Problem #1

Team 11

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Problem/Solution/Rationale

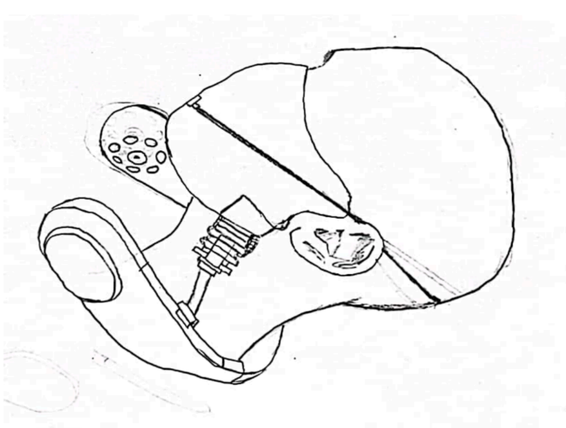
The problem we were presented entails the challenges faced by rhinoplasty and other nose surgery patients during their initial week of recovery, as they are unable to breathe through their nose, necessitating exclusive mouth breathing for a duration of around seven days or potentially longer. The nose's customary role in conditioning, humidifying, and filtering inhaled air before it enters the respiratory system is disrupted during this time, and when considering this, we pinpointed inhaling dry air as a primary source of patient discomfort and consequently we decided to focus our efforts on addressing this specific aspect of reduced nasal function during the recovery period. We achieved this by creating a selectively permeable mask that can be attached to a portable humidifier worn around the neck. By doing so, we aim to enhance patient comfort by mitigating airway dryness which is anticipated to result in a more comfortable recovery process with fewer symptoms of fatigue and sleep deprivation.

Design Components and Principles of Operation

The device we have developed to address this issue comprises a portable humidification system designed to be worn around the neck. During nighttime use, a mask is connected to the system to ensure optimal delivery of water vapor generated by the machine to the patient. This system effectively replicates the natural humidification function of the nose.

Our initial task involved determining the volume of water supplied by the nasal mucosa to the inhaled air over an eight-hour period, as we aimed to, at least, match this quantity with the device's water reservoir capacity. Firstly, we ascertained that the average adult inhales air at a rate of approximately 6 liters per minute [1]. Subsequently, we determined that at airflow rates of 5, 10, and 20 liters per minute, a single nostril contributes 297.6 ± 12.6 mg, 509.1 ± 32.0 mg, and 794.1 ± 62.1 mg of water, respectively, to the humidification of the inhaled air [2]. Plotting this data revealed an exponential relationship (equation: $y = 185.01e^{x}$), establishing the water contribution of a single nostril at an airflow rate of 6 liters per minute to be 333.29 mg/min. Converting this value to grams of water for both nostrils was accomplished using the equation illustrated below.

$$333.29\ \frac{mg}{min}\ H_2O \times 480\ min\ \times\ \frac{1\ g}{1000\ mg} \times 2\ nostrils =\ 319.96\ g\ H_2O$$



Considering that the neckpiece is primarily intended to humidify the ambient air around the patient, without the mask attachment, we opted to allocate approximately 25% more water than the calculated minimum requirement, resulting in a total water reservoir capacity of 400.0 grams (H_2O). A view of the mask and neckpiece is in Figure 1.

Figure 1: Mask and portable humidifier on a patient

The neck piece contains 10 internal humidifiers to convert the water reserved into a gentle and refreshing water vapor. When mouth breathing post-surgery, wearers can enjoy a revitalizing mist that humidifies breathed air to the same extent that breathing through the nose would. Each humidifier has a fan that serves to disperse and move the water vapor up toward the patient's face allowing for minimal patient involvement. This device and one of its humidifiers can be seen in Figures 2 and 3.

For optional use at night, the device will have the ability to attach a mask to the neck piece. This ensures that the water contained within the neck piece can last a patient for the entire 8 hours that they might sleep. The mask itself would be made of a layer impermeable to water but permeable to air, like hydrophobic acoustic mesh. This attachment is depicted in Figure 4.

