SCONA 2019

Society for Computational Fluid Dynamics of the Nose & Airway

June 5, 2019 | Chicago, USA

CONFERENCE PROGRAM

WELCOME

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

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 Rhinoworld, in the spectacular city of Chicago.

We look forward to the pleasure of your company in Chicago on Wednesday June 5th, 2019.

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

REGISTRATION: 07:30 TO 8:00 Sheraton Superior Rooms A and B

SESSION #1: CFD IN THE NOSE: THE MISSING LINK IN RHINOLOGY? (8:00 - 10:00)

No.	TIME	TITLE	SPEAKER
1.1	8:00	Convener's Welcome	Guilherme Garcia/ Dennis Frank-Ito
1.2	8:10	CFD in Rhinology: Clinical motivation and historical perspective	Julia Kimbell/ John Rhee
1.3	8:30	Experimental validation of CFD in the nose and upper airways	Denis Doorly
1.4	8:50	CFD validation of nasal airflow under various breathing conditions	Chengyu Li
1.5	9:10	Automatic reconstruction of the nasal geometry from CT scans	Walter Koch
1.6	9:30	Impact of segmentation uncertainty on CFD variables	Dennis Frank-Ito

10:00: MORNING COFFEE

SESSION #2: CLINICAL APPLICATIONS OF SINONASAL CFD (10:30 - 12:15)

No.	TIME	TITLE	SPEAKER
2.1	10:30	Clinical perspective: The importance of objective testing in rhinology	Narinder Singh
2.2	10:45	Diagnosis of nasal obstruction via CFD	Guilherme Garcia
2.3	11:00	Virtual surgery driven by nondimensional estimators	Manuel Burgos
2.4	11:15	Virtual septoplasty using CFD	Masoud Moghaddam
2.5	11:30	Nasal obstruction and empty nose syndrome – what are our noses sensing?	Kai Zhao
2.6	11:45	Modelling respiratory airflow in obstructive sleep apnea with prescribed motion from cine MRI	Alister Bates
2.7	12:00	Personalized surgical planning for obstructive sleep apnea with modeling & simulation	Goutham Mylavarapu

12:15: LUNCH

SESSION #3: NASAL DRUG DELIVERY (13:15 - 15:00)

No.	TIME	TITLE	SPEAKER
3.1	13:15	Computational fluid dynamics modeling of nasally administered drug products in regulatory science research at the US Food and Drug Administration	Ross Walenga
3.2	13:30	Multiphase flow analysis to improve therapeutic outcomes for treating nasal diseases	Kiao Inthavong
3.3	13:45	Exploring nasal sprays positioning to improve targeted drug delivery	Saikat Basu
3.4	14:00	Improving olfactory targeting: tackling the bottle-neck problem in nose-to-brain drug delivery	Jinxiang Xi
3.5	14:15	How to measure sinus ventilation with CFD	Hadrien Calmet
3.6	14:30	Distribution, pressure, and shear stress mapping within an anatomically accurate nasal airway model during simulated saline irrigation	David White
3.7	14:45	Nasal NO dynamics and the ostiomeatal complex: Fertile ground for CFD?	Dennis Shusterman

PROGRAM CONTINUED

15:00: AFTERNOON COFFEE

SESSION #4: FRONTIERS AND NEW RESEARCH (15:30 - 17:00)

No.	TIME	TITLE	SPEAKER
4.1	15:30	CFD in Rhinology: Where are we and what comes next?	Julia Kimbell
4.2	15:45	Quantifying airflow limitation due to dynamic lateral nasal wall collapse	Hillary Newsome
4.3	16:00	Critical evaluation of methods determining the influence of elasticity of the lateral nasal wall	Klaus Vogt
4.4	16:15	Looking for a relationship between chronic otitis media and nasal obstruction: a CFD analysis	Manuel Burgos
4.5	16:30	Quantifying the effect of maxillary skeletal expansion on the airway in adult orthodontic patients using computational fluid dynamics	Andrew Fraser
4.6	16:45	Airflow limitation in a collapsible model of the human pharynx	Trung Le
4.7	17:00	Future novel targeted treatment options of nasal obstruction and olfactory losses	Kai Zhao

17:15: CONFERENCE ENDS

SPEAKERS

JULIA KIMBELL, PHD
University of North Carolina at Chapel Hill, USA

1.2 CFD in Rhinology: Clinical motivation and historical perspective

Dr. Julia Kimbell is an Associate Professor in the Department of Otolaryngology/Head & Neck Surgery at the University of North Carolina at Chapel Hill (UNC). She received mathematics degrees from Middlebury College (B.A.) and Duke University (M.A., Ph.D.) and conducted postdoctoral research at the Chemical Industry Institute of Toxicology (later The Hamner Institutes for Health Sciences) in Research Triangle Park, NC modeling regional dosimetry of inhaled formaldehyde in the nasal passages of laboratory animals and humans. As a staff scientist at The Hamner, Dr. Kimbell led an 18-year research program on the development and use of computational fluid dynamics (CFD) models to study the effects of nasal anatomy and physiology on airflow, inhaled gas uptake, and particle deposition. In collaboration with Dr. John Rhee at Medical College of Wisconsin, Dr. Kimbell began CFD research on nasal surgery and in 2009 she moved to UNC, where she helped found the Otolaryngology Department's Computing and Clinical Research Laboratory. She has been conducting CFD research since then on effects of pathology and surgery on upper respiratory tract airflow, air-conditioning, and topical drug delivery. Dr. Kimbell is an adjunct faculty member of the UNC/NC State Joint Biomedical Engineering Department and the Department of Statistics at NC State. Her work has been funded by the American Chemistry Council, the National Institutes of Health, the U.S. Environmental Protection Agency, the National Institute for Occupational Safety and Health, and a number of chemical and pharmaceutical organizations. She has published over 100 peer-reviewed scientific articles and given numerous invited presentations at professional, academic, government and private organizations on CFD modeling in the upper respiratory tract of laboratory animals and humans.

JOHN S. RHEE, MD, MPH
Professor and Chairman,
Department of Otolaryngology,
Medical College of Wisconsin
USA

Dr. John Rhee is the John C. Koss Professor and Chairman of the Department of Otolaryngology and Communication Sciences and the Chief of the Division of Facial Plastic and Reconstructive Surgery and Professor of Dermatology at the Medical College of Wisconsin (MCW). He is the past Chair of the Board and Interim CEO of the Medical College Physicians multispecialty practice and Interim Senior Associate Dean of Clinical Affairs. He has also served as Interim Chair of the MCW Departments of Dermatology and Ophthalmology.

He attended Dartmouth College for his undergraduate education and SUNY at Stony Brook for medical school. Following completion of his otolaryngology–head and neck surgery residency at the Mount Sinai Medical Center in New York City in 1998, he did an additional fellowship year in facial plastic surgery at The University of Miami/Jackson Memorial Hospital. After joining the faculty at MCW in 1999, he obtained a MPH degree at MCW while building his research career on clinical outcome studies. He has held multiple funded grants as the Principal Investigator from the National Institutes of Health (NIH) in various aspects of clinical care including skin cancer (R03, National Cancer Institute), surgical nasal airway correction (R01, National Institute of Biomedical Imaging and Bioengineering). He has served on NIH study sections and is a co-investigator and mentor on numerous NIH sponsored grants.

Dr. Rhee has been listed in the Best Doctors of America every year since 2003 and has been awarded a Top Doctor award from Froedtert Memorial Lutheran Hospital, the main hospital affiliate for MCW. Amongst his other notable awards include the George Adams Young Faculty Award from the Triological Society, The Distinguished Service Award from the American Academy of Otolaryngology – Head Neck Surgery, and Excellence in Professionalism from the Medical College Physicians. He has been invited internationally to speak on topics ranging from outcomes studies, nasal airway surgery, and biomedical research.

