

# Robotic Mechanism Using Water Jet for Scalp Wash and Massage Servicing Patients

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**Abstract**—The stressful speedily pace of daily lives promotes over-stimulation and over-scheduling, which become chronic anxieties that lead to everyone's need to rest and recover. The exhausting fast pace of daily life promotes over-stimulation and over-scheduling, which become chronic stressors that lead to everyone's needs sometimes to relax. One of the best ways to treat it is by taking a shower underwater and doing scalp massage, it helps to alleviate scalp ache acne or relieves stress anxiety, hair cleansed after a long day particularly helps to reduce high blood pressure, migraine disappears and other health benefits many patients are unable to move alone in need of special family and assistant assistance, In some cases, the spread and negative effect of Virus CoV-19 may lead to cross-transmission, particularly at this time. In this paper, by combining traditional acupuncture, acupressure, scalp massage technic and complex movement of water jet robotic mechanism, which is working and acting on different type scalp of a patient such as ages, gender, long or short hair with the pressure of water and hot air by automation. The study investigated the role of effective water jets at different pressure and distance from nozzle to human scalp which explains the interaction between human feeling and massage by using water jet mechanism. We detail the design of the scalp massage and wash at the same time to reduce time-consuming and by affordable price, which imitates massage experts with complex operations, then was enhanced through an intelligent controller to determine the trajectory of nozzles impacting on human scalp

**Index Terms**—robotic mechanism, sphere robot, scalp wash, massage, acupuncture, acupressure, water jet, cross-transmission, nozzle

## I. INTRODUCTION

Massage therapy has been applied to patients for many centuries. In many Asian countries, massage through the action of acupuncture points is researched and developed and is being applied to the scalp as well as acupuncture points on the scalp. This technique is known as scalp massage, sometimes known as scalp massage therapy, and it is a type of physical stimulation that penetrates nerves, skin, blood vessels, and sensory organs such as the heart, kidney. This method is called scalp massage, also known as scalp massage therapy, a physical stimulation that directly affects the skin, nerves, blood vessels, and sensory organs. Receptors cause changes in nerves, fluids, and hormones thereby improving the capacity of the nervous system, improving the nutrition

process of the body [1]. According to traditional oriental medicine, the method is the effect on the acupuncture points as well as the nerves on the scalp below the hair [2], in this paper, the combination of scalp wash and massage is used for patients, who do not want to affect nurses or family around them too much, the use of machinery or equipment with special care for reducing the stress of patients in the flu epidemic spread throughout the world. The scalp massage and wash are aimed at supporting patients who have difficulties in movement, washing their hair, ensuring hygiene, to reduce the situation of hospital infections due to personal hygiene problems of patients. Washing and massaging is simply the mechanism of 2 degrees of freedom robotic, using a water jet to clean the scalp and to prevent hair also avoiding scalp diseases while stimulating circulation in the scalp. This therapy treatment not only helps patients feel comfortable and hair cleaning but also promotes the healing process of the patient. Bed shampoos are directed at helping patients, cleansing the scalp and hair protection, even preventing scalp disorders and improving blood channels in the scalp for patients with mobility challenges, lying down for a long time and unable to do hair-wash on their own, maintaining sanitation, minimizing the condition of hospital illnesses owing to patients' personal hygiene issues.

Secondly, the immune system becomes weak to the environment when we get sick, as well as resistance to the bacteria will decrease, bacteria will penetrate the body through the skin, mucous membranes, adversely affecting the treatment of disease. Moreover, for bedridden patients with regular medicine or injection medications to treat sweating that produces psoriatic plaque, scalp for a long time without washing will become sticky due to sweat, sebum secretion. It becomes dangerous for bedridden patients because nurses or family members cannot shower regularly leading to infection or gangrene. While body hygiene is treated not well, bacteria will penetrate the body through the skin, mucous membranes, adversely affecting the treatment of disease. Therefore, it is necessary to keep good hygiene for patients to contribute to the prevention, avoid dangerous complications that may occur, and shorten treatment time.