The final portion of this design is a Humidity Sensor BME280 (Bosch Sensortec, Germany, BME280, 2.5 x 2.5 x 0.93 mm^3) [3] which would be coded effectively as an event listener. It would be placed on the inner layer of the mask and coded to sense the humidity of the air in the space between the mask and the patient. Once the air reaches a 87% humidity reading (the natural humidity value that the nose would condition the air to is 90% [4], the sensor has a relative humidity tolerance of ±3.0%), the sensor would stop the rest of the machine so no more water entered the air from the neck piece until the humidity level dropped. Its position can be seen in Figure 5.

Design Goals and Design Requirements

Our device effectively meets the design goals that we as a group have decided to implement. Since one of the main troubles of mouth breathing is less humidity, we wanted the device to increase the humidity of air to 87% with a tolerance of ±3.0%. Another aspect we thought would be important, is to have the device weigh less than 900.0grams. We want to carry out this goal because it will make the device portable and easy to work around, while also doing day to day activities. Furthermore, we want the device to be able to hold up to 400 grams of water so it assures that the user doesn't have to replace the water at night. Lastly, the device should have a maintenance frequency of about 6-7 days to provide a safe and optimum cleanliness. Ensuring this, would allow the user to go 6-7 days without having to clean or replace parts of the device which is more convenient for a patient who should be focused on recovering.

As for design requirements, our primary objective is to enhance comfort and get rid of the discomfort associated with mouth breathing, during both day to day activities and more importantly during sleep. In order to achieve this our device must imitate a key nasal function: humidifying the air. We chose our focus to be the humidity issue, due to the problem of throat and airway irritation caused by lack of humidity during the recovery process, which can lead to worsened irritation in certain individuals with increased sensitivity to dry air. Our device displays ease of wear, which ensures that it is suitable for everyday wear as well as overnight wear, which is where the mask comes into play. In reference to overnight wear, the device operates continuously for a minimum of 8 hours without needing any replacements or additional maintenance, therefore securing reliability. The device avoids potential hazards such as electric shock risks, which is achieved by the power source being self contained. Additionally the device prevents accidental inhalation of fluids which is accomplished by the humidity sensor turning off all vapor creation once humidity in the mask chamber gets too high.

Safety and Efficacy

The device we have developed prioritizes user safety while ensuring its efficacy meets both standard requirements and project goals, effectively addressing the issue of providing a wearable device that can humidify the dry air inhaled during mouth breathing.

Our device is designed for easy wear around the neck, with the weight evenly distributed to provide a lightweight and comfortable experience throughout the day. As outlined in the Design Components and Principle of Operation, and as per [1] and [2], nasal mucosa utilizes approximately 320 grams of water over an 8-hour period at a breathing rate of 6 liters per minute. With our device featuring a reservoir capable of holding 400 grams of water, we exceed the necessary supply by ~25%, ensuring users have a steady source of humidified air for over 8 hours, thereby fulfilling our efficacy goal of an 8-hour device lifespan. Additionally, we recommend that users use distilled water to prevent mold growth, not only for their safety but also to ensure that their product works as efficiently as possible. Using distilled water additionally extends the amount of time the product can be used without thorough cleaning due to this decreased bacterial concern.

Furthermore, our device incorporates sensors that act as event listeners. As previously stated, these sensors detect when humidity levels reach 87% rather than 90% [4] (the natural nasal humidity conditioning point), and this is due to our sensor's relative humidity tolerance being ±3% [3]. With these tolerances, we guarantee users receive optimal humidity while still maintaining comfortable breathing conditions based on the ambient moisture content in the air.

Wearability and Feasibility

Our wearable humidifier offers a favorable and comfortable solution to address health concerns with mouth-breathing, as well as in dry or low-humidity environments. The neck piece portion of our design provides a convenient and non-obstructive way to disperse humidified air into the surroundings and therefore fighting the discomfort associated with dry throats.

The feasibility of our design that concludes a neck component as well as an optional attachable mask is an appealing concept, yet comes with noteworthy challenges. In terms of technicality, creating an effective and compact humidifier while also ensuring things like minimal noise production, efficient battery, and durability can be complicated. Biologically, concerns with microbial growth [5], and good quality of air should be addressed through hygiene tests. Finally, in terms of the bioengineering aspect, ensuring an accommodating neck fit and size for the user is important, as well as maintaining a sleek, user-friendly design.

