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Original Research Article (Experimental)

Impact force measurement in *Shirodhara*

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ABSTRACT

Background: *Shirodhara* is an ayurvedic procedure usually administered to alleviate mental stress. The process involves impact on the forehead by a free fall of a continuous stream of temperature controlled fluid.
Objective: In this study, the impact force generated on the forehead due to fluid falling from *dhara* pot held at a standard height of 4 *angulas* is measured passing through a traditional wick.
Materials and methods: The variation of this impact force for different medicinal oils such as Ksheerabala oil, Mahanarayana oil and water is studied. The measurements are made using an Integrated Circuit Piezoelectric force sensor designed to measure low loads.
Results: The impact force is found to be order of 10^{-2} N and is observed to marginally vary with the type of liquid used in the experiment. The force was found to build up an average duration of 7.2 ms linearly over a time.
Conclusion: It was observed that the impact force generated on the human forehead due to *Shirodhara* treatment was low and is invariant to the medicinal oils used in the treatment. The measured forces correlate closely with the force estimates made from simple fluid mechanics. These forces have an important role in the estimate of stresses, displacements and voltage generated due to the impact associated with *Shirodhara*.

1. Introduction

Ayurveda is practiced for centuries and has proven itself to be helpful in curing various types of diseases. In this paper, we attempt to study one of the popular Ayurvedic treatment procedures called *Shirodhara*. *Shirodhara* is a combination of two words '*Shiro*' and '*Dhara*', the former meaning head and latter meaning the continuous flow of thin stream of liquid [1]. The treatment process as shown in Fig. 1 involves a continuous impact of medicated oil due to gravity flow from a *dhara* pot at a height of 4 *angulas* through a wick, on the forehead of the subject at a controlled temperature for a prolonged duration (approx. 30–45 min) [2].

Shirodhara is a recommended Ayurvedic therapy for treating neurological conditions such as mental stress (depression/anxiety), headache and insomnia along with medicines and therapeutic nutrition [1,3,4]. The precise quantification of the treatment which follows the scientific understanding of *Shirodhara* which is a successful ayurvedic procedure [3,4]. The details of administration of *Shirodhara* are addressed in classical texts such as '*Dharakalpah*' [2] where some physical parameters like the height of fall, type of liquid, the material of *dhara* pot etc. are recommended. One of the slokas addressing the height of fall of the liquid which is relevant to this study is quoted below:

Quotation

धारोच्चं चतुरंगुलं तु शिरसः सेके तदन्यत्र तत्

प्रोक्तं तत्त्रिगुणं मन्दपतनात् तद्रोगवृद्धिर्भवेत्

Transliteration

dhāroccaṃ catur aṃgulaṃ tu śirasaḥ seke tadanyatra tat

proktaṃ tatriguṇaṃ manda patanāt tadroga vṛddhir bhavet

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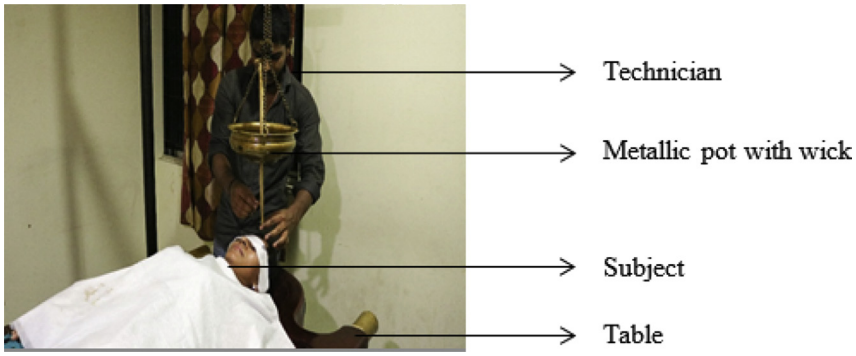

Fig. 1. Subject undergoing Shirodhara treatment using traditional wick assembly.