Finally, being aware of the imbalance between the number of nurse, medical facilities and the bedridden patients, while more and more patients are hospitalized because of strokes, cancer, paralyzed patients, people

who living in vegetative state especially in Vietnam and worldwide in general. Scalp washing and massaging robot is created to reduce the overcrowding of hospital and labor cost. In addition, nowadays, world is being faced with novel coronavirus 2019, known as CoV-19 virus, which means in isolated areas, doctors or even family members limited to contact with infected victims, to avoid cross-transmission. With this robot, patient will no longer wait for ages in overcrowding medical centers to be massaged or treated because this robot can perform washing and massaging to share work with therapists. Now, patients can clean their own hair to ensure hygiene with the better services, to reduce the situation of hospital infections and relax with scalp massage using water jets system integrated with robotic mechanism. This robot is also for sensitive people who feel embarrassed and uncomfortable when touched by strangers. This makes sense because there are many contagious diseases caused by skin touching. Moreover, this robot also helps people understand intensively and approach traditional medicine. It contributes to preserving this culture

Especially, the robot can give out suitable massage therapies depending on diseases, ages, gender and so on. It can learn and update the database continuously to become smarter and more reasonable. Users and their families can conveniently track their progress via a smartphone as all the data on the internet portal is updated. The method has done experiments on some patients that reach relaxed and comfortable, especially for patients with severe illness. This procedure is used to manage central nervous system diseases, meridians, control the activity of viscera and severe or persistent pain muscles. By this phase, water jet therapy not only helps stimulate blood flow, increases blood supply, reduces grey hair, hair loss but also prevent some neurasthenia, scalp ache, insomnia, forgetfulness. This robot is expected to help people approach traditional medical treatment as well as enhance the quality of current medicine.

## II. ACUPUNCTURE AND TREATMENT BASED ON WATER JET

Soft tissue (ST) is defined in modern medicine as skin, fatty layer. Then fascia and muscle are in the group of ligaments and tendons and finally was cartilage. The bones are rigid. The mechanical properties of ST were particularly by the elastic coefficient and degree of deformation. With the exception of acupressure, it is important to consider the distributed nature of force loading during massage (Fig. 1). Yet in addition we use the analogous integrated environmental resistance force  $F_e$  which is offset by drive force for touch interface models. A six-component vector is given to demonstrate the other force image of the physician's hand or the touch of the robot device with a patient's body:

$$\mathbf{F} = (F_x, F_y, F_z, M_x, M_y, M_z)^T \quad (1)$$

Where,  $F_x$ ,  $F_y$ , and  $F_z$  are projections of the force exerted on the robot actuator from the patient's body;  $M_x$ ,  $M_y$ ,  $M_z$

are moment around axes  $x$ ,  $y$ ,  $z$ . In the medicine model, the scalp can be modeled like as inertial, anisotropic, plastic, multilayered, viscoelastic, and non-stationary environment.

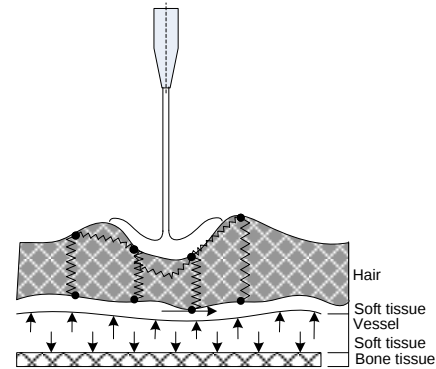


Figure 1. The modeling of impacting process cooperative between the water jet and scalp's skin.

Modeling of dynamic forces exerted by water jet on scalp under the hairs, this compact utilizes particular tasks including hair wash and massage. The illustration shows the force generated by water jet on the scalp in the direction of jet. In the direction of force, the rate of change of momentum is as follows:

$$F_x = \rho \cdot a \cdot V^2 \quad (2)$$

When  $a$  and  $V$  are the cross-sectional area and velocity of jet respectively, then the mass of liquid per second striking the hair is shown in Fig. 1. After striking the hairs, the water jet compacts on scalp and diffuse in the hair as well as leaves apart to surrounding. A contact model describes both the forces that can be transferred by interaction and the authorized relative movements of the hairs and soft tissue of the scalp. The shape of the contacting surfaces and the mechanical properties of the skin, which dictate friction and potential contact deformation, define these features. The application of analysis that must be performed significantly impacts the selection of a contact model.