Despite these challenges, a successfully developed device can offer many benefits especially in terms of respiratory health and personal comfort.

Bibliography

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Figures

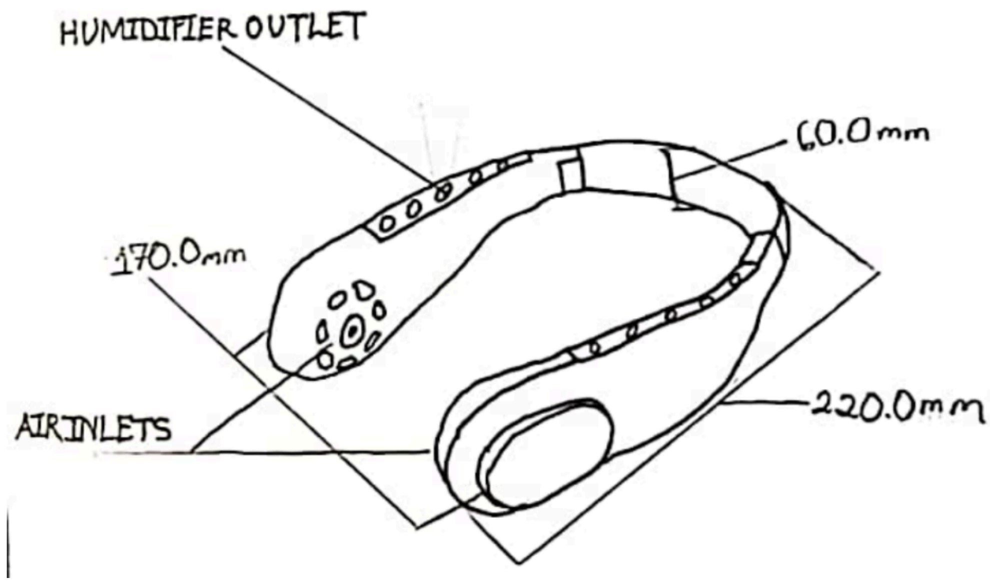

Figure 2: Neckpiece without mask attachment