Translation

The *dhara* over head should be poured from a height of 4 *angulas* and to the other body part, it should be done from a height of 12 *angulas*. In case of procedure done deviated from above mentioned rules, the diseased state gets enhanced.

Kajaria. D et al. (2013) made a hypothesis regarding the mechanics of *Shirodhara*. According to their hypothesis, the fluid at height possesses potential energy (PE) and this PE gets converted into kinetic energy (KE) during free fall. The authors also explain that when the fluid is falling from a height over the subject's forehead, it generates a momentum which causes a change in voltage which stimulates the nerve impulses or accentuate the nerve impulse conduction [5]. Uebaba et al. (2005) characterized *Shirodhara* in a randomized and control group of subject's achieved in the control supine position by the robotic system [6,7]. The effectiveness of *Shirodhara* are quantified using physiological parameters such as heart rate, CO_2 output, blood pressure and also electrocardiogram (ECG) and electroencephalogram (EEG) to measure the electrical activity of heart and brain [3,6,8].

Clearly, the mechanism of *Shirodhara* is complicated involving (a) generation of a force due to impact (b) translation of impact force into mechanical stress waves (c) transformation of mechanical stresses into neurological signals and (d) translation of neurological signals into long-term physiological effects like tranquility of the subjects. Even though a mechanism of treatment is postulated by Kajaria et al. (2013) and the effectiveness of *Shirodhara* are documented by Uebaba et al. (2008), has no substantial literature exists in understanding the mechanics of process involved in *Shirodhara*. The measurement of force generated due to *Shirodhara* has not been widely reported in the literature and was the primary focus of the current paper.

The study primarily focuses on measurement of (a) magnitude of impact force and (b) duration of force build up, using sensitive piezoelectric force sensors. The variation of these parameters with medicinal oil was documented. The measured forces were also compared with the force estimates from simple fluid mechanics.

1.1. Treatment procedure

The subject is made to lie on a supine position on droni and a *dhara* pot (earthen/copper/brass) which has a hole at the bottom of approximately to the size of a little finger (standard size) hung above the subject [2,9]. The wick assembly in the *Shirodhara* pot is aligned around four *angulas* (approximately 7.5 cm) [10–12] above, from the subject's forehead [2]. Under the supervision of medical assistant, the *Shirodhara* pot is oscillated along the length of the forehead ensuring continuous flow. After completing the treatment, the subject is recommended to take rest. The liquids (medicinal oil) used for the treatment are cow's ghee, gingelly oil, ksheerabala oil, mahanarayana oil, and warm milk, kasaya (medicated water). The type of the liquid chosen depends upon the subject's health condition. The liquid is heated to subject body temperature or to the temperature comfortable to subject and spouted via *Shirodhara* pot along the length of the forehead [2,9].

2. Materials and methods

2.1. Materials

The different liquids taken for the experiment are Ksheerabala oil, Mahanarayana oil and water. The medicinal oil is manufactured by Nagarjuna Herbal Concentrates Ltd (ref. Ashtanga hridayam). An Integrated Circuit Piezoelectric (ICP) force sensor is used for measuring the impact force [13,14]. Signal conditioners are used for conditioning the output signals from the sensor to the readout instrument and also to provide power to drive the sensor. The signal conditioning unit is connected to the computer via NI data acquisition card and the voltage output is measured.

2.2. Measurement of impact force (ΔF_{exp})

The schematic diagram for the experimental setup for measuring impact force is shown in Fig. 2. A copper *dhara* pot was used with a hole bored at the bottom of the *Shirodhara* pot with wick assembly as marked in Fig. 2. The wick made of *gaurda* cloth of minimum diameter to ensure the fluid drips without clog as directed by an Ayurvedic Physician.