Dr. Rhee served as a Board member and Coordinator for Research & Quality for the American Academy of Otolaryngology – Head and Neck Surgery Foundation (AAO-HNSF). He is the Editor-in-Chief of JAMA Facial Plastic Surgery, the premier peer-reviewed medical journal for the subspecialty. He holds multiple leadership positions within the boards and committees of Facial Plastic and Reconstructive Surgery and Otolaryngology – Head Neck Surgery. He has authored or co-authored over 100 scientific publications and has served in the past as a residency program director for MCW. He currently serves as a Board Director for the American Board of Otolaryngology and a Senior Advisor for the American Board of Facial Plastic and Reconstructive Surgery. He also serves as the Chair of the Otolaryngology Residency Review Committee of the ACGME.

ABSTRACT

Many extremely useful technologies could not be used safely today if it weren't for tests and data collection using computational fluid dynamics (CFD): air travel, weather prediction, bridge design, flood control, satellite placement… Anything involving flows can benefit from CFD analysis – including Rhinology. Dr. Rhee and Dr. Kimbell have been working together on CFD in Rhinology for some time now and will give an introduction to this field from their joint perspectives in clinical research together and their own backgrounds in medicine and mathematics.

1.3 Experimental validation of CFD in the nose and upper airways

DENIS DOORLY, PHD
Imperial College, London, UK

Denis Doorly obtained his bachelor degree in engineering science from Trinity College Dublin and his DPhil (PhD) degree from Oxford University. After postdoctoral research in the applied mathematics departments at Imperial and at University College London, he joined the Aeronautics Department at Imperial College where he is now Professor of Fluid Mechanics and Director of Teaching. His research interests include respiratory and cardiovascular fluid mechanics and he supervises PhD and MD students from clinical and engineering backgrounds.

ABSTRACT

Computational fluid dynamics (CFD) is applied to determine detailed airflow distributions as well as airflow mediated transport, for a broad range of upper airway applications and by a growing number of users. Experimental validations of particular CFD methodologies applied to specific problems are, however, less common. In many areas, experimental validations are still lacking. In-vivo it is difficult or impossible to directly measure necessary boundary conditions, (e.g. surface temperature, humidity, or concentration), let alone to determine detailed flow patterns. Faced with such difficulties, in-vitro testing offers an alternative approach to validate the use of CFD. In vitro models hold several advantages - they permit detailed measurement, can be manufactured at near arbitrary scale and allow a much broader range of techniques to be applied than would be possible in-vivo.

However in-vitro models as yet do not reproduce the full set of boundary conditions that pertain in vivo. In this work, we will review in-vivo measurements and their limitations. We will then outline procedures for in-vitro model definition, model construction and measurement techniques. Results from tests that permit direct comparison between CFD and measurement will be reviewed. Finally the implications for the validation of current and future CFD applications will be discussed.

CHENGYU LI, PHD
Villanova University, USA

1.4 CFD validation of nasal airflow under various breathing conditions

Dr. Chengyu Li received his PhD in Mechanical and Aerospace Engineering from the University of Virginia in 2016. After graduation, he joined The Ohio State University as a postdoctoral researcher in the Department of Otolaryngology. In August 2018, Dr. Li joined Villanova University as an Assistant Professor of Mechanical Engineering. His research is situated at the intersection of fluid dynamics and computation with an emphasis on engineering and healthcare applications. In particular, he focuses on developing state-of-the-art computational methods that leverage mathematical models and numerical simulations to improve understanding of biological and physiological flows.

ABSTRACT

Human nose functions (like warming, humidification, and olfaction) involve complex transport phenomena and are determined by nasal airflow patterns and turbulence. Accurate prediction of these airflow properties requires careful selection of computational fluid dynamics models and rigorous validation. The current study aims to validate various numerical methods based on an anatomically accurate nasal model against published experimentally measured data under breathing flow rates from 180 to 1100 ml/s. The numerical results of velocity profiles and turbulence intensities were obtained using the laminar model, four widely adopted Reynolds-averaged Navier-Stokes (RANS) turbulence models (i.e., k-epsilon, standard k-omega, shear stress transport k-omega, and Reynolds stress model), large eddy simulation (LES) model, and direct numerical simulation (DNS). Our results revealed that, despite certain irregularity in the flow field under restful breathing condition (180 ml/s), the laminar model could achieve good agreement with experimental results and performed even better than the RANS models. As the breathing flow rate increased, the RANS models achieved more accurate predictions than the laminar model but still performed worse than LES and DNS. As expected, LES and DNS can provide accurate predictions of the nasal airflow under all flow conditions but have an approximately 100-fold higher computational cost. Among all the RANS models tested, the standard k-omega model agrees most closely with the experimental values in terms of velocity profile and turbulence intensity. This outperformance originates from its treatment of the viscous near-wall region and its handling of streamwise pressure gradients for wall-bounded flows.

WALTER KOCH, PHD
Professor emeritus Technical University of Graz, Director of AIT Applied Information Technique Research Inc., Austria

1.5 Automatic reconstruction of the nasal geometry from CT scans

Univ.-Prof. Dr. 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), guest professor of the Donau-University in Austria and lecturer at the University of Graz. Furthermore he is chairperson of the CSC Content Service Centre and head of the Steinbeis Transferzentrum (IMCHI – Information Management, Medical- and Cultural Heritage Informatics). Since 2010 he is giving lectures on Knowledge Management at the University of Graz. From 1971 to 2010 he was professor at the Institute for Mathematics at the Technical University in Graz giving lectures on computer science and mathematics (health insurance mathematics, life insurance mathematics, information systems, projects and quality management). From 1976 to 1998 Professor Koch was head of a research institute at JOANNEUM RESEARCH Ltd. and Rechenzentrum in Graz. In this function he elaborated and coordinated amongst others a successful EU-funded proposal in the medical domain: "Harmonisation of Nephrology Data Systems within Regional Networks".

Prof. Koch's recent projects concern CFD simulations for rhinologists and radiologists and he is leader of an international research consortium that aims at implementing coordinated morphological-functional diagnostics for ear, nose, and throat (ENT) physicians. Currently he takes part in an OMG (Object Management Group) Working Group (BPM-Health Pilot) that is concerned with the establishment of an inventory of BPMN (Business Process Model and Notation) clinical pathways.

ABSTRACT

As part of the Rhinodiagnost.eu Project, high quality 3D models of nasal cavities and paranasal sinuses had to be constructed in a time-efficient manner. Standard software which use a thresholding based approach in general make extensive post-processing necessary which can take up to 24 hours to deliver a high quality 3D model. To speed up this process, a Convolutional Neural Network (CNN) has been developed to segment images and deliver 3D models within minutes.

The anonymized DICOM images on which this procedure is based are taken from a given modality (CT scanner) which provides a slice thickness of 0.6 mm. Around 160 images are used to train a network to identify two different classes (air vs tissue: "air segmentation"). Given new image data, the trained network classifies pixels with an accuracy of over 99% when separating air filled regions (nasal cavities including paranasal sinuses) from tissue and bone. Another network has been trained to identify classes which represent bone structures ("bone segmentation").

Using the Marching Cubes algorithm, the segmented CT images are used to automatically generate 3D surface meshes (air and bone segmentation) in minutes. These meshes are considered as two point clouds for which the difference is calculated using the ICP (Iterative Closest Point) algorithm. In combination with two other methods – "mesh labelling" and "ray casting" - for three paranasal sinuses (Maxillary, Frontal, and Sphenoidal Sinus) the grade of mucosal swelling can be determined. The whole process has been implemented as web based Rhinodiagnost Service.

1.6 Impact of Segmentation uncertainty on CFD variables

DENNIS FRANK-ITO, PHD
Duke University, USA

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. While working on his PhD at NCSU, Dr. Frank-Ito received another Master degree in Operations Research in December 2008. Upon completion of his PhD, Dr. Frank-Ito did a postdoctoral 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 interest include computational modeling of upper respiratory physiology to better understand the effects of airflow dynamics, olfaction, deposition of inhaled gases and particle transport on airway function. Dr. Frank-Ito has published over 45 peer-reviewed articles on computational modeling of airway function and his group has received multiple funding from the National Institutes of Health (NIH) to work on several projects involving sinonasal dysfunction. He currently has an NIH R01 grant to investigate unilateral cleft lip nasal deformity on nasal patency before and after functional nasal surgery.

