A Gravity-Balancing System for the Head-Neck

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***Abstract*—Our group designed a gravity-balancing system for the head and neck to help patients with Dropped Head Syndrome (DHS), which occurs in patients with various neurological, neuromuscular, and muscular conditions. The first part of the report is an overview of Dropped Head Syndrome including its symptoms and causes. Next, we discuss our approach and considerations when designing our product. In the third part of the report, we analyze neck motion and how it factors into our model. Lastly, we talk about our results and any future extensions that can improve our design as a whole.**

***Keywords*—** Spring-Structure, Neck Support, Dropped head syndrome(DHS)

I. Introduction

Dropped Head Syndrome, or DHS, is a severe kyphotic deformity of the cervico-thoracic spine [3]. This syndrome is defined by weakness of neck extensor muscles against gravity with or without weakness of neck flexor muscles [4]. This syndrome is very prevalent in many neurological, neuromuscular, and muscular conditions such as Parkinson's Disease, Amyotrophic Lateral Sclerosis (ALS), and Myasthenia gravis [3]. A study in Japan showed that 6 percent of Parkinson's patients who visited them had Dropped Head Syndrome [5], while a study on ALS indicated that there are around 1-3 percent of ALS patients suffer from DHS as well [4]. From the figure, we can observe that for every inch forward, the head exerts significantly more force on the spine, with a normal head weighing about 12 lbs, a head that has a posture one inch forward weighs about 32 lbs, and a head position that is 2 inches forward weighs an astonishing 42 lbs. For patients of DHS, their head position is usually much worse, with some patients' chins touching their chests, which is why we decided to design a gravity-balancing system to alleviate the burden on their necks and spines.

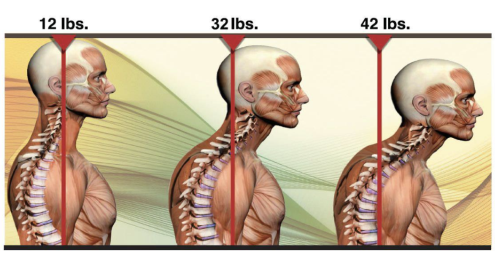

Fig. 1. Weight of head based on posture

There are three basic types of devices that are commonly used by DHS patients: mechanical structure, soft-material structure, cable-driven structure, or any combination of the above. These devices have different features which satisfy the demands of patients. For example, mechanical and soft-material structures are most commonly seen in commercial products, which need to be portable and supportive. Cable-driven structures are more widely used in research-based facilities such as hospitals and labs, they usually aim for precise motion control to help with rehabilitating patients.

A. Previous Structures

Mechanical structures such as dynamic braces are one of the most common ways to support the head and neck. A dynamic brace [1] is designed to measure the range of motion of the human neck. It uses three RRS (Revolute-Revolute-Spherical) chains to simulate the three degrees of freedom of the neck. The shortcoming of this device is that it often lacks flexibility due to its rigid structure, which could be restricting for the patients.

Vacuum and silicon supports (Fig3) are another kind of common support structures seen in commercial products. Compared with mechanical structures, they are more compliant, which increases their wearability. However, these products do not provide external forces and depend solely on elastic deformation. In addition, some inflatable neck braces require pumps, which makes them heavier and less portable.

Cable-driven structures are mainly used for training and rehabilitation purposes. A cable-driven parallel platform with a pneumatic muscle active support [2] is designed to imitate the motion of the human neck. The volume (Fig2) of this device is much greater than the aforementioned devices, so it is most commonly used in a lab setting. The advantage of this structure is that it can control an explicit range of motion, which is helpful when measuring rehabilitation results.

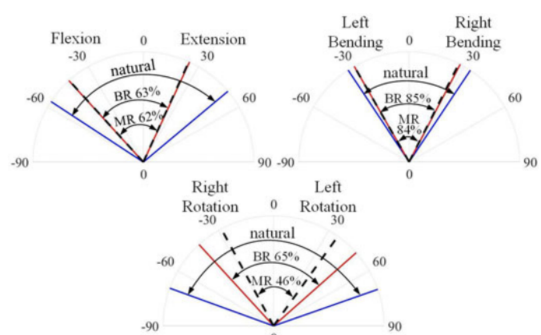

Fig. 2. ROM for the dynamic brace, the blue solid line shows the actual ROM of the human neck, the red solid line shows the Rom of this device

B. Our Goal

Considering all the approaches above,

1) we propose a spring-structure neck brace. It is compliant, portable, and does not require external equipment to function.
2) The structure needs to be ergonomic, and practical.
3) Sensors can be added to the device in order to collect data that can be used for analysis.

Fig. 3. left: Vacuum support Right: Silicon support

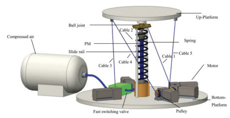

Fig. 4. Structure of CPPPMS

4) The shortcoming is the spring constant due to different conditions of users, and the durability of the spring is another problem to be considered.

II. Approach Analysis

Currently, the team's focus is on addressing the issue of neck flexion/extension. The current model we have developed is designed to provide the necessary support to maintain the user's head in a neutral position when performing tasks that require neck flexion or extension. This is achieved through the use of two springs that mimic the muscle contraction and expansion process, which provides the necessary force for neck extension and flexion motions. As the team continues to develop our model, the focus might also expand to address other issues related to neck and spine health.

A. Neck Motion Analysis

To understand the force analysis of neck motion, let's take a look at the different forces that act on the cervical spine during these movements. When humans flex the neck to look down or extend the neck to look up, the forces acting on the cervical spine are determined by the weight of the head, the muscles involved in the movement, and the position of the head and neck.