The experimental setup is designed and fabricated as shown in Fig. 3. The experimental setup consists of a stand to hold the copper *dhara* pot and the sensor was placed exactly below the outlet of the *dhara* pot over which the liquid impacts. An adjustable stand is also designed to maintain the impact height of four *angulas* (~7.5 cm). The experiment is done when the liquid is falling from a copper *dhara* pot through a wick assembly. The force sensor measures the input force by converting the impact force into an electrical charge. When an impact force is applied, the quartz crystals generate an electrostatic charge which is directly proportional to the input force. The force sensor takes only dynamic load and hence it cannot be used for measuring static load. For a quasi-static, the electrostatic charge leaks faster than the rate of the changing force. Hence the discharge time is important for the sensor which limits to a few seconds. The liquid was maintained at room temperature of 29°*C* and the experiment is done at room temperature. Between two trials, delay of 500 s (discharge time of sensor) was absorbed so that charge reduces and the sensor will be ready for the next trial. After a discharge time period, the

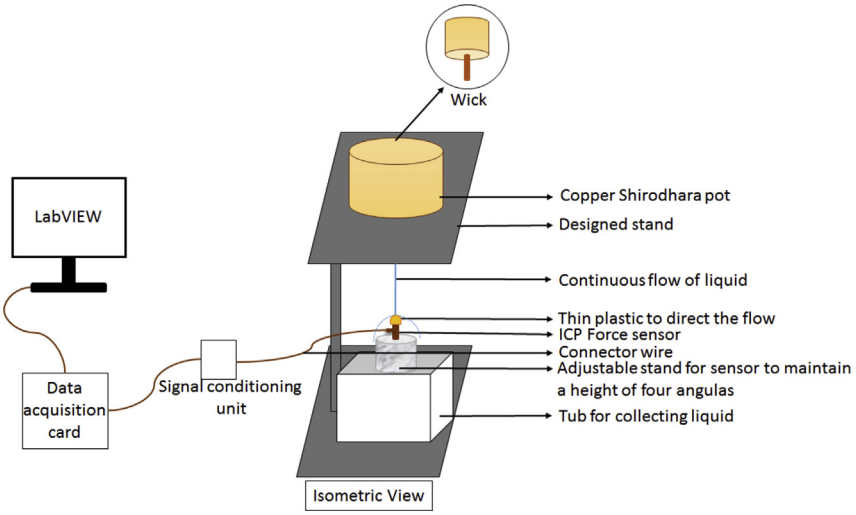

Fig. 2. Schematic diagram of the experimental setup to measure the fluid impact from Shirodhara pot.

liquid is allowed to impact at the sensor surface. The sensor is covered by a hemisphere-shaped thin plastic to protect the sensor from the liquid. From simple mechanics that the presence of thin layer of membrane will affect the displacements, mechanical stresses and strains in the material but not the force due to fluid impact.

LabVIEW program is used to acquire the output data. Voltage is defined as analogue input and for every five milliseconds a data is collected and the output data is processed in MATLAB.

2.3. Density measurement (ρ)

The density of the experimental fluids was determined by taking 200 mL of fluid and weighing it on the weighing scale. The estimated density of various fluids is given below in Table 1. It is noted from Table 1 that the density of the medicinal oil is lesser than the reference fluid water.

2.4. Theoretical impact force (F_{th})

A detailed investigation of impact force is carried out, for the impact height of 7.5 cm from the wick to the sensor. The impact velocity (V) is calculated using the relation given below [15]:

$$V = \sqrt{2gh} \tag{1}$$

where h is the height from the wick to the sensor and g is the acceleration due to gravity (9.81 m/s^2). Flow rate (Q) of different fluids is calculated to understand the flow characteristics. The fluid (1 L) was allowed to freely flow through wick of the *dhara* pot to capture the flow behaviour. The time of flow is noted to calculate the flow rate of the fluid. From simple fluid mechanics, the impact force due to fluid flow impacting a stationary plate is estimated from the relation given below [16]

$$F_{th} = \rho QV \tag{2}$$

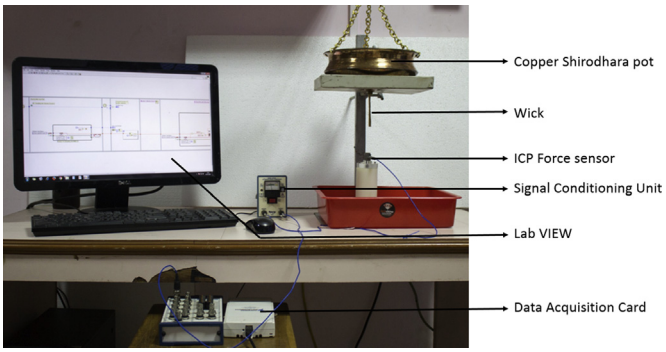

Fig. 3. Experimental setup to measure the fluid impact.