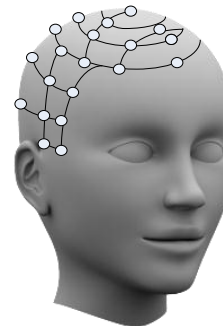


Figure 2. Illustration of acupuncture points on scalp.

A typical contact interface between a water jet and a collision scalp is shown in Fig. 2 when proper analytical models are utilized. Because the contact interface is complicated, we assume that the effect between the water jet and scalp is not linear elastic. A linear extension

model for nonlinear elastic contact has been performed with equation of power-law including Hertzian exposure theory as below the equation.

$$a = c.N^\gamma \quad (3)$$

where  $\gamma = n/(2n + 1)$  is the normal force exponent,  $n$  is the stiffening exponent of deformation, and  $c$  is the constant dependent on the mechanical properties as well as the water jet values such as velocity, flow rate, pressure, etc. Equation (1) is a modern law of power relating to the development of circular touch radius to the force usually applied to a soft interface, the derivative equation assumes a circular contact area.

There are many acupuncture points on the scalp. Based on oriental medicine, acupuncture zones are mapped onto the scalp that is associated with body and broad body regions [3, 4]. From references, we can define positions of standard acupuncture points like as forward part of the zones (nearer the face) for treatments of the upper body, rear ones for the lower body. Besides, the back and sides of scalp are zones for treating sensory, memory, and motor.

At a particular pressure difference, any nozzle will generate a certain flow rate. The pressure drop is the change between the pressure of the fluid in the pipe shortly preceding exit and the pressure into the tub system in which the fluid is being sprayed, therefore it is necessary to account for friction losses and whether the liquid has been splashed into a pressured vessel. The flow rate at pressure P1 can be calculated from the flow rate at pressure P2 as follows:

$$Q_1 = \sqrt{\frac{P_1}{P_2}} Q_2 \quad (4)$$

We can determine the impact force of water jet for descaling by below formulas.

$$H = \gamma.Q.C_v.V \quad (5)$$

Where

- $H$  : impact force N (kg.m/s<sup>2</sup>)
- $\gamma$  : Density of water
- $Q$  : Flow rate m<sup>3</sup>/2
- $C_v$  : Atmosphere velocity deceleration coefficient
- $V$  : Flow velocity immediately after nozzle (m/s)
- $C$  : Flow rate coefficient
- $P$  : Water pressure (Pa)

In this section, several characteristics of water jets are described. The basic spray patterns include flat fan, full cone, Solid stream, Misting/fog. The patterns of spraying are formed by the sizes of the nozzle. If the limited orifice nozzle was being used in elevated pressures, fluid included water and foam will be pushed through a very small opening to split it up into a fog. The mean droplet size is a measure of the fluid's total surface area. For any given rate of flow, the larger the droplet size, the larger the surface area of the spray. If the mean droplet size of a spray is cut in half, the spray's surface area doubles. It quadruples if you divide it in half, and so on.

For any given flow rate, the wider the spray angle is the smaller the droplet size will be. This explains why bigger spray angles simply have more area to spread the droplets, resulting in less recombination and better potential to atomize. Depending on the pressure, certain nozzles maintain a constant spray angle. Others will have pressure-dependent patterns. As pressure increases in a specific tangential swirl, design nozzles will increase their angle of spray. This is due to the fact that they function by creating a whirlpool of fluid within the nozzle, which is subsequently expelled into a hollow cone shape by centrifugal forces. As pressure rises, so do centrifugal forces, which reduce droplet size while increasing the angle at which they are distributed. A spiral design hollow cone nozzle, on the other hand, will generate more or less the same spray angle regardless of pressure since it operates by sheering the fluid into droplets by the impact on the spiral form.

