DEVELOPMENT AND CLINICAL APPLICATION OF AN IONTOPHORESIS DEVICE FOR HYPERHIDROSIS TREATMENT

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Abstract
This paper presents the development and implementation of a Hyperhidrosis treatment device using the water Iontophoresis technique. Hyperhidrosis is a condition where the human body sweats more than required due to the malfunctioning of the glands. The device developed for the treatment targets Hyperhidrosis at the palms of the human body. The design is implemented using commonly available electronic devices such as Arduino Nano, H-bridge, OLED displays, and other electronic components. The device costs $100, which is significantly lower than the devices available for treatment in the biomedical market, either for sale or for rent. Trials involving 100 patients from different age groups and treatment histories were conducted. The data of all the patients, along with the HDSS treatment, was analysed, and it was found that the device is capable of reducing the HDSS scores from 4 to 2.39 with only two sessions. The analysis further revealed that the disease is common in both male and female genders, with most patients having not opted for any treatment in the past. The HDSS scores had an inverse relationship with age, indicating that the scores decreased for older patients.

INTRODUCTION

Hyperhidrosis is a medical condition characterised by excessive sweating, typically caused by overstimulation of eccrine glands. These glands are predominantly found on the hands, feet, and face, and their overactivity leads to sweating beyond the body's physiological needs [1]. Affecting approximately 3% to 5% of the population in the United States, hyperhidrosis can significantly impact a patient's social life, mental well-being, and day-to-day activities [2]. The disorder is categorised into primary and secondary forms: primary hyperhidrosis often begins in early life with localised symptoms, while secondary hyperhidrosis results from medications or underlying medical conditions such as diabetes, hyperthyroidism, or neurological disorders [3–5]. Diagnosis can be made clinically or through laboratory methods, with visible symptoms like palmar hyperhidrosis (Figure 1) being common indicators.

Figure 1. Palmary Hyperhidrosis [3]

The disorder can hinder routine tasks—students may struggle to write due to sweat-induced grip issues, athletes may find it difficult to handle equipment, and the use of electrical appliances can become dangerous due to the risk of electric shock or device damage [6][7]. Additionally, excessive sweating may lead to skin complications like fungal infections and dermatitis. Although treatments such as antiperspirants, botulinum toxin injections, and iontophoresis exist, they are often costly, time-consuming, and temporary in effect [8]. This underscores the need for an accessible, home-based solution to manage hyperhidrosis effectively.

1. Literature review

Hyperhidrosis is a condition where the body experiences excessive sweating, impacting the individual both physically and emotionally. People suffering from this disorder often find it challenging to manage the excessive sweating in their daily lives, leading to significant social and psychological consequences. Many individuals with hyperhidrosis avoid seeking medical help, relying instead on personal coping mechanisms such as carrying towels or wearing extra layers of clothing to absorb the sweat. Research by the International Hyperhidrosis Society reveals that nearly half of people with the condition do not seek professional medical advice, sometimes for a decade or longer. This reluctance stems from limited treatment options and a general lack of awareness about available therapies, as well as the high cost and scarcity of FDA-approved treatment options.

Several treatment methods have been developed for hyperhidrosis, including pharmacological options like aluminium salts, anticholinergics, and botulinum toxin injections. Aluminium salts work by blocking the sweat glands and are commonly used for treating sweating in the palms. Anticholinergics function by inhibiting acetylcholine, a neurotransmitter involved in sweat production, but they often cause side effects such as dry mouth, urinary infections, and vision problems. Botulinum toxin, known widely for its cosmetic use as Botox, blocks the nerve signals responsible for triggering sweat production and is particularly effective in treating palmar hyperhidrosis. These treatments, although somewhat effective in reducing sweating (by 25% to 50%), provide relief for a limited period, typically ranging from three to six months, and can cause discomfort such as numbness, pain, and digestive issues.

In addition to pharmacological options, various medical devices have been developed to treat hyperhidrosis, using techniques like microwave, radiofrequency, ultrasound, and iontophoresis. One notable treatment, fractional microneedle radiofrequency (FMR), utilises thermal energy to target and damage the sweat glands without harming the epidermis, using a principle called irreversible thermolysis. Another popular method is laser treatment, which has found success in various cosmetic applications but has shown mixed results in hyperhidrosis treatment due to uneven tissue destruction. Micro-focused ultrasound also uses ultrasonic waves to generate heat, targeting sweat glands. Liposuction curettage, which uses a cannula to remove sweat glands, can be effective in reducing sweat but is accompanied by side effects such as scarring and infection. Similarly, microwave thermolysis works by applying focused heat to the sweat glands, although the results are often temporary and accompanied by potential side effects.

