AIRWAY EVALUATION BEFORE AND AFTER APPLICATION OF IMPLANT SUPPORTED PALATAL EXPANSION VS CONVENTIONAL PALATAL EXPANSION USING COMPUTATIONAL FLUID DYNAMICS (CFD)

Dissertation submitted to

THE TAMILNADU Dr. M.G.R. MEDICAL UNIVERSITY

In partial fulfillment for the degree of

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ORTHODONTICS AND DENTOFACIAL ORTHOPAEDICS

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CHENNAI

DECLARATION BY THE CANDIDATE

I hereby declare that this dissertation titled **"AIRWAY EVALUATION BEFORE AND AFTER APPLICATION OF IMPLANT SUPPORTED PALATAL EXPANSION VS CONVENTIONAL PALATAL EXPANSION USING COMPUTATIONAL FLUID DYNAMICS (CFD)"** is a bonafide and genuine research work carried out by me under the guidance of **Prof. Dr. N.R. KRISHNASWAMY, M.D.S., M.Ortho (RCS, Edin), D.N.B. (Ortho), Diplomate of Indian board of Orthodontics,** Head, Department of Orthodontics and Dentofacial Orthopedics, Ragas Dental College and Hospital, Chennai.

Dr. Sam Prasanth. S
Post Graduate Student
Department of Orthodontics and
Dentofacial Orthopedics,
Ragas Dental College and Hospital,
Chennai

Date: 29/01/2018

Place: **Chennai**

CERTIFICATE

This is to certify that this dissertation titled **"AIRWAY EVALUATION BEFORE AND AFTER APPLICATION OF IMPLANT SUPPORTED PALATAL EXPANSION VS CONVENTIONAL PALATAL EXPANSION USING COMPUTATIONAL FLUID DYNAMICS (CFD)"** is a bonafide record work done by **Dr. SAM PRASANTH. S** under my guidance during his post graduate study period 2015-2018.

This dissertation is submitted to **THE TAMILNADU Dr. M.G.R. MEDICAL UNIVERSITY,** in partial fulfillment for the degree **of MASTER OF DENTAL SURGERY in BRANCH V** - Orthodontics and Dentofacial Orthopedics. It has not been submitted (partially or fully) for the award of any other degree or diploma.

Guide & Head of the Department:

29/1/18

Prof. (Dr.) N.R. Krishnaswamy M.D.S.,
M. Ortho R.C.S. (Edin) Dip N.B. (Ortho)
Diplomate-Indian Board of Orthodontics
Department of Orthodontics,
Ragas Dental College and Hospital,
Chennai.

Dr. N. R. KRISHNASWAMY

PROFESSOR & HEAD
Dept. of Orthodontics
RAGAS DENTAL COLLEGE & HOSPITAL
2/102. East Coast Road
Uthandi, Chennai-600 119

Dr. N. S. Azhagarasan, M.D.S.,
Principal,
Ragas Dental College and Hospital,
Chennai.

PRINCIPAL
RAGAS DENTAL COLLEGE AND HOSPITAL
UTHANDI, CHENNAI-600 119.

THE TAMIL NADU Dr. MGR MEDICAL UNIVERSITY CHENNAI

PLAGIARISM CERTIFICATE

This is to certify the dissertation titled **"AIRWAY EVALUATION BEFORE AND AFTER APPLICATION OF IMPLANT SUPPORTED PALATAL EXPANSION VS CONVENTIONAL PALATAL EXPANSION USING COMPUTATIONAL FLUID DYNAMICS (CFD)"** of the candidate **Dr. S. Sam Prasanth** for the award of **MASTER OF DENTAL SURGERY** in **BRANCH V - Orthodontics and Dentofacial Orthopedics.**

On verification with the urkund.com website for the purpose of plagiarism check, the uploaded thesis file from introduction to conclusion contains **3 percentage** of plagiarism, as per the report generated and it is enclosed in Annexure – II.

Date: 29/01/2018
Place: Chennai

29/1/18

Dr. Sam Prasanth. S
Post Graduate Student,
Department of Orthodontics,
Ragas Dental College and Hospital,
Chennai

Prof. (Dr.) N.R. Krishnaswamy M.D.S.,
M. Ortho R.C.S. (Edin) Dip N.B. (Ortho)
Diplomate-Indian Board of Orthodontics.,
Guide & Head of the Department,
Department of Orthodontics,
Ragas Dental College and Hospital,
Chennai.

Dr. N. R. KRISHNASWAMY.

PROFESSOR & HEAD
Dept. of Orthodontics
RAGAS DENTAL COLLEGE & HOSPITA
2/102. East Coast Road
Uthandi. Chennai-600 119

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CONTENTS

LIST OF TABLES

LIST OF FIGURES

ABSTRACT

Introduction:

Maxillary transverse deficiency is one of the most common skeletal problems in craniofacial region. Constricted upper dental arch may result from abnormal functions such as abnormal breathing pattern. RME has been used as a routine clinical procedure in orthodontics, with its main purpose to expand the maxilla in young patients who had transversal maxillary constriction. An increase in nasal cavity width occurs after RME, particularly at nasal floor adjacent to mid-palatal suture. With advent of TADs, skeletal expansion is possible even in adults. As maxillary halves separate, outer walls of nasal cavity move laterally, and thus intranasal capacity increases.

Purpose:

The purpose of this study is to evaluate the airway changes in adults using two different expansion appliances: a traditional hyrax expander versus a hybrid hyrax expander appliance by employing Computational Fluid Dynamics.

Materials and Methods:

10 patients treated with a hybrid-hyrax RME and 10 treated with a hyrax RME were utilized for this study. CBCT scans were taken before treatment and after removal of appliance. 3D volume of pharyngeal airway was generated using MIMICS and Computational fluid dynamics assessment

was done using ANSYS. Changes in pre-and post-treatment measurements were measured and differences between the two treatment groups were evaluated using Mann-Whitney test and Wilcoxon signed rank test.

Results:

In hybrid hyrax RME, there was a statistical significant intragroup difference in Pressure (Pa) and Flowrate (sec). However, Maximum Velocity(m/s) showed no statistically significant change. In hyrax group all three parameters showed difference without statistical significance. Overall, the hybrid hyrax RME produced more changes in airway compared to conventional hyrax RME device.

Conclusions:

Comparative improvement of nasal airflow characteristics was seen in mini implant assisted expander group (MSE-1) which might be due to increased skeletal effects of implant supported palatal expansion as it produced statistically significant differences at nasal, frontonasal and zygomatic bone level. Further studies could be designed to examine the long-term effects of the hybrid hyrax expansion on pharyngeal airway.

Key word: *Hyrax RME, Implant-supported RME-hybrid hyrax RME, Cone beam computed tomography, Adult expansion, Pharyngeal airway changes, Computational fluid dynamics.*

Introduction

INTRODUCTION

Rapid maxillary expansion has been widely used by orthodontists to correct the maxillary transverse deficiency which is one of the most common skeletal problems in craniofacial region.

Naso-respiratory function and its relation to craniofacial growth are of great interest today, not only as an example of basic biological relationship of form and function but also because of great practical concern to paediatricians, otorhinolaryngologists, allergists, speech therapists, orthodontists, and other members of health-care community as well, to provide a better quality of life to patients. [1][43][75]

The only option for palatal expansion in adults was surgically assisted rapid palatal expansion but due to the discomfort caused, the option is declined by many adults. [8]

With the advent of TADs expansion is possible in adult without surgical intervention. These appliances anchor the expansion screw either directly to the palatal bone or along with a stabilizing wire to a dental unit.

It has been demonstrated by clinical studies that nasal cavity width increases, nasal airway resistance decreases, and nasal breathing improves. [71][75]

Previous methods of evaluating nasal airway ventilation include x-rays[41], computed tomography[83], rhinomanometry[42], acoustic rhinometry[22] and polysomnography[10].

Rhinomanometry and acoustic rhinometry are objective tests for the assessment of nasal airway patency. Rhinomanometry measures air pressure and rate of airflow during inspiration and expiration, which are used to calculate resistance in nasal airway. Acoustic rhinometry uses a reflected sound signal to measure the cross-sectional area and volume of nasal passage. Rhinomanometry gives a functional evaluation of the pressure and flow relationships during the human respiration but acoustic rhinometry gives only an anatomic description of a nasal cavity lumen.

Postero-anterior cephalometric head films are routinely used for the evaluation of treatment effects of RME and nasal cavity width measurements. It has been well accepted by all clinicians that RME increases nasal air way dimensions.

However, acoustic rhino metric measurements cannot correctly detect constrictions and expansions less than 3 to 4 mm. Lateral and anteroposterior cephalometric evaluations have been used to assess the changes in upper airway dimensions, but the complex morphological variations of the airway after RPE treatment is not represented well with 2-dimensional images. [20]

Hence, it is difficult to take precise measurements of nasal airway ventilation with these methods because of the complicated form of the nasal airway lumen. Therefore, there is no sufficient evidence that states nasal airway ventilation improves with rapid maxillary expansion.

When compared with magnetic resonance imaging and traditional CT techniques, CBCT is a better method for airway volume measurement because of easier access, availability, and much lower overall effective absorbed dose of radiation than conventional CT and also it is cost effective.[44][52][59]

To better evaluate the relationship between respiratory function and nasal morphology, a 3-dimensional (3D) model of each subject’s nasal cavity was constructed from computed tomography data and used to create computational fluid dynamics models of respiratory status during quiet respiration.

Computational Fluid Dynamics (CFD) is a computer-based tool for simulating the behavior of systems involving fluid flow, heat transfer, and other related physical processes. CFD works by solving the equations of fluid flow over a region of interest, with specified (known) conditions on the boundary of that region. [73]

As conventional methods that cannot separate nasal airflow from nasopharyngeal airflow, computational fluid dynamics can evaluate airflow in the nasal cavity alone, giving a more accurate evaluation of the effect of rapid maxillary expansion. [39]

Aim of the study

1) To evaluate velocity, pressure and flow rate in pre-and post treatment models in implant supported palatal expansion group (hybrid hyrax) and conventional hyrax appliance group.
2) To compare the treatment outcomes between both the groups
3) To find the effect of palatal expansion of both groups on maximum constricted area of pharyngeal airway.

Review of Literature

REVIEW OF THE LITERATURE

History of Rapid Maxillary Expansion

The concept of widening the dental arch by means of opening the mid-palatal suture dates back to 1860 when **Angell** described rapid expansion of the upper arch in a paper he presented to the dental community. In the first issue of Dental Cosmos in 1860, he wrote of an apparatus that "at the end of two weeks, the jaw was so widened as to leave a space between the front incisors, showing conclusively that the maxillary bones had been separated."[2]

This concept of splitting the suture to expand the maxilla flourished during the early 1900s. These years have been referred to as the "maxillary expansion years" by both orthodontists and rhinologists. It was during this time that rhinologist **Brown**, as well as many others, promoted maxillary expansion for increasing nasal permeability and obtaining greater nasal width. [31][33]

Pfaff supported this concept with the opinion that expansion of the dental arch lowered the palatal vault and induced straightening of the nasal septum. [57]

Indications for RME are widespread in the literature. These include lateral discrepancies resulting in unilateral or bilateral crossbites, anteroposterior discrepancies, cleft lip and palate and to gain arch length. Rapid maxillary expansion as a means of increasing arch width and perimeter became a popular area of investigation resulting in numerous clinical and animal studies on the subject in the mid-1900s.

Haas' pig study indicated that the midpalatal suture could indeed be opened to a degree sufficient to cause a widening of the dental arch and an increase in intranasal capacity. [29]

Haas became one of the leaders in research regarding palatal expansion at that time and wrote numerous articles on the effects of palatal expansion. In an article in 1970, Haas noted the specific skeletal effects of rapid palatal including a triangular pattern of opening with the apex being in the nasal cavity. He also noted that the procedure produced forward and downward movement of the maxilla and downward and backward rotation of the mandible. [30]

Expansion Appliances

Since Angell and White’s first appliances, continuous efforts had been made to modify and improve Rapid Maxillary Expansion (RME) appliances.

In 1958, **Haas** introduced what is now referred to as the Haas appliance. This is a fixed appliance with orthodontic bands on the maxillary first molars and first premolars which are then allied to a jackscrew located in the center of the appliance; two acrylic plates cover the soft tissue of the palate.[31]

In 1968, **William Biederman** created an different design to the Haas appliance that was initially called the Biederman or Hygienic appliance, but later in time it came to be known as the Hyrax. [6]

This appliance contains bands on the maxillary first premolars and first molars, they were then soldered onto steel arms connected to a jackscrew. Overtime, countless modifications of the Hyrax have been made, but they are all termed Hyrax appliances to differentiate them from the Haas appliance.

Biederman appealed that his appliance was easier to construct, decreased irritation of the palatal mucosa, and had less effect on speech.

There have been numerous studies comparing the effects and side effects of the Haas and Hyrax appliances, showing a variety of results. Current studies have shown there is no significant difference in the results of expansion between the different appliance designs.

As a result, most practitioners tend to use one or the other appliance based on personal preference rather than differences in effectiveness or efficiency of one appliance design over the others.

Bone-anchored Rapid Maxillary Expansion

Traditional tooth-borne expansion appliances have been effectively used for decades to correct transverse maxillary deficiencies, yet this treatment is not without negative side effects. Disadvantages have been identified with traditional tooth-borne expansion appliances including limited skeletal movement, undesirable tooth movement, root resorption, dehiscence, a decrease in the thickness of the buccal cortical plate and relapse. Because of these disadvantages, alternative methods have been developed including the implant-supported rapid maxillary expander. These appliances anchor the expansion screw directly to the palatal bone, avoiding direct tooth contact. Likewise, bone-anchored expansion appliances may be indicated when a patient has missing or compromised posterior permanent teeth and periodontal concerns, providing an alternative when traditional RME cannot be used.

Lagravère et al. used CBCT to evaluate the transverse, vertical, and anteroposterior changes associated with bone-anchored and traditional rapid maxillary expansion in adolescents. [46]

The experimental group (bone-anchored maxillary expander) consisted of an appliance with two custom-milled onplants and 2 mini-screw implants (12 x 1.5 mm) to secure the expansion appliance directly to the palatal bone. This required the reflection of the periosteum and a second surgery to remove the appliance after treatment. Long term and short term changes were evaluated and the authors found that immediately after completion of appliance activation, the skeletal and dental changes for both treatment groups were similar.

The primary difference was greater expansion at the maxillary first premolars in the tooth-anchored maxillary expander group. Furthermore, root apex expansion was less than crown expansion for both the bone-anchored maxillary expander group and the tooth-anchored maxillary expander subjects, resulting in significant buccal crown inclination.

The results of this study indicate that tooth-anchored expansion appliances and bone-anchored expansion appliances produce similar results.

Carlson et al in his case report describes the use of a micro-implant-assisted rapid palatal expansion (MARPE) appliance to correct a transverse maxillary deficiency in a 19year old adult patient. The appliance was secured to the palatal bones with 4 micro-implants and it was expanded by 10 mm. Pre-and post-cone-beam computed tomography comparisons showed 4 to 6 mm of expansion of the maxillofacial structures. [11]

According to **Wilmes et al** the anterior palate is an ideal site for predictable and reliable placement of mini-implants. Within the segregations of the T-Zone, the orthodontist has a freedom of positioning mini-implants in either a median or a paramedian pattern. [76]

The clinician must determine the biomechanics needed to achieve treatment goals, considering the anatomical morphology of the insertion site and then adapt the selected location for specific appliance design. Median insertion of the implant is more than sufficient for sagittal and vertical tooth movements and for maxillary expansion in patients.

Paramedian insertion is preferable for rapid maxillary expansion and subsequent sagittal and vertical tooth movements.

Cone Beam Computerized Tomography in Orthodontics

Three-dimensional imaging offers many advantages with respect to diagnosis and treatment planning in orthodontics. Cone beam computerized tomography (CBCT) associates computerized volumetric reconstruction and conventional radiography to yield a three-dimensional image that is practical for orthodontic use. It is capable of imaging both hard and soft tissues, which adds to its usefulness.

Several authors have investigated the accuracy of measurements obtained from CT and CBCT images.[84][85][86] When compared to physical measurements on a dry skull, **Cavalcanti** found the measurement error to range from only 0.45 – 1.44%. This was deemed to be within a clinically tolerable range. [13]

Measurements on a precision grid from i-Cat scans showed the spatial accuracy to be universally within the tolerance of ±1 pixel.

Periago and Scarfe et al. also found that while there were small differences in linear measurements between CBCT scans and those on dry skulls, the differences were not significant. They concluded that measurements made in Dolphin 3D (Dolphin Imaging & Management Solutions, Chatsworth, CA) are clinically accurate for craniofacial analyses.[83]

Regardless of the study, the volumetric data rendered with CBCT systems provides highly accurate data compared with the gold standard of physical measures directly from skulls, with less than 1% relative error.