The speed of fluid rises as it flows into a narrower channel. As a result, its kinetic energy rises. Where does the kinetic energy change originate from? The increased kinetic energy results from the work done on the fluid by the network to push it into the channel, as well as the work done on the fluid by the gravitational pull of the fluid changes vertical position. Consider the work-energy theorem:

$$W_{net} = \frac{1}{2}mv^2 - \frac{1}{2}mv_0^2 \quad (6)$$

### III. STRUCTURAL DESIGN AND KINEMATICS OF SCALP WASH AND MASSAGE

To carry out the design and development of a scalp washing and massaging machine for the patients, it is extremely important and essential to know all the factors that influence the washing and massage process on the patient's scalp, in which the important factors are the basic size of anthropology as well as the physical condition of the Vietnamese, the distribution of acupuncture points per person and the trajectory of movement to meet the washing, massage, therapy, which applied to the patient's scalp. Also in this section, the research team discusses the theoretical basis of acupuncture points, the therapies applied to the dorsal area, and the ways of movement and control on them. In addition, to conduct the study of massage robots, we need to study medical theoretical foundations such as acupuncture points, theories used in motor control, theories applied in image processing, etc. The shampooing and massaging procedure will decide the actuator's working area before developing a comprehensive configuration of the device so that it can be adjusted following the requirements. In the case of hair shampooing and massaging, the actuator must conduct shampooing and massage operations to ensure that it operates on the whole hair growth so that other areas of the scalp do not get affected. To fully perform the task, the shampoo and massage device must work on the interacting part of the skull where the hair grows.

How does this actuator always have an axis toward the center of the skull, when we consider the skull meeting as a spherical shell and when the actuating act of motion creates it should move along the normal of the forehead and scalp skull. The structure when designing should have a few degrees of freedom but still ensure operational features.

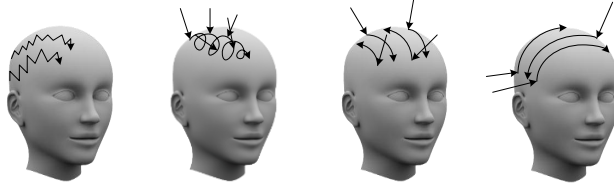


Figure 3. Given trajectories for water jet nozzles generating hair wash and massage.

The advantages of robots in the field of medicine include more accurate and dependable actions that are independent of physician nerve tension and subjective assessments, as well as the potential of multiple repeats of the process. The impact between water jet and scalp is determined by an exchange of energy and the distance where its effect on a particular area on the scalp. As a result, precisely modeling the energy characteristics of physical systems is a first step towards controlling interaction.

When using a cooperative water jet robot system for massage, it is critical to regulating both the absolute motion of the scalp massage tip as well as the internal pressures given to it. As a result, the majority of control approaches to cooperative robotic systems can be classified as force/motion control schemes, in that they divide the control action into a motion control loop aimed at tracking the desired object motion and a force control loop aimed at controlling the internal loading of the object.

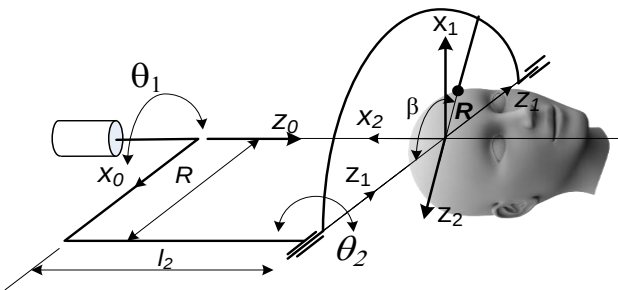


Figure 4. Schematic of robotic mechanism.