ABSTRACT

Computational fluid dynamics (CFD) modeling has shown significant promise in elucidating the impact of airway anatomy on physiology and pathophysiology. However, the accuracy of CFD modeling relies on correct segmentation of airway anatomy during reconstruction of anatomically realistic 3D airway model from high-resolution patient-specific radiographic images. Preservation of the natural state of the airway during manual or automatic segmentation is important in reducing uncertainties in simulated results. This presentation highlights how lack of attention to details during segmentation can compromise the validity of computationally derived results from CFD simulations.

NARINDER SINGH, MD
University of Sydney, Australia

2.1 Clinical perspective: The importance of objective testing in rhinology

Dr Narinder Singh is a Rhinologist and Head of the ENT Dept at Westmead Hospital in Sydney, Australia's largest Hospital complex and Clinical Associate Professor at The University of Sydney, Australia's oldest and largest medical school. He specialises exclusively in complex and extended endoscopic sinus procedures, anterior skull base surgery, functional and aesthetic rhinoplasty and surgery for OSA. Dr Singh undertook his medical degree at The University of Sydney and Otolaryngology training in NSW, Australia. He was awarded a fully-funded three year clinical/ research fellowship in rhinology and anterior skull base surgery by The Guy's and St Thomas' NHS Foundation Trust, London, UK. He completed his Thesis on "Allergen specific cytokine production by cells derived from human nasal polyps" through the Randall Division of Cell and Molecular Biophysics at King's College, London, UK. He has been awarded several research grants including The GPRWMF Trust Grant-in-aid, The University of Sydney John B Moore Memorial Scholarship, The University of Sydney Vernon Barling Memorial Fellowship and the Garnett Passe and Rodney Williams Memorial Foundation Conjoint Grant. Dr Singh's early use of computer technology in surgery led to an interest in CFD (Computational Fluid Dynamics) and AI (Artificial Intelligence) and their revolutionary capacity to bring scientific rigour to the field of Otolaryngology. Dr Singh convened the First World Congress of the Society for CFD (Computational Fluid Dynamics) of the Nose and Airway (SCONA: www.scona.org) in London, UK, 2018, as well as the First Australian Congress of the Society for AI in Medicine, Surgery and Healthcare (AMSAH: www.amsah.org) in Westmead, Sydney, 2019.

ABSTRACT

Objective testing in Rhinology

Despite the critical significance of nasal airflow on many aspects of daily living, in scientific terms, nasal airflow remains a poorly understood area of physiology. The primary reason for this lack of detailed understanding is the paucity of robust scientific methods for testing nasal airflow. Numerous objective testing methods exist, including anterior and posterior rhinomanometry, acoustic rhinometry and peak nasal inspiratory flow. However, all available methods are marred by significant variability, lack of specificity, sensitivity and reproducibility. Furthermore, these methods provide little insight into the specific cause or site of obstruction. Subjective methods of testing including questionnaires such as visual analogue scores and the NOSE (Nasal Obstruction and Septoplasty Effectiveness) scale are of limited clinical usefulness in determining the site of obstruction. Typically, surgeons rely on nasendoscopy, imaging (such as CT, or MRI) and clinical experience to determine the need for surgery, the precise site of obstruction and the procedure offered. This surgeon-specific interpretation of clinical findings is subjective, highly variable and correlates poorly with airflow testing.

As the incidence of nasal airway obstruction (NAO) is high, surgery to relieve NAO is a commonly performed elective procedure. However, the vast majority of such procedures are performed without a convincing body of high-level scientific evidence. Most of the techniques used are based principally on surgeons' handed-down and own experience, along with patient self-reporting of results. In order to bring the "art" of NAO surgery into the modern scientific domain, new methods of testing, diagnosis and outcome reporting are required.

In this overview, we examine the available methods of testing in Rhinology with regard to nasal physiology, pre-operative planning and post-operative assessment. We assess the role of CFD in resolving the unanswered questions in this field.

GUILHERME GARCIA, PHD
Marquette University and Medical College of Wisconsin, USA

2.2 Diagnosis of nasal obstruction via CFD

Guilherme Garcia received a bachelor's degree (1996-1999), a master's degree (1999-2001), and a PhD (2001-2005) in Physics from Universidade Federal de Minas Gerais in Brazil. He received training in computational fluid dynamics (CFD) and nasal physiology as a post-doctoral fellow (2005-2008) in Dr. Julia Kimbell's laboratory at The Hamner Institutes for Health Science in Research Triangle Park, NC. He also received postdoctoral training in computational biology and mucociliary clearance (2008-2011) at the Department of Pharmacology and the Cystic Fibrosis Center at the University of North Carolina at Chapel Hill. In 2012, he joined the Medical College of Wisconsin (MCW) as an Assistant Professor in the Department of Otolaryngology and Communication Sciences. In 2015, he also joined the Department of Biomedical Engineering at Marquette University and The Medical College of Wisconsin. His research interests includes virtual surgery planning for upper airway diseases, respiratory drug delivery with pharmaceutical aerosols, and the mechanics of airway collapse in obstructive sleep apnea. He has published over 50 peer-reviewed scientific articles. His research has been funded by the National Institutes of Health and the Advancing a Healthier Wisconsin Endowment.

ABSTRACT

Nasal airway obstruction (NAO) is a subjective feeling of reduced nasal airflow. Today treatment decisions for NAO patients rely on the patients' subjective symptoms, a physical exam, and surgeons' judgement without objective measurements of nasal airflow. Many research studies have used rhinomanometry to quantify nasal airflow and acoustic rhinometry to quantify nasal anatomy. However, these objective measures have not been universally adopted to select patients for surgery due to their inconsistent correlation with subjective symptoms. There is hope that computational fluid dynamics (CFD) simulations of nasal airflow in 3-dimensional models created from computed tomography (CT) scans may be a more effective technique to select surgical patients. Many CFD variables have been shown to correlate with subjective sensation of nasal obstruction, including nasal resistance, airflow partitioning between the left and right nostrils, various measures of mucosal cooling, wall shear stress, and intranasal flow distribution. But it is unclear which CFD variable can best distinguish NAO patients from healthy subjects. In this study, we performed CFD simulations of nasal airflow in 27 patients with NAO and 47 healthy subjects at a steady-state flowrate of 15 L/min. A receiver operating characteristic (ROC) analysis was used to quantify the sensitivity and specificity of CFD variables to distinguish NAO patients from healthy individuals. We found that unilateral variables, rather than bilateral variables, have greater ability to distinguish NAO patients from healthy individuals. Our preliminary results also suggest that the distribution of airflow into inferior, middle, and superior regions of a coronal section in the turbinate region had the best performance to distinguish NAO patients from healthy individuals. Further studies are needed to validate these findings and to investigate a potential role of intranasal airflow distribution in sensation of nasal airflow.

MANUEL BURGOS, PHD
Universidad Politéncia de Cartagena, Spain

ALEJANDRO PARDO ANTUNEZ
Universidad Politéncia de Cartagena, Spain

2.3 Virtual surgery driven by nondimensional estimators

Dr. 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.