3. Results and discussion

3.1. Impact force/impact duration for medicinal liquids

The force–time curve measured from the ICP force sensor is shown in Fig. 4a,b for the liquids namely Ksheerabala oil and Mahanarayana oil. The focus of the experiment is on the impact force and the impact duration. The gradual decrease in the force is due to the electrostatic charge leakage in the sensor with respect to the rate of changing force. The decrease in the force is due to the inherent property of the piezoelectric sensor and hence baseline calibration is done. Initially, the force decreases due to the leakage in the sensor and when the fluid is released from the beaker, the sample data of impact force of liquid at that instance is collected. The high peak in the plot corresponds to the impact force in time series. Hence ΔF_{exp} is the average impact force value and Δt is the impact duration in the experiment. Similarly, experiments are done for all liquids (Water, Mahanarayana oil and Ksheerabala oil). Each set of experiment is repeated for 15 times of trials. Table 2 shows the mean experimental values of all trials of the Impact force 'ΔF_{exp}' and Impact duration 'Δt' for the fluid impact. The impact force of 0.03912 N is measured for the reference liquid water which is high compared to other liquid which has the least impact force of 0.018766 N. There is only a small percentage difference between the impact force of Ksheerabala oil and Mahanarayana oil. The water shows high impact force and less impact duration compared to the other two liquids due to the higher density of water. From the experiments, it is clear that Mahanarayana

Table 1
Density of liquids used in the experiment.

S. No.	Liquid	Density ($\frac{kg}{m^3}$)
1	Water	1000
2	Mahanarayana oil	800
3	Ksheerabala oil	810

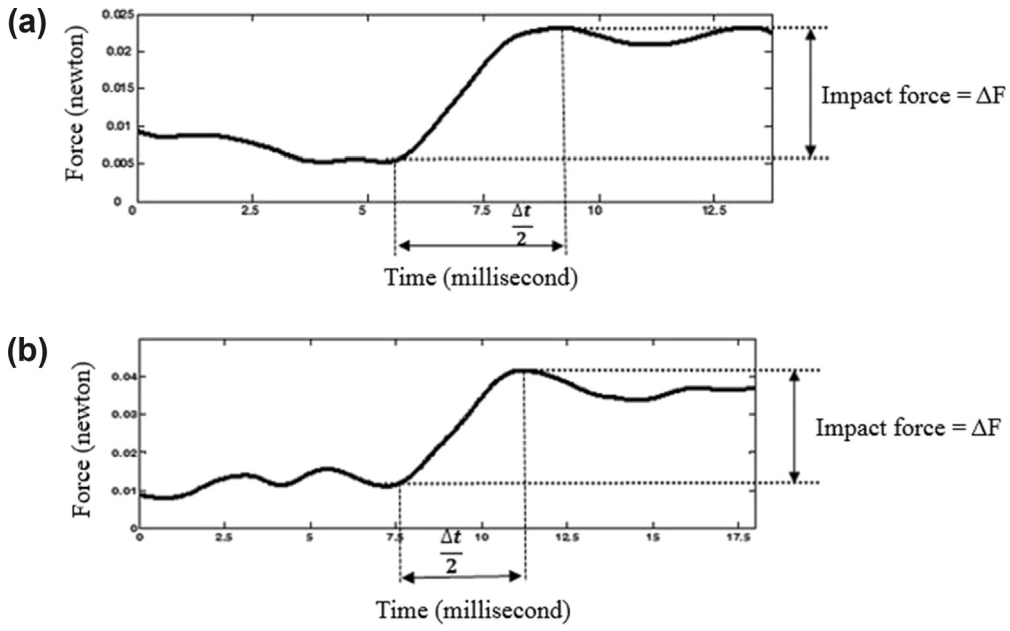

Fig. 4. (a) Force vs. Time for Ksheerabala oil. (b) Force vs. Time for Mahanarayana oil.