Airway evaluation in CBCT

Guijarro-Martı´nez in 2011, in a Systematic review confirmed that CBCT is an accurate and reliable tool for upper airway evaluation. This includes the assessment of the paranasal sinuses. Lateral head films offer limited information about the airway, with the inherent errors of a 2D representation of a 3D structure and the lack of information about cross-sectional area and volume. The advent of CBCT has provided the opportunity to assess the cross-sectional area and volumetric depiction of the upper airway precisely with an accessible, rapid, noninvasive, and low-radiation scan. [28]

Stratemann in this study utilized cone-beam computed tomography and airways were evaluated for 30 adults. He concluded that CBCT provides a method to acquire 3D volume of the airway through segmentation of voxels. He also states that by defining landmarks of the airway, superimposition of airways is also feasible. [66]

Yamashina evaluated the reliability of cone beam CT (CBCT) values and accuracy of pharyngeal dimensions and compared it with those of multidetector row CT (MDCT). He concluded that the measurement of the air space was quite accurate. [79]

Tamara Smith in 2012 conducted a retrospective study with 3-dimensional computed tomography and evaluated airway volume, soft-palate area, and soft-tissue thickness changes before and after rapid maxillary expansion in adolescents. 20 patients were treated with rapid maxillary expansion. Before and after RME measurements demonstrated statistically significant increases in nasal cavity and nasopharynx volumes were found.[65]

Kim et al assessed the pharyngeal airway in children with retrognathic mandible and compared it with children who had normal craniofacial growth. By using CBCT scans concluded that in preadolescents accurate volumetric evaluation of 3D pharyngeal airway is possible. [44]

Tso in 2009, in his study concluded that the CBCT system provides a low-radiation rapid scan capability to assess patients' airway using highly correlative linear, cross-sectional area, and volumetric measurements that include assessing the morphometry of the airway. [36]

Sadeghian assessed the effect of rapid maxillary expansion treatment on nasal cavity and upper airway using cone beam computed tomography. He evaluated 15 patients with maxillary width deficiency treated with rapid maxillary expansion. Patients were subjected to CBCT at the beginning of the RME treatment and again after the retention period of 4 months to measure the changes of retropalatal and retroglossal airways, nasal cavity and cephalometric parameters. His study showed that RME causes significant increase in transverse width of the nasal cavity, upper and retropalatal airways when assessed using CBCT. [60]

Ribeiro in his study evaluated fifteen patients with maxillary transverse deficiency treated with RME. CBCT was taken at the commencement of RME and after the retention period of 4 months. Significant transversal increase in the lower third of the nasal cavity 4 months was noted after the procedure, when assessed using CBCT. [59]

Mattos assessed the intra-examiner and inter-examiner reliabilities of upper airway dimensions and volumetric measurements in cone-beam computed tomograph**y.** His study concluded that airway assessments by different examiners might have reliable anteroposterior linear measurements; cross-sectional areas at the levels of the palatal plane and sagittal area and volume. [52]

Software reliability

Weissheimer assessed 6 imaging software programs for their precision and accuracy in measuring upper airway volumes. He concluded that all software programs were reliable. Mimics, Dolphin3D, OsiriX and ITK-Snap were comparatively same and better than others. [72]

Hakan El compared 3 commercially available digital imaging and communications in medicine (DICOM) viewers for their reliability and accuracy in measuring upper airway volumes and found that for airway volume calculations 3 commercially available DICOM viewers were highly reliable.[32]

Airway changes following Rapid Maxillary Expansion

Dale Hartgerink assessed the changes caused by rapid maxillary expansion in nasal resistance and reevaluated it l-year after follow-up. He concluded by saying RME causes an expansion at the anterior nares and contribute to reduction in nasal resistance. [34]

Timms in his trial with a sample of 26 patients, receiving rapid maxillary expansion as part of their orthodontic mechano-therapy, appraised for nasal airway resistance before and after expansion. His findings justify the use of RME in cases of high Nasal airway resistant due to anterior nasal stenosis. [21]

Hershey concluded in his study that Rapid maxillary expansion produced a significant reduction in nasal resistance measured at both 0.50 L.

per second and 0.25 IA. per second air flow. The reduction of nasal resistance by maxillary expansion was stable through a 3- month period of retention. [23]

Baccetti et al studied the long-term effects of the Haas appliance in nasal cavity width before and after growth peak on 42 patients and 20 controls. Three posteroanterior radiographs were used to evaluate arch changes (initial, immediately after treatment, and 5 years posttreatment). Long-term evaluation was 8 years. In the early-maturing group, the RME group had more internasal width changes (4.5mm) than the control group (2.2 mm). In the late-maturing group, the RME group had more internasal width changes (2.2 mm) than the control group (0.7 mm). The early-maturing group showed a larger increase than the late-maturing group. [3]

Langer et al evaluated dimensions of the nasopharyngeal space and and its changes due to rapid maxillary expansion (RME) also its relation to nasal airway resistance. 25 children of age from 7yrs to 10yrs were chosen. Rhinomanometry was performed at four different times, before treatment, immediately after expansion, 90 days after treatment and 30 months after treatment after RME. He concluded by saying RME does not interfere in nasal resistance or in nasopharyngeal area in long-term evaluation. [49]

Buccheri et al., concluded in their study that RME would increase nasopharyngeal space because of its orthopedic effect in the tissues that delimit the maxilla, thus improving the position of the tongue and increasing nasopharynx space. [7]

Castillo in his systematic review said that there is sufficient scientific evidences suggesting, changes after RME in growing children ameliorate the conditions for nasal breathing and stable results were seen for at least 11 months post retention.[12]

Zhao et al studied the long-term effects of RPE in the volume of the oropharynx. They used the Hyrax appliance with a protocol of 1 to 2 turns per day until the required expansion with a slight overcorrection, followed by fixed orthodontic treatment. This study used CBCT to measure airway volume, airway length, and MCA. 24 patients were included in the study with an age range from 8.9 to 15.1 years, and 24 patients were in the control group with an age range from 8.6 to 15.8 years. The long-term evaluation was 15 months. No significant differences were found between the study group and the control group. There is no evidence that RPE could enlarge oropharyngeal airway volume. [93]

Pereira-Filho evaluated volume changes in the upper airway in 15 adult patients with transverse maxillary deficiency who undertook surgically assisted rapid maxillary expansion (SARME). CBCT volumetric images were obtained. He concluded that maxillary expansion when done as a distinct procedure, does not result in a statistically significant enhancement in the airway measurements whereas it results in an inferior relocation of the smallest transverse section area. [56]

Zeng conducted a prospective study to investigate the upper airway changes after rapid maxillary expansion utilizing CBCT. 16 children (a mean age of 12.73 ± 1.73 yr) underwent RME as part of their treatment with 4,6-banded hyrax expanders. CBCT images were taken directly before (T1) and three months after expansion (T2) in upright position, with patients' heads kept in consistent position. He concluded that, after RME, the nasal cavity expands, which may play a major role in the breath function. Parallel opening configuration in expansion pattern may be seen in nasal cavity. But the influence on the pharyngeal airway is limited. [81]

Vale in a systematic review & meta-analysis in 2017 revealed that the RME has a significant effect on Obstructive Sleep Apnea Syndrome improving the apnea-hypopnea index and opinioned that this therapeutic approach may be considered as an auxiliary in the treatment of children with OSAS. [69]

Kilic in his literature review observed that although orthodontic treatment is carried out to correct dental and skeletal discrepancies, treatment outcomes may be effective on naso respiratory problems and OSA of the growing children, especially during pre-pubertal and pubertal growth period. [43]

Buck et al in 2017 conducted a systematic review & meta-analysis and concluded that RME in growing patients with transversal maxillary constriction might be associated with a short-term increase in the total upper airway volume. [9]

De Felippe et al assessed the effects of rapid maxillary expansion on the morphology of the maxillary dental arch and nasal cavity dimensions. Thirty-eight subjects participated in this study (mean age, 13 years). Data were collected before expansion, when the expander was stabilized, when the expander was removed, and 9 to 12 months after the expander was removed.

3D imaging and acoustic rhinometry were used to assess the simulated cast and the nasal cavity, correspondingly. He concluded in his study that Nasal airway resistance had a statistically significant reduction between T1 and T2 (25.5%) and stabilized until T4. Nasal volume improved significantly by 18% between T1 and T2, steadied until T3, and increased significantly by 13.7% until T4. Subjective impression of improved nasal breathing was testified by 61.3% of subjects after RME. [19]

Cordasco did a retrospective clinical trial in growing subjects by employing low dose computer tomography, to evaluate the effects of rapid maxillary expansion on skeletal nasal cavity size. Rapid maxillary expansion yielded significant upsurges of linear transverse skeletal measurements, these increments were bigger in the lower portion of the nasal cavities: nasal floor width (+3.15 mm; SD 0.99), maximum nasal width (+2.47 mm; SD 0.99). Rapid maxillary expansion produced significant increment of the total nasal volume (+1.27 cm^3 SD 0.65). The anterior volume upsurge was 0.58 cm3 while the posterior one was 0.69 cm3. He concluded that RME causes significant skeletal transverse augmentations in the palatal and nasal regions. These increments are bigger in the lower portion of the nasal cavities.

Moreover, RME can increase significantly skeletal nasal cavity volume. The volume increase is equally distributed amongst the anterior and the posterior part of the nasal cavity. [18]

Baratieri in his systematic review, qualified and identified the evidence of long-term reports on the effects of rapid maxillary expansion (RME) on airway dimensions and functions. His findings are i) nasal cavity width increase was seen in posteroanterior radiographs; decreased cranio-cervical angulation which was perceived along with increases of posterior nasal space was seen in lateral radiographs, ii) Cone-beam computed tomography did not reveal significant increases of nasal cavity volume iii) Rhinomanometry presented reduction of nasal airway resistance and upsurge of total nasal flow, and increase in minimal cross-sectional area and nasal cavity volume was found using acoustic rhinometry. He suggests there is rational evidence that, changes after RME in children who are growing, improve the conditions for nasal breathing and the results can be predicted to be stable for at least 11 months after therapy. [4]

Computational fluid dynamics

The history of CFD

Computers have been used to unravel fluid flow problems for several years. Numerous programs have been inscribed to solve either explicit problems, or specific classes of problem. From the mid-1970's the complex mathematics required to oversimplify the algorithms began to be understood, and general-purpose CFD solvers were developed. These began to emerge in the early 1980's and the need of very powerful computers was vital, as well as an in-depth knowledge of fluid dynamics, and large expanses of time to set up simulations. Consequently, CFD was a tool used solely in research.

Recent developments in computing supremacy, organized with powerful graphics and collaborative 3-D use of models mean that the method of creating a CFD model and investigating the results is much less labour-intensive, plummeting the time and therefore the cost. Advanced solvers contain algorithms, which enable healthy solution of the flow field in a rational time.

Because of these influences, Computational Fluid Dynamics is now an established industrial design instrument, serving to reduce design timescales and improve progressions all over the engineering domain. CFD provides a cost-effective and true alternative to scale model testing, with variations on the simulation being performed rapidly, offering noticeable advantages.

There are a number of different solution methods which are used in CFD codes. The most common, and the one on which CFX is based, is known as the finite volume technique. In this method, the area of interest is divided into small sub-regions, and are named as control volumes. The equations are discretized and solved iteratively for each control volume. As a result, a guesstimate of the value of each variable at specific points all over the domain can be obtained. In this way, one derives a full picture of the behavior of the flow.

Any kind of CFD computation requires the specification of inlet and boundary conditions. Obviously, these conditions determine the flow and temperature field resulting from the CFD computation. The specification of inlet and boundary conditions requires appropriate measurements. [73]

Governing equations of CFD

CFD is playing a strong role as a design tool as well as a research tool. In CFD the physical aspects of any fluid flow is governed by three principles.

The fundamental equations of fluid mechanics are based on the following

Universal laws of conservation:

1. Conservation of mass
2. Conservation of momentum
3. Conservation of energy

These fundamental physical principles can be expressed in terms of basic mathematical equations. These equations are generally in integral or partial differential form. These equations and their derivatives are replaced in CFD by discretised algebraic forms, which are in turn solved to get flow field values at discrete points in space and/or time. The end product is a collection of numbers, in contrast to closed-form analytical solution. In CFD approach, the equations that govern a process of interest are solved numerically.

The equation that results from applying the conservation of mass to a fluid is called the continuity equation. Conservation of momentum is based on application of Newton's Second Law to a fluid element, which yields a vector equation, which is also called Navier-Stokes Equation. The conservation of

Energy is based on the application of First Law of Thermodynamics to a fluid element.

In addition to the equations developed after these universal laws, it is necessary to establish relationships amid fluid properties to close the system of equations. An instance of such a relationship is the equation of state, which describes the thermodynamic variables pressure p, density , and Temperature T. Factually, there have been two different approaches taken to derive the equations of fluid mechanics viz., **phenomenological approach** and **kinetic theory approach**. In the phenomenological approach certain relationship amongst stress and rate of strain, heat flux and temperature gradient are claimed, and the fluid dynamic equations are then developed from the conservation laws. The required constants of proportionality amongst stress and rate of strain and heat flux and Temperature gradient must be estimated experimentally. In the kinetic theory approach also known as the mathematical theory of non-uniform gases, the fluid dynamic equations are obtained with the transport coefficients defined in terms of certain integral relations, which involves dynamics of colliding particles. [73]

Computational fluid dynamics assessment of airway

Iwasaki in 2012 conducted a longitudinal study to use computational fluid dynamics to estimate the effect of rapid maxillary expansion. Twenty-three children of mean ages, 9.74 +_ 1.29yrs, who required rapid maxillary expansion as part of their orthodontic treatment had cone-beam computed tomography images taken before and after rapid maxillary expansion. The computed tomography data were used to restructure the 3-dimensional shape of the nasal cavity. Two measures of nasal airflow function (pressure and velocity) were emulated by using computational fluid dynamics. The pressure after rapid maxillary expansion (80.55 Pa) was significantly lesser than before rapid maxillary expansion (147.70 Pa), and the velocity after rapid maxillary expansion (9.63 m/sec) was gentler than before rapid maxillary expansion (13.46 m/sec). He concluded that enhancement of nasal airway ventilation by rapid maxillary expansion was noticed by computational fluid dynamics. [38]

Iwasaki in 2014, in his retrospective study using computational fluid dynamics evaluated changes induced by RME in ventilation conditions. Twenty-five subjects (14 boys, 11 girls; mean age 9.7 years) who required RME had cone-beam computed tomography (CBCT) images taken before and after RME. Airflow pressure measures was assessed using computational fluid dynamics for calculating nasal resistance. Nasal resistance after RME was significantly lesser than that before RME. He concluded that Pharyngeal airway pressure during inspiration is reduced with the reduction of nasal resistance by RME. [39]

Zhao et al aimed to use computational fluid dynamics (CFD) in concurrence with patient upper airway scans to appreciate the upper airway response to treatment. Seven OSA patients were selected based on their varied treatment response. Anatomically-precise upper airway computational models were reconstructed from magnetic resonance images with and without MAS. CFD simulations of airflow were done at the maximum flow rate during inspiration. A physical airway model of one patient was fabricated and the. The CFD analysis clearly proved effects of MAS treatment on the patient's UA airflow patterns. The CFD results indicated the lowest pressure often occurs close to the soft palate and the base of the tongue. Percentage change in the square root of airway pressure gradient with MAS was found to have the strongest relationship with treatment response in correlation analysis. They provide additional support of CFD as a potential tool for forecast of treatment outcome with MAS in OSA patients without requiring patient specific flow rates. [82]

Shah et al investigated and compared the pharyngeal airflow characteristics pre- and post–mandibular setback surgery in patients with Class III skeletal dysplasia using cone beam computed tomography (CBCT) and computational fluid dynamics (CFD). Mean airway volume was significantly decreased from 35,490.324 mm3 at T1 to 24,387.369 mm3 at T2 and 25,069.459 mm3 at T3. Significant escalation in mean negative pressure was noted from 3.110 Pa at T1 to 6.116 Pa at T2 and 6.295 Pa at T3. There was a statistically significant negative relationship amongst the change in airway volume and the change in pressure drop at both the T2 and T3 time points. He clinched that following mandibular setback surgery, pharyngeal airway volume was abridged, and relative mean negative pressure was increased, inferring an increased effort required from a patient for preserving constant pharyngeal airflow. [62]

Sittitavornwong evaluated the soft tissue change of the upper airway after maxillomandibular advancement (MMA) using computational fluid dynamics. After MMA, laminar and turbulent air flows were significantly decreased at every level of the airway. The cross-sectional areas at the soft palate and tongue base were significantly amplified. His study showed that MMA enlarged airway dimensions by increasing the distance from the occipital base to the pogonion. An increase of this distance showed a significant correlation with an improvement in the apnea-hypopnea index and a decreased pressure exertion of the upper airway. Reducing the pressure effort will decrease the breathing workload. [63]

Mylavarapu conduct detailed Computational Fluid Dynamics (CFD) simulations during expiration, to investigate the fluid flow in the airway regions where obstruction could occur. An identical physical model of the same airway was built using stereo lithography. Pressure and velocity measurements were conducted in the physical model. Both simulations and experiments were performed at a peak expiratory flow rate of 200 L/min. They found that among all the approaches, standard k e turbulence model resulted in the best agreement with the static pressure measurements, with an average error of ~20% over all ports. The maximum positive pressures were renowned in the retroglossal regions beneath the epiglottis, though the lowest negative pressures were noted in the retropalatal area. He concluded that good agreement between the calculations and the investigational results suggest that CFD simulations can be used to exactly compute aerodynamic flow features of the upper airway. [54]

Iwasaki evaluated the effect of a Herbst appliance on ventilation of the pharyngeal airway (PA) using computational fluid dynamics (CFD). His result indicates the change in oropharyngeal airway velocity in the Herbst group (1.95 m/s) was significantly larger than that in the control group (0.67 m/s). Similarly, the reduction in laryngopharyngeal airway velocity in the Herbst group (1.37 m/s) was significantly higher than that in the control group (0.57 m/s). He concludes that the Herbst appliance advances ventilation of the oropharyngeal and laryngopharyngeal airways and these results may provide a useful valuation of obstructive sleep apnea treatment during growth. [40]

Zheng et al in 2017 investigated the changes of the upper airway in adult class I bimaxillary protrusion patients after extraction treatment using the functional images based on computational fluid dynamics (CFD). His study reveals that there was statistically significant correlation between pressure drop and anatomic parameters, pressure drop, and treatment outcomes was found and no statistical significance changes in pressure drop and volume of nasopharynx was found. [94]

Wakayama in 2016 conducted a study to model the effects of nasal obstruction on airflow parameters under CPAP using computational fluid dynamics (CFD), and to elucidate quantitatively the relation between airflow velocity and pressure loss coefficient in subjects with and without nasal obstruction. He found a strong correlation amid the inspiratory pressure loss coefficient and maximum airflow velocity. [70]

Wootton in 2016 reported the application of dynamic image-based CFD and rhinomanometry to estimate effective compliance of four segments of the pharyngeal airway in awake obese adolescent children with and without OSAS. They found an actual compliance in the nasopharynx during wakefulness was significantly associated with AHI and significantly lower in subjects with OSAS. Passive critical closing pressure was also significantly correlated to AHI as well as nasopharynx effective compliance. [78]

Yu et al considered three-dimensional models of upper airways attained by computed tomographic scanning with geometric quantities and computational fluid dynamics (CFD) analysis and appraised the correlations with AHI. They concluded that the geometry of pharyngeal airway and its CFD recreation correlate well with AHI and this model may be further applied for clinical evaluation. [80]

Material and Methods

MATERIALS AND METHODS

This study was approved by the Institutional Review Board; all the patients who underwent treatment were explained about the procedure and consent of both the parents and patients were taken.

