity's complex and unique physiology makes flow characterisation difficult to generalise as either laminar, transient or turbulent. This presentation discusses fluid dynamics fundamentals and how this is applied to the nasal cavity flow, to better resolve our own understanding of the types of flow behaviour that is occurring. Specific types of flows, and the model selection, whether laminar or turbulent, steady or unsteady, is discussed with respect to the flow physics, the problem class, computational resources, and time considerations.

3.1 Drug delivery and particle deposition

Spray atomization occurs at extremely short time bursts, along with high velocities. A challenge here is to better control the atomization to achieve the desired atomized droplet conditions. The convergence of fluid dynamics, computational science, and medical imaging disciplines has spawned a new flourishing interdisciplinary research field in computational modelling fluid-droplet transport mechanisms involved in nasal drug delivery. This presentation reviews the past ten years of work in advancing the research capability of nasal drug delivery, discussing the current challenges and opportunities available.

PROF. GUILHERME GARCIA

Profesor Guilherme Garcia is an Assistant Professor in the Joint Department of Biomedical Engineering at Marquette University and the Medical College of Wisconsin. He has 13 years of experience working on experiments and computer simulations of airflow, heat transfer, moisture transport, and particle transport in the human nasal cavity. Dr. Garcia was inspired to pursue a career in nasal physiology after attending a seminar by a visionary ear-nose-throat doctor while he was pursuing his PhD in statistical physics in Brazil. The visionary doctor, Dr. Dário Martins, discussed the need to develop better objective tools for diagnosis and treatment planning for patients with nasal obstruction, in particular patients with atrophic rhinitis and empty nose syndrome. With this goal in mind, Dr. Garcia moved to the United States, where he completed a post-doctoral fellowship in Dr. Julia Kimbell's laboratory in North Carolina (2005-2008). He also completed a second post-doctoral fellowship in computational biology at The University of North Carolina Cystic Fibrosis Center (2008-2011). In 2012, he joined the faculty at the Medical College of Wisconsin. In collaboration with several clinicians, especially Dr. John Rhee (Department of Otolaryngology and Communication Sciences), Dr. Garcia has developed a vibrant research program applying fluid mechanics to obstructive upper airway diseases. The Garcia lab has received funding from the National Institutes of Health (NIH) to develop virtual surgery planning methods for nasal airway obstruction and also to optimize the delivery of inhaled aerosolized medications to the paranasal sinuses of chronic rhinosinusitis patients.

1.7 Interpreting simulation results

Computational fluid dynamics (CFD) simulations of nasal airflow can quantify several physical phenomena important to nasal physiology, including flow resistance, warming and humidification of inhaled air, and transport of odorant particles to the olfactory cleft. Therefore, CFD technology has the potential to become the basis for virtual surgery planning software aimed at optimizing surgical outcomes for patients with nasal diseases. In this talk, we will review the main assumptions made when performing CFD simulations and how these assumptions must be considered when interpreting the simulations. Some assumptions are well understood by most CFD users, including (1) steady vs. unsteady flow, (2) laminar vs. turbulent flow, (3) incompressible fluid (constant density, constant temperature), and (4) rigid walls. However, other assumptions are often overlooked, including (A) the effect of segmentation threshold when reconstructing the airway from medical images and (B) how the soft palate configuration can have a major impact on airflow resistance from nostrils to the nasopharynx. Furthermore, CFD users must keep in mind that mucosal engorgement is dynamic due to the nasal cycle and mucosal changes in supine versus upright positions, which means that CFD models represent only a snapshot of the nasal anatomy. Finally, CFD users should bear in mind that the nasal anatomy varies substantially among individuals, so that studies with small sample sizes should be interpreted carefully.