The robot mechanism is sphere manipulators that consist of serial circular segments connecting with the water jet nozzle like as Fig. 4 end effector as well as servo motors. When compared to other structures, this one has the following advantages: simple control, higher kinematical accuracy, lower weight, superior rigidity, more load-bearing ability, stable capacity, and appropriate positioning actuator configurations. They do, however, provide a restricted workspace for other tasks. This mechanism equipped with two revolute, and a workspace of nozzles on the circular segment can move

following the surface of a sphere with high velocities and accelerations.

TABLE I. DENAVIT – HATENBERG PARAMETERS

| # | l | $\theta$          | d  | $\alpha$ | Variable   |
|---|---|-------------------|----|----------|------------|
| 1 | 0 | $\pi/2+\theta_1$  | L2 | $\pi/2$  | $\theta_1$ |
| 2 | 0 | $-\pi/2+\theta_2$ | 0  | $\beta$  | $\theta_2$ |

$$\begin{bmatrix} P_x \\ P_y \\ P_z \end{bmatrix} = \begin{bmatrix} (R-l_3)[\cos \theta_2 \sin \theta_1 \sin \beta - \cos \theta_1 \cos \beta] \\ (-R+l_3)[\sin \theta_1 \cos \beta + \cos \theta_1 \cos \theta_2 \sin \beta] \\ l_2 + (R-l_3) \sin \theta_2 \sin \beta \end{bmatrix} \quad (7)$$

Suppose we consider the shape of human's scalp as a sphere [5] with the following parametric equation:

$$\begin{aligned} x &= R \sin \varphi \cos \theta \\ y &= R \sin \varphi \sin \theta \\ z &= R \cos \theta \end{aligned} \quad (8)$$

Where  $0 \leq \varphi < 2\pi$  and  $0 \leq \theta < 2\pi$ . Suppose we place the pressure force from the water jet nozzles on the surface of the scalp below the hairs in the shape of a spiral equation, which is a logarithmic curve equation with the angle for the force from the nozzle to reach the scalp according to varying trajectories depending on various purposes. The set of equations would have the parametric equation with time parameter  $t$  of the spiral curve (one of the most basic) placed on the scalp surface as follows:

$$\begin{aligned} x(t) &= t \cdot \cos(t) \\ y(t) &= t \cdot \sin(t) \\ z(t) &= R \cdot \cos(t) \end{aligned} \quad (9)$$

Where  $R$  is the equivalent radius of the sphere covering the scalp like in Fig. 5.

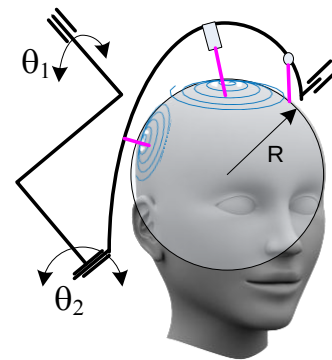


Figure 5. Given trajectories for water jet nozzles generating hair wash and massage

A spiral path is added to be the massage trajectory on the scalp to establish the motion trajectory for scalp washing and massage according to the specified paths requirement. In the inverse kinematic problem, the parametric equation of time is typically substituted as this:

$$\begin{aligned}\theta_1 &= \arctan\left(\frac{-\cos(t)}{\sin(t)}\right) \\ \sin \theta_2 &= \frac{R \cdot \cos(t) - l_2}{r} \\ \cos \theta_2 &= \sqrt{1 - \left(\frac{R \cdot \cos(t) - l_2}{r}\right)^2} \\ \theta_2 &= \arctan\left(\frac{\sin \theta_2}{\cos \theta_2}\right)\end{aligned}\quad (10)$$