20 patients in the mean age group of 20.5 years were selected and divided into two groups the study group, Group A – hybrid hyrax (n=10) and control, Group B- Conventional hyrax (n=10).

The inclusion and exclusion criteria for the participants were as follows:

Inclusion criteria: Adolescents patients with normo-divergent pattern, age group above 18 years, posterior cross bite and Constricted maxillary arch.

Exclusion criteria: Patients with Systemic disease, age group below 18year, Cleft lip/cleft palate patients, and severe A-P skeletal discrepancies were excluded.

The study group will receive a hybrid hyrax expander and the control group a Conventional Hyrax Expander.

Hypothesis of the study is as follows

a) The hybrid hyrax expander would produce same pressure and velocity changes compared to conventional hyrax expander device.

b) Particle flow rate between hybrid hyrax expander will be same as conventional hyrax expander device

c) Maximum constricted area would show no change with both hybrid hyrax expander and conventional hyrax expander device

The study was performed on a sample of 20 patient selected according to inclusion and exclusion criteria

Pretreatment, study models, photographs and cone beam computed tomography (CBCT) were taken

Fabrication of hybrid hyrax expander

At first visit, separators were placed to gain space between second pre-molar and first molar, first molar and second molar.

At the second visit a preformed molar band was inserted and alginate impression was obtained.

Depending upon the constriction of the palatal vault, the screw size was determined **(Manufactured by *BIO-MATERIAL KOREA)** (8mm, 10mm, 12mm).

As recommended by the manufacturer, the stainless steel arms that emerges from the body of the appliance was adapted to palatal contour and soldered at mesial and distal palatal aspect of first molar bands.

Once, the fabrication was completed, the appliance was cemented in place, using glass ionomer cement (*FUJI cements)

The 4 Mini-Implants measuring 1.8mm×11mm **(Manufactured by *BIO-MATERIAL KOREA)** were inserted into the palate with Mini handle driver **(Manufactured by *BIO-MATERIAL KOREA)** for anchorage.

The screw was inserted at 90 degree angle, the screws insertion followed an order of 1-2-3-4. This pattern of insertion as recommended by the manufacturer was to prevent distortion/moving of the device and lifting up of one side of the appliance when the opposite side is being installed.

Patients were educated regarding the usage of activation key

Fabrication of hyrax expander

At first visit separators was placed to gain space between canine and first pre-molar, first pre-molar and second pre-molar, second pre-molar and first molar, first molar and second molar.

At the second visit a preformed molar band was inserted and alginate impression was obtained.

Depending upon the constriction of the palatal vault, the screw size was determined **(Manufactured by *LEONE, Italy) (9mm, 11mm).**

As recommended by the manufacturer, the stainless steel arms that emerges from the body of the appliance was adopted to palatal contour and soldered at mesial and distal palatal aspect of first premolar and first molar bands .

Once, the fabrication was completed, the appliance was cemented in place using glass ionomer cement (*FUJI cements)

Patients were educated regarding the usage of activation key **(Manufactured by *LEONE, Italy)** (Figure 4.6-b).

Patients in both the groups were given instruction with regard to hygiene and maintenance, and were advised to take analgesic if they experienced pain.

After achieving hemostasis trial activation was done.

The patients were reviewed after 7 days of initial placement for the stability of mini screw implants, after which activation was initiated.

For both the groups screw activation protocol was initiated, rotating two turns per day.

Patients were then recalled once in 12 days once to assess the progress of treatment procedure.

Once the required amount of expansion was achieved the activation protocol would be stopped and stabilized.

After achieving intended expansion of the maxillary width, the expansion screw was blocked, and the appliance was left in place for 4 months after which post treatment Cone beam computed tomography, models and Photographs were taken.

The CBCT scanning was performed on a Panmeca scanning station with the following parameters: 120 kVp, 360 mA, rotation time of 0.5 seconds, pitch 3, thickness 1.25 mm, HQ mode. Scanning was conducted at the end point of the expiration from the supraorbital margin through the 2cm inferior to the hyoid bone.

No subject had used a nasal decongestant at the time of the cone-beam computed tomography scan. The data were sent directly to a personal computer and stored in digital imaging and communications in medicine (DICOM) format.

Airway segmentation

The DICOM files would then be imported to Materialise Medical Mimics software version 17.0 (Materialise, Belgium) for airway segmentation.

A threshold which isolates the airway in a best way was set to segment both the pre-and post-treatment scans. Manual adjustments were also done after thresholding for accurate segmentation in the nasal area.

Airway segmentation was done from nostrils till Oropharynx. Its boundaries are, Anterior boundary - Line extending from PNS to the tip of the epiglottis, Posterior boundary - Line extending from the tip of the odontoid process to the posterior superior border of CV4, Superior boundary - Line extending from PNS to the tip of the odontoid process, Inferior boundary - Line extending from the base of the epiglottis to the posterior superior border of CV4.

After segmentation the file was saved in a stereolithographic (STL) and exported to meshing software, Ansys CFX Pre-Processor v17.0 (Canonsburg, PA, USA). The CFX file was exported to ANSYS WORKBENCH v17.0 (Canonsburg, PA, USA) for Computational fluid dynamic assessment.

Computational fluid dynamic assessment.

Computational Fluid Dynamics (CFD) is the science of calculating a numerical explanation to the governing equations of fluid flow while advancing the solution through space or time to obtain a numerical description of the complete flow field of interest.

Solutions in CFD are obtained by numerically solving a number of balances over a large number of control volumes. The numerical solution is obtained by supplying boundary conditions to the model boundaries and iteration of an initially guessed solution.

The balances, dealing with fluid flow, are based on the Navier Stokes Equations for conservation of mass (continuity) and momentum.

The software can simulate and evaluate various kinds of computational fluid dynamics under a set of given conditions. In the present study the stimulation involved air flowing from the choana horizontally, and air would get inhaled through both nostrils. The flow was assumed to be a Newtonian, homogeneous, and incompressible fluid.

The computational fluid dynamics of the nasal airway were performed under the following conditions by using ANSYS:

(1) the volume of air flowed with a velocity of 200 mL per second and pressure was constant

(2) the wall surface was nonslip, and

(3) the simulation was repeated 1000 times to calculate the mean values.

Convergence was judged by monitoring the magnitude of the treatment residual sources of mass and momentum, normalized by the respective inlet fluxes. The iteration was continued until all residuals fell below 0.2%. The simulation estimated airflow pressure, velocity and particle flow.

Evaluation of Pressure and Velocity

In ANSYS Software, Pressure and Velocity was measured. Apart from the maximum velocity of the upper airway, velocity were calculated in three different planes (XY, YZ, ZX) to evaluate the ventilatory condition. Velocity in XY, YZ and ZX planes are represented as velocity u, velocity v and velocity w respectively.

Evaluation of particle flow

A partical flow stimulation was made using the ANSYS software. A spherical ball object was chosen as a elementary particle. The flow was stimulated with inlet as starting point and outlet as exit point. Time taken for the object to exit via outlet was noted for pre and post treatment models.

Maximum constricted area

Maximum constricted area refers to the most constricted region in the pharyngeal airway. In ANSYS WORKBENCH, the maximum constricted area was found, and a pointer was used to measure the pressure and velocity.

Clinical Photographs

(Figure-1) The Maxillary Skeletal Expander (MSE-1)

(Figure-2) The conventional hyrax expander

(Figure 3.1) Pre-treatment intra-oral photograph of the patient in Hybrid Hyrax group (Group A)

(Figure 3.2) Occlusal view of maxilla at various stages in Hybrid Hyrax group

PRE-Expansion **On the day of appliance fixation**

After activation **POST-Expansion**

(Figure 3.3) Post treatment intra-oral photograph of the patient in Hybrid Hyrax group

(Figure 4.1) Pre-treatment intra-oral photograph of the patient in Hyrax group (GROUP B)

(Figure 4.2) Occlusal view of maxilla at various stages in Hyrax group

PRE-Expansion

On the day of appliance fixation

After activation

POST-Expansion

(Figure 4.3) Post treatment intra-oral photograph of the patient in Hyrax group

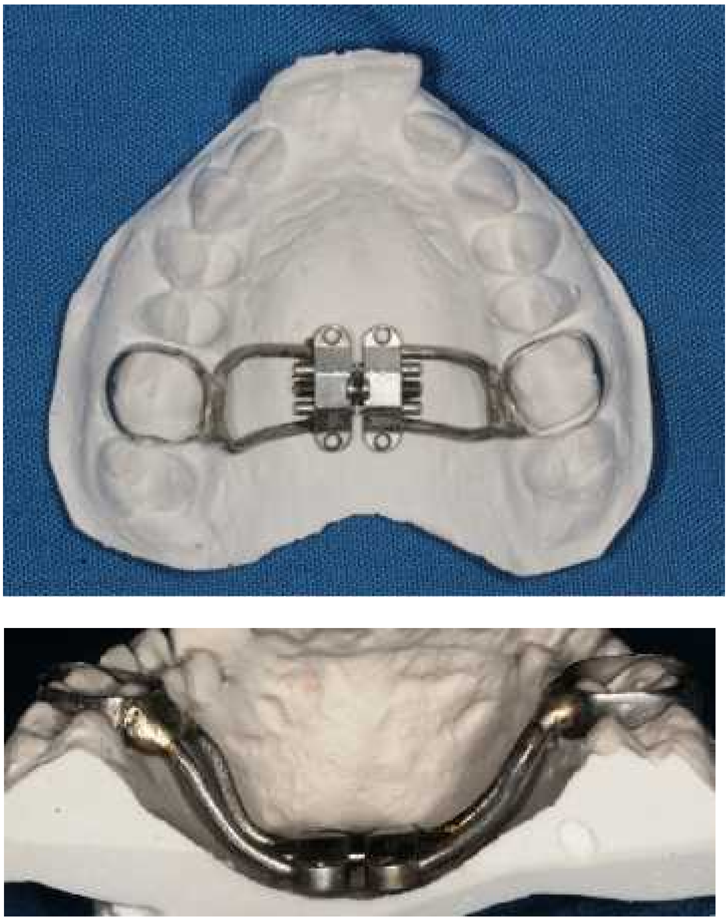
(Figure 4.4) Transpalatal arch with extension arms

(Figure-4.5) Hybrid hyrax RME - Materials

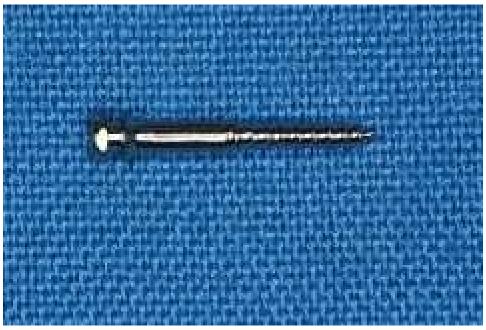
a) Maxillary skeletal expander screw

(*BIO-MATERIAL KOREA, South korea)

b) Fabrication of expansion device on plaster model

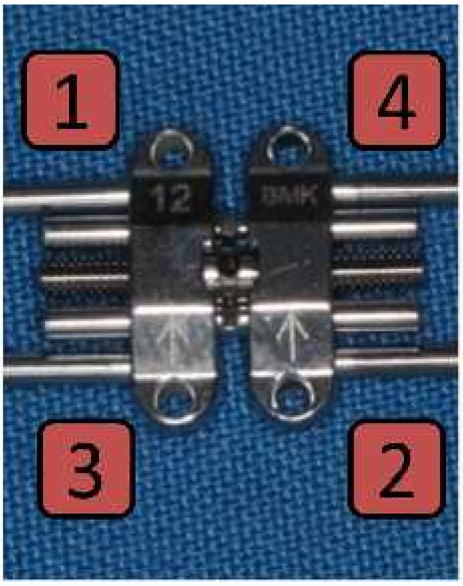


c) Mini-Implant



d) Mini handle driver

e) Screw insertion order

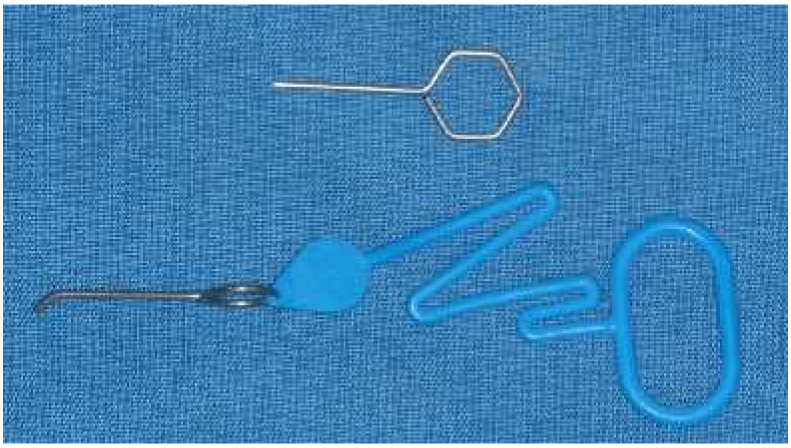


f) Activation key

(Figure-4.6) Hyrax RME - Materials

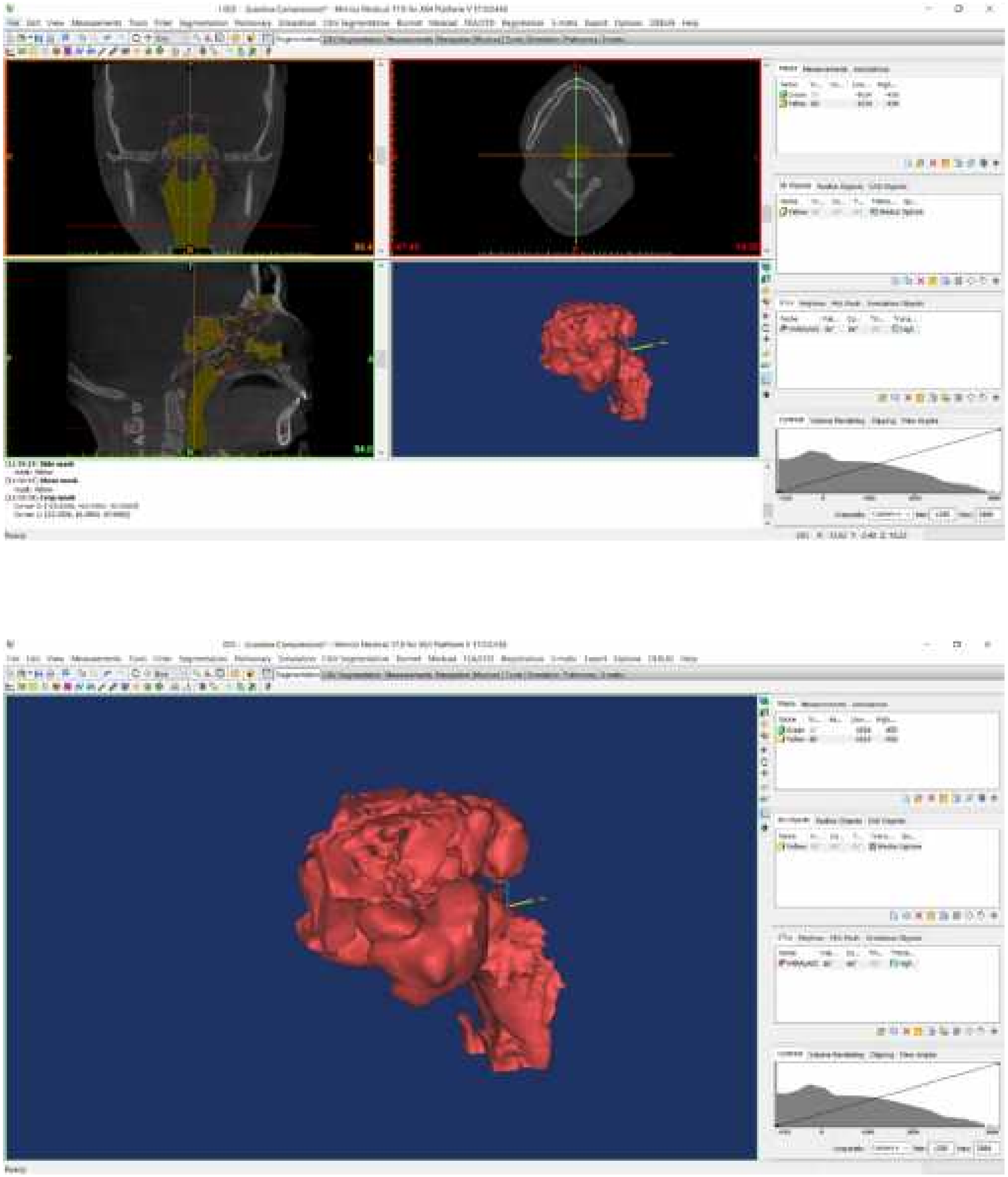
a) Traditional hyrax screw (*LEONE, Italy)

b) Activation key

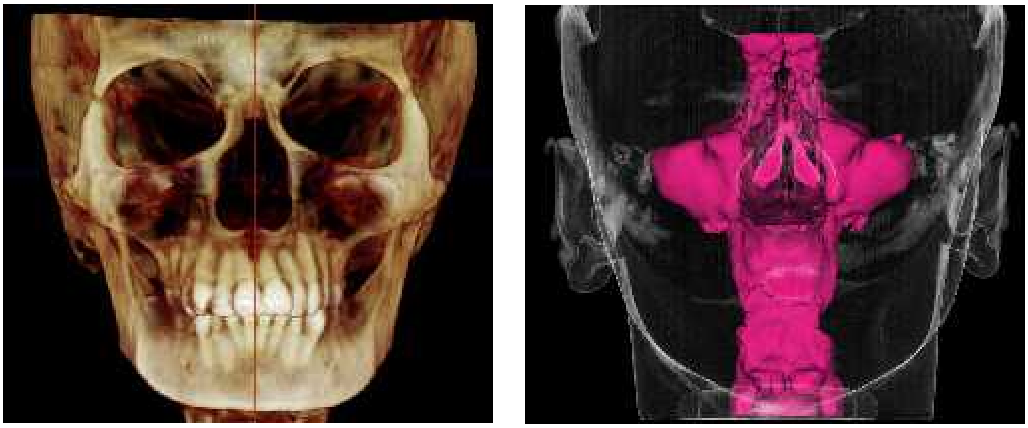


Airway Modelling & CFD

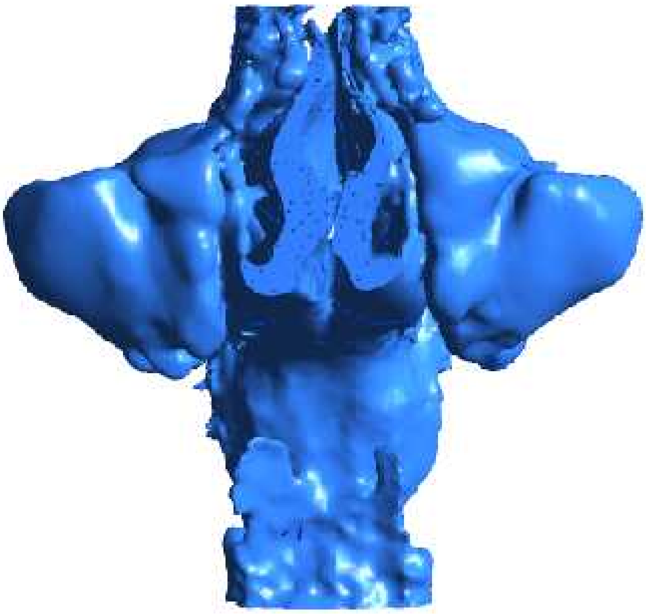
(Figure-5 a and b) Airway segmentation in MIMICS software