2.2 Correlating CFD with objective clinical testing and physical models

To date, few studies have compared nasal resistance estimated from computational fluid dynamics (CFD) simulations with in vivo measurements using rhinomanometry. We performed active anterior rhinomanometry in 25 patients with nasal airway obstruction after decongestion with a nasal spray with 0.05% oxymetazoline. Pre-surgery computed tomography (CT) was used to reconstruct the nasal airspace using a range of -1,024 to -550 Hounsfield Units. Steady CFD simulations were performed using the standard k-ω model. Plastic replicas of the nasal cavities of 6 individuals created with stereolithography were used in laboratory experiments to measure the pressure-flow curve. Nasal resistance was quantified as unilateral airflow divided by a pressure drop of 75 Pa. Nasal resistance at 75 Pa derived from the CFD simulations was on average 93.1% of the in vitro measurements in the plastic replicas. A strong correlation was found between the nasal resistances obtained with CFD and the in vitro measurements (Pearson $r = 0.97$, $p < 0.001$). In contrast, nasal resistance obtained with CFD was on average 64.6% of the resistance measured using rhinomanometry. A statistically significant correlation was found between nasal resistance obtained with CFD and rhinomanometry (Pearson $r = 0.75$, $p < 0.001$). In summary, although a very good agreement was found between the pressure-flow curves obtained with CFD and measured in vitro, nasal resistance obtained with CFD under-predicted in vivo measurements. Possible explanations include the assumption of rigid walls in the CFD simulations and imprecise segmentation of the nasal airspace due to a suboptimal segmentation threshold.

PROF. MANUEL ANTONIO BURGOS OLMOS

Professor Manuel Antonio Burgos Olmos is an Associate Professor in Fluid Mechanics at the Polytechnic University of Cartagena Murcia-Spain since 2004, Aeronautical Engineer since 1993 and Doctor of Aerospace Engineering since 2001. He completed his Ph.D. in Computational Fluid Dynamics (CFD) Engineering at the Polytechnic University of Madrid in the Industria de Turbo Propulsores (ITP. Aero is owned by Rolls-Royce plc) company and at Department of Fluid Dynamics and Aerospace Propulsion, School of Aeronautics and Space, UPM, Madrid. Between 2001 and 2004 he worked as a project manager in MTorres Ingeniería de Procesos company developing software for the assembly of the A380 Airbus in Hamburg (Germany). Currently he continues to be a collaborator of the ITP. Aero Company in the Technology and Methods department. Currently, his main line of research focuses on the application and software development of latest generation of CFD models for virtual surgery and air flow simulation in nasal cavities.

1.8 Software considerations – current and future

Computational fluid dynamics (CFD) is a mathematical tool to analyse airflow. As CFD is not a typical tool for rhinologists, a group of engineers in collaboration with experts in Rhinology have developed new, intuitive CFD software. The program MeComLand® only requires snapshots from the patient's cross-sectional (tomographic) images, then outputs the results of CFD processing, such as airflow distributions, velocity profiles, pressure, temperature, or wall shear stress. This is useful complementary information to cover diagnosis, prognosis, or follow-up of nasal pathologies based on quantitative magnitudes linked to airflow. In addition, the user-friendly environment NoseLand® helps the medical assessment significantly in the post-processing phase with dynamic reports using a 3D endoscopic view. Specialists in Rhinology have asked for a more intuitive, simple, powerful CFD software to offer more quality and precision in their work to evaluate the nasal airflow. We present MeComLand® and NoseLand® which have all the expected characteristics to fulfil this demand and offer a proper assessment with the maximum of quality plus safety for the patient. It includes virtual surgery software, known as DigBody®, within the same user interface using the mouse as the scalpel or surgical knife. This virtual surgery, including cosmetic or plastic, allows ENT surgeons to perform enough interventions for training purposes before final surgery, thus observing the best performance in terms of airflow patterns.

3.6 Virtual surgery - modifying the model

Recent studies have pointed out that a significant number of surgical procedures for nasal airway obstruction (NAO) show significant postoperative problems. This high failure rate has been attributed to the fact that there are no available objective parameters of clinical significance to aid surgeons. Currently, there are modeling tools to perform virtual surgery that work directly from computed tomography (CT) or magnetic resonance imaging (MRI) images. However, specialists in Rhinology have called for a more intuitive, friendly and powerful software to make virtual surgery more realistic. In this talk we present the new virtual surgery software DigBody®. Specifically, it is a module integrated into the computational fluid dynamics (CFD) program MeComLand®, which was developed exclusively to analyze nasal airflows. DigBody® works directly with a 3D nasal model that mimics real surgery. Furthermore, this surgery module allows a direct check of the operated cavity during the virtual surgery by CFD simulations. Other fields of application of this new tool are cosmetic surgery or training courses for future otolaryngologists.