Table 2
Average Impact force 'ΔF_{exp}' and Impact duration 'Δt' for the fluid impact of different fluids used in the experiment.

Liquid ↓ Parameters →	Impact Force 'ΔF_{exp}' (N)	Impact duration 'Δt' (ms)
Water	0.0391	6.96
Mahanarayana oil	0.0192	7.30
Ksheerabala oil	0.0187	7.35
% difference (Mahanarayana & Ksheerabala)	2.6	0.68

oil and Ksheerabala oil produces the same impact force of 0.02 N at an average impact duration of 7.33 ms.

3.2. Comparison of impact force 'ΔF_{exp}' and impact duration 'Δt'

When the copper pot with wick assembly is used, the flow appears smooth and continuous. Fig. 5 shows the statistical variation

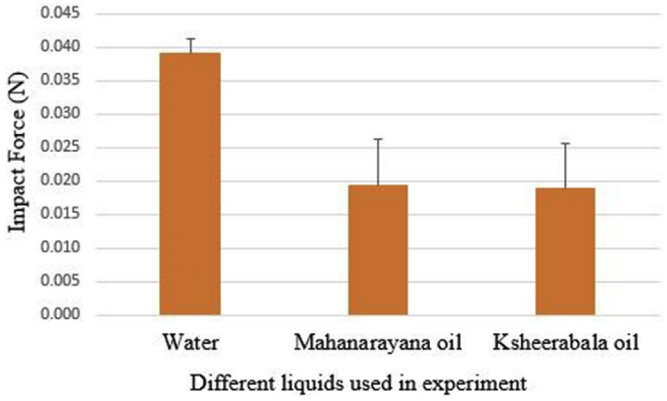

Fig. 5. Impact force (Mean ± SD) for different liquids used in the experiment.

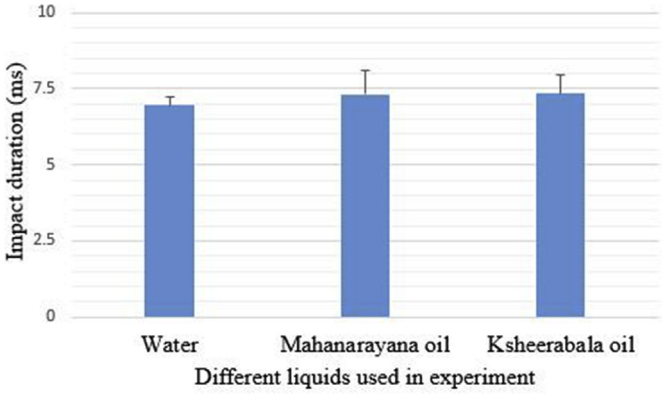

Fig. 6. Impact duration (Mean ± SD) for different liquids used in the experiment.

(Mean ± SD) of force measured by the sensor due to fluid impact for different fluids. There is a decrease in the impact force for Ksheerabala oil and Mahanarayana oil when compared with variations due to water impact. From Fig. 5, we can also observe a subtle variation of Impact force between Ksheerabala oil and Mahanarayana oil.

The impact duration (Mean ± SD) for different liquids used in the experiment is shown in Fig. 6. The shorter duration associated with water impact seem to indicate that higher accelerations are associated with the impact of this fluid compared to other two fluids. These acceleration levels may have implications on signals generated on the forehead due to impact.

Table 3
Theoretical and experimental Impact force.

Liquid	F_{th} (N)	F_{exp} (N)
Water	0.0221	0.0391
Mahanarayana oil	0.0108	0.0192
Ksheerabala oil	0.0098	0.0187

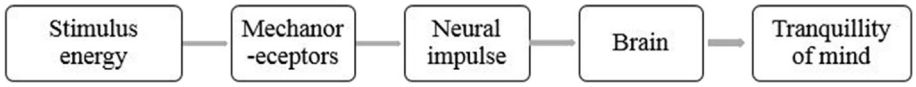

Fig. 7. Pathway of mechanoreceptors.