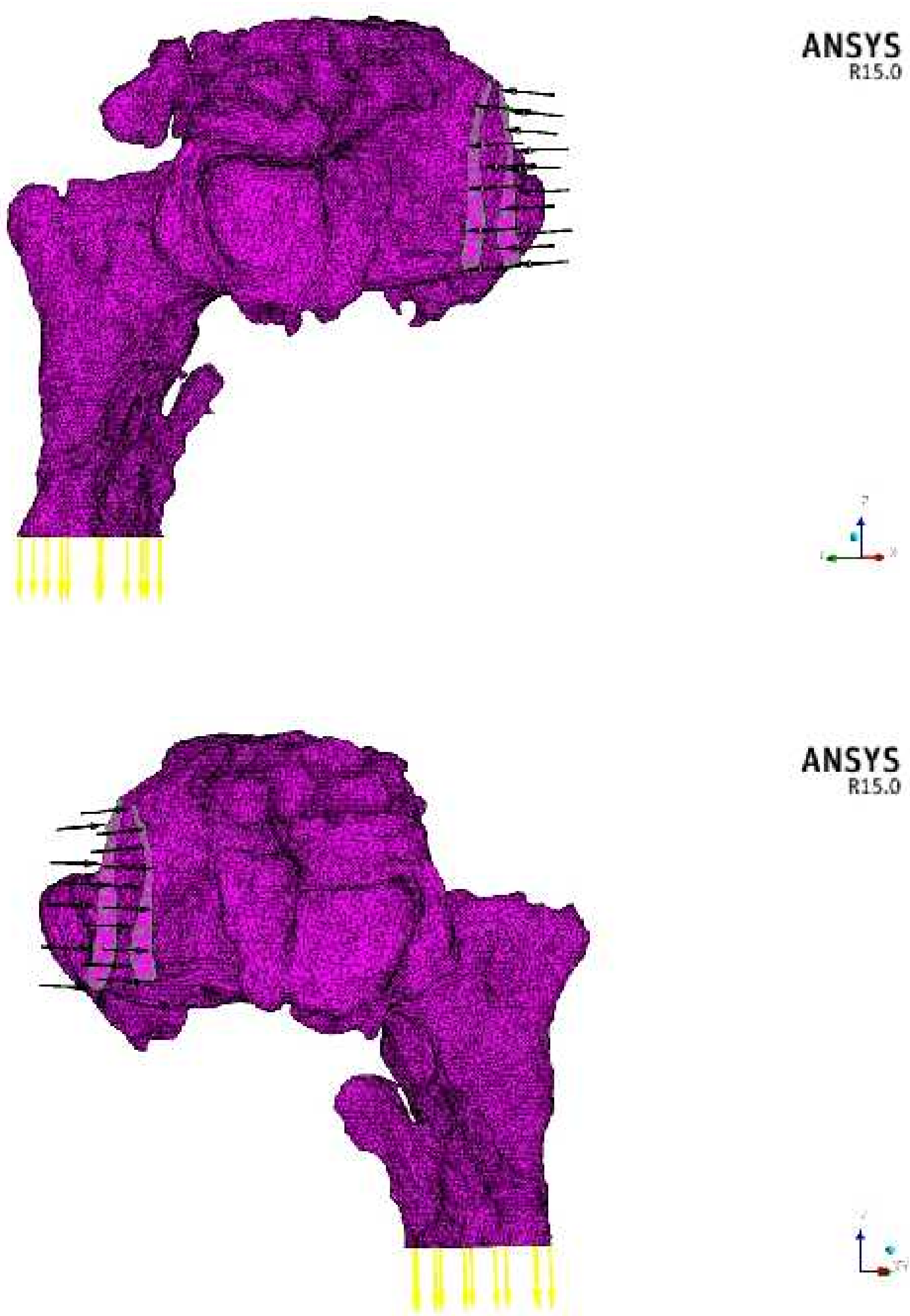
(Figure-6.1) Orientation of skull with respect to airways in Dolphin imaging system



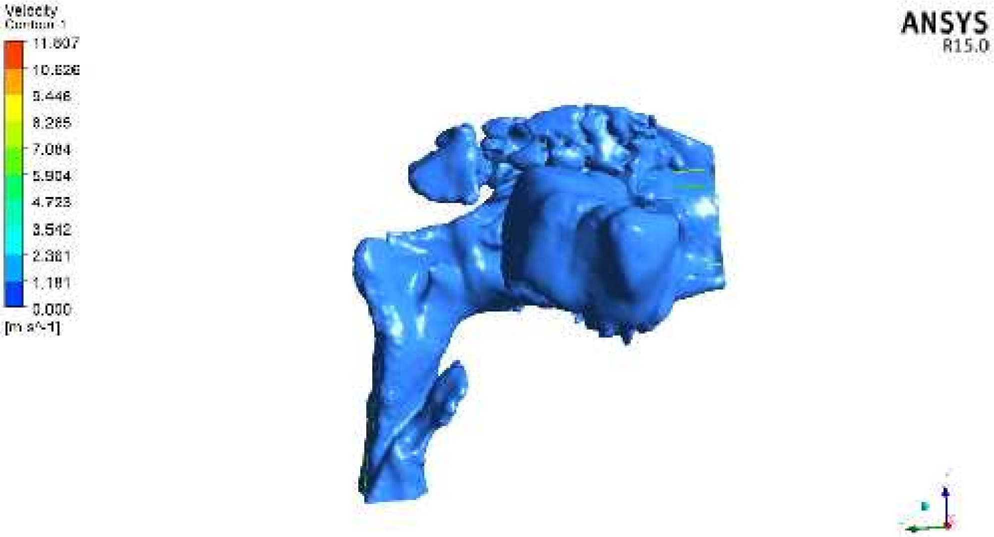
(Figure-6.2) Airway extracted from MIMICS software

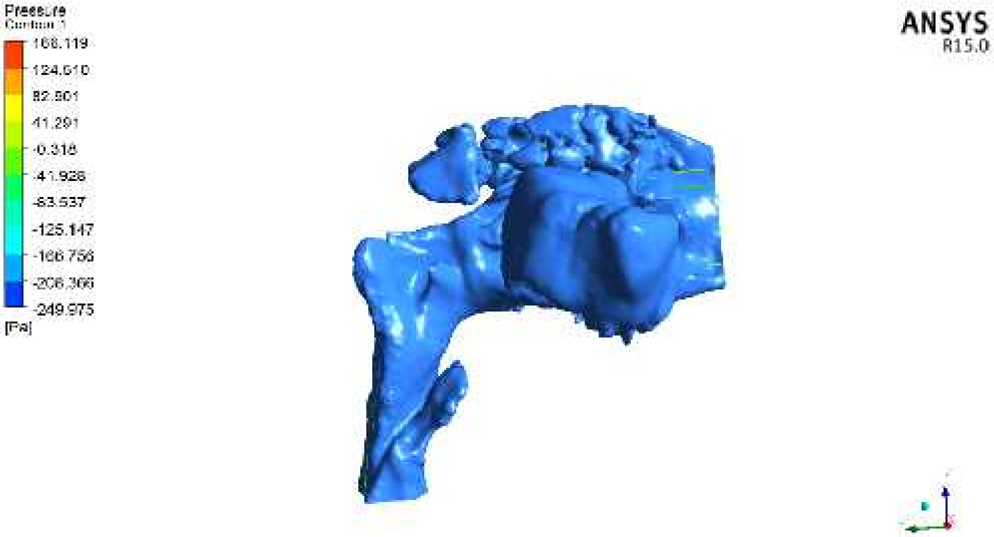


(Figure-6.3) Meshing of 3D Airway Model
[Black arrows denote airway inlet and
yellow arrows denote airway outlet]

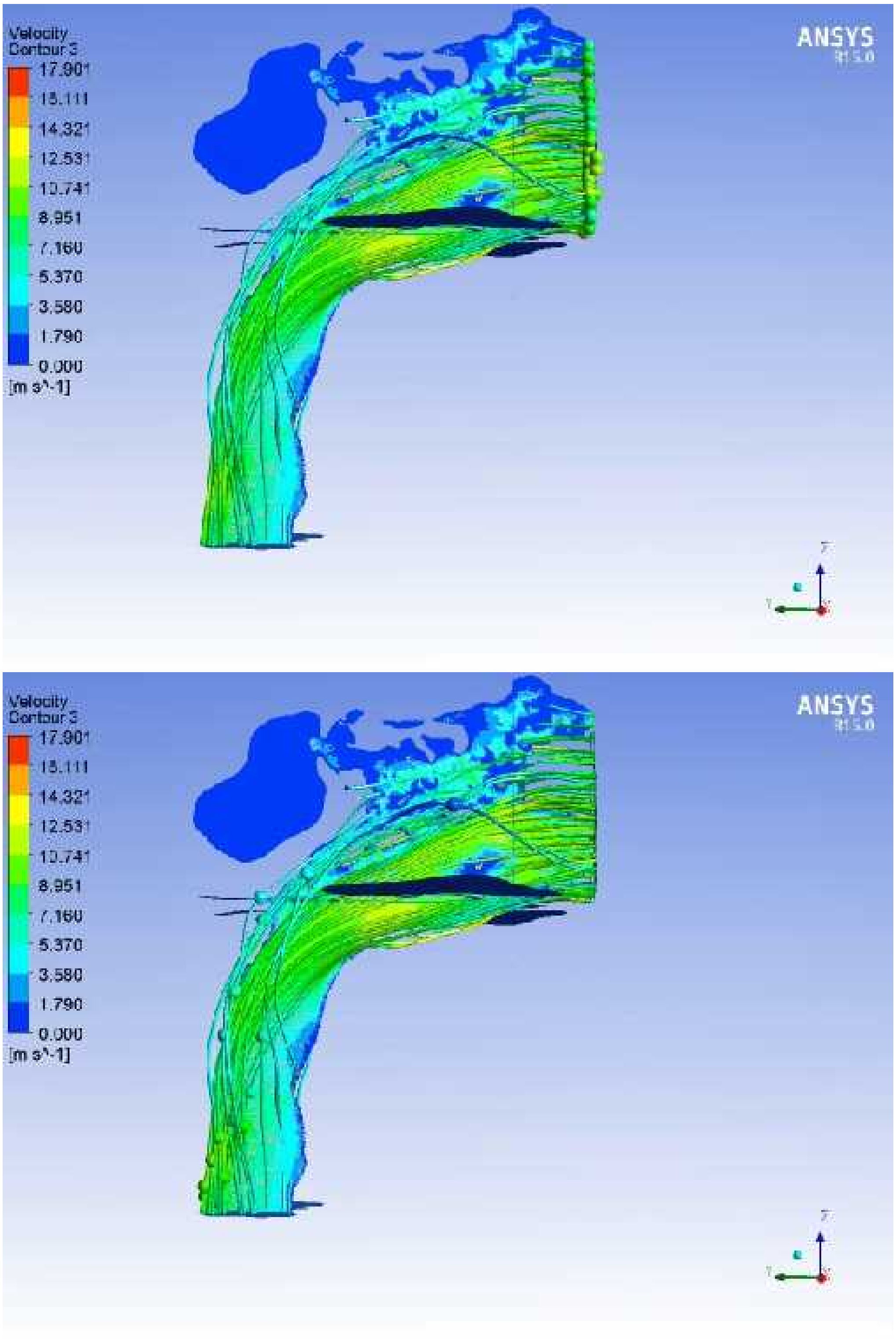


(Figure 7) Measurement of Velocity and Pressure in ANSYS software

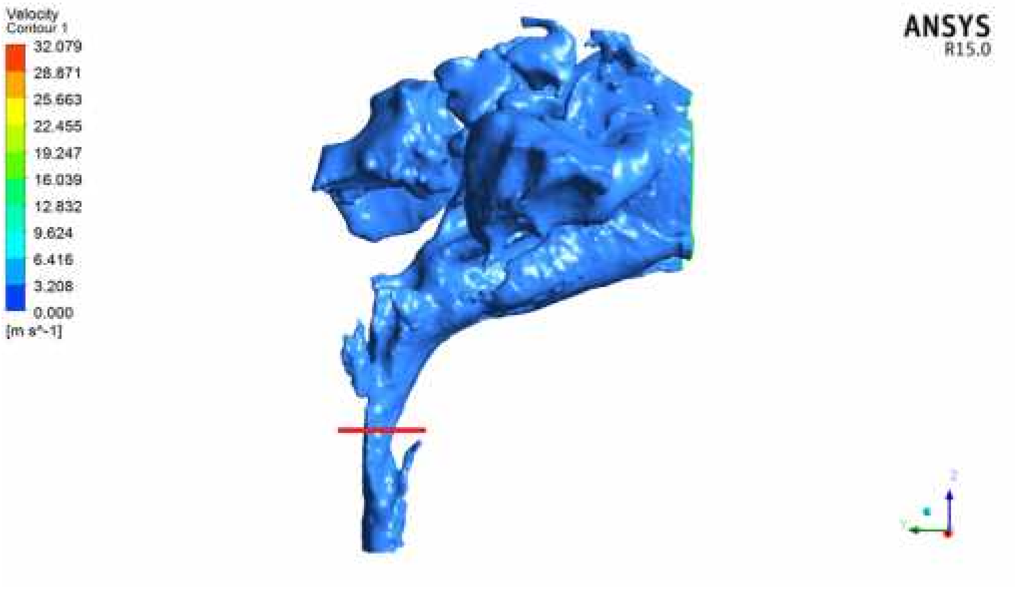




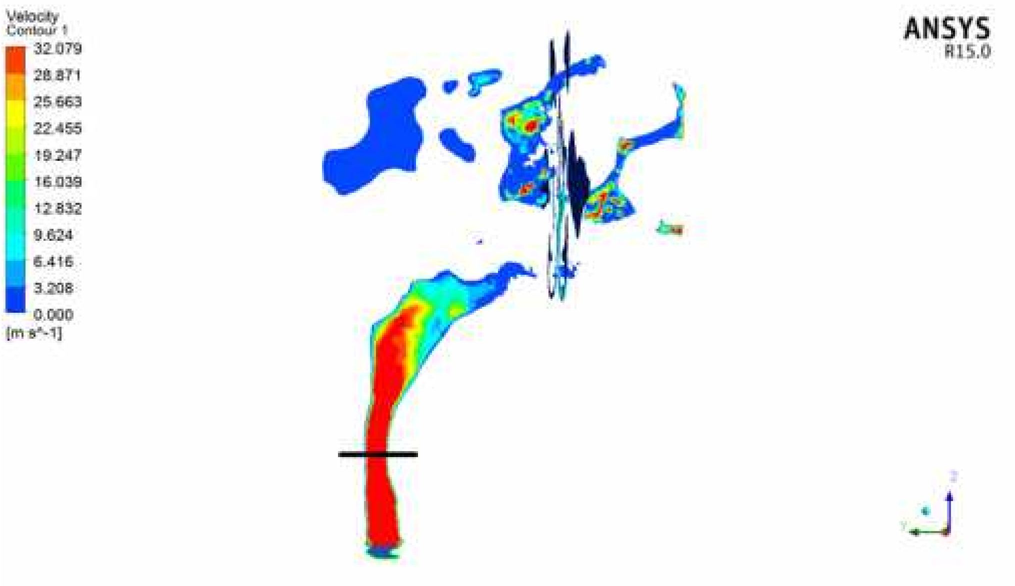
(Figure 8) Captured images of Particle flow stimulation a) Particle at Inlet b) Particle at Outlet