PROF. DENNIS FRANK-ITO

Dr. Dennis Onyeka Frank-Ito received his Bachelor of Science in Statistics with first class honors from the University of Nigeria, Nsukka, Nigeria. In January 2003, Dr. Frank-Ito moved to the United States to pursue a Master of Science in Mathematics at Youngstown State University (YSU). After graduating from YSU in December 2004, he proceeded to North Carolina State University (NCSU) in August 2005 to pursue a PhD degree. He received his PhD in Mathematics under the guidance of Dr. Hien T. Tran in December 2010. His PhD dissertation was on the development and validation of a mathematical model to predict acute inflammatory response to endotoxin challenge, and derivation of optimal therapeutic interventions for the control of acute inflammation triggered by endotoxins. While working on his PhD at NCSU, Dr. Frank-Ito also received another Master's degree in Operations Research in December 2008. Upon completion of his PhD, Dr. Frank-Ito did a post-doctoral training in the Department of Otolaryngology/ Head and Neck Surgery at the University of North Carolina, Chapel Hill, under the mentorship of Julia S. Kimbell, Ph.D. and John S. Rhee, MD (Medical College of Wisconsin). In September 2013, Dr. Frank-Ito joined the Division of Head and Neck Surgery & Communication Sciences faculty at Duke University. His research interests include computational modeling of upper respiratory physiology to better understand the effects of airflow dynamics, olfaction, deposition of inhaled gases and particle transport on respiratory function. Dr. Frank-Ito has published over 30 peer reviewed articles on computational modeling of airway function.

2.3 CFD results for airflow in the normal nose

Aims: The normal human nose is characterized by natural morphological variations in nasal cavity, as well as spontaneous, reciprocal fluctuation of nasal patency due to phases of unilateral congestion and decongestion of the nasal mucosa (nasal cycle). To this end, the aim of this study is to provide qualitative and quantitative descriptions of the human airflow profile in the presence of intra- and inter-individual nasal cavity variabilities.

Methods: Computational fluid dynamics modeling of nasal airflow profile was conducted in multiple individuals to assess the role of race/ethnicity, gender, inspiratory pressure and anterior anatomic variability on normal nasal function. Males and females from four different racial classifications were studied: Blacks; Asians; Caucasians; and Latin Americans. Further, steady state incompressible flow simulations were performed in every nasal cavity under physiological, pressure-driven conditions at 15pa and 35pa inspiratory pressure drops.

Results: Aspects of intra- and inter-individual similarities and differences were noted across the cohort of subjects investigated in this study.

Conclusion: These preliminary results showed expected normative airflow ranges across varying characteristics of normal human nose investigated in the present study.

4.2 Predicting Patient-Reported Improvement Scores After Nasal Airway

Aims: Computational fluid dynamics (CFD) derived airflow-related variables have the ability to provide important insight into treatment options for nasal airway obstruction (NAO) that will allow clinicians to optimize surgical outcome. However, an underlying component of a successful NAO surgery is patient's postoperative satisfaction, measured by patient-reported quality-of-life survey. Thus, the goal of this pilot study is to propose a predictive model based on CFD-derived variables to predict patient-reported improvement after NAO surgery.

Methods: Patient-reported Nasal Obstruction Symptom Evaluation (NOSE) questionnaires were obtained from 10 subjects before and after NAO surgery. Furthermore, three-dimensional (3D) reconstruction of subjects' pre' - and post-surgery nasal airways were generated from subject-specific computed tomography scans. Steady-state laminar inspiratory airflow and heat transfer simulations were performed in 3D models, at resting breathing. A multivariate regression equation involving pre- to post-surgery change from three airflow-related variables was formulated for predicting patient-reported NOSE improvement.

Results: Our proposed predictive regression equation is defined using unilateral pre- to post-surgery change in airflow on the predominately obstructed side (x_1); change in airflow partition on the predominately obstructed side as a fraction of bilateral airflow (x_2); and change in unilateral surface area of the nasal cavity where heat flux exceeds $50 W/m^2$ (x_3). The equation predicting pre- to post-surgery change in NOSE was

$$\hat{y} = 58.98 - 4.53x_1 + 141.44x_2 + 36.92x_3 + 6.10x_3^2 + 0.31x_3^3 + 0.01x_3^4.$$

Our regression model has $r^2 = 0.955$ and adjusted $r^2 = 0.865$.

Conclusion: These combination of CFD techniques and statistical predictive modeling to accurately predict patient-reported satisfaction levels is an important next-step in demonstrating the potential of CFD in advancing treatment outcomes for NAO.

PROF. DAVID WOOTTON

Professor David Wootton is an engineer with main research interests in biofluid and biosolid mechanics and biotransport modelling. His projects include MR image based upper airway fluid and solid mechanics models to better understand anatomic and neuromuscular factors contributing to OSA, and novel manufacturing methods for tissue engineering scaffolds and constructs.