Alejandro Pardo Antunez graduated in Naval Architecture and Marine Engineering at the Polytechnic University of Cartagena Murcia-Spain in 2018. Currently studying a master's degree in industrial engineering. He was introduced in the CFD world in 2017 when he began the end of degree project, "Analysis by Computational Fluid Mechanics about the problems associated with scuba diving", supervised by Dr. Manuel Antonio Burgos Olmos, with whom he has been collaborating until now improving the software to Nasal flow simulation and virtual nasal surgery. This software has been specially designed for the ENT specialist and is ready to be used. This software allows the ENT specialist to perform a complete simulation of CFD of the nasal airflow (including the analysis and visualization of the results) and a virtual surgery in a three-dimensional model, synchronized with the CT scan or similar. It has been integrated in only one application all the necessary steps and all of them in the user's own computer where the simulation and virtual surgery wiil be done, all in an easy, fast and intuitive way for the user. Now, working on a new module for this software, the water transport equation to simulate the moisture exchange that occurs in the nasal cavity. Also investigating the relationship between chronic otitis media and nasal obstruction

ABSTRACT

Hundreds of thousands of surgical interventions related to nasal airway obstruction are performed in the world every year. Recent studies have pointed out that a significant number of these interventions are associated with postoperative problems. We present a new methodology for surgery in nasal cavities that could improve the success rate. This new methodology is based on virtual surgery on a 3D nasal model of the patient with CFD tools carried out before the real operation. However, its main goal is to help the surgeon throughout the virtual operation by mathematical estimators. The surgical intervention ends as soon as the estimators fall into a region of a Cartesian coordinate system with a high success probability. As examples of this application, this study includes two surgical operations performed with this innovative methodology in patients with severe nasal obstruction. The patients underwent nasal surgery according to the final nasal geometry revealed by CFD-guided virtual surgery. Currently, both patients showed a high degree of satisfaction.

MASOUD MOGHADDAM, PHD
Marquette University and Medical College of Wisconsin, USA

2.4 Virtual Septoplasty using CFD

Masoud Moghaddam's expertise is in the areas of applied and computational mechanics. He is currently a postdoctoral research fellow in the Biomedical Engineering Department at the Medical College of Wisconsin (MCW). His current research includes virtual surgery planning in patients with nasal airway obstruction (NAO) and studying the deformation mechanisms of the human pharyngeal tissues in patients with obstructive sleep apnea (OSA). Masoud's role at MCW allows for the collaboration of the Biomedical Engineering and Otolaryngology Departments. Prior to joining MCW, he completed his PhD in Mechanical Engineering at Clarkson University, NY (2016). There, he collaborated with NASA Glenn Center to develop microstructural based models for studying mechanical components working in extreme environmental conditions. Masoud has obtained his MSc and BSc degrees in Mechanical Engineering from Iran.

ABSTRACT

Virtual surgery planning using computational fluid dynamics (CFD) has the potential to improve surgical outcomes for patients with nasal airway obstruction (NAO). In this study, we develop a systematic virtual septoplasty method to identify which patients may benefit from septoplasty and to design a septoplasty that improves nasal airflow variables. The method has three steps, namely (1) normative ranges for septal thickness and deviation, and airflow variables are obtained in healthy individuals, (2) patients with abnormal airflow due to a deviated septum are identified, and (3) virtual septoplasty is implemented by correcting the deviation and thickness in the deviated septum while preserving the anatomical septal shape. A cohort of 47 healthy individuals and 1 NAO patient were selected for this study. The degree of septal deviation was quantified as the deviation from the midline on coronal sections. The morphology of the nasal septum from all the healthy individuals revealed a maximum septal deviation and a maximum average septal thickness of 3.5mm and 8.5mm anywhere in the septum, respectively. In the NAO patient, a significantly higher septal deviation of 6mm and a maximum septal thickness of 10 mm were observed, which were associated with a nasal resistance substantially higher than normal. After implementing the virtual septoplasty, the nasal resistance in the NAO patient was reduced (91% unilaterally and 50% bilaterally) within the normal range. We conclude that normative ranges of anatomic and flow variables can serve as templates for designing virtual surgery techniques that improve nasal function in NAO patients.

KAI ZHAO, PHD
The Ohio State University, USA

2.5 Nasal obstruction and empty nose syndrome—what are our noses sensing?

4.7 Future novel targeted treatment options of nasal obstruction and olfactory losses

Kai Zhao, PhD, is currently an Associate Professor in the Department of Otolaryngology - Head and Neck Surgery at The Ohio State University College of Medicine since August 2015. Dr. Zhao received his PhD in Bioengineering from the University of Pennsylvania, where he was trained in respiratory biofluid mechanics. During his subsequent postdoctoral and independent research at Monell Chemical Senses Center in Philadelphia, he focused on theoretical and experimental approaches to understand the physiological fluid and transport problems in the nasal airway, and its implications in nasal functions, especially in olfaction. He also has held an adjunct faculty position in otolaryngology at Thomas Jefferson University, where he engaged in active clinical collaborations on investigating obstructive nasal sinus symptoms and treatment planning, including nasal obstruction, conductive olfactory losses, sinus surgery simulation and optimization. His research has been supported in the past by the U.S. Air Force, NIH and private foundations. More recently, Dr. Zhao and a team of multidisciplinary researchers have been awarded an R01 grant by the National Institute of Health to further develop methodology to objectively evaluate conductive nasal symptoms and to assist clinicians in planning for more effective treatment.

ABSTRACT

2.5: Nasal obstruction is the hallmark symptom of sinonasal disease that severely impacts patients' quality of life. However, despite concentrated research since the early 19th century, we continue to lack a clear understanding as to why nasal obstruction reported by patients often bear little relationship to the actual measurement of physical obstruction of nasal airflow. Without validated objective tools, the current diagnosis and treatment of nasal obstruction are based primarily on subjective opinion and patient feedback, leading to inconsistent outcomes. This disconnection may underlie the empty nose syndrome (ENS), a rare and debilitating disease that often lead patients to suicidal attempts and even fatal atrocities against medical staff. ENS is characterized by a paradoxical sensation of nasal obstruction and suffocation, despite a wide open nasal airway, often after nasal surgery.

In this presentation, we will first introduce recent studies that implicated nasal cooling and trigeminal sensory function being associated with the feeling of nasal obstruction. Next, we will apply these findings to investigate ENS patients and other patient populations who have received aggressive turbinate reduction or skull base surgeries, in similar degree as to ENS patients, but do not present ENS symptoms. The results indicated that a combinatory of factors, including paradoxically distorted nasal aerodynamic, impaired sensorineural sensitivity that are unique to ENS patients, may contribute to their sensation of nasal obstruction.

Finally, we will discuss future novel treatment options of nasal obstruction inspired by this line of research, through TRPM8 agonists and airflow modulations. TRPM8 is a temperature sensitivity receptor that mediated the trigeminal cooling sensation.

4.7: Abnormal nasal aerodynamics due to nasal obstruction or due to nasal structure anomaly likely contributes to many nasal sinus symptoms, including nasal obstruction, empty nose syndrome (ENS), as well as smell losses. For the latter, the etiology of olfactory losses may involve anatomical obstructions that block the air and odor flow to the olfactory region. These symptoms significantly impact patients' quality of life.

Surgical remodeling of nasal airway may improve these symptoms, but outcomes are highly variable. Currently, surgical planning involves history and physical findings often augmented with CT imaging, which does not predict functional outcome. We have been developing a virtual planning tool aimed at simulating and pre-operatively predicting surgical outcomes related to nasal airflow, so that surgeon can iteratively design an optimal targeted surgical approach based on each patient's unique nasal anatomy. We will also discuss future novel treatment options of nasal obstruction inspired by this line of research, through TRPM8 agonists and airflow modulations that may reduce the need for future sinus surgery. TRPM8 is a temperature sensitivity receptor that mediated the trigeminal cooling sensation.

ALISTER BATES, PHD
Cincinnati Children's Hospital
Medical Center, USA

2.6 Modelling respiratory airflow in obstructive sleep apnea with prescribed motion from cine MRI

Alister Bates, PhD is an Instructor in the Division of Pulmonary Medicine and Center for Pulmonary Imaging Research at Cincinnati Children's Hospital Medical Center. His research specializes in computational modelling of the human airway. In particular, he focuses on airflow in children with obstructive sleep apnea and using computational modeling to improve surgical outcomes in this population. He has recently been awarded an NIH grant to pursue this research. Dr. Bates also leads analysis of dynamic airway collapse in infants born extremely prematurely as part of the Cincinnati Bronchopulmonary Dysplasia Center. These infants often have comorbid lung and airway abnormalities, and determining the relative contributions of these problems to symptoms can drastically alter a patient's treatment path.