Iontophoresis is another promising treatment method that involves applying a low electrical current to the skin, helping to drive charged molecules into the deeper layers of the skin. The process, based on electro-osmosis, uses the repelling forces of like charges to transport therapeutic molecules through the skin. Continuous DC is believed to be beneficial for treating acute skin conditions, while pulsed DC is more effective for treating chronic skin disorders.

The treatment landscape for hyperhidrosis is further enhanced by the integration of microcontroller-based systems such as Arduino Nano and LM293 H-Bridge for controlling therapeutic devices. The Arduino Nano, a low-cost microcontroller, is commonly used in experimental setups to create customised treatment devices. With features like 14 digital pins, analogue inputs, and a compact design, it is a popular choice for integrating sensors and actuators in various medical and therapeutic devices. The LM293 H-Bridge module, often used in these devices, provides motor control functionality, allowing precise management of mechanical components used in treatments like iontophoresis or thermolysis. This versatility enables the development of more efficient and affordable treatment systems for hyperhidrosis.

In addition to these technologies, OLED displays are increasingly used to provide real-time feedback during treatment sessions. OLED screens, with their low power consumption and high resolution, can be integrated into therapeutic devices to monitor treatment progress and display important parameters like current levels, time, and treatment status. The compact nature of OLED displays makes them ideal for integration into portable treatment systems, enhancing the user experience by providing precise and immediate visual data.

Despite the variety of treatments and technologies available, many of them are not FDA-approved, which contributes to their limited accessibility and high cost. As a result, patients often face challenges in obtaining effective care. The development of more affordable, FDA-approved treatments and the increased awareness of available options are crucial steps in improving the quality of life for individuals who have hyperhidrosis.

Material and methods

The research methodology of the machines starts with understanding the process of iontophoresis and how this treatment works. The process utilises tap water, which results in an improvement in excessive sweating. The therapy works in a short period, and the use of any surgical processes or medicines is not required. The early machines were invented to transfer the drugs into the body; the process was known as transdermal drug delivery. Later, the iontophoresis methods started utilising the minerals in the tap water, which were transferred into the skin by the machines, and the process is known as antiperspirant. The working is such that the machine stops the electrical signals coming from the central nervous system for some time, and meanwhile releases the electrically charged chemicals which surround the glands, and these glands then contract and as a result, secrete the sweat. The glands, which are now having a chemical flood, cause over-sweating, and in case there is no release of the chemical, there will be no sweating.

The flowchart of the research methodology is depicted in Figure 3.1. Here, the research initiative is taken by reviewing the articles for the literature review to identify the previous and existing technologies for iontophoresis and current research and development for the technology. The next part of the research methodology is to look for existing technologies in the local market and the technology used by these devices. The prices of these existing devices are also taken into account, as the device needs to be cost-effective to compete in the local market. The following process is to design the circuit and simulate it using the circuit simulator. This ensures the testing and control of the current and pulses to ensure the safety of the patient and protection of the device components. After a successful simulation of the circuit, the hardware is then implemented on a breadboard to check the functionality. Once the hardware is working satisfactorily, the PCB design is then finalised to create a circuit with a minimum size. After the electrical design is completed, the casing is then designed using 3d modelling. Once the design is finalised, the 3d printed case is obtained using the 3d printer. The product then goes through necessary testing and troubleshooting for functionality and satisfactory performance. Once satisfactory results are obtained, the thesis is compiled.