2.4 CFD results for airflow in the normal airway

3.8 The upper airway - pathology and surgery

DR. FABIAN SOMMER

Dr. Fabian Sommer is a consultant surgeon at the department of ORL, Head and Neck Surgery at Ulm University. His interests are in imaging modalities in ENT surgery, application of navigation systems in ENT-surgery and computational fluid dynamics and nasal climatisation.

2.5 Temperature, humidity and olfaction

PROF. DE YUN WANG

Professor De Yun Wang is currently Research Professor (Tenure) and Director of Research, Department of Otolaryngology at the National University of Singapore. He trained and practiced as an ENT surgeon in China until his appointment as research associate at the ENT department of the Free University of Brussels (AZ–VUB, Belgium) in 1989. He obtained his PhD Degree in Medical Sciences (Free University Brussels, VUB) in 1995 and was appointed Director of Rhinology and Clinical Immunology Research at the Department of Otorhinolaryngology, University of Ghent, Belgium from 1996-1997. He started as Research Scientist at the Department of Otolaryngology, National University of Singapore in 1997.

2.6 Ethnic variation

3.4 Inferior turbinate surgery and The Empty Nose Syndrome/Atrophic rhinitis

DR. CATHERINE RENNIE

Dr. Catherine Rennie is an ENT surgeon with specialty interest in rhinology based at the Imperial College Healthcare NHS Trust.

3.2 Septal deviation

PROF. DR. JOERG LINDEMANN

Professor Dr. Joerg Lindemann is an ENT surgeon and professor from Ulm University at the Department of ORL and Head and Neck Surgery. His research fields include *in vivo* and numerical studies of the respiratory function of the nose, clinical studies of functional-aesthetic nasal and sinus surgeries and clinical studies of sleep disorders in children and adults.

3.3 Septal perforation

PROF. NEIL TOLLEY

Professor Neil Tolley was born in Birmingham. He attended medical school at Cardiff. He trained in London, South Africa and Australia. He has particular research interest in computational flow dynamics of the airway.

3.5 The nasal valve

PROF. SEUNG-KYU CHUNG

Professor Seung-Kyu Chung is an ENT surgeon affiliated with Sungkyunkwan University, and based in Samsung Medical Center. He was drawn into the rhinology area during his residency program and started a fellowship in rhinology. His interest is in the anatomy and physiology of the nose and paranasal sinuses and the title of his doctoral thesis (1989) was "MORPHOLOGIC STUDY OF THE OLFACTORY EPITHELIUM AFTER DEPRIVATION AND RESTORATION OF THE AIR CURRENT" using light microscopy, transmission and scanning electron microscopy. Since the beginning of 21st century, he has started studies on the 3D reconstruction of nose and paranasal sinus area for anatomy, physiology of airflow and effect of the surgical modification on the airflow using CFD technique with engineering co-workers. More recently he has been interested in the role of airflow in the pathogenesis of sinusitis.

3.7 Sinus surgery

4.4 The role of CFD in the pathogenesis of chronic rhinosinusitis

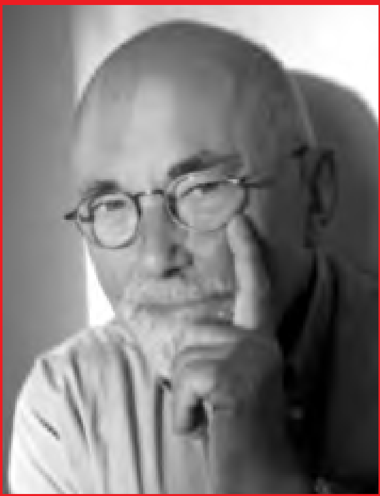
PROF. MASAAKI SUZUKI

Professor Masaaki Suzuki is a Professor of Otolaryngology affiliated with Teikyo University Chiba Medical Center. He is also the editor in chief of Journal of Japan Society of Paediatric ORL and president of the Division of Otolaryngology, Sleep Disordered Breathing Research Society of Japan.