Dr. Bates obtained his PhD from Imperial College London under the supervision of Professors Denis Doorly and Bob Schroter. At Imperial, Dr. Bates' research focused on airflow in the human nasal passages and the effect of tracheal abnormalities on respiratory flow in collaboration with St. Mary's Hospital, London. He was awarded a Doctoral Prize Fellowship and a Junior Research Fellowship based on this research. Prior to his PhD, Alister was an aerodynamicist for the Williams Formula One Grand Prix team and completed his Master's and undergraduate studies at the University of Cambridge.

ABSTRACT

Obstructive sleep apnea (OSA) is a sleep-related breathing disorder characterized by recurrent partial or complete collapse of the upper airway during sleep. Each collapse limits airflow, causing impairment of gas exchange and recurrent arousals from sleep. Surgeries that aim to treat OSA are often not effective. Computational fluid dynamics (CFD) modelling of respiratory airflow in patients with OSA offers the potential to determine the efficacy of various surgical approaches prior to surgery and thereby improve outcomes.

Upper airway motion in OSA is hard to predict, as it is influenced by neuromuscular control of structures including the tongue, soft palate, jaw and pharynx, as well as pressure forces due to the airflow inside. The resulting motion is not necessarily in phase with the respiratory cycle, and one region of the upper airway may expand while another collapses.

In order to model the relationship between airflow and the complex airway motion, a novel technique to determine in vivo motion and prescribe it to simulation models has been developed. Fast cine magnetic resonance imaging (MRI) captured the airway motion. Image registration extracted motion vectors from these images, which are then applied to an airway surface model segmented from high resolution static MRI.

Comparison of the directions of airway motion and pressure forces reveals that much of the airway motion in OSA is due to neuromuscular control of the airway and not due to passive collapse of the airway in response to respiratory forces, contrary to conventional clinical assumptions.

GOUTHAM MYLAVARAPU, PHD
Cincinnati Children's Hospital Medical Center, USA

2.7 Personalized surgical planning for obstructive sleep apnea with modeling & simulation

Dr. Goutham Mylavarapu is an interdisciplinary researcher at the Division of Pulmonary Medicine, Cincinnati Childrens Hospital. He obtained his BS in Mechanical Engineering from IIT Madras, India and a PhD in Aerospace Engineering from University of Cincinnati in 2013. He worked as a research associate at University of Cincinnati until 2013 in the Department of Aerospace Engineering in several multidisciplinary projects, before moving to Cincinnati Childrens to pursue focused biomedical research. His interests include biofluids, CFD, FSI, obstructive sleep apnea, virtual surgeries, software development, aortic blood flows, lung vasculature modeling and artificial intelligence. Dr. Mylavarapu is author of 15 journal publications and received external funding from US Department of Defense for developing virtual surgery software for evaluating upper airway surgical plans in patients with obstructive sleep apnea.

ABSTRACT

Obstructive Sleep Apnea (OSA) is a common sleep disorder afflicting nearly 25 million in the US alone. It is characterized by intermittent obstruction of the upper airway during sleep. Unresolved OSA is associated with excessive daytime sleepiness, reduced alertness, reduced quality of life and poor cardiovascular health. Although continuous positive airway pressure (CPAP) is effective in maintaining airway patency during sleep, it is poorly tolerated by most patients leading many to opt for a long-term surgical solution. However, success rates for OSA surgeries typically range between 50-70%. Furthermore, many patients require multiple procedures to effectively treat OSA, which increases the risk of post-operative complications and the cost of care. At present, the choice of surgical procedures is subjective and guided mainly by the experience of the clinical team. The central hypothesis of our research work is that evaluating OSA surgical plans in patient-specific anatomical models in a virtual setting

prior to the actual intervention would felicitate a more personalized approach and achieve higher OSA cure rates. In this talk, I'll present few case studies to demonstrate the virtual OSA surgeries using Computational Fluid Dynamics (CFD) and Flow-Structure Interaction (FSI) and discuss advantages, issues and future directions for these approaches.

3.1 Computational fluid dynamics modelling of nasally administered drug products in regulatory science research at the US Food and Drug Administration

ROSS WALENGA, PHD
Food and Drug Administration, USA

Dr. Ross Walenga joined the FDA in 2015 as an Oak Ridge Institute for Science and Education (ORISE) Fellow. He is currently a Chemical Engineer at the Division of Quantitative Methods and Modeling at the Office of Research and Standards. He began his career at Virginia Polytechnic Institute and State University (Virginia Tech), where he earned a Bachelor Science in Aerospace Engineering. He later earned his PhD in Engineering (mechanical track) from Virginia Commonwealth University in 2014, where he also spent seven months as a postdoctoral fellow prior to joining the FDA. His research interests include computational fluid dynamics modeling of orally inhaled, nasal, ophthalmic, and dermal drug products to answer questions pertaining to bioequivalence.

ABSTRACT

The inability of currently available in vitro and in vivo methods to directly measure the rate and extent of drug absorption in human nasal tissue presents challenges for drug product development of locally-acting suspension nasal sprays. This is problematic for both brand-name and generic drug developers who either want to demonstrate efficacy or to establish bioequivalence with the reference product, respectively. Drug developers would benefit from greater assurance that the results of in vitro and in vivo studies necessary for drug approval would be favorable. Opioid abuse deterrent formulations (ADFs) represent another class of drug products that may be administered nasally by abusers and presents challenges for drug developers designing deterrence through that route. Although opioids are targeted for systemic absorption, abuse deterrence via the nasal route is currently assessed using in vivo studies, which makes formulation development difficult due to uncertainty in the impact of various formulation changes. For both opioid ADFs intended for abuse deterrence via the nasal route and suspension nasal sprays, a method is needed to predict the impact of device and formulation changes on metrics that indicate either abuse deterrence, efficacy, or bioequivalence. Computational fluid dynamics (CFD) is a useful technique for connecting device and formulation changes of nasal drug products to local drug delivery. As part of a broader generic regulatory research program, the Office of Generic Drugs at the US Food and Drug Administration is investigating the use of CFD for facilitating development of nasally administered drug products.

KIAO INTHAVONG, PHD
RMIT University, AUS

3.2 Multiphase flow analysis to therapeutic outcomes for treating nasal diseases

Kiao Inthavong received his PhD from RMIT in 2009, and is currently an Associate Professor at the School of Engineering. His research is in computational and experimental fluid-particle and multiphase flow dynamics with applications in nasal drug delivery, respiratory health, and air-quality in the indoor built environment. He has over 100-peer reviewed publications including scholarly books with Springer (incl. "Computational Fluid Particle Dynamics in the Respiratory System") and a h-index of 21. He has received over $1mil in research funds including 2 ARC Discovery Grants, and 1 Linkage-Grant, and 1 Garnett-Passe grant.

ABSTRACT

A common presentation of nasal obstruction is chronic rhinosinusitis (CRS) which is a persistent inflammatory disease of the nasal cavity and paranasal sinuses. Topical steroid therapy into the nasal cavity is one of the mainstays in the medical management. However, drug delivery devices miss targeted regions, leading to poor efficacy, thereby rendering the treatment ineffective. To unlock the clinical potential of new drug formulations that can reduce surgical intervention, there is a need to improve the current medical devices by exploiting the multiphase flow dynamics of air-liquid within the nasal cavity. This will bring full realisation to the opportunities of personalised health care, providing improved health outcomes for patients, and keeping them out of surgery. This talk presents advanced multiphase flow analysis of liquid flows changing into either jets or atomized droplets and delivered into the human nasal cavity. New computational techniques for visualization and quantitative analysis is shown to better understand the multiphase flow dynamics inside a human nasal cavity.