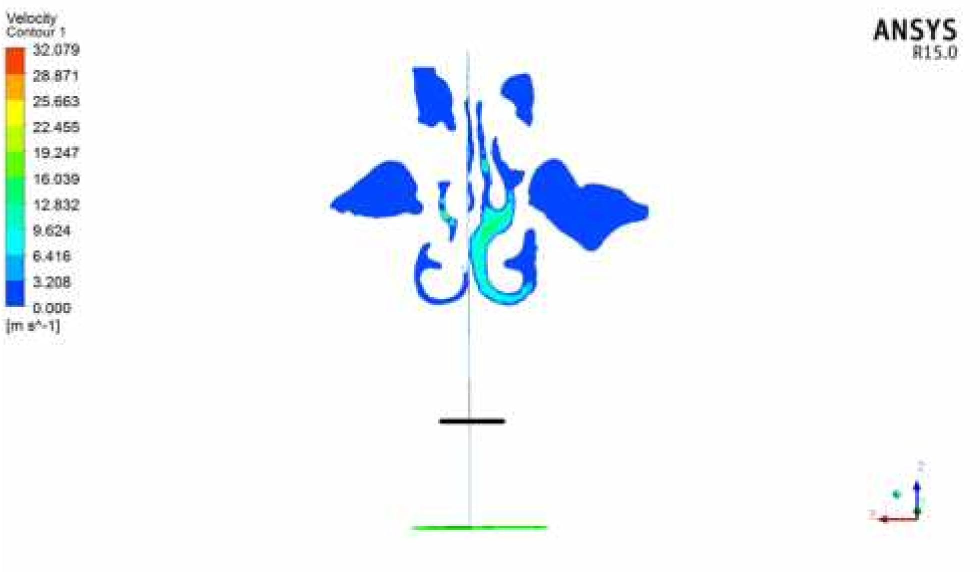
(Figure 9)- Maximum Constricted Area measurements



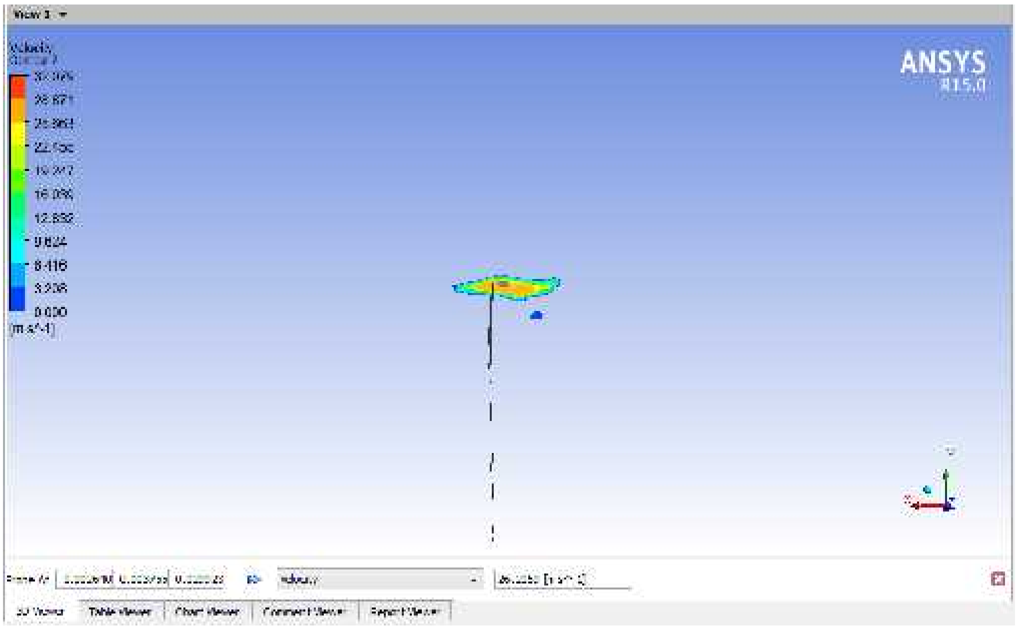
a) **Location of Maximum constricted area marked in red line**



b) **Based on volume, MCA is traced in YZ plane denoted in Black line**



c) MCA orientation in XZ



d) Probing method employed to find Velocity and Pressure

Results

RESULTS

All statistics were calculated using SPSS Statistical Software for each parameter. [37] To check the normality Shapiro-Wilks test was performed and it was observed that data was not normally distributed (Table T1).

The following measurements were observed in order to derive statistical data,

1) Maximum Velocity
2) Velocity u
3) Velocity v
4) Velocity w
5) Pressure
6) Flow Rate
7) Velocity in Maximum constricted area
8) Pressure in Maximum constricted area

For Intragroup comparisons, Wilcoxon Signed Ranks Test was used. (Table T2 and T3)

The level of significance was defined as $P < 0.05$.

Additionally, each parameter was compared between the two groups to determine any differences that existed before treatment and after treatment in addition to comparing the differences in treatment changes. This was done using Mann-Whitney Test. (Table T4 and T5)

In Group A, there was a statistical significant intragroup difference in Velocity u (m/s), Velocity v (m/s), Pressure (Pa), Flowrate (sec), Maximum Constricted area – Velocity (m/s) parameters between pre-and post. There was a decrease of Maximum Velocity (m/s) in post treatment model, however it was not statistically significant. (Table T2 & T6)

Similarly, In Group B, there was a statistical significant intragroup difference in Velocity u (m/s), Velocity v (m/s), Velocity w (m/s), Maximum Constricted area – Velocity (m/s) parameters between pre-and post. There was a decrease of Maximum Pressure (m/s), Pressure (Pa), Flowrate (sec), Maximum Constricted area – Pressure (Pa) in post treatment model, however it was not statistically significant. (Table T2 & T7)

A comparison of the mean and standard deviation values for changes resulting from the two groups is shown in Table T6 & T7 and in Figure 10 & 11.

On comparing the outcomes of Group, A and Group B, Group A showed improved results when compared to Group B. However, that difference was not statistically significant. (Table T4 & T5)

Tables and Graphs

Table T1- Tests of Normality

	Kolmogorov-Smirnov[a]			Shapiro-Wilk		
	Statistic	df	Sig.	Statistic	df	Sig.
maxvelprea	.263	6	.200*	.871	6	.230
uprea	.213	6	.200*	.949	6	.735
vprea	.248	6	.200*	.876	6	.250
wprea	.253	6	.200*	.844	6	.140
paprea	.248	6	.200*	.888	6	.310
frprea	.185	6	.200*	.909	6	.429
maxvelposta	.199	6	.200*	.946	6	.706
uposta	.219	6	.200*	.942	6	.676
vposta	.211	6	.200*	.907	6	.417
wposta	.270	6	.197	.887	6	.305
paposta	.320	6	.054	.794	6	.052
frposta	.224	6	.200*	.905	6	.406
maxveprelb	.328	6	.043	.852	6	.162
upreb	.234	6	.200*	.894	6	.338
vpreb	.270	6	.198	.841	6	.133
wpreb	.221	6	.200*	.875	6	.247
papreb	.393	6	.004	.664	6	.002
frpreb	.260	6	.200*	.877	6	.254
maxvelpostb	.154	6	.200*	.964	6	.852
upostb	.332	6	.038	.860	6	.189
vpostb	.241	6	.200*	.939	6	.649
wpostb	.286	6	.138	.812	6	.076
papostb	.262	6	.200*	.915	6	.473
frpostb	.393	6	.004	.694	6	.005

*. This is a lower bound of the true significance.

Lilliefors Significance Correction

Table -T2 (a and b) Intra group comparisons

	GROUP A – HYBRID HYRAX					
	Maximum Velocity (m/s)	U (m/s)	V (m/s)	W (m/s)	Pressure (Pa)	Flowrate (sec)
Asymp. Sig. (2-tailed)	.249	.028*	.046*	.249	.028*	.028*

	GROUP B –HYRAX					
	Maximum Velocity (m/s)	U (m/s)	V (m/s)	W (m/s)	Pressure (Pa)	Flowrate (sec)
Asymp. Sig. (2-tailed)	.046*	.028*	.028*	.046*	.075	.345

*P < 0.05 significance

Table T3- Intra Group Comparisons for Maximum constricted area (Group A – HYBRID HYRAX and Group B- HYRAX)

	Group A – Velocity (m/s)	Group A – Pressure (Pa)	Group B – Velocity (m/s)	Group B – Pressure (Pa)
Asymp. Sig. (2-tailed)	.028*	.075	.028*	.075

*P < 0.05 significance

Table T4- Inter Group Comparisons for test parameters (Group A - HYBRID HYRAX and Group B- HYRAX)

	Maximum Velocity (m/s)	U (m/s)	V (m/s)	W (m/s)	Pressure (Pa)	Flowrate (sec)
Asymp. Sig. (2-tailed)	.873	.873	.423	.200	1.000	.262

Table T5 - Inter Group Comparisons for Maximum constricted area (Group A - HYBRID HYRAX and Group B- HYRAX)

	Velocity (m/s)	Pressure (Pa)
Asymp. Sig. (2-tailed)	.522	.150

*P < 0.05 significance

Table T6 - Comparison of parameters for Group A (HYBRID HYRAX)

GROUP A - Parameter	Mean & SD - Pre	Mean & SD - Post	P value
Max. Velocity (m/s)	30.06 ± 12.76	22.85 ± 9.49	.249
Velocity u (m/s)	11.38 ± 4.08	7.85 ± 3.07	.028*
Velocity v (m/s)	22.58 ± 10.18	20.67 ± 10.97	.046*
Velocity w (m/s)	9.89 ± 5.34	8.60 ± 6.33	.249
Pressure (Pa)	2096.92 ± 1401.39	826.68 ± 1180.49	.028*
Flowrate (sec)	2.57 ± 1.46	4.62 ± 5.06	.028*
MCA – Velocity (m/s)	11.24 ± 5.36	10.64 ± 2.50	.028*
MCA – Pressure (Pa)	15.43 ± 20.40	-5.01 ± 14.04	.075

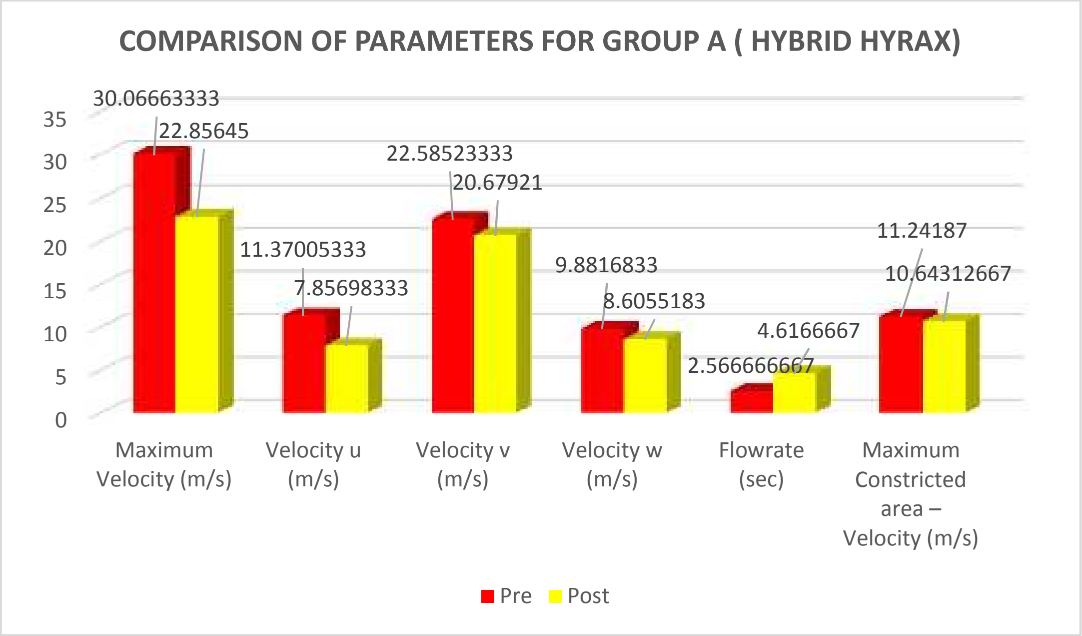
*P < 0.05 significance

Table T7 - Comparison of parameters for Group B (HYRAX)

GROUP B - Parameter	Mean & SD - Pre	Mean & SD- Post	P value
Max. Velocity (m/s)	25.75 ±4.85	20.26 ±7.54	.046
Velocity u (m/s)	10.27 ± 2.28	4.53 ± 2.30	.028*
Velocity v (m/s)	21.58 ± 4.88	16.58 ± 4.62	.028*
Velocity w (m/s)	11.69 ±5.26	5.49 ± 0.81	.046*
Pressure (Pa)	1451.58 ±1775.70	510.68 ± 360.37	.075
Flowrate (sec)	2.32 ±1.23	2.96 ± 3.87	.345
MCA – Velocity (m/s)	12.63 ±7.61	10.65 ±5.52	.028*
MCA – Pressure (Pa)	40.11 ± 51.65	24.37 ± 35.88	.075

*P < 0.05 significance

Figure 10 a and b) – Group A - Intergroup comparison of Parameters



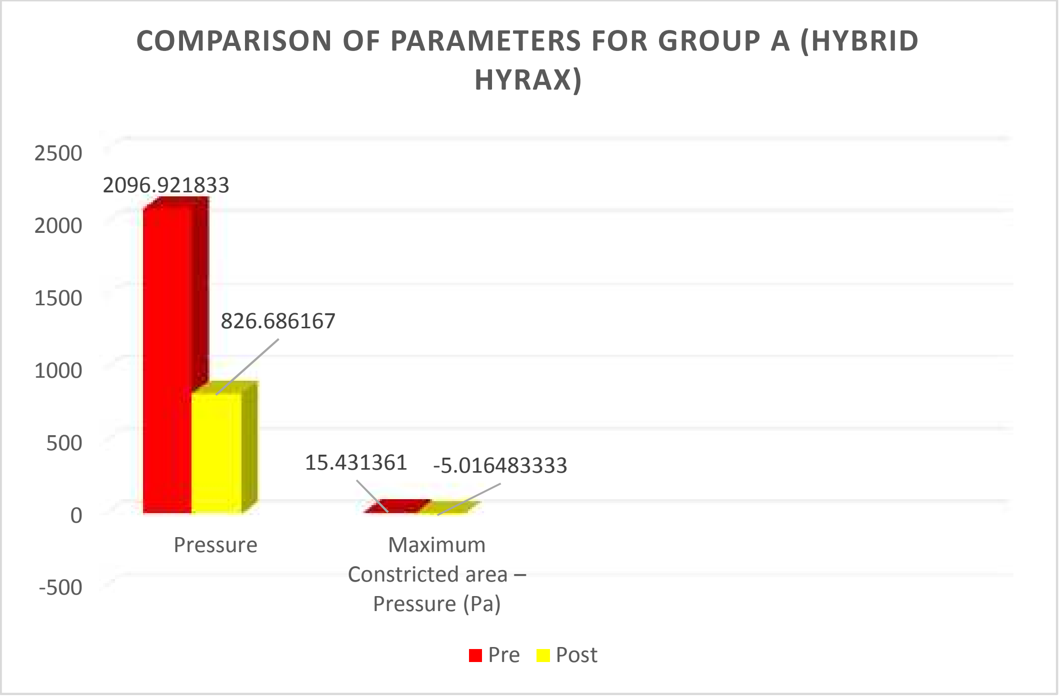
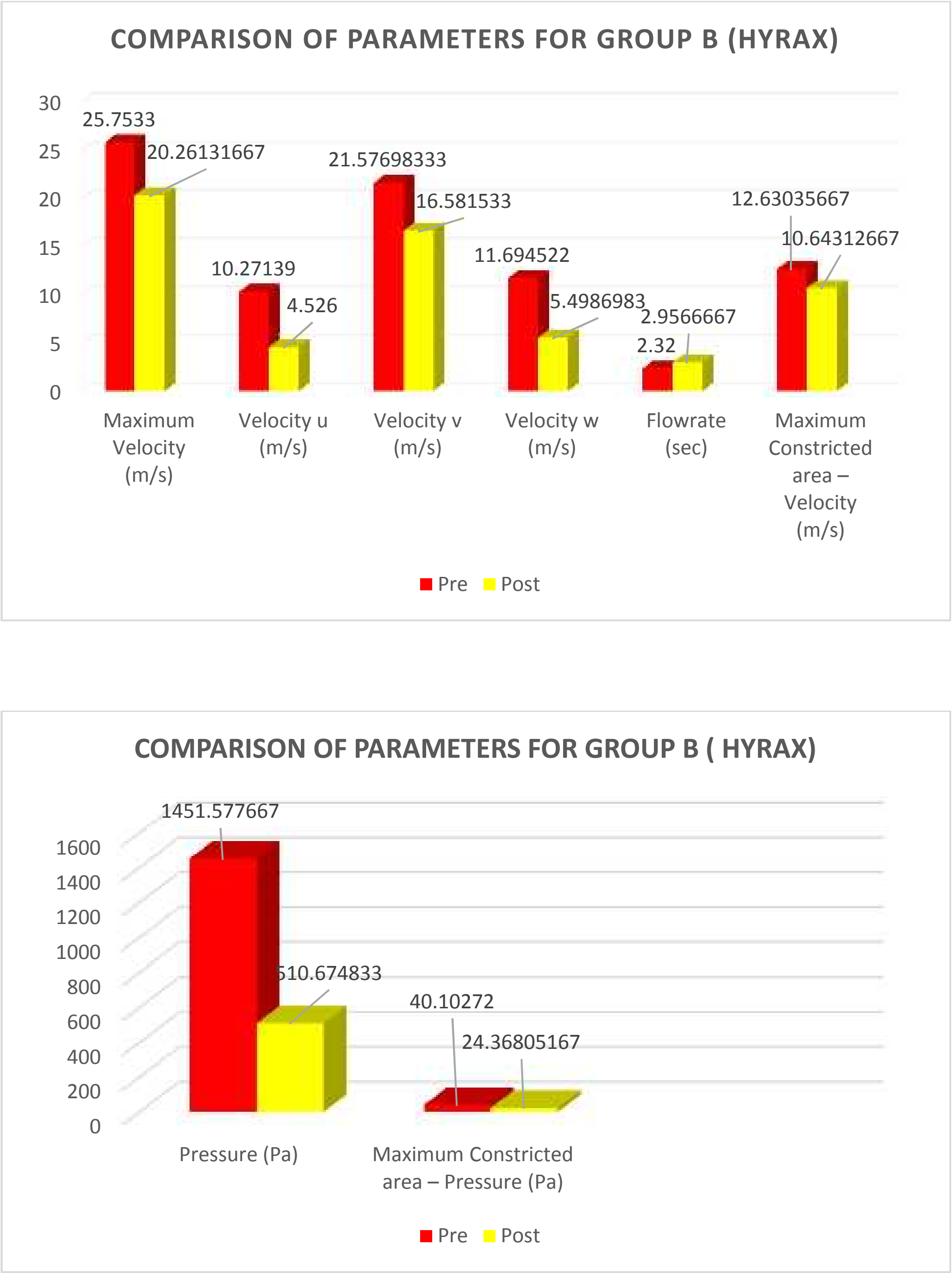


Figure 11 a and b) – Group B - Intergroup comparison of Parameters



Discussion

DISCUSSION

The human respiratory system can be divided into the upper and lower respiratory tract. The upper respiratory tract consists of the, nasal cavity, nasopharynx, oropharynx and hypopharynx. The shape and diameter of these passages determine the volume of air passing through them.