3.9 CFD modelling: under CPAP and during nasal and oral breathing

Nasal obstruction is a common problem in nasal continuous positive airway pressure (CPAP) therapy for obstructive sleep apnea (OSA) and limits treatment compliance. The purpose of the first study is to model the effects of nasal obstruction on airflow parameters under CPAP using CFD. CPAP airflow simulations were conducted using FINETM/Open (NUMECA, Brussels, Belgium), then, airflow streamlines and velocity contours in the nasal cavities and nasopharynx were compared between subjects with and without nasal obstruction. Under 10 cmH2O CPAP, average maximum airflow velocity during inspiration was 17.6 ± 5.6 m/s in the nasal obstruction group but only 11.8 ± 1.4 m/s in the control group. The average pressure drop in the nasopharynx relative to inlet static pressure was 2.44 ± 1.41 cmH2O in the nasal obstruction group but only 1.17 ± 0.29 cmH2O in the control group. The nasal obstruction and control groups were clearly separated by a velocity threshold of 13.5 m/s, and pressure loss coefficient threshold of approximately 10.0. We found a strong correlation between the inspiratory pressure loss coefficient and maximum airflow velocity (PLOSONE 2016).

The next series of studies performed CFD analyses to investigate the effect of the breathing route on OSA under non-CPAP conditions. Velocity, wall shear stress, and static pressure in the nasal cavities and pharynx were analyzed on a patient with OSA during nasal breathing with closed mouth, nasal breathing with open mouth, and oral breathing with open mouth. There were no differences between nasal breathings with closed and open mouth in maximum velocity, wall shear stress, and static pressure. On the contrary, the airflow during oral breathing with open mouth became the highest rapid stream, and negative static pressure during oral breathing with open mouth decreased the most. CFD analyses revealed that oral breathing with open mouth is the primary condition leading to pharyngeal collapse, and mouth opening doesn't lead to pharyngeal collapse as long as nasal breathing is maintained.



PROF. KLAUS VOGT

Professor Klaus Vogt is a current member of the German ENT society, European rhinologic society, International rhinologic society. He was a past chairman of the International committee for the objective assessment of nasal airway at the International Rhinologic Society. Initiator of the international interdisciplinary consensus conference on Nasal Airway Function Tests Riga, November 2, 2016 and author of the new standard publication 2018.

Throughout his career, he has presented more than 300 lectures in national and international congresses with 72 publications and 6 patents.

4.1 Physical Parameters determining Clinical Indications for CFD Simulations: The New Agreement of the International RIGA Consensus Conference on Nasal Airway Function Tests

The indication for a CFD investigation is given by a clinical diagnosis, which can be either a disturbance of the nasal air stream by congenital or traumatic abnormalities of the nasal channel or a pathological finding of the paranasal sinuses. In impaired nasal ventilation the basic information is coming from rhinomanometry, i.e. the simultaneous measurement of narino-choanal pressure and nasal flux and the following calculation of standardized parameters for the nasal resistance. The new standard parameters are due to the RIGA standard the Effective Resistance and the Vertex resistance. Effective Resistance is given by the quotient of RMS of pressure and flow, while vertex resistance is the peak flow measured under resting conditions because it is characteristic for the quasi-steady phase of the nasal breathing wave. For clinical purposes the logarithmic transformation is used because of the significant correlation with the sensing of obstruction (LogReff, LogVR). For these parameters is existing a classification for Caucasian noses from 36,500 measurements. As additional parameters and information in CFD also work and performance in every moment can be calculated by using the originally measured data. From the view-point of standardization of nasal function tests the synopsis of contemporary data from the so-called 4-phase-rhinomanometry and CFD is desirable and therefore used within the RHINODIAGNOST research program.

DR. HADRIEN CALMET

Dr. Hadrien Calmet studied Applied Physics of Ocean and Atmosphere and he obtained a Master degree in UTV (University of Toulon Var in France) with 6 months exchange Erasmus in UPC (University Polytechnic of Catalonia, Barcelona, Spain) in 2002. He decided to stay in Barcelona and carried out a masters at the International Center for Numerical Methods in Engineering (CIMNE) in Finite Elements Method. In parallel, he studied a DEA in Applied Physics in UPC (University polytechnic of Catalonia, Barcelona, Spain) with Prof. Jose-Manuel Redondo. To validate both diplomas, he made six months internship in EDF, Paris (Electricity of France) in CFD and turbulence modeling. One year later, he joined the newly created Barcelona Supercomputing Center-Centro Nacional de Supercomputación (BSC-CNS) to make the CFD pre and post processing tasks of the Department of Computer Applications in Science and Engineering. Since then, he has done engineering and biomedical research such as the respiratory system. Therefore, all issues related to big data, such as massive data I/O and visualization of large data sets are part of his main interests.