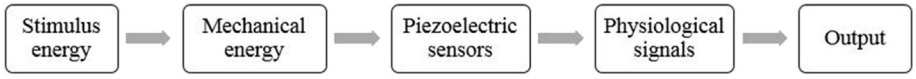

Fig. 8. Classical model for Shirodhara process.

3.3. Comparison of impact force 'F_{th}' and 'F_{exp}'

The impact force calculated using equation (2) was also found to be order of 10^{-2} N and is compared with the average experimental impact force as given below in Table 3.

The wide variation of the estimated force from equation (2) with the experimental observation indicates that the assumption made in the derivation of equation (2) is not totally valid for the fluid impact that is measured in the experiments. However, there is a subtle variation of impact force for the different liquids used, in the presence of a wick indicates that the wick plays an important role in fluid flow. A more detailed fluid flow simulation and analysis is required to resolve this issue and this is beyond the scope of current investigation.

3.4. Understanding the mechanics

The physical understanding of the problem is formulated as shown in Fig. 7. During *Shirodhara* treatment, the continuous pressure by falling of fluid on the forehead produces a vibration which generates electromagnetic waves and it reaches the brain cortex producing a tranquilizing effect [5].

A classical model of transfer of mechanical stimulus to brain assumes the impact force to be sensed by mechanical receptors, which later are converted into neural impulses which are transmitted to the brain which leads to the tranquility of mind by accentuating the nerves [5]. The present paper emphasizes the nature of forces generated (both magnitude and time-dependent response) on the forehead by the fluid flow during treatment.

The mechanism of cure in *Shirodhara* postulates that it is due to the electrical pulses generated due to impact force associated with fluid fall. An alternate paradigm, which helps us in understanding the mechanics of the force generated on the forehead and how it is transmitted to the brain is proposed in Fig. 8. The anatomy of the forehead includes skin from the surface to the underlying rigid bone of the skull. The soft tissue of the human forehead includes skin, subcutaneous layer and muscle [17]. The epidermis and neurons embedded in the skin show the piezoelectric effect [18]. The piezoelectric effect is observed when this epidermal surface is connected to the central nervous system [19,20]. The proposed model explains the stress waves generated during the fluid impact over forehead are converted to electrical signals; analogues to the electrical output produced by piezoelectric sensor due to mechanical stress applied.

4. Conclusion

The magnitude of the impact force in *Shirodhara* was found to be order of 10^{-2} N. The percentage of variation of the impact force was found to be 2.6% and the variation is approximately consistent with 1.3% variation of density between the two tested liquids. In this experimental study, the authors did not find any significant change in the time for force build up between the two tested liquids. Hence the nature of stresses as well as the neurological signals generated due to impact are likely to be the same from both the oils tested in the study. Hence, this study proves that some non-mechanical causes maybe behind the observed differences between the two oils in *Shirodhara*. It is suspected that the time of raise of the force along with its magnitude will play a crucial role in the effectiveness of the treatment. This time is likely to change with the height of fall of the *dhara* on the forehead. This may also be the reason behind the restriction of four *angulas* for the treatment in the traditional process. This aspect needs further investigation in future studies.

This study is not to be correlated with the *in vivo* practices and studies. It is limited to the *in vitro* experiments that are effective in assessing the effectiveness of the treatment. The impact force which has subtle variations will have to be better understood using a controlled experimental study. This experiment can be done on direct force measurement on the subject using the appropriate sensor in future. The results presented in this paper are purely based on experimental observations. An analytical estimate of the force would involve a detailed analysis of a free flow of fluids under the action of gravity. A more detailed analysis of the flow, taking all other effects (such as vortices in the flow, flow rate, viscosity of the fluid, density of fluid, surface tension etc.) is required to estimate the impact force more accurately.

Sources of funding

None.

Conflicts of interest

None.

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