Functional matrix theory by Melvin Moss states that nasal breathing allows proper growth and development of the craniofacial structures along with other functions such as mastication and swallowing. Thus, a constant stimulus is provided in the nasal passage by continuous airflow during breathing which persuades for the lateral growth of maxilla and for lowering of the palatal vault. [45]

Kilic has indicated that maxillary morphologic differences happen between individuals with normal airway systems and persons with airway problems. [43]

Transverse maxillary deficiency is a pathological condition that may be associated with other types of dentoskeletal alterations, with esthetic and functional implications, including respiratory problems. The incidence is around 3– 18% in orthodontic patients. Patients with this condition have a narrow nasal cavity, which increases the resistance to nasal airway flow. [15]

Gray documented that 70% of the cases with maxillary constriction and 56% of the subjects having poor nasal breathing had respiratory infection, cold, sore throat, and allergic rhinitis. In another study the same author reported the same incidences in patients having impaired nasal respiration and constricted maxilla. [26][27]

It has been postulated that higher nasal resistance is associated with mouth breathing and various dentofacial developmental aspects involving the dentition and the skeleton. [50]

In the English literature, the descriptive term adenoid facies has been used for at least a century. Laptook in 1981 supported this theory, describing it in a case report. The characteristics of this skeletal development syndrome are a decrease in nasal permeability resulting from elevation of the nasal floor, nasal stenosis, bilateral dental maxillary cross-bite along with a high palatal vault, mouth breathing and, due to the enlargement of the nasal turbinates, resulting in a decrease in nasal airway size. [92]

Earlier literature by Goddard, 1893; Schroeder-Benseler, 1913; Hershey et al. 1976; Hartgerink et al., 1987 opinioned that Rapid Maxillary expansion facilities nasal airflow and hearing, although scientific investigations producing evidence-based data were missing. [15][34]

In recent times, Rapid maxillary expansion (RME) has been widely used by Orthodontists to increase the maxillary transverse dimensions of young patients. Several studies have suggested that RME also increases nasal width and volume.

Timms observed favorable effects of RME in the treatment of poor nasal airway, septal deformity, recurrent ear or nasal infection, allergic rhinitis and asthma, since RME increases the transverse dimensions of maxilla and nasal cavity by separating the two maxillary halves from mid-palatal suture in a short period. [21]

Haas popularized correction of maxillary transverse deficiencies with a maxillary rapid palatal expander before 40yrs. Maxillary width deficiencies when detected before or during the adolescent growth spurt do not present as an orthodontic challenge. [29][30][31]

Proffit reports that “by the late teens”, sutural interdigitation and areas of bony bridging in mid palatal region develop to the point that maxillary expansion becomes impossible. [58]

The concept of widening the dental arch by means of opening the mid palatal suture dates to 1860 when Angell described rapid expansion of the upper arch in a paper he presented to the dental community. [2]

Haas-1958, introduced what is now referred to as the Haas appliance. It has an acrylic plate which covers the soft tissue which makes it a tooth-tissue borne appliance of the palate. This acrylic plate caused irritation to the palate which is a drawback of this design. [29]

William Biederman in in the year 1968 created an alternative design to the Haas appliance that was at first called the Biederman or Hygienic appliance, but later referred to as the Hyrax. It is a complete tooth-borne appliance since it derives anchorage only from the tooth. [6]

Both Hass and Hyrax were effective in children and young adolescent patient, but when used during late adolescent and adults it caused more dental tipping and less to no skeletal expansion.

The only option for palatal expansion in adults was surgically assisted rapid palatal expansion where paramedian incision are made and the muco-periosteum is released, mid-palatal suture is separated with a midline cut, about 3mm deep.

Buck in his systematic review found moderate quality evidence suggesting a significant increase in nasal cavity volume following SARME in the short term that was stable for 63months. There was also evidence to suggest that there was significant increase in palatal volume. [8]

However, SARME is an invasive procedure associated with post - operative pain and tissue impingement, swelling and micro trauma of TMJ, leading to patients discomfort hence the option is declined by many adults.

With the advent of TADs expansion is possible in adult without surgical intervention. These appliances anchor the expansion screw directly to the palatal bone, avoiding direct tooth contact. Thereby, bone-anchored expansion appliances may be indicated when a patient has missing or compromised posterior permanent teeth and periodontal concerns, providing an alternative when traditional RME or SARPE cannot be used.

Advantages of implant-supported rapid maxillary expansion appear to be less dental tipping and more skeletal expansion, shorter treatment times, increased anchorage for expansion, and less periodontal effects.

The current available design utilizes either 2 or 4 mini-screws to support the expander in palate, Besides the number of mini-screws for anchoring the expansion device, there are other variations such as the location of the mini-screw, the length of the mini-screw and the depth of screw penetration, which may involve either palatal cortex or both palatal and nasal cortices.

Zeng et al conducted a prospective study to investigate the upper airway changes after rapid maxillary expansion utilizing CBCT. He states, after RME, the nasal cavity expands, which may play a major role in improvement of breathing. The expansion pattern of the nasal cavity may follow the parallel opening configuration which in turn causes increase in airway volume. But the influence on the pharyngeal airway is limited. [81]

Nelson et al evaluated a sample of 28 females who were in their late-adolescence. These patients were divided into two groups one group received a bone-borne (C-expander) and the other group tooth-borne (hyrax, bands on premolars and molars) The age group of the confined sample was 15 to 22 years and the outcome was evaluated through CBCT. He concluded that in patients in late adolescence, bone-borne expanders produced greater orthopedic effects and fewer dentoalveolar side effects compared to the hyrax expanders [51]

Also, **Buccheri** et al., concluded in their study that RME would increase nasopharyngeal space because its orthopedic effect in the tissues that delimit the maxilla, thus improving the position of the tongue and increasing nasopharynx space. [7]

Although the bone borne expansion should produce true skeletal expansion, most of the studies that have been done using bone borne expansion appliance have not documented significant skeletal expansion. The bone-borne device has the potential to get distorted either due to peri-implantitis, implant failure or due to residual force that builds up during expansion. [88][89][90]

It also suffers from the possibility/limitation that the implants might get loosened, aspirated/swallowed by the patients. These drawbacks can be overcome by hybrid-hyrax expansion such as Maxillary Skeletal Expander (MSE-1), which derives most of the anchorage by the mini-screw, and the appliance can be further stabilized by using a stabilizing wire to a dental unit.

Won moon et al, reported that bi-cortical mini-implant anchorage results in improved mini-implant stability, decreased mini-implant deformation and fracture, more parallel expansion in the coronal plane, and increased expansion in bone-borne palatal expansion. [53][87]

Our study comprised of patients with normo-divergent pattern above 20 years of age with posterior cross bite or Constricted maxillary arch. The purpose of choosing this age group is to precisely assess the effects of hybrid hyrax and conventional hyrax expansion on nasal cavity after fusion on sutures and completion of growth.

In a recent study by **Evan et al,** it was observed that the use of skeletally anchored expansion appliance resulted in widening of the nasal cavity, the zygomatic arch, and frontonasal area in addition to expansion of maxillary dental arch. [17]

To the best of our knowledge there is very little scientific evidence pertaining to the efficacy of using a mini implant supported expansion device (MSE-1) on airway dynamics, which is fixated with 4 bi-cortical mini-screws and in addition anchored to the first permanent molar.

Hence the purpose of the study was to compute the efficacy of such skeletally anchored maxillary expander and compare it with conventional RME in adults on nasal airway, and observe the outcomes through computational fluid dynamics.

Activation protocol

Various advocates of palatal expansion have suggested different activation protocols for the conventional hyrax expander. The most commonly used is the **Timms** activation protocol where he prefers 90 degree rotations in morning and evening until the age of 15 yrs, for those in the age of 15-20 yrs 45 degrees activation 4 times a day is preferred, for those over 20yrs Initial 90 degrees, followed subsequently by 45 degrees in the morning and evening has been advocated . And for patients over 25yrs he prefers SARME. [67]

Moon recommends 3 turns/per week for patients in the age group of 10 -15yrs, 1 turn/day for patients between 15-19yrs, 2 turns/day for patients between 20-25yrs, over 25yrs more than 2 turns/day. After the appearance of a diastema it is essential to activate the hybrid expander 1turn/day, till desired amount of expansion is achieved.

Other authors such as **Mcnamara, Handelman and Alpern** recommend activation turn; no more than 1 turn every third to fifth day in older patients. If expansion is done at a faster rate palatal suture does not separate in mature patients**.** [24][33]

Handelman stated that skeletal expansion in younger patients to be more successful as there is less resistance at the suture. He further argues that non-surgical skeletal expansion in adults is a necessary and safe practice resulting from displacement of the alveolar process. This bending of the alveolar process was reported to be of 12.90% to 33.01% of the total expansion achieved. it is reasonable to expect that alveolar expansion would contribute more to the expansion in adults, unlike in children where there is more sutural expansion. [33]

We preferred an activation protocol of 2 turns per day since the mean age group of our patients was 20.5 years.

This protocol has been advocated by Moon, the same activation protocol was followed in both the study as well as the control group to ensure that there is no difference in the surface response due to the activation protocols.

This study evaluates the effects of hybrid hyrax expander (MSE-1) versus conventional hyrax RME on airway dynamics.

The approval for the study was obtained from the appropriate authority, and the patients consent was obtained.

Airway Analysis

Testing of nasal airway should be convenient, reliable, repeatable, and should provide for objectively measuring the nasal passage. Further, test for nasal airway should also be able to document the effect of surgical intervention on the nose on nasal airflow, volume, and physiology.

Nasal endoscopy, nasal peak flows, anterior and posterior rhinomanometry, rhinostereometry, and acoustic rhinometry have been used for clinical study of the nasal airway. Acoustic rhinometry is a technique first described by Hilberg et al in 1989. It can be used complementarily with the other tests to judge different aspects of nasal anatomy and function. [41][83][42][22]

Melo in his systematic review on acoustic rhinometry states that even though this technique has already been applied for almost twenty years, no controlled studies have been carried out assessing efficacy of measuring the area of nasal cavities for complementary diagnosis of respiratory mode. [20]

Caprioglio in his prospective study investigated the effects of rapid maxillary expansion on the airway correlating airway volumes computed on cone beam computed tomography and polysomnography evaluation of oxygen saturation and apnea/hypopnea index. He reported that there was an increase of total airway volume, oxygen saturation and apnea/hypopnea index which were statistically significant. [10]

But polysomnography is a sleep study carried out in specific sleep centers. The patients sleep pattern itself may be altered due to the new ambience and this makes validity of the results questionable. Moreover, the procedure is not cost effective.

McNamara assessed upper and lower airways using cephalometric variables. Linear parameters were employed for assessing airways. Although he had established the norm and provided us baseline information, these linear measurements have inherent shortcomings and suffers from the drawback of evaluating a three-dimensional structure in a 2-D imaging system.[41]

Moreover, with all the above methods it is difficult to make precise measurements of nasal airway ventilation because of the complicated form of the nasal airway lumen.

Three-dimensional imaging offers many advantages with respect to diagnosis and treatment planning in orthodontics. Cone beam computerized tomography (CBCT) utilizes conventional radiography and volumetric reconstruction to produce a three-dimensional image. This image is used for orthodontic purpose. Both hard and soft tissues can be visualized, which adds to its usefulness. [44][52][59]

Several authors have investigated the accuracy of measurements obtained from CT and CBCT images. [84][85][86] When compared to physical measurements on a dry skull, **Cavalcanti** et al found the measurement error to range from only 0.45 – 1.44%. This was deemed to be within a clinically tolerable range. [13]

Sadeghian assessed the effect of rapid maxillary expansion treatment on nasal cavity and upper airway using cone beam computed tomography. Patients were subjected to CBCT at the beginning of the RME treatment and again after the retention period of 4 months to measure the changes of retropalatal and retroglossal airways, nasal cavity and cephalometric parameters. His study showed that RME causes significant increase in transverse width of the nasal cavity, upper and retropalatal airways when assessed using CBCT. [60]

Zimmerman in his recent systematic review stated that upper pharyngeal airway assessment with CBCT demonstrated moderate-to-excellent intra- and inter-examiner reliability for volume and minimum cross-sectional area. Furthermore, he states airway volume demonstrated greater intra and inter-examiner reliability than did minimum cross-sectional area. In our study we have assessed both upper pharyngeal airway and minimum cross-sectional area. [95]

To study the airways from CBCT several softwares are used to extract the airway volume. In our study we have used Mimics Medical innovation suite v17.0 (Materialise, Leuven, Belgium) to extract airway volume.

Weissheimer assessed the 6 imaging software programs for their precision and accuracy in measuring upper airway volumes. He concluded that all software programs were reliable. Mimics, Dolphin3D, OsiriX and ITK-Snap were comparatively same and better than others.[72]

Hakan El compared the reliability and accuracy of 3 commercially available digital imaging and communications in medicine (DICOM) viewers for measuring upper airway volumes and found that 3 commercially available DICOM viewers are highly reliable in their airway volume calculations and showed high correlation of results, but its accuracy is questionable because of the parameters employed for segmenting the airway. [32]

Computational Fluid Dynamics

Recently computational technologies and biomechanical theories have been applied to study upper airway mechanics. [82]

Computational fluid dynamics (CFD) is a branch of fluid mechanics. Numerical analysis and data structures are used to solve and analyze problems that involving fluid flows.

From the mid-1970’s the complex mathematics required to generalize the algorithms began to be understood, and general-purpose CFD solvers were developed. In early 1980’s it started to appear and it required very powerful computers additional to it in-depth knowledge of fluid dynamics, and large amounts of time to set up simulations were needed. Consequently, CFD was a tool used almost exclusively in research. [73]

Computational fluid dynamics (CFD) has been used to model the upper airway (UA) flow field and were originally based on simplified airway models. More recent refinements enabled its use for patient specific geometrical characteristics obtained from medical imaging, hence providing a more accurate assessment of airflow characteristics.

CFD is now being utilized to assess the effects of treatment interventions that alter upper airway anatomical structure. For example, CFD analysis has been combined with upper airway geometries obtained before and after pharyngeal surgeries to determine the effects on parameters such as pressure drop and flow resistance. [82]

Computational Fluid Dynamics (CFD) is a validated method to accurately compute aerodynamic flow characteristics of the upper airway, which allows describing regional flow and pressure profiles in the upper airway.

There is sufficient evidence in the literature to justify that a CFD model is more sensitive or accurate than anatomical parameters alone in evaluating the effects of airway restriction in OSAS. Therefore, CFD simulation together with 3D upper airway model makes it possible to provide a more comprehensive understanding of pharyngeal airway after rapid maxillary expansion**.** [64][77][80][55]

Hence, we decided to perform CFD stimulation with 3D upper airway model in our study.

Iwasaki et al in their longitudinal study used computational fluid dynamics to estimate the effect of rapid maxillary expansion in children with age group of 9.74 ±1.29yrs. The pressure after rapid maxillary expansion (80.55 Pa) was significantly lower than before rapid maxillary expansion (147.70 Pa), and the velocity after rapid maxillary expansion (9.63 m/sec) was slower than before rapid maxillary expansion (13.46 m/sec). He concluded that

Improvement of nasal airway ventilation by rapid maxillary expansion was detected by computational fluid dynamics. [38]

Ghoneima et al in their case report assessed the effect of RME in an 9-year-old child, by comparing the fluid dynamics results on the airway flow rate and pattern of pre- and post-treatment finite element models. Laminar and turbulent analyses were applied in his study. His findings reveal that following RME there were positive effects in terms of decrease in pressure, velocity, and resistance of airway. This method may help comprehend the key mechanisms behind relieving the symptom of breathing disorders because of treatment with RME. [25]

Human airflow is assumed to be turbulent in general while Iwasaki et al’s study did not specify the type of flow. Ghoneima et all in a case report used turbulent model.

Hence, to better evaluate the relationship between respiratory function and nasal morphology, a 3-dimensional (3D) model of each subject’s nasal cavity was constructed from computed tomography data and used to create computational fluid dynamics models of respiratory status during quiet respiration. We followed standard **k-ε** (K-epsilon) model and analyzed turbulent flow.

SPSS Statistical Software was used in our study. Shapiro-Wilks test was performed, and it was observed that data was not normally distributed.

Wilcoxon Signed Ranks Test was used to check intragroup comparisons. Mann-Whitney Test was used to check intergroup differences. [37]

Velocity changes

In hybrid hyrax (MSE-1) group, there was a statistical significant intragroup difference in Velocity u (m/s), Velocity v (m/s), parameters between before and after expansion. There was a decrease of Maximum Velocity (m/s) in the post treatment model, which was not statistically significant. (Table T2 & T6)

Similarly, in hyrax RME group, there was a statistically significant intragroup difference in Velocity u (m/s), Velocity v (m/s), Velocity w (m/s), parameters between before and after expansion. There was a decrease of Maximum Velocity (m/s), which was not statistically significant. (Table T2 & T7)

We have assessed Maximum velocity in the model as well as velocity in x,y and z planes represented as u, v, and w respectively. Even though the maximum velocity differences between pre-and post is not significant the mean value denotes a sharp change in value which might be of clinical significance.