SAIKAT BASU, PHD
South Dakota State University, USA

3.3 Exploring nasal sprays positioning to improve targeted drug delivery

Dr. Saikat Basu is an Assistant Professor at the Department of Mechanical Engineering at South Dakota State University (Brookings, SD, United States). Professor Basu received his PhD in Engineering Mechanics from Virginia Tech in 2014, which was followed by two postdoctoral stints at the Okinawa Institute of Science and Technology (Japan) from 2014 – 2016, and at the University of North Carolina Chapel Hill from 2016 – 2018. He started his tenure-track position at SDSU from January 2019. Basu's research group leverages tools from theoretical and computational fluid mechanics to explore interdisciplinary questions arising along the following tracks: (a) respiratory transport: on flow physics therein and on strategies to improve targeted medical therapeutics, (b) vortex dynamics: on bluff body wakes and flow-induced clean energy innovations. Dr. Basu's recent collaborative work on interfacial dynamics has been recognized by the prestigious Fluid Dynamics Research Prize (2018) of the Japan Society of Fluid Mechanics. His doctoral dissertation on vortex wake dynamics was earlier nominated for the outstanding dissertation award and was also awarded the Paul Torgersen Research Excellence Award, both at Virginia Tech. Basu's research on respiratory transport has been covered on popular press by ScienceDaily, NewsWise, and by other international media outlets in Europe.

ABSTRACT

Targeted delivery at diseased sinonasal sites is essential to improve efficacy of topical sprays as a nasal therapeutic. Considering that ostiomeatal complex (OMC) is the mucociliary drainage pathway and airflow exchange corridor between the main airway and the frontal, maxillary, and anterior ethmoid sinuses, this work explores sprayer techniques to target OMC, along with the sinus cavities.

Nasal airflow and drug transport were numerically simulated in five CT-based sinonasal airway reconstructions, drawn from pre-operative chronic rhinosinusitis patients. In each digital model, we applied two different spray orientations at 5-mm insertion: (a) package insert-

based direction – an upright spray axis with subject-head inclined slightly forward (22.5°), (b) revised use (RU) – with spray axis directed at OMC and through centroid of visible OMC's projection on the view-plane for best OMC-sighting. RU, detected visually, was compared to algorithmic evaluation of all possible lines-of-sight (LoS) between OMC and nostril plane.

RU registered an average 6-fold higher targeted delivery, with the finding supported ($p<0.05$) by both parametric t-test and non-parametric Wilcoxon signed rank test. Simulated dose in two representative models was validated by in vitro spray experiments in 3D-printed replicas, with Pearson correlation>0.85. Finally, sinonasal scores, based on how much of OMC was visible from nostrils, correlated exactly with computational LoS scores calculated algorithmically from the number of unobstructed lines-of-sight between the nostril plane and OMC.

These CFD-based findings may eventually translate to new personalized spray usage instructions, to be recommended by physicians to individual patients during clinic visits.

3.4 Improving olfactory targeting: tackling the bottle-neck problem in nose-to-brain drug delivery

JINXIANG XI, PHD
California Baptist University, USA

Dr. Jinxiang Xi is an Associate Professor of Mechanical Engineering and of Biomedical Engineering at California Baptist University. He obtained his Ph.D. in Mechanical Engineering from Texas A&M University in 2005 in thermal-fluid sciences. Before joining Cal Baptist, he has worked as an Assistant Professor at the University of Arkansas and Central Michigan University.

Dr Xi has sixteen years' research experience in biomedical devices and pharmaceutical research. His research in respiratory aerosol dynamics is highly interdisciplinary, which bridges biology, medicine, and engineering. Applications include inhalation toxicology, aerosol-based tumor diagnosis, and personalized drug delivery. Dr. Xi won the 2012 Monaghan-Trudell Award from American Respiratory Care Foundation for his contributions to "Aerosol Technology Development".

ABSTRACT

The convoluted nasal passage filters the majority of nasally inhaled aerosols and prevents effective drug delivery to the olfactory region or parasinus. Different methods have been explored to improve drug targeting to such secluded regions. These include pointed drug release, bi-directional intranasal delivery, electro-magnetic guidance, and pulsating flows. Both in vitro experiments and computational modeling were used to quantify the deposition rate to the olfactory region. A Sar-Gel based method was used to visualize the deposition distribution inside the nasal cavity. Results showed that point drug release and the bi-directional technique both yielded improved but limited deposition in the olfactory region. Aerosols with electric charges or magnetic properties can further improve olfactory targeting by applying an appropriate external electric or magnetic field in the nose. The olfactory deposition was sensitive to the voltage of the electrode close to the nose. For both the normal and bi-directional deliveries, electric field guidance resulted in a significant increase (3~5 times) in the olfactory deposition.

HADRIEN CALMET, PHD
Barcelona Supercomputing Center, Spain

3.5 How to measure sinus ventilation with CFD

After studying Applied Physics of Ocean and Atmosphere Hadrien Calmet obtained a Master degree in UTV (University of Toulon Var in France) with a 6 months exchange Erasmus in 2002 at the UPC (University polytechnic of Catalonia, Barcelona, Spain). Determined to stay in Barcelona Hadrien carried out a second masters degree at the

International Center for Numerical Methods in Engineering (CIMNE) in the Finite Elements Method. In parallel he studied a DEA in Applied Physic in UPC (University polytechnic of Catalonia, Barcelona, Spain) with Prof. Jose-Manuel Redondo. To validate both diplomas, he fulfilled a 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 realized various studies on engineering and biomedical research such as the respiratory system which he has done collaborations with many institutions worldwide including Imperial college of London, North Carolina State University, Gifu college in Japan or RMIT University of Melbourne. 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.

ABSTRACT

Physiologically, sinus ventilation is a critical aspect of good functionality for human respiratory function. The understanding of this physiologic function is still unclear. In this study we develop a method to measure sinus ventilation. Spatial and temporal features of the sinus recirculation are provide through Dynamic mode descomposition (DMD). We associate the recirculation feature on the sinus epithelial surface through the wall shear-stress to the 3D airflow features corresponding into the sinus. The LES turbulence model was used to describe the airflow in a patient who receives an endoscopic sinus surgery of the ethmoid+sphenoid sinus. We analyze the flow rate through the ostium and the average wall shear-stress on the sinus epithelial surface. Based on the results we then use dynamic mode decomposition method on the sinus which accurately measure the recirculation on the cavity. We suggest that sinus ventilation using DMD is a powerful method in the analysis and understanding of this complex pathophysiology problem.

DAVID WHITE, PHD
Auckland University of Technology, New Zealand

3.6 Distribution, pressure, and shear stress mapping within an anatomically accurate nasal airway model during simulated saline irrigation

Dr. David White is a senior lecturer leading mechanical design and biomedical modelling subjects at the Auckland University of Technology School of Engineering, Computer and Mathematical Sciences. Acting in his role as Director of the AUT BioDesign Lab, David is a strong advocate of interdisciplinary research ranging from sleep and stroke to metabolic disease studies, and is very active in the New Zealand Medical Technologies Centre of Research Excellence as an Associate Investigator providing medical device design expertise. With a strong industry and academic background in mechanical design, David has focused on applied research centered on innovating breathing devices or therapies and is listed inventor in five patents.

With an emphasis on the human upper airway, and in particular the nose, David has recently been investigating the role augmented air pressure has airway physiology and new forms of breathing therapy and devices are now being developed as a result of this on-going work including the role of the nasal cycle and how breathing influences human physiological/neurological systems. The thrust of this work being the design of new breathing therapy devices which has led to the design of the Rest-Activity Cycler (RACer) breathing system. This therapy offers a new treatment paradigm for obstructive sleep apnea and has opened a new research theme that investigates how nasal breathing can influence health and well-being.