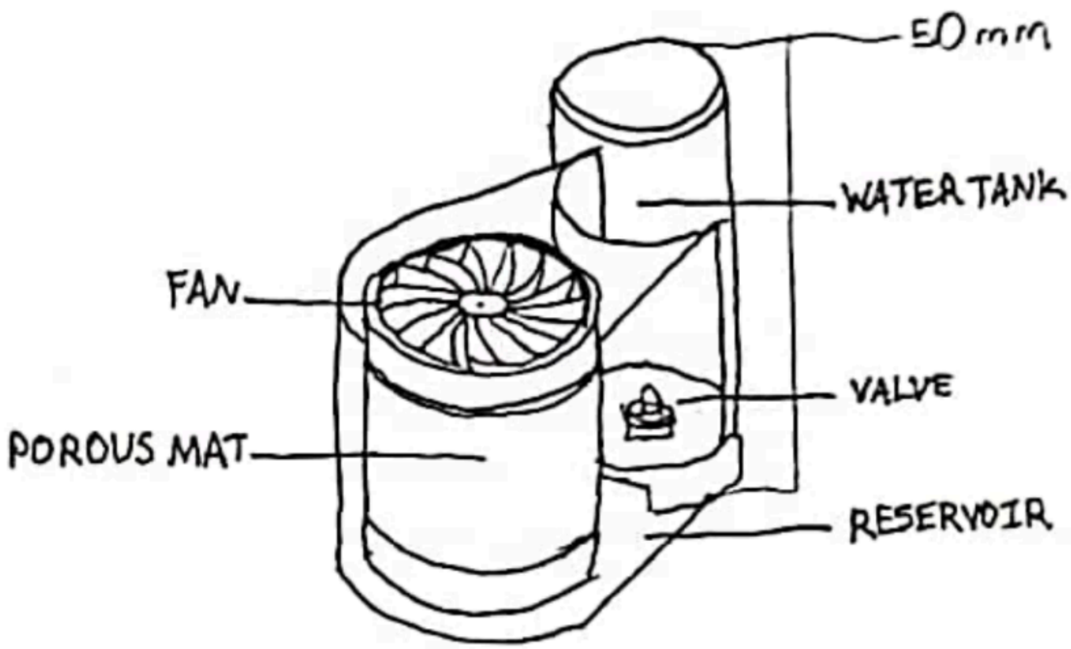

Figure 5: One of the humidifiers within the neckpiece

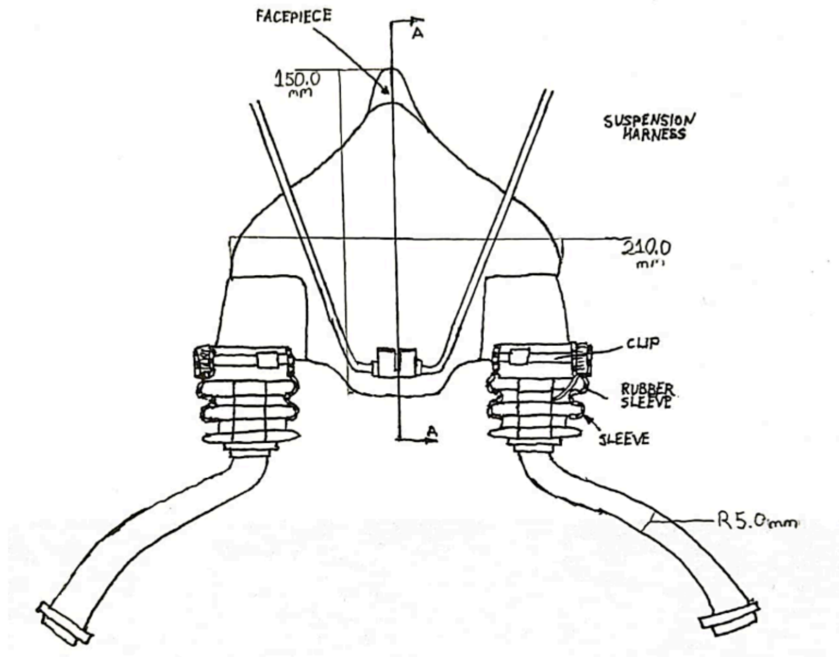

Figure 4: The facepiece and tubing component of the design

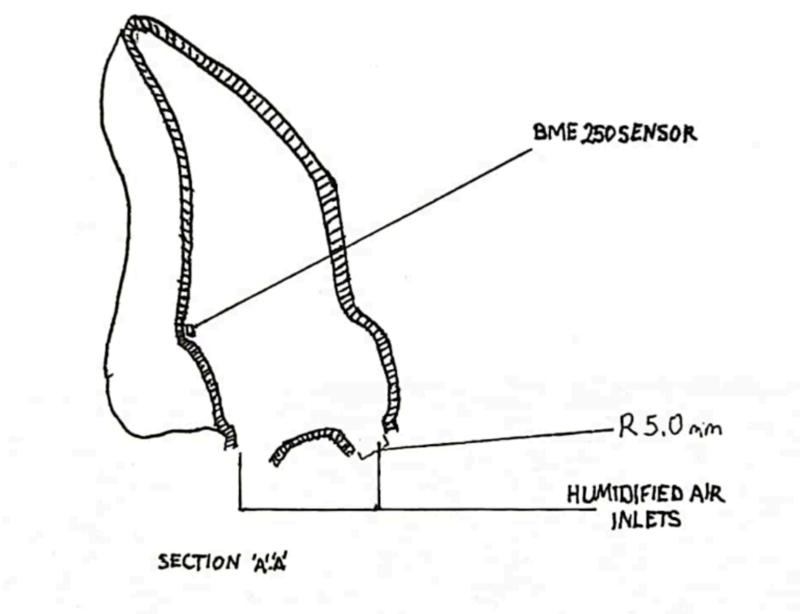

Figure 5: Alternate viewing of mask to show placement of BME250 sensor