Our study results correlate with the results of **Iwasaki's** and that of **Ghoenima's** for airway changes with Rapid palatal expansion. [25][38]

Pressure changes

In hybrid hyrax (MSE-1) group, there was a statistical significant intragroup difference in Pressure (Pa) (Table T2 & T6).

In hyrax RME group there was a decrease of Maximum Pressure (m/s),) in post treatment model, however it was not statistically significant. (Table T2 & T7)

Pressure is created in nasal cavity during inspiration and expiration as the lungs pulls in and pushed out the air. Further the pressure might be increased when the nasal passage is constricted, as seen in our pre-treatment models. Since, implant supported expansion caused more skeletal expansion it is logical to assume that it is the reason as to why pressure difference is more in hybrid hyrax (MSE-1) group than Hyrax RME group.

The quantum of change in pressure correlates with **Iwasaki's** studies but it should be noted that his study has not specified about the type of appliance used and type of flow assessed. [38]

Flowrate changes

In hybrid hyrax (MSE-1) group, there was a statistical significant intragroup difference in Flowrate (secs) and in Hyrax RME group, there was a decrease of Flowrate (sec), in post treatment model, however it was not statistically significant. (Table T2 & T7).

To our knowledge this is the first study to evaluate the flowrate stimulation of nasal flow after expansion.

Maximum constricted area changes

In addition to this we have assessed the influence of palatal expansion on Maximum constricted area in terms of velocity and pressure.

In both the groups Velocity at the maximum constricted area showed a statistically significant difference. Even though there was a drop-in pressure it was not statistically significant.

It should be noted that these two parameters can be influenced by structures overlying it. Pressure and Velocity parameters of upper pharyngeal airway has an influence over Maximum Constricted Area.

However, as demonstrated by other authors, there were no significant increases in the airway volume in the posterior oropharynx. Lack of change in volume in the posterior oropharynx was attributed to the lack of proximity between oropharynx and the maxillary complex. [14][83]

The results of our study confirm that the effect of RME in the upper airway is restricted to nasopharynx and the effect decreases as it “descends” in the upper airway.

Comparison between the groups

On comparing the outcomes of hybrid hyrax (MSE-1) and Hyrax RME group hybrid hyrax (MSE-1) showed improved results. However, the difference was not statistically significant. (Table T4 & T5).

This signifies that the improvement in airflow characteristics is due to the effect of MSE in inducing greater skeletal expansion as compared to conventional hyrax where the expansion is more dentoalveolar. The amount of expansion was significant and varies from first molar to the canine region.

In hybrid hyrax group, in the transverse plane, the expansion was 4.5 mm in the region of I molar, II pre-molar, I pre-molar and gradually increased to 4.8 mm in the canine region and the greatest amount of expansion was seen at the incisor region amounting to 5.3mm.

Similar findings were greater amount of skeletal expansion with the use of hybrid hyrax has been reported by **Won moon**. [11]

The skeletal gain in the hybrid hyrax (MSE-1) group average 61% of total expansion. In the hyrax RME group, no skeletal expansion was observed. Lack of skeletal expansion in adults can be attributed to the fusion of mid-palatal suture and the inability of the RME device to open the sutures due to the fact that it is anchored to the dentition. Similar lack of sutural expansion and predominant dentoalveolar changes have been reported with the use of RME in adults. [47][48][61]

A similar observation was also reported by **Mary Ellen Helmkamp**, where greater skeletal expansion was seen over dental expansion. However, the quantum of skeletal expansion reported in her study is not concurrent with our study. She had employed a complete bone-borne expansion appliance unlike in our study which is a hybrid of bone supported and tooth supported expansion appliance. The skeletal gain in bone borne appliance that was reported in their study is only 56% as compared to 61% in our sample. [68]

However, an interesting finding was that the hybrid hyrax RME expansion device provided a significantly different pattern of mid palatal suture opening. On an average we found that the suture diverged only 3.56 degrees from the posterior to anterior region of the suture after expansion. This led to more uniform and equal opening along the length of the suture. No significant opening was noted in the Hyrax group.

Expansion not only alters the maxilla but also the nasal cavity and the surrounding cranial structures. The hybrid hyrax RME group produced statistically significant differences at nasal, frontonasal and zygomatic bone level.

Comparative improvement of hybrid hyrax (MSE-1) is more due to increased skeletal effects of implant supported palatal expansion. There was an increase in width at lateral borders of the nasal cavity, frontonasal suture and zygoma which was 4.16 mm, 0.5mm and 2.66 mm respectively. Whereas, in the tooth borne hyrax RME group there was no statistical difference found in those parameters.

According to a systemic review by **Farhan** et al when expansion is done with tooth-borne hyrax, nasal cavity expands to an average of 1.2mm to 2mm at the zygomatic level it expands up to 0.30 to 0.45mm which is not statistically significant. [91]

In a recent report using hybrid expander **Carlson and Moon** reported that nasal cavity expands to an average of 3mm to 4mm and at the zygomatic level it expands up to 4.4 mm which is significant. This is supported by the results in this study. The quantum of expansion is like our study. [11]

Still, we cannot underestimate the clinical value of short-term effects of RME on the immediate relief of respiratory symptoms, which was substantially demonstrated in this research.

Even if RME affects the upper airway transiently, it should be regarded as an important therapeutic approach for patients with upper airway disturbances. Because of the substantial respiratory improvements described by patients in this study, controlled clinical trials are suggested to be conducted to assess subsequent respiratory effects of RME in patients.

Limitations

1) Even though CFD is a reliable for testing the flow, the CFD model assumes the airway tissues are stationary during each phase increment and does not model airway collapse. But, it is more dynamic.
2) Low sample size and the age group were the limitation of the study. Further studies with a larger sample size and matched ages are indicated.

Summary & Conclusion

CONCLUSION

This study was designed to evaluate airway changes produced by hybrid hyrax RME and compare it with conventional hyrax RME in non-growing individuals by employing Computational Fluid Dynamics.

The following conclusion can be made

a) The hybrid hyrax RME produced more changes in airway compared to conventional hyrax RME device.

b) In hybrid hyrax RME, there was a statistical significant intragroup difference in Pressure (Pa) and Flowrate (sec). However, Maximum Velocity(m/s) showed no statistically significant change.

c) In conventional hyrax, there was a intragroup difference in Pressure (Pa), Flowrate (sec) and Maximum Velocity(m/s) but were not statistically significant.

d) In Maximum Constricted Area, in both the groups Velocity (m/s) change showed a statistically significant difference. Even though there was a drop-in pressure, it was not statistically significant.

f) Further studies could be designed to examine the long-term effects of the hybrid hyrax expansion on pharyngeal airway.

Bibliography

BIBLIOGRAPHY

1. **Al Shaban K. K, F. M. Abdullah.** Nasal Airway Obstruction and the Quality of Life. American Scientific Researhch Journal for Engineering, Technology, and Sciences (ASRJETS) (2016) Volume16, No 1, pp328-333.
2. **Angell EH**. Treatment irregularities of the permanent or adult dentition. Dental Cosmos. 1860; 1:540–4.
3. **Baccetti T, Franchi L, Cameron C G, James A. McNamara Jr**. Treatment Timing for Rapid Maxillary Expansion. Angle Orthod 2001; 71:343–350
4. **Baratieri C, Alves M Jr, de Souza MM, de Souza Araujo MT, Maia LC** Does rapid maxillary expansion have long-term effects on airway dimensions and breathing? Am J Orthod Dentofacial Orthop 2011;140(2):146-56
5. **Bazargani F, Feldmann I, Bondemark L**. Three-dimensional analysis of effects of rapid maxillary expansion on facial sutures and bones. Angle Orthod. 2013; 83:1074–1082.
6. **Biederman W. A** hygienic appliance for rapid expansion. J Clinical Orthod 1968; 2:67-70.

7. **Buccheri A., G. Dilella, R. Stella**, Rapid palatal expansion and pharyngeal space cephalometric evaluation, Prog. Orthod. 5 (2004) 160–169.

8. **Buck LM, Dalci O, Darendeliler MA, Papadopoulou AK**, The Effect of Surgically-Assisted Rapid Maxillary Expansion (SARME) on Upper Airway Volume: A Systematic Review, Journal of Oral and Maxillofacial Surgery (2016), doi: 10.1016/j.joms.2015.11.035.

9. **Buck, O Dalci, M. A Darendeliler, S N. Papageorgiou, and A K. Papadopoulou,** Volumetric upper airway changes after rapid maxillary expansion: a systematic review and meta-analysis. European Journal of Orthodontics, 2016, 1–11. doi:10.1093/ejo/cjw048

10. **Caprioglio A, M.Meneghel, R. Fastuca, P. A. Zecca, R.Nucera, L. Nosetti.** Rapid maxillary expansion in growing patients: Correspondence between 3-dimensional airway changes and polysomnography. International Journal of Pediatric Otorhinolaryngology 78 (2014) 23–27

11. **Carlson, J. Sung, R.W. McComb, A.W. Machadod and W. Moon**, Micro-implant-assisted rapid palatal expansion appliance to orthopedically correct transverse maxillary deficiency in an adult. Am J Orthod Dentofacial Orthop 2016; 149:716-28.

12. **Castillo.** Maxillary Expansion may Increase Airway Dimensions and Improve Breathing. J Evid Base Dent Pract 2012;12:14-17

13. **Cavalcanti MG, Haller JW, Vannier MW.** Three-dimensional computed tomography landmark measurement in craniofacial surgical

planning: Experimental validation in vitro. J Oral Maxillofac Surg 1999;57:690-694.

14. **Chang Y., Koenig L.J., Pruszynski J.E., Bradley T.G., Bosio J.A. and Liu D.** Dimensional changes of upper airway after rapid maxillary expansion: a prospective cone-beam computed tomography study. Am J Orthod Dentofacial Orthop 2013, 143, 462–470.

15. **Chiari S., P. Romsdorfer, H. Swoboda, H. Bantleon and J. Freudenthaler.** Effects of rapid maxillary expansion on the airways and ears — a pilot study. European Journal of Orthodontics 31 (2009) 135–141.

16. **Chuse Lin, Yiju,** comparison of skeletal and dental changes with MSE (Maxillary Skeletal Expander) and Hyrax appliance using CBCT imaging 2015 UCLA Electronic Theses and Dissertations.

17. **Clement EA, Krishnaswamy NR.** Skeletal and dentoalveolar changes after skeletal anchorage-assisted rapid palatal expansion in young adults: A cone beam computed tomography study. APOS Trends Orthod 2017;7: 113-9.

18. **Cordasco , R Nucera, R. Fastuca , G. Matarese , Steven J. Lindauer, P. Leone, P. Manzo , Martina**. Effects of orthopedic maxillary expansion on nasal cavity size in growing subjects: A low dose computer tomography clinical trial. International Journal of Pediatric Otorhinolaryngology 76 (2012) 1547–1551.

19. **De Felippe, Adriana C. Da Silveira, G. Viana, B. Kusnoto, B. Smith, and C. A. Evans**. Relationship between rapid maxillary expansion and nasal cavity size and airway resistance: Short- and long-term effects. Am J Orthod Dentofacial Orthop 2008;134:370-82.

20. **de Melo AC, Gomes AO, Cavalcanti AS, da Silva HJ**. Acoustic rhinometry in mouth breathing patients: a systematic review. Braz J Otorhinolaryngol. 2015;81:212---8.

21. **Donald J. Timms** (1986) The Effect of Rapid Maxillary Expansion on Nasal Airway Resistance, British Journal of Orthodontics, 13:4, 221-228

22. **Doruk C, Sokucu O, Bicakci AA, Yilmaz U, Tas F**. Comparison of nasal volume changes during rapid maxillary expansion using acoustic rhinometry and computed tomography. Eur J Orthod 2007; 29:251-5.

23. **Garland Hershey, Bruce 1. Stewart, DAD., and Donald W. Warren**. Changes in nasal airway resistance associated with rapid maxillary expansion. Am J Orthod 1976: 69; 274

24. **Geran RG, McNamara JA Jr, Baccetti T, Franchi L, Shapiro LM. A** prospective long-term study on the effects of rapid maxillary expansion in the early mixed dentition. Am J Orthod Dentofacial Orthop. 2006 May;129(5):631–40

25. **Ghoneima A., S. AlBarakati, F. Jiang, K. Kula1 and T.Wasfy.** Computational fluid dynamics analysis of the upper airway after rapid maxillary expansion: a case report. Progress in Orthodontics (2015) 16:10

26. **Gray L.P.** Rapid maxillary expansion and impaired nasal respiration, Ear Nose Throat J. 66 (1987) 248—251.
27. **Gray LP**. Results of 310 cases of rapid maxillary expansion selected for medical reasons. J Laryngol Otol 89:601–614, 1975.
28. **Guijarro-Martı´nez, G. R. J. Swennen**: Cone-beam computerized tomography imaging and analysis of the upper airway: a systematic review of the literature. Int. J. Oral Maxillofac. Surg. 2011; 40: 1227–1237
29. **Haas A.** Gross reactions to the widening of the maxillary dental arch of the pig by splitting the hard palate. Am J Orthod 1959; 45:868.
30. **Haas AJ.** Palatal expansion: Just the beginning of dentofacial orthopedics. Am J Orthod 1970; 57:219-255.
31. **Haas** and Hyrax expanders. J CraniofacSurg 2007; 18:1322- 1326
32. **Hakan El and Palomo J M.** Measuring the airway in 3 dimensions: A reliability and accuracy study. Am J Orthod Dentofacial Orthop 2010; 137: S50.e1-S50.e9.
33. **Handelman C**. Palatal expansion in adults: The nonsurgical approach. Am J Orthod Dentofacial Orthop. 2011 Oct;140(4):462–8.
34. **Hartgerink D.V., P.S. Vig, D.W. Abbott**, The effect of rapid maxillary expansion on nasal airway resistance, Am. J. Orthod. Dentofacial Orthop. 92 (1987) 381—389.

35. **Hilberg O, Jackson AC, Swift DL, Pederson OF**. Acoustic rhinometry: evaluation of nasal cavity geometry by acoustic reflection. J Appl Physiol 1989; 66(1):295– 303.
36. **Hung Hsiag Tso, BS, Janice S. Lee, DDS, MD, MS, John C. Huang**. Evaluation of the human airway using cone-beam computerized tomography. Oral Surg Oral Med Oral Pathol Oral Radiol Endod 2009; 108:768-776
37. IBM Corp. Released 2013. **IBM SPSS Statistics for Windows**, Version 22.0. Armonk, NY: IBM Corp.
38. **Iwasaki T, I. Saitoh, Y. Takemoto, E. Inada, R. Kanomi Haruaki H., and Y. Yamasaki.** Improvement of nasal airway ventilation after rapid maxillary expansion evaluated with computational fluid dynamics. Am J Orthod Dentofacial Orthop 2012;141:269-78
39. **Iwasaki T, Y.Takemoto, E. Inada, H. Sato, H. Suga, I. Saitoh, E. Kakuno, R. Kanomi, Y. Yamasaki,** The effect of rapid maxillary expansion on pharyngeal airway pressure during inspiration evaluated using computational fluid dynamics, International Journal of Pediatric Otorhinolaryngology 2014; 78(8): 1258–1264
40. **Iwasaki T.; H Satob; H Sugac; AMinamid; Y Yamamoto; Y Takemoto; E Inadac; I Saitohe; E Kakuno; R Kanomi; Y Yamasaki.** Herbst appliance effects on pharyngeal airway ventilation evaluated using computational fluid dynamics. Angle Orthod. 2017;87:397–403.

41. **James A. McNamara, Jr.** A method of'cephalomettic evaluation. Am. J. Orthod. December 1984; 86(6) 449-460.

42. **Jones AS, Lancer JM.** Rhinomanometry. Clin Otolaryngol Allied Sci 1987; 12:233-6.

43. **Kilic N, Oktay H.** Effects of rapid maxillary expansion on nasal breathing and some naso-respiratory and breathing problems in growing children: A literature review. International Journal of Pediatric Otorhinolaryngology (2008) 72, 1595—1601

44. **Kim Y, Hong. J, Hwang. Y and Park. Y**. Three-dimensional analysis of pharyngeal airway in preadolescent children with different anteroposterior skeletal patterns. Am J Orthod Dentofacial Orthop 2010; 137: 306.e1-306.e11

45. **L. Moss-Salentijn, L. Melvin**, Moss and the functional matrix, J. Dent. Res. 76 (1997) 1814—1817.

46. **Lagravere MO, Carey J, Toogood RW, Major PW**. Three-dimensional accuracy of measurements made with software on cone-beam computed tomography images. Am J Orthod Dentofacial Orthop 2008; 134:112-116.

47. **Lagravere MO, Major PW, Flores-Mir C.** Long-term skeletal changes with rapid maxillary expansion: a systematic review. Angle Orthod. 2005; 75:1046–1052.