ABSTRACT

Introduction: Nasal saline irrigation therapy is used in inflammatory nasal and paranasal disease treatment and after nasal and sinus surgery. Saline irrigation is thought to improve nasal airway surface liquid (ASL) hydration and mucociliary transport. Previous in-vitro studies have demonstrated hypertonic saline solution, combined with cyclic pressure and wall shear stress mechano-stimulation, can positively influence mucociliary clearance. Aims: This study aims to use in-vitro findings to improve clinical management. Method: The distribution of saline solution, along with the mucosal pressures and wall shear stresses exerted on the nasal cavity and maxillary sinus walls, were mapped during simulated nasal saline irrigation using computational fluid dynamics in four different head positions. An anatomically accurate in-vivo nasal airway geometry which reflected the nasal cycle status with one side being 'congested' and the other 'patent' was used. Particle image velocimetry measurements were used to confirm the validity of the numerical methodology used in this study. Results: For all head positions, except the 90° head position, the saline distribution in the nasal cavity was greater when saline entered from the patent side of the nose. Patent side irrigation also resulted in saline pressure and mucosal wall shear stress distributions capable of improving ASL hydration and stimulating mucociliary clearance along the epithelium surfaces of both conducting nasal airways. Conclusions: Head position and nasal patency influence nasal saline irrigation effectiveness. Distribution, pressure field and wall shear stresses in the nasal cavity and maxillary sinuses during nasal saline irrigation have been mapped to provide clinical guidance to treatment.

3.7 Nasal nitric oxide (nNO) dynamics and the ostiomeatal complex: Fertile ground for CFD?

DENNIS SHUSTERMAN, MD, MPH
University of California San Francisco, USA

Dr. Shusterman graduated from the University of California, Davis School of Medicine and the University of California, Berkeley School of Public Health. He holds boards in Family Medicine and Preventive (Occupational and Environmental) Medicine. During his sixteen years in public health (California Department of Public Health and California Environmental Protection Agency), he studied air pollution from industrial operations, hazardous waste sites, urban wildfires, and accidental chemical releases, as well as tracking workplace chemical hazards. Based on clinical and epidemiologic practice, he developed a special interest in the interacting effects of air pollutants and allergens on the upper airway. During his thirteen years in academia (University of California, San Francisco and the University of Washington), he established the Upper Airway Biology Laboratory and completed numerous studies of nasal sensory and physiologic reactivity to chemical irritants. These studies involved collaborations with colleagues in allergy, otolaryngology, pulmonary medicine and sensory science. He currently evaluates and treats patients at the University of California, Berkeley Occupational Health Service.

ABSTRACT

Nitric oxide (NO) is an endogenously produced airway gas, and has been used in the lower airway to monitor inflammation in asthma. In the upper airway, however, the paranasal sinuses serve as a reservoir of NO, and nasal NO (nNO) levels are affected by the patency of communication between the sinuses and nasal cavities (principally through the ostiomeatal complex - OMC). Because the OMC can be obstructed in inflammatory sinus disease, there is a complex relationship between upper airway inflammation and nNO. Aims: 1) To review empirical studies relating radiographic indices of OMC patency with nNO levels. 2) To review studies that have compared nNO levels sampled under baseline ("quiet") and acoustically stimulated conditions; 3) To propose that computational fluid dynamic (CFD) methods may have relevance to understanding nNO flux vis-à-vis anatomical and inflammatory variations in OMC patency. Methods: Summary of authors' published nNO study of 33 human subjects utilizing three-dimensional CT reconstructions. Review of literature.

Results: Published studies verify that OMC patency predicts baseline (but not acoustically stimulated) nNO in nonallergic individuals. Radiographic correlates of nNO in inflammatory disease have been variable, however. Treatment of chronic rhinosinusitis with polyposis with oral steroids has been shown to produce a paradoxical increase in nNO, presumably by restoring OMC patency. Conclusions: Nitric oxide is an inflammatory marker that is difficult to model in the upper airway. Application of CFD methods to NO flux through the OMC might be a logical extension of existing CFD models of aerosol penetration into the sinuses.

JULIA KIMBELL, PHD
University of North Carolina at Chapel Hill, USA

4.1 CFD in Rhinology: Where are we and what comes next?

ABSTRACT

From basic anatomy and physiology to complex devices and surgical decision-making, CFD is helping clinical and basic science researchers frame new hypotheses and try out exciting ideas. In this talk, we'll see where we currently stand, including current limitations, and take a very brief look at some of the many intriguing roads ahead for our field.

HILLARY NEWSOME, MD
Medical College of Wisconsin, USA

4.2 Quantifying airflow limitation due to dynamic lateral nasal wall collapse

Hillary Newsome is a third year otolaryngology resident at the Medical College of Wisconsin. She completed her medical degree at the University of Pittsburgh after obtaining a bachelor's degree in biomedical engineering at her hometown institution, Washington University of St. Louis. She hopes to pursue a fellowship in facial plastic and reconstructive surgery after residency. Her research interests include nasal airflow obstruction and narrative medicine. Hillary is also interested in the experience of underrepresented minorities in academia.

ABSTRACT

Background: Nasal airway obstruction (NAO) surgery has a high failure rate partially due to lack of objective tools to quantify airflow and identify which patients would benefit from surgery. Virtual surgery planning based on CFD simulations holds the promise to improve the efficacy of NAO surgery, but currently does not account for lateral nasal wall (LNW) collapse. This study aimed to develop an experimental system to quantify the relationship between LNW stiffness and airflow limitation. Methods: Flexible models of the external nose based on a CT of a healthy subject were fabricated using silicone molding. LNW stiffness was varied by using silicone with different moduli of elasticity (E=14kPa or 361kPa). In vitro experiments were performed to quantify the pressure (P) vs. flow (Q) curve using a flowmeter, a pressure catheter, and an animal ventilator (capable of producing a physiologic sinusoidal breathing profile). Unilateral nasal resistance ($R=\Delta P/Q$) was calculated at a pressure drop of ΔP =150Pa (standard for rhinomanometry). Results: Inhalation rate at ΔP =150Pa was 363.3mL/s in the most flexible model (E=14kPa) and 568.3mL/s in the least flexible model (E=361kPa). Resistance was 0.414Pa.s/mL in the most flexible model and 0.264Pa.s/mL in the least flexible model. Conclusion: This is the first study of an anatomically-accurate model of airflow limitation from LNW collapse. Our results are consistent with clinical symptoms of LNW collapse and resulting NAO. Further experiments will investigate the interplay between LNW stiffness and reduced airspace cross-sectional area, and can be used to validate computational models of LNW collapse

KLAUS VOGT, MD, DDS, PHD
University of Latvia, Latvia

4.3 Critical evaluation of methods determining the influence of elasticity of the lateral nasal wall

Practiced as Assistant Doctor in Dentistry, General Medicine, Surgery and Anaesthesiology till 1965 at the University-Hospital Halle and the Regional Hospital Wolfen.

1966 - 1977 Specialisation and ongoing work in Otorhinolaryngology at the Ernst-Moritz-Arndt-University Greifswald/ Germany. Research in salivary gland physiology and pathophysiology of the nose and the paranasal sinuses. Since 1971 senior surgeon.

1977 Doctor of Medical Sciences (Dr.sc.med.).

1977-1990 Senior Surgeon at the ENT-Dept. of the University Hospital Charité in Berlin, since 1982 1st Senior Surgeon. Special experience in rhinosurgery, surgery of the paranasal sinuses, parotid surgery, head and neck surgery, ear surgery. Leader of the clinical department.

1982 Vocation as "High School Docent" (Assoc. Professor).

Ongoing Research in nasal physiology and technical development of diagnostic procedures. Scientific cooperation with the Institute of Postgradual Medical Education in Tbilisi/Georgia.

1989 Associate Professor of the University of Addis Ababa/Ethiopia

1990-2009 Private Practice and Clinic for Outpatient ENT-Surgery in Rendsburg / Germany, since 2006 in partnership with Dr. M. Klopf.