#### IV. EXPERIMENTS AND DISCUSSIONS

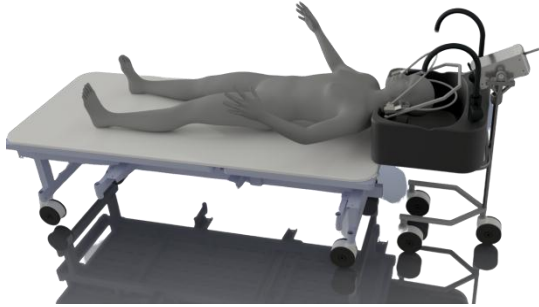


Figure 6. Robotic mechanism in 3D modeling



Figure 7. Robotic mechanism in reality modeling and experiment

The scalp is washed and massaged by moving the device in a specified trajectory based on acupuncture as well as a scratch by controlling two axes, the impact of water jet on human's scalp is perpendicular to the scalp and following circular shape of human scalp, in such a way that the distal ends of the fingers move away from each other and then move towards each other, sliding on the scalp. When moving away from each other, the water jets impact the scalp due to the scalp expanding in the directions oriented quite relative to the aforementioned axis. The impacted areas of water jets are relatively small in size as well as relatively small scalp, which is modeled and shown in Fig. 6 and Fig. 7. A robotic mechanism, which is described specification in Table II, is used two 35W gearbox motors to control the rotation of the two copper conductors independently but ensure concentricity and shoot water jets on the patient's scalp, combined with a third motor attached to the system by swaying joint which to create the trajectory of a water jet into a certain trajectory on the scalp of a person. The trajectories could be a straight line sliding along the human scalp from the nape to the front scalp.

TABLE II. SPECIFICATION OF SCALP WASHING AND MASSAGE MECHANISM

| No | Specification                                  | Value                                                   |
|----|------------------------------------------------|---------------------------------------------------------|
| 1  | Maximum rotation angle of mechanism            | 180 degree sweep over nape to forehead of human's scape |
| 2  | The resolution                                 | 5° per second                                           |
| 3  | Outside radius                                 | 250 millimeters                                         |
| 4  | Inside radius                                  | 150 millimeters                                         |
| 5  | Nozzles welded on water pipe                   | 5 Pcs each pipe                                         |
| 6  | Nozzle water jet size                          | 01 millimeter                                           |
| 7  | Spray nozzle                                   | 3 x 135 degree wide, 0.5 millimeter                     |
| 8  | High pressure pump                             | 60W, 4 bar pressure maximum                             |
| 9  | Motor driver 12VDC with Worm Gear              | 35W x 3                                                 |
| 10 | DC motor Driver with RM Coretex-M3, 30VDC, 10A | 3 Pcs                                                   |



Figure 8. Water jet nozzles, integrated on rotation ring was performed the trajectories to generate scalp wash and massage on the real man



Figure 9. Water nozzle with high pressure (13Psi), jetting directly on the dynamic weight scale surface (left) and jetting on the scales surface through hair resistance (right)

In this experiment, shown in Fig. 7, Fig. 8, and Fig. 9 described a stainless steel nozzle with size 1.0 mm diameter is used, pumping with the same water volume per second for each experiment is a litter of pure water to make sure there are no more any heavy metal or dust inside the water source, the main cause of increasing the force on human scalp, this helps the experiment collects precisely force values. On the other hand, the force exerted on the scalp, depending on the thickness of the hair, has been shown that when the scalp of patients receiving radiotherapy and chemotherapy to fight cancer,

they almost do not have hair. This makes the force of water applied to the scalp without hair is much stronger despite the same conditions of pressure, water volume, the distance between nozzles, and human scalp or nozzle size. The experiment was used with two pressure values, distance range from 10 mm to 100 mm between nozzle water jet to the experiment surface (human's scalp).

In order to experiment on the force of the water spray on a human scalp, an experiment was set up as follows: the water jet was placed opposite and perpendicular to the plate of scale, the distance could be changed by screw. A series of experiments to initially determine the direct impact of water jets on the scalp when no hair is shown in Fig. 9. In this figure, we see that the closer the nozzle distance is, the greater the force, and this force will be inversely proportional to the distance as a nonlinear function. After the experiment of the impact force without hair, the experiments to determine the force spreading in hair were also performed shown in Fig. 9. A wig is placed on the plate of scale, the water jet is also perpendicular to the scale plate as well as the wig layer, which is not combed but tangled in order to imitate the patient's hair when performing the wash and massage. The distance is calculated from the wig to the nozzle, as well as in the previous experiments, the distance would also be changed. We can observe this series of experiments, the results showed that as the previous graph is shown in Fig. 10 the closer the water jet is, the greater the force on the surface of the scale, but the distance must be greater than 1 mm. And the farther the distance away from the scale plate, the smaller the force and will reach approximately zero as the distance. So we can see, the use of a water jet with variable pressure can replace the washing and massage for patients. Depending

on the procedure and requirements of each patient, we may have different pressure as well as the distance between the nozzles.