4.3 Airflow and particle deposition in large airways under sniff condition

Flow simulation in the human respiratory tract is a great challenge. A rapid and short inhalation, also called a sniff is considered here as the inflow boundary. An extensive upper airways is used, that encompass: face exterior, nasal cavity, trachea, and up to the third lung bifurcation. The simulation is carried out with a subject-specific derived from a contrast-enhanced computed tomography (CT) scan of a 48-year-old male.

Unstructured mesh with finely resolved boundary layer is used and the Navier-Stokes equations are solved using a variational multi-scale method (VMS). The Lagrangian approach was used to track the micro-particles and evaluate the total and local deposition in the large airways. This study shows the new potential of HPC-based large-scale simulations combined with an accurate numerical model to simulate simultaneously the flow dynamics and micro-particle transport of human airways and thus to study the drug delivery of aerosols and to explore new treatments and diagnosis.

DR. JOCHEN SCHACHENREITER

Dr. Jochen Schachenreiter is an ENT specialist and is involved in functional and aesthetic head and neck surgery. Since 2002, he has been a full time consultant in Graz Sanatoria. He has a particular interest in plastic head and neck surgery, endoscopic sinus surgery and surgery for snoring.

4.5 Ventilation of the Anterior Ethmoid, the Maxillary and Frontal Sinus with Special Consideration of the Ethmoid Infundibulum with Computational Fluid Dynamics (CFD)

DR. JOSE LUIS CERCOS-PITA

Dr. Jose Luis Cercos-Pita obtained his MSc at Naval Architecture in 2011. After a short period of work in the field of physics simulations at SimSpace Ingeniería S.L., he undertook the study of Smoothed Particle-Hydrodynamics (SPH) methodology, an alternative meshless CFD method, to achieve his International PhD in Aerospace Engineering Cum Laude in 2016. Currently he undertakes his activity at Laboratorio Avanzado de Flujo Aéreo Nasal (N.A.S.A.L.) S.L, as a Research Director, leading the development of the NASAL~Flow tool.

4.6 Nasal-Geom, a free software program for nasal cavity reconstruction

NASAL-Geom is the first free-software specifically designed to reconstruct 3D nasal cavities from Computerised Tomographies (CTs). Developed in Python, NASAL-Geom is able to process CTs, producing 3D surfaces of the nasal cavity wall and the head, as well as nostrils and pharynx patches. All the processing is carried out without human intervention, a critical feature to avoid biased results. On top of that, NASAL-Geom transcends the usually considered threshold-based segmentations, by the application of image pre-processing filters, being able to detect both sub-pixel and super-pixel features. Robustness has been assessed by the reconstruction of a set of 95 CTs, while precision has been evaluated by a convergence analysis of 3 publicly released CTs. Finally, the tool has been validated by comparisons with third party manually generated surfaces, in which NASAL-Geom has outperformed manual reconstructions.

DR. ISMAEL RODRIGUEZ

Dr. Ismael Rodríguez Cal obtained his Bachelor's Degree in Mathematics from the University of Santiago de Compostela. Subsequently he completed a Master's Degree in the University of Vigo, in the topic of Mathematical Engineering, focusing on Computational Fluid Dynamics and Solid Mechanics. Currently he combines his PhD thesis in Technical University of Madrid with his work as an Engineering Consultant in the company Inspiralia. His field of study is the application of computational fluid dynamics techniques for the analysis of human nasal airflow. He holds three years of experience in the technical development of FP7/H2020 projects.

4.7 Nasal-flow: an automatised web service for airflow analysis of the human upper airways

The simulation of airflow in the human upper airways provides valuable quantitative information about patient's breathing. It involves expertise in scientific areas such as image processing, 3D reconstruction and CFD. This kind of analysis traditionally required a multidisciplinary team of experts. NASAL-FLOW service integrates all these stages under an automatised unique work-flow.

In this manner, patient CT scans can be uploaded by medical doctors, using the conveniently provided web service. On top of such CT imagery, the segmentation, 3D surface reconstruction and CFD simulation are automatically carried out. Results can be analysed two-fold: a standard PDF report with the main data or by the use of an interactive web postprocessor. A customised tool for virtual modification of the nasal cavity is also included within the service.

As a result, a standardised procedure is set to study systematically the flow patterns of each patient. All the quantities obtained in a typical CFD analysis are computed. The service is fully automatised and only requires CT images as input. The barriers associated with the know-how needed for the computations are removed. All patients are processed with the same methodology and software tool, allowing comparison among different cases. Outcomes of several surgery methodologies can be evaluated computationally without invasive procedures for the patient.