Since 2005 Guest Professor Medical Faculty, University of Latvia, Riga.

2000-2013 CEO of Rhinolab GmbH

Since October 2013 Head of MedTecResearch, a private research institute for medicotechnical research in D- 18292 Krakow am See/Germany

Member of the German ENT-Society, European Rhinologic Society, International Rhinologic Society. Past Chairman of the International Committee for the Objective Assessment of the Nasal Airway (ISOANA) at the International Rhinologic Society. Initiator of the international and interdisciplinary Consensus Conference on Nasal Airway Function Tests Riga, November 2, 2016 and author of the new standard publication 2018.Founding member of the German-Austrian project "Rhinodiagnost."

2019 Doctor Honoris cause (Dr.h.c.) of The University of Latvia in Riga/Latvia.
More than 300 Lectures in national and international congresses, 76 publications, 6 patents

ABSTRACT

The nasal entrance with the so-called nasal valve is the narrowest compartment of the entire upper airway. "Valve phenomena" have been diagnosed only by visual estimation and subjective complaints. Loops in the patterns of 4-phase-rhinomanometry indicate weak valve structures by loops. A quantitative clinical test to evaluate the elastic properties of the nasal valve is missing, but the onset of mobility of the valve in minimal nasal airstream was detected in 2018.

Laser distance measurements, simple optical distance measurements, improved strain gauge applications, inductive distance measurements and spectroscopic methods have been compared to find out the most reliable method for the determination of the elongation of the nasal wing in 42 volunteers after precision testing in mechanical models.

Laser distance measurements deliver the most precise results and show the movement of the nasal soft tissues from the first onset of a breath, but the method is not applicable in practice. Simple optical measurements are not precise enough to locate the distance. Spectroscopy of the nasal cavity is unreliable because of the influence of vibrissae. Calibrated inductive measurements deliver reproducible results as well as strain gauge measurements within an improved setting

The dynamic analysis of the nasal air stream must consider the elastic properties of the nose and its influence on the shape of the air channel. Therefore, an initial physical analysis by 4-phase-rhinomanometry including an elastometric test with the same equipment, should be developed as medical product.

ALEJANDRO PARDO ANTUNEZ
Universidad Politéncia de Cartagena, Spain

4.4 Looking for a relationship between chronic otitis media and nasal obstruction: a CFD analysis

Dr. 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.

ABSTRACT

There are many studies in the past which have reported a relationship between chronic otitis media (COM) and nasal problems. Eustachian tube dysfunction, septal deviation, adenoids are some of the pathologies involved. However, although clinicians know that most of the patients with COM usually have nasal pathology, the significance of this relationship is uncertain. We present here a CFD approach to the understanding of nasal physiology in patients operated of COM. 92 patients operated of COM and 55 controls were analyzed using CFD software. Most patients with COM had altered CFD parameters, whereas most of the controls were considered normal. To our knowledge, this is the first report dealing with COM patients though a CFD analysis.

ANDREW FRASER, MD, MS
University of California Los Angeles, USA

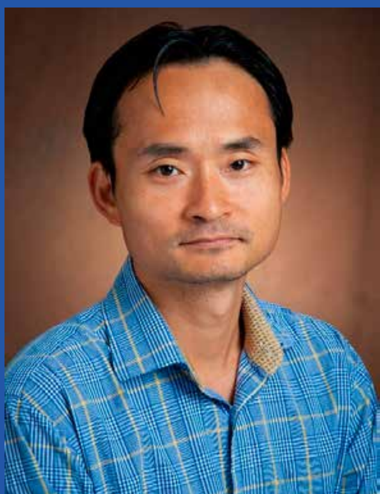
4.5 Quantifying the effect of maxillary skeletal expansion on the airway in adult orthodontic patients using computational fluid dynamics

Dr. Andrew Fraser is the chief resident at the University of California Los Angeles School of Dentistry Section of Orthodontics. In addition, Dr. Fraser is the lab manager for Professor Won Moon's research lab, focused on clinical investigation into the effects of Dr. Moon's patented non-surgical expander, the MSE. Dr. Fraser's research is focused on the effects of maxillary skeletal expansion on the adult orthodontic patient's ability to breath and on changes to airway. Dr. Fraser earned his D.M.D. degree from the University of Pennsylvania School of Dental Medicine in 2016. Dr. Fraser has an M.S. in biomedical engineering from Tufts University and was the recipient of a research fellowship in immunology and microfluidics at Harvard University in 2010.

ABSTRACT

Transverse maxillary arch deficiencies commonly complicate treatment in orthodontics. In the adult patient, a problem arises as to how to expand the maxilla when the mid-palatal suture has already fused without the usage of surgery. Traditional expanders would not correct the skeletal deficiency as the resulting movement would be dental tipping. Therefore, for adult patients, the maxillary skeletal expander (MSE) by Professor Won Moon is ideal. MSE uses four temporary anchorage devices (TADs) to transmit shear forces from a jackscrew to the hard palate via shear force, ultimately forcing the mid-palatal suture open in patients for which the suture has already fused. Progressive changes in patients who undergo MSE expansion and successfully split may shed light on an incidental finding suggesting that breathing can improve after treatment. As expansion occurs, the boney housing of the nasopharynx expands, potentially allowing for more air input and less resistance. To gain more insight into these changes, a computational fluid dynamic (CFD) model could be made for MSE patients to examine how the flow of air changed post treatment as well as changes to pressure, velocity,

and turbulence. Previous studies have modeled patient airways post orthodontic treatment using CFD, however, these models are non-physiologic and have not shown how flow rate of air changes after MSE treatment. In this discussion, we demonstrate the process to measure changes to airway via segmentation and CFD after non-surgical expansion with the MSE and examine the overall effects of MSE on the patient's ability to breathe.



TRUNG LE, PHD
North Dakota State University, USA

4.6 Airflow limitation in a collapsible model of the human pharynx

Dr. Trung Bao Le is an Assistant Professor at the Department of Civil and Environmental Engineering, North Dakota State University (NDSU). Before joining NDSU, Dr. Trung Bao Le has worked at several universities including the Medical College of Wisconsin/Marquette University, University of Minnesota and Stony Brook University. His research focuses on fundamental phenomena in fluid mechanics at variety of temporal and spatial scales. His techniques involve the development for scalable numerical algorithms that can run from desktop computer to supercomputers to study such problems. In particular, the main theme is studying vortex structures resulted from fluid-structure interaction processes between tissues and medical devices in human heart, brain and upper airways under healthy and pathological conditions.

ABSTRACT

We investigate the validity of the Starling Resistor model for airway collapse in obstructive sleep apnea (OSA). This work focuses on investigating the limits of the wave-speed flow limitation (WSFL) theory in OSA patients. Fluid-structure interaction (FSI) simulations are emerging as a technique to quantify how the biomechanical properties of the upper airway determine the shape of the pressure-flow curve. This study aimed to test two predictions of the WSFL theory, namely (1) the pressure profile upstream from the choke point becomes independent of downstream pressure during flow limitation and (2) the maximum flowrate in a collapsible tube as predicted by WSFL theory. FSI simulations were performed in a model of the human upper airway with a collapsible pharynx whose wall thickness varied from 2 to 8 mm and modulus of elasticity ranged from 2 to 30 KPa. Experimental measurements in an airway replica with a silicone pharynx validated the numerical methods. Our experimental data and FSI simulations show that the flow limitation in our model can be predicted well by the WSFL theory. Other key findings include: (i) the pressure-flow curve is independent of breathing effort (downstream pressure vs. time profile); (ii) the shape of the pressure-flow curve reflects the airway biomechanical properties, so that the maximum flowrate is a surrogate measure of pharyngeal compliance.

INDUSTRY PARTNERS

SCONA 2019 is generously supported by our industry partners.

We acknowledge the collaboration and assistance of our principal sponsor in the success of SCONA 2019.

NeilMed®
PHARMACEUTICALS PTY. LTD.