## V. CONCLUSION

Supporting patients to maintain their hygiene needs while in the hospital is a fundamental aspect of nursing care, but now cross-infection, overcrowding work by a nurse or physician. As a result, works such as washing and massaging of patients need to be replaced by machines so that hospital nurses spend more time on other professional tasks. In addition, the use of machinery or equipment for shampooing and massage makes the care of patients more comprehensive, creating a sense of comfort for patients. Water jets on the scalp in addition to massaging and cleansing and deep penetration in the hair of the patient because it ensures shampoo penetrates deep into the scalp of the sick person to remove all specks of dirt and dead skin that accumulates on the scalp. The shampoo acts as an exfoliator. The water spray on the scalp acts as a massage machine, especially to avoid direct contact between the waiter and the patient, in addition to helping overcome the difficulty of massaging the scalp with nails weak and brittle hands. Massage with water jets helps increase blood circulation in the scalp, thereby improving the supply of oxygen and other nutrients to the hair roots and promote hair growth. Massaging the scalp with water spray on the scalp reduces stress and headaches, making patients feel relaxed and refreshed. By removing dirt and dead skin cells accumulated on the scalp, the water jet with herbs also helps the patient get rid of dandruff. It also distributes natural oils on your scalp and eliminates dryness, thus preventing flaking and itching on it.

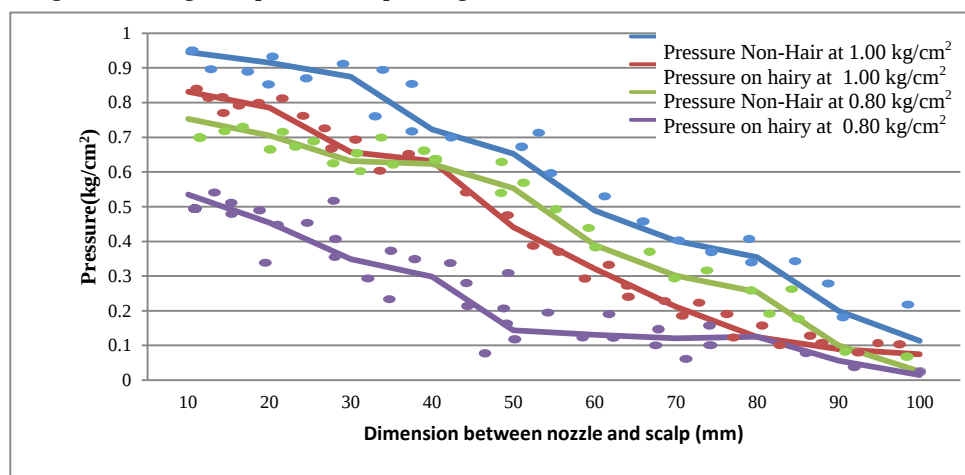


Figure 10. The force of water on hairless surface and second case with normal woman's wig

## CONFLICT OF INTEREST

The authors declare no conflict of interest.

## AUTHOR CONTRIBUTIONS

Nguyen Truong Thinh, Nguyen Dao Xuan Hai, contributed to the analysis and implementation of the

research, to the analysis of the results and to the writing of the manuscript. All authors discussed the results and contributed to the final manuscript. Besides, Nguyen Dao Xuan Hai conceived the study and were in charge of overall direction and planning. Nguyen Truong Thinh is a corresponding author.

#### ACKNOWLEDGMENT

This research was supported financially by the Ho Chi Minh City University of Technology and Education, Viet Nam.

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