NASAL-FLOW web service provides fast, robust and systematic CFD analysis of the human upper airways, thus making easier its medical use and integration in daily clinical practice.

PROF. WALTER KOCH

Professor Walter Koch received a PhD in Mathematics and Physics from University of Graz in 1970. He is director of AIT Ltd. (Angewandte Informationstechnik Forschungsgesellschaft mbH) and lecturer at the University of Graz (European Masters programme for "European Heritage, Digital Media and the Information Society" – EuroMACHS). He is chairperson of CSC – Content Service Centre Austria and head of the Steinbeis Innovation Transferzentrum (IMCHI – Information Management and Cultural Heritage Informatics).

4.8 Segmentation of the Nasal Cavities and Paranasal Sinuses Using Artificial Intelligence

DR. ANDREAS LINTERMANN

Dr. Andreas Lintermann leads the Simulation Laboratory "Highly Scalable Fluids & Solids Engineering" (SimLab FSE), Jülich Aachen Research Alliance, High Performance Computing (JARA-HPC), RWTH Aachen University since 2014. The SimLab FSE is a research group with two PostDoc research scientist and two PhD students. It is concerned with the development of multiphysics codes in the field of engineering, enhances code performance by optimization and tuning, and supports university researchers in scalability analysis and enhancement of their simulation codes. Lintermann is furthermore associated with the profile section "Computational Science & Engineering" of RWTH Aachen University, where he is responsible for the pillar "Computing." He received his diploma in Computer Science from the RWTH Aachen University in 2009 (Dipl.-Inform.) and majored in Computer Graphics & Multimedia. During his studies, he was a research assistant at the Institute of Aerodynamics and Chair of Fluid Mechanics (AIA) at the Faculty of Engineering, RWTH Aachen University, from 2005 to 2009. From 2009 to 2014, he was a PhD student at AIA and graduated with a PhD (Dr.-Ing.) in 2014. In his thesis, he investigated the flow in the human nasal cavity and developed a massively parallel grid generator. His research focuses on respiratory flows, i.e., nasal cavity and lung flows, lattice Boltzmann methods, Lagrangian particle methods, fluid structure interaction, meshing methods, and high performance computing.

4.9 Analyses of nasal cavity flows based on highly-resolved CFD computations

Aims: The fluid mechanical quality of nasal cavities is determined by a mixture of respiratory efficiency, temperature, wall-shear, and heat-flux distributions. These properties allow the ability to classify pathologies and are used to juxtapose simulation results of three cavities. To avoid uncertainties, highly resolved simulations are performed without incorporating any turbulence model. The flow regime is analyzed by means of energy spectra and the mesh resolution impact is addressed.

Methods: Realistic geometries are extracted from CT-data using an in-house version of the Medical Interaction Toolkit. Simulations of the flow, pressure, and temperature distributions are based on a highly efficient lattice-Boltzmann method (LBM). The LBM employs hierarchical Cartesian octree-meshes, generated by a massively parallel grid generator. Post processing of the simulation data is done in ParaView, Matlab, and by in-house analysis tools.

Results and Conclusion: To fully resolve all flow features, meshes with O (108) cells are required. In general, the flow in the cavity can be assumed laminar to transitional for respiration at rest. Total pressure loss along the flow channel enables to quantify respiratory efficiency. Wall-shear stress distributions allow to localize potential regions of inflammations.

The heat-flux distribution and temperature increase indicate how efficient a cavity prepares inhaled air for the human lungs. The combination of these features defines the fluid mechanical quality of nasal cavities.

PROF. ENRIQUE SANMIGUEL-ROJAS

Professor Enrique Sanmiguel-Rojas is an Associate Professor in Fluid Mechanics at the University of Malaga-Spain. He completed his Ph.D. in Computational Fluid Dynamics (CFD) Engineering at the University of Malaga. He was a fellow of the prestigious Ramón y Cajal research program. He carried out research stays at prestigious research centers such as the École polytechnique in Paris or the School of Physics and Astronomy of the University of Manchester. Currently, his main line of research focuses on the application and development of the latest generation CFD models for virtual surgery in nasal cavities.

4.10 Dimensionless Parameters to distinguish health from disease

There are significant variations in healthy nasal airflow patterns, so it is difficult to identify a universal template for normal nasal airflow. In the case of diseased nasal cavities, the flow presents even more random characteristics than healthy cavities. For this reason, a consensus has not been reached yet for what constitutes normal nasal airflow patterns. In addition, there is no general agreement regarding the identification of different diseases after examining only the nasal airflow. In this work, we introduce two dimensionless mathematical estimators for helping in the medical diagnosis of human nasal cavities. In general, these estimators take low values for healthy cavities and high values for nasal cavities with a disease. Basically, these estimators need only global information as nasal geometrical parameters or fluid magnitudes determined by computational fluid dynamics (CFD) simulations.