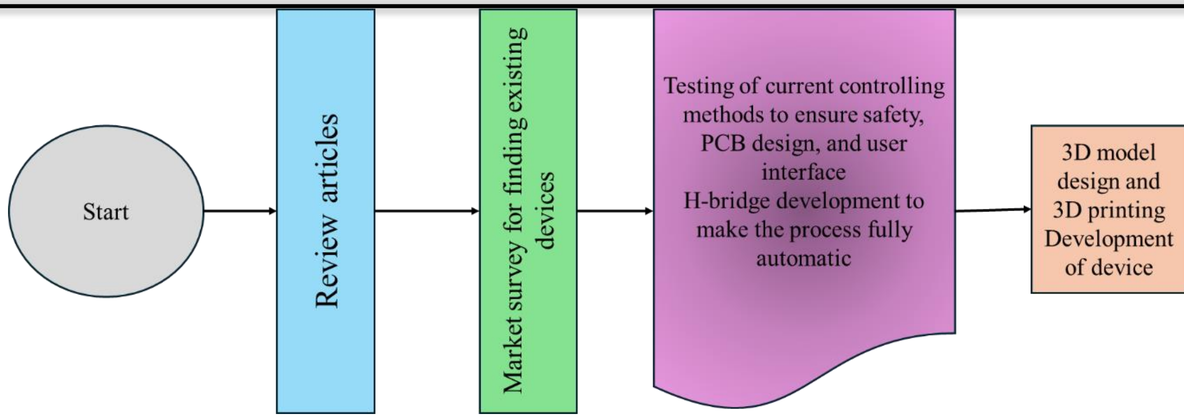

Figure 2. Flowchart of Research Methodology

3.1 Block Diagram

The block diagram of the proposed system can be seen in Figure 2, where the various components and their interconnection with each other are shown. The microcontroller works as the brain and central processing unit of the system. Here, Arduino Nano is used to serve the purpose. The inputs for the system are minimal user input. Here, the user sets the priorities of the functionality of the machine and the duration of the treatment, along with other significant parameters such as voltage and current required for the treatment. The adjustment is mandatory as there can be different skin types and patients with various stages of the disorder. In contrast, some patients will require less voltage and time to cure the disorder; there will be some who will need longer spans of the treatment with higher magnitude of voltages, as the severity of the disorder is greater for such patients. The microcontroller then gives the output signals to the relay driver to limit the current as per the patient's preset values. The relay module switches on and off the suitable contacts to provide the required output power for the treatment. Similarly, the H-bridge is utilised to give the required pulses. The PWM value depends on the preset values of the machine set by the user. For larger magnitudes of pulses, the PWM values are set higher, whereas the PWM values are lower for the operation with smaller magnitudes.

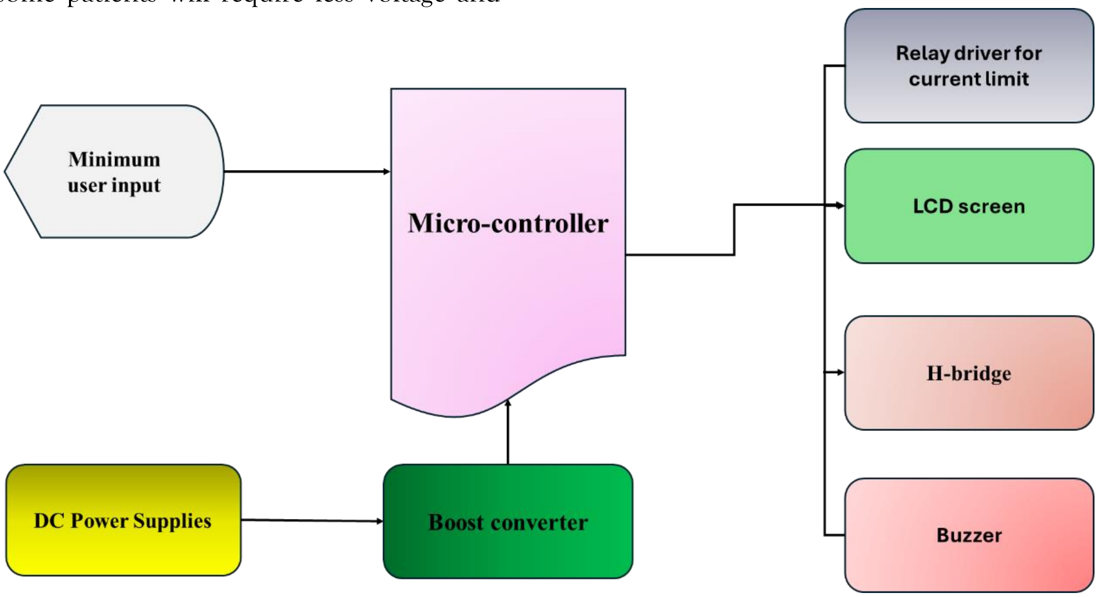

Figure 3. Block Diagram of the proposed system

The OLED is included to display the various parameters and time. A total of 3 OLED displays are placed on board for time and setting preset values. This gives the user an interactive interface to use the device and, per their requirements, also monitor the progress of the treatment using these OLEDS. The buzzer is also placed for the users for alarm and reminder from the machine for preset, performing operation and completion of the set treatment time. The power to the system is provided using the DC power supply via a boost converter. The DC power supply is generally provided using a 12 V adapter via a jack. In contrast, the boost converter is installed on board to provide the necessary power to the circuit and prevent fluctuations in the power supply.

3.2 Schematic Diagram of the Proposed System

The schematic diagram of the proposed system is shown in Figure 4.. The system comprises Arduino Nano, which is the machine's programming. The Arduino Nano R3 is a tiny and compact board with ATmega328. It has no input for the DC power jack and is fed power using the Mini-B USB cable. The controller is fed input by the user for various parameters using the Membrane 1x4 Matrix Keypad. The set parameters are then displayed on the OLEDS.