During neck flexion (looking down), the weight of the head applies a force in the anterior direction, putting stress on the front of the neck and the vertebral discs. The muscles at the front of the neck, such as the sternocleidomastoid and scalene muscles, contract to counteract this force and maintain stability.

During neck extension (looking up), the weight of the head applies a force in the posterior direction, putting stress on the back of the neck and vertebral discs. The muscles at the back of the neck, such as the suboccipital muscles, semispinalis, and splenius capitis, contract to counteract this force and maintain stability.

When the neck is in a neutral position, the weight of the head is balanced between the front and back of the neck. However, when the neck is flexed or extended, the distribution of weight would change, and the muscles must work to maintain balance and stability.

Fig. 5. neck flexion and extension

B. Force Analysis

To understand the forces acting on the cervical spine during head flexion and extension, The team first create a model of head extension of flexion. As shown in Fig.6, CG denote as center of gravity of head, O represent the rotational joint , W is the weight of head, F_{MB} and F_{MF} represent the neck supporting force from back and front of the body. We know:

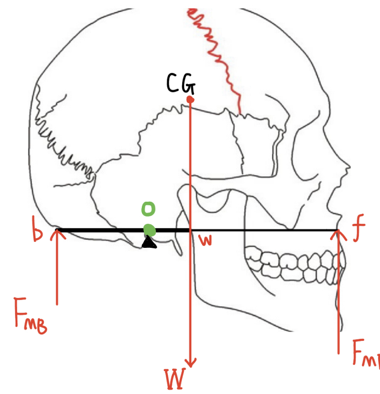

Fig. 6. Free body diagram of neck force

$$\tau = r \times F \tag{1}$$

To keep the head in a neutral position, let the sum of torque be 0. Applying equation (1) to our constructed Free body diagram, we get:

$$\tau = -r_{ow} \times W - r_{ob} \times F_{MB} + r_{of} \times F_{MF} = 0 \tag{2}$$

From equation (2), it is very clear that the torque generated by the neck muscle is counteracted by the torque from the mass of the head if the head is in the neutral position.

C. Model Analysis

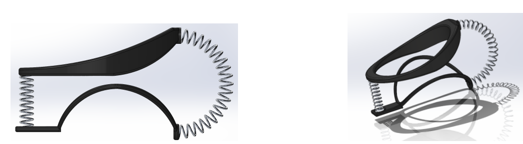

Fig. 7. Current solution with Side View

The team has developed a solution to help individuals maintain a neutral position of their head by using two springs that mimic the process of muscle contraction and expansion to provide the necessary force for neck extension and flexion motions. The trajectory of the contact point between the jaw and the anterior spring is approximately a straight line. Therefore a linear spring is applied. The trajectory of the contact point between the occipital and posterior spring is an arc. Therefore, a nonlinear spring can be applied, and the force calculation will involve an integral. As the head conducts the task of flex or extension, a change of two springs' length will result in a change in the potential energy of each spring respectively. By selecting the proper spring constant or spring stiffness, the system will be able to prevent the user from over-extension or over-flexion of the neck.

In Fig. 8, it is shown that when the user flexes their head, the spring in front of the body compresses, while the one on the backside of the body expands. The team has modeled the spring in the front of the body as a linear spring because wearing the device may limit the

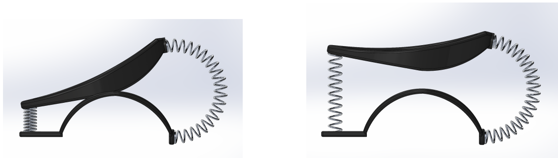

Fig. 8. Current solution: flexion(Left) and extension(Right)

range of flexion and extension. A linear spring is a type of spring that follows Hooke's law, which means that the force exerted by the spring is directly proportional to its displacement from its equilibrium position.

On the other hand, the spring on the backside of the body is treated as a non-linear spring. A non-linear spring is a type of spring whose force-displacement relationship is not linear. This means that the force exerted by the spring is not directly proportional to its displacement from its equilibrium position.

Then, it is necessary for the team to find the proper spring with a proper stiffness to compensate for the spring potential energy change during the motion. If the stiffness is too low, the spring may not be able to provide enough support for the user's head. Therefore, finding the proper spring with a similar stiffness is important to ensure that the device functions properly and provides the user with the necessary support.

To ensure each user could conduct the task when wearing the devices, the proposed solution provides personalized features such as the shape of the brace and the spring constant to meet the demands of different users. These features are offered at a low cost, making our model accessible to a wide range of individuals.

Furthermore, to ensure that our model is comfortable to wear during prolonged use, we have followed the concepts of ergonomics. Our model provides the necessary comfort and support to enable individuals to perform their tasks efficiently without experiencing discomfort or fatigue.

III. Results and Conclusion

In this report, we first established an understanding of Dropped Head Syndrome (DHS), its symptoms, and its causes. Then, we surveyed the market to understand what kind of help is available for patients with DHS. From there, we realized that each of those traditional methods has at least one very obvious shortcoming such as being too bulky or restricting. Next, we analyzed the motion of the neck and decided what kind of structure should we build based on the results. We decided to design a neck brace that is supported by a spring structure so that it would maximize flexibility and minimize restriction and bulk. Our structure consists of two springs that would each aid the extension and flexion motions respectively, and minimal support structures to keep the neck brace secure on the patient's head and neck. In conclusion, the system can provide support for the user's neck and prevent head drop through its spring mechanism. It is also portable and user-compliant. However, it may still affect the lateral bending and rotation of the user's neck.

IV. Future Extensions

Reducing the device's impact on other degrees of freedom is the most important future extension. Adding degrees of freedom to side-link joints will be considered. Furthermore, the following optimization will also improve the system.

1) Incorporating motors to control springs to broaden the angle range of support;
2) Reducing weight by using light materials;
3) Improving stability of fixing the system on human's body;

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