4.11 Custom CFD software for Rhinologists (MeComLand, NoseLand)

Annually, hundreds of thousands of surgical interventions related to nasal airway obstruction are performed in the world. Recent studies have pointed out that a significant number of these interventions show postoperative problems. Computational fluid dynamics (CFD) is a mathematical tool to analyse airflow. As CFD is not a typical tool for rhinologists, a group of engineers in collaboration with experts in Rhinology have developed new, intuitive CFD software. The program MeComLand® only requires snapshots from the patient's cross-sectional (tomographic) images, then outputs the results of CFD processing, such as airflow distributions, velocity profiles, pressure, temperature, or wall shear stress. This is useful complementary information to cover diagnosis, prognosis, or follow-up of nasal pathologies based on quantitative magnitudes linked to airflow. In addition, the user-friendly environment NoseLand® helps the medical assessment significantly in the post-processing phase with dynamic reports using a 3D endoscopic view. Specialists in Rhinology have asked for a more intuitive, simple, powerful CFD software to offer more quality and precision in their work to evaluate the nasal airflow. We present MeComLand® and NoseLand® which have all the expected characteristics to fulfil this demand and offer a proper assessment with the maximum of quality plus safety for the patient.

DR. CHARLOTTE MCINTYRE

Dr. Charlotte McIntyre is an ENT specialist registrar and research fellow based at the Imperial College Healthcare NHS Trust.

She is undertaking a PhD in Aeronautical and astronautical engineering.

4.12 A prospective CFD study assessing Retrosternal Goitres

DR. GUILLERMO SANJUAN

Dr. Guillermo Sanjuán de Moreta, is a medical doctor specialist in otorhinolaryngology with more than 18 years of clinical experience and a member of the department of rhinology of the Otorhinolaryngology Service of Hospital General Universitario Gregorio Marañón in Madrid since 2006. He is also a member of the Spanish ORL society, member of the Spanish society of skull base and founder of NASAL in 2008.

He underwent a fellowship in endonasal endonscopic approaches to the skull base at Insitituto Felippu (Sao Paulo, BR) in 2006. He is involved as a practical teaching assistant of the Department of Ophthalmology and Otolaryngology at the Universidad Complutense de Madrid in General University Hospital Gregorio Marañón, director of numerous postgraduate courses in Rhinology, and regular lecturer as international guests at national and international conferences in Europe and Latin America, with publications in international journals in rhinology and engineering.

He is also the Principal Investigator in several Clinical Trials in HGUGM in vertigo and rhinology.

4.13 Study of Sensitivity and Specificity of Fully Automated CFD Solution in Patients Affected by Nasal Airway Obstruction (NAO)

DR. NARINDER SINGH

CONVENER

Dr. Narinder Singh is a Rhinologist (Nose & Sinus Specialist) and Chief of Otolaryngology, Head & Neck Surgery at Westmead Hospital in Sydney, Australia's largest hospital complex and a clinical school of The University of Sydney, Australia's oldest and largest Medical Faculty.

Dr Singh specialises exclusively in nasal airway surgery, complex and extended endoscopic sinus procedures, anterior skull base surgery, rhinoplasty (functional and aesthetic) and surgery for OSA.

Dr. Singh undertook his medical degree at The University of Sydney and Otolaryngology training in Sydney, Australia. He undertook a three year clinical/ research fellowship in rhinology, fully funded by The Guy's and St Thomas' NHS Foundation Trust, London, UK. During his fellowship, Dr Singh completed his Master's Thesis on "Allergen specific cytokine production by cells derived from human nasal polyps" through the University of Sydney, with laboratory experiments at King's College, London. He was awarded three research grants during his thesis: The Garnett Passe and Rodney Williams Foundation Trust Grant-in-aid, The University of Sydney John B Moore Memorial Scholarship and The University of Sydney Vernon Barling Memorial Fellowship.

Dr Singh is a frequent keynote and invited speaker on rhinology topics, with an extensive background in research, publication and editorial board membership. His early use of computer technology in surgery led to an interest in CFD and its revolutionary capacity to bring scientific rigour to the field of rhinology.

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