48. **Lagravère. O, Giseon Heo, Paul W. Major, C. Flores-Mir.** Meta-analysis of immediate changes with rapid maxillary expansion treatment. JADA 2006;137:44-53.
49. **Langer, Itikawa, Valera F.C.P , Matsumoto M. A. N, Anselmo-Lima.** Does rapid maxillary expansion increase nasopharyngeal space and improve nasal airway resistance? International Journal of Pediatric Otorhinolaryngology 75 (2011) 122–125.
50. **Linder-Aronson S, Aschan G.** Nasal resistance to breathing and palatal height before and after expansion of the median palatal suture. Odont Rev 1963; 14:254-70.
51. **Lu Lina, Hyo-Won Ahnb; Su-Jung Kimc; Sung-Chul Moon; Seong-Hun Kim; Gerald Nelson** Tooth-borne vs bone-borne rapid maxillary expanders in late adolescence Angle Orthod. 2015; 85:253–262
52. **Mattos, Cruz, Sobreira, Matta, Pereira, Solon-de-Mello, Ruellas and Sant'Anna**. Reliability of upper airway linear, area, and volumetric measurements in cone-beam computed tomography. Am J Orthod Dentofacial Orthop 2014; 145:188-97)
53. **Mluiz Henrique Hideo Suzuki1, Won Moon**, Miniscrew-assisted rapid palatal expander (MARPE): the quest for pure orthopedic movement Previdente Dental Press J Orthod. 2016 July-Aug; 21(4):17-23
54. **Mylavarapu, S Murugappan , M. ManinderKalra, S. Khosla, E Gutmark.** Validation of computational fluid dynamics methodology

used for human upper airway flow simulations. Journal ofBiomechanics42(2009)1553–1559

55. **Nie P, Xiao-Long Xu, Yan-Mei Tang, X Wang, Xiao-Chen Xue**. Computational Fluid Dynamics Simulation of the Upper Airway of Obstructive Sleep Apnea Syndrome by Muller Maneuver. J Huazhong Univ Sci Technol. [Med Sci]. 35(3):464-468,2015.
56. **Pereira-Filho, Monnazzi, Gabrielli, R. Spin-Neto, E. R. Watanabe, C. M. M. Gimenez, A. Santos-Pinto, M. F. R. Gabrielli.** Volumetric upper airway assessment in patients with transverse maxillary deficiency after surgically assisted rapid maxillary expansion. Int. J. Oral Maxillofac. Surg. 2014; 43: 581–586
57. **Pfaff W**. Stenosis of the nasal cavity caused by contraction of the palatal arch and abnormal position of the teeth: Treatment by expansion of the maxilla. Dental Cosmos. 1905; 47:570–3.
58. **Proffit WR, Henry W. Fields,** Jr. Contemporary Orthodontics. 3rd Edition Mosby, Inc. 2000
59. **Ribeiro, Paivab J, Rino-Netoc J; E.Illipronti-Filhoa; T. T, Fantini S M**. Upper airway expansion after rapid maxillary expansion evaluated with cone beam computed tomography. Angle Orthod. 2012; 82:458–463.

60. **Sadeghian, Ghafari, M. Feizbakhsh, S. Dadgar.** Dimensional changes of upper airway after rapid maxillary expansion evaluated with cone beam computed tomography. Orthodontic waves 75 (2016) 10– 17

61. **Schiffman PH, Tuncay OC**. Maxillary expansion: a meta analysis. Clin Orthod Res 2001; 4:86-96.

62. **Shah D.H; K.B. Kim; M. W. McQuilling; R. Movahed; Ankit H. Shah; Y. I. Kim.** Computational fluid dynamics for the assessment of upper airway changes in skeletal Class III patients treated with mandibular setback surgery. Angle Orthod. 2016; 86:976–982

63. **Sittitavornwong S, P. D. Waite, A. M. Shih, G. C. Cheng, R Koomullil, Y.Ito, Joel K. C M. Harding, and M Litaker**. Computational Fluid Dynamic Analysis of the Posterior Airway Space After Maxillomandibular Advancement for Obstructive Sleep Apnea Syndrome. J Oral Maxillofac Surg 71:1397-1405, 2013.

64. **Sittitavornwong , Peter D. Waite, A M. Shih, R Koomullil, Y Ito, Gary C. Cheng, and D Wang.** Evaluation of Obstructive Sleep Apnea Syndrome by Computational Fluid Dynamics. Seminars in Orthodontics, Vol 15, No 2 (June), 2009: pp 105-131.

65. **Smith T., A. Ghoneima, K. Stewart, S. Liu, G. Eckert, S.Halum, and K. Kula.** Three-dimensional computed tomography analysis of airway volume changes after rapid maxillary expansion. Am J Orthod Dentofacial Orthop 2012; 141:618-26

66. **Stratemann, John C. Huang, Koutaro Maki, David Hatcher, and Arthur J. Millere**. Three-dimensional analysis of the airway with cone-beam computed tomography. Am J Orthod Dentofacial Orthop 2011; 140:607-15.

67. **Timms D J, et al.,** A study of basal movements with rapid maxillary expansion. Am J Orthod,1980, 77: 500 – 507.

68. **Tiraujo Eustaquio A. Donald R. Oliver Mary Ellen helmkamp** Three-dimensional evaluation of implant-supported rapid maxillary expansion vs. traditional tooth-borne rapid maxillary expansion using cone-beam computed tomography, Thesis- 2012.

69. **Vale F, Albergaria M, Carrilho E, Francisco I, Guimarães A, Caramelo F, Maló L**, Efficacy of rapid maxillary expansion in the treatment of Obstructive Sleep Apnea Syndrome: a systematic review with meta-analysis, The Journal of Evidence-Based Dental Practice (2017), doi: 10.1016/j.jebdp.2017.02.001

70. **Wakayama T, Suzuki M, Tanuma T (2016)** Effect of Nasal Obstruction on Continuous Positive Airway Pressure Treatment: Computational Fluid Dynamics Analyses. PLoS ONE 11(3): e0150951. doi:10.1371/journal.pone.0150951.

71. **Warren D.W., H.G. Hershey, T.A. Turvey, V.A. Hinton, W.M. Hairfield.** The nasal airway following maxillary expansion, Am. J. Orthod. Dentofacial Orthop. 91 (1987) 111—116.

72. **Weissheimer, Menezes, Glenn T. Sameshima, Reyes Enciso,d John Pham, and Dan Grauer**. Imaging software accuracy for 3-dimensional analysis of the upper airway. Am J Orthod Dentofacial Orthop 2012;142:801-13.

73. **Wendt, John F, and John D. Anderson.** Computational Fluid Dynamics: An Introduction. Berlin: Springer-Verlag, 1992.

74. **Wertz R.A**, Changes in nasal airflow incident to rapid maxillary expansion, Angle Orthod. 38 (1968) 1—11.

75. **Wertz R.A.**, Skeletal and dental changes accompanying rapid midpalatal suture opening, Am. J. Orthod. 58 (1970) 41—6.

76. **Wilmes B, Björn Ludwig,** T-Zone: Median vs. Paramedian Insertion of Palatal Mini-Implants Jco/september 2016

77. **Wootton D.M., H. Luo, Steven C. Persak, S. Sin, J. M. McDonough, Carmen R. Isasi, and R. Arens**. Computational fluid dynamics endpoints to characterize obstructive sleep apnea syndrome in children. J Appl Physiol 116: 104–112, 2014.

78. **Wootton DM, Sin S, Luo H, Yazdani A, McDonough JM, Wagshul ME, Isasi CR, Arens R**. Computational fluid dynamics upper airway effective compliance, critical closing pressure, and obstructive sleep apnea severity in obese adolescent girls. J Appl Physiol 121: 925–931, 2016

79. **Yamashina A, K Tanimoto, P Sutthiprapaporn1, and Y Hayakawa**. The reliability of computed tomography (CT) values and dimensional

measurements of the oropharyngeal region using cone beam CT: comparison with multidetector CT. Dento-maxillofacial Radiology (2008) 37, 245–251.

80. **Yu, Hung-Da Hsiao, Tzu-I Tseng, Lung-Cheng Lee, C Yao, N-H Chen, C Wang, and Y Chen.** Computational Fluid Dynamics Study of the Inspiratory Upper Airway and Clinical Severity of Obstructive Sleep Apnea. J Craniofac Surg 2012;23: 401-405.

81. **Zeng J, Gao X.** A prospective CBCT study of upper airway changes after rapid maxillary expansion. International Journal of Pediatric Otorhinolaryngology 77 (2013) 1805–1810.

82. **Zhao M, T.Barber, P. Cistulli , K. Sutherland , G. Rosengarten.** Computational fluid dynamics for the assessment of upper airway response to oral appliance treatment in obstructive sleep apnea**.** Journal of Biomechanics 46(2013)142–150.

83. **Periago DR, Scarfe WC, Moshiri M, Scheetz JP, Silveira AM, Farman AG.** Linear accuracy and reliability of cone beam CT derived 3-dimensional images constructed using an orthodontic volumetric rendering program. Angle Orthod 2008;78:387-395.

84. **Brown; W. C. Scarfe; J. P. Scheetz; Anibal M. Silveirad; Allan G. Farman.** Linear Accuracy of Cone Beam CT Derived 3D Images. Angle Orthod. 2009; 79:150–157

85. **M. Jones, M. Papio, B. Ching Tee, Frank M. Beck, Henry W. Fields, and Z Sun**. Comparison of cone-beam computed tomography with multislice computed tomography in detection of small osseous condylar defects. Am J Orthod Dentofacial Orthop 2016; 150:130-9

86. **O. Lagravère, J. Carey, R. W. Toogood, and Paul W. Major.** Three-dimensional accuracy of measurements made with software on cone-beam computed tomography images. Am J Orthod Dentofacial Orthop 2008; 134:112-16

87. **R. J. Lee, W. Moon, and C. Hong.** Effects of monocortical and bicortical mini-implant anchorage on bone-borne palatal expansion using finite element analysis. Am J Orthod Dentofacial Orthop 2017;151:887-97

88. **Crismani AG, Bertl MH, Celar AG, Bantleon HP, Burstone CJ.** Miniscrews in orthodontic treatment: review and analysis of published clinical trials. Am J Orthod Dentofacial Orthop 2010;137: 108-13.

89. **Wu TY, Kuang SH, Wu CH**. Factors associated with the stability of mini-implants for orthodontic anchorage: a study of 414 samples in Taiwan. J Oral Maxillofac Surg 2009; 67:1595-9.

90. **Kim YH, Yang SM, Kim S, Lee JY, Kim KE, Gianelly AA, et al.** Midpalatal miniscrews for orthodontic anchorage: factors affecting clinical success. Am J Orthod Dentofacial Orthop 2010;137:66-72.

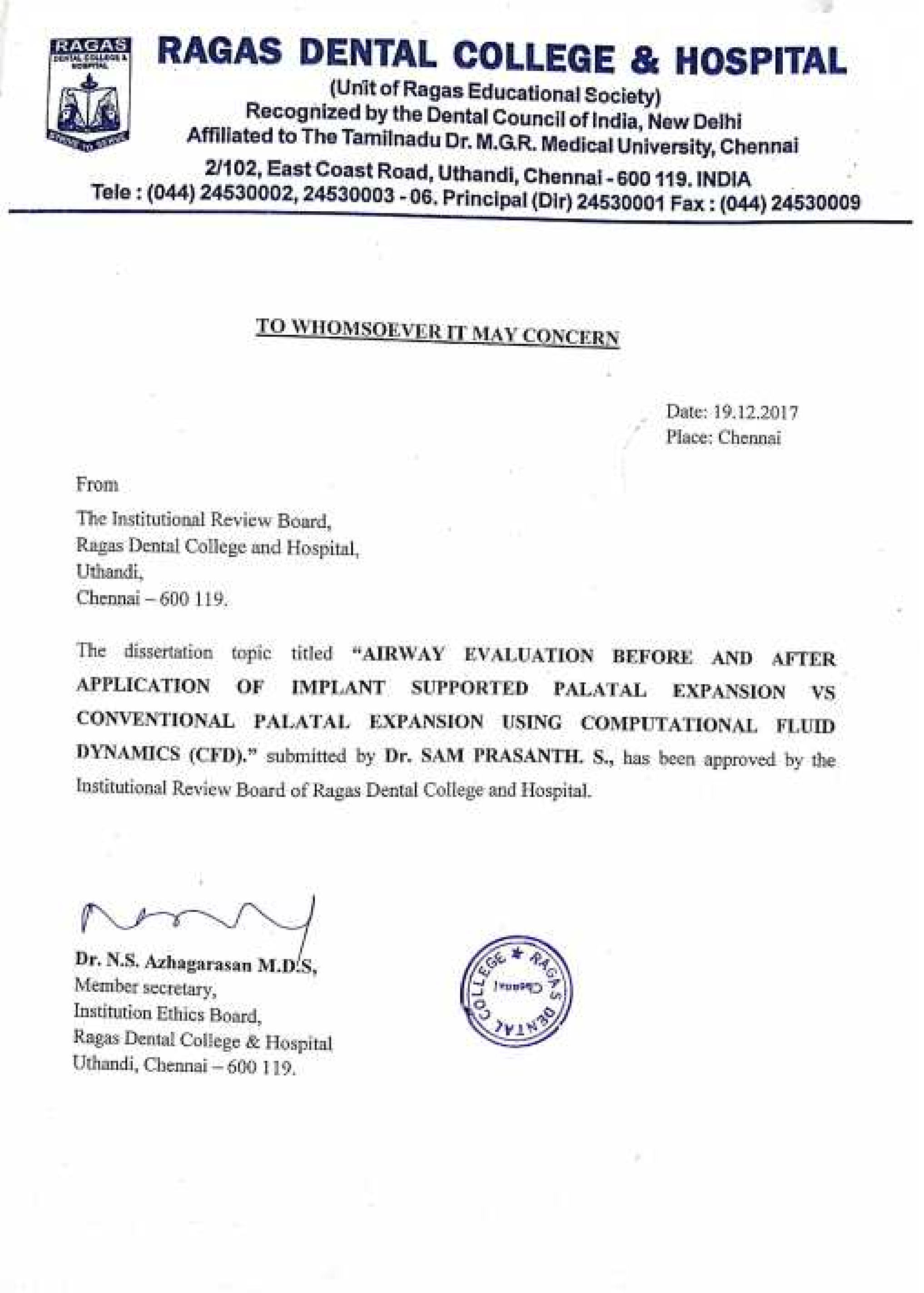
91. **Timothy Farhan, B.I Feldmann** hree-dimensional analysis of effects of rapid maxillary expansion on facial sutures and bones A systematic review Angle Orthod. 2013;83: 1074–1082.
92. **Laptook T.** Conductive hearing loss and rapid maxillary expansion, Am. J of Orthod , 1981, vol. 80 (pg. 325-331)

93. **Zhao Y, Nguyen, Gohl, K. Mah, Sameshima, and Enciso**. Oropharyngeal airway changes after rapid palatal expansion evaluated with cone-beam computed tomography. Am J Orthod Dentofacial Orthop 2010; 137: S71-8
94. **Zheng, Z. et al**. Computational fluid dynamics simulation of the upper airway response to large incisor retraction in adult class I bimaxillary protrusion patients. Sci. Rep. 7, 45706; doi: 10.1038/ srep45706 (2017).

95. **Zimmerman J.N , J. Lee and Benjamin T. Pliska**. Reliability of upper pharyngeal airway assessment using dental CBCT: a systematic review. European Journal of Orthodontics, 39 (5), 2017, 489–496.

Annexures

Annexure – I



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(Unit of Ragas Educational Society)
Recognized by the Dental Council of India, New Delhi
Affiliated to The Tamilnadu Dr. M.G.R. Medical University, Chennai
2/102, East Coast Road, Uthandi, Chennai - 600 119. INDIA
Tele : (044) 24530002, 24530003 - 06. Principal (Dir) 24530001 Fax : (044) 24530009

<u>**TO WHOMSOEVER IT MAY CONCERN**</u>

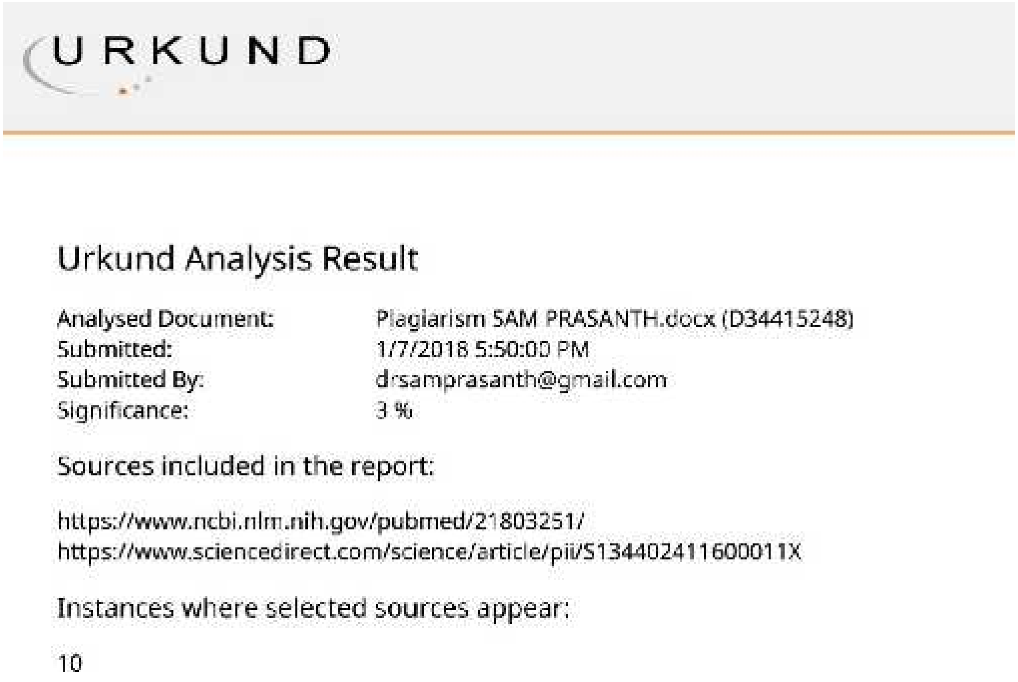
Date: 19.12.2017
Place: Chennai

From
The Institutional Review Board,
Ragas Dental College and Hospital,
Uthandi,
Chennai – 600 119.

The dissertation topic titled **"AIRWAY EVALUATION BEFORE AND AFTER APPLICATION OF IMPLANT SUPPORTED PALATAL EXPANSION VS CONVENTIONAL PALATAL EXPANSION USING COMPUTATIONAL FLUID DYNAMICS (CFD)."** submitted by **Dr. SAM PRASANTH. S.,** has been approved by the Institutional Review Board of Ragas Dental College and Hospital.

Dr. N.S. Azhagarasan M.D.S,
Member secretary,
Institution Ethics Board,
Ragas Dental College & Hospital
Uthandi, Chennai – 600 119.

Annexure – II



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