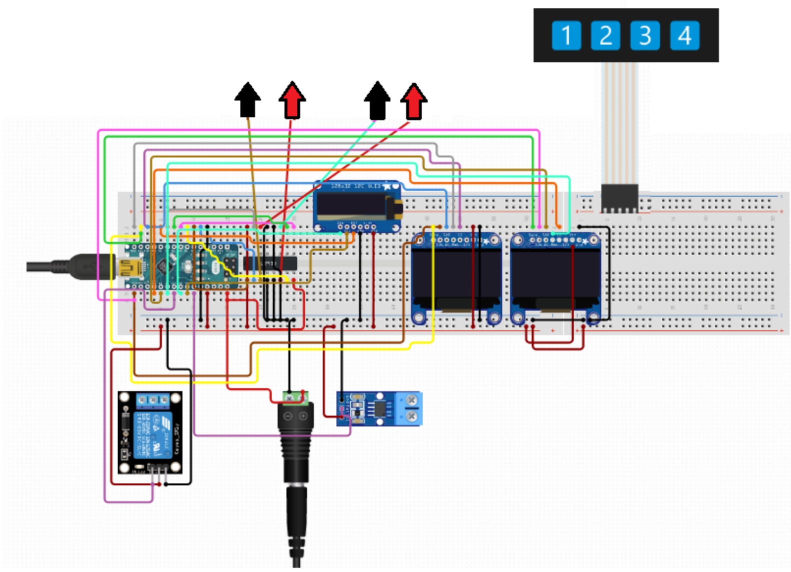

Figure 4. Schematic Diagram of the Proposed System

A total of 3 OLEDS are installed in the system for the parameters and clock. Two of these OLEDS are the Monochrome 1.3-inch 128x64 OLED graphic display, a small monochrome white on black OLED capable of displaying a large amount of graphics. The other is the Monochrome 128x32 I2C OLED graphic display. It is a diagonal OLED breakout board of 1 inch, communicating by means of I2C. The OLED is small but readable as it has high contrast.

Table 3.1 Components of the proposed system

Component	Quantity	Features
Relay Module	1	Switches electrical circuits
Wall Adapter Power Supply - 12vdc 2a	1	Provides power to electronic components
Monochrome 128x32 I2C OLED graphic display	1	Displays graphics and text
Monochrome 1.3-inch 128x64 OLED graphic display	2	Displays graphics and text (larger size)

USB Cable A to B	1	Connects devices with USB ports
Tall Male Headers Pack- Break-Away	1	Stackable headers for breadboards
Arduino Nano	1	Microcontroller for development
1x4 Matrix Keyboard	1	Grid of keys for user input
Boost Converter	1	Steps up the voltage
Alligator Clips	2	Connections

The L293D Motor Driver provides the necessary PWM pulses for the process, which is further connected to the alligator clips. The relay module is used to isolate the components and provide the critical current for the processes. The boost converter is used to supply the required power to the components. The list of all the elements is mentioned in Table 3.1 above.

3.3 CAD Modelling of Casing

The CAD modelling of the protective case starts with the designs available and chooses the best suitable case. The instance for the CAD modelling is to design a robust and low-cost case. As there was no design available to fit our circuitry, the case had to be custom-made. The tools required are a scanner or digital camera, a calliper, a ruler, vector-based graphics software, AutoCad, Adobe Illustrator, Solid Works or any other tool you have access to. The modelling of a sculpture or model is first represented in 3d. In case the 3d scanner is not available, the projections for orthogonal views are constructed from scratch. The correct sizing is another aspect to look for, and it needs to be taken care of, as the proper sizing will result in fitting the circuitry and peripherals into the casing. The drafting starts with the basic layout of the case using the vector graphics editor, layering and grouping it as required. The design and draft should look like the device looks, with correct sizing for the circuitry to fit in.

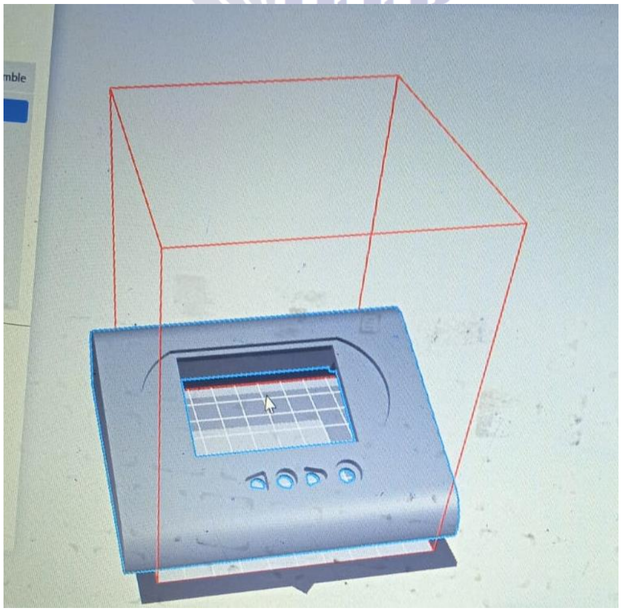

Figure 5. Orthogonal projections of the casing

The orthogonal projection of the casing is shown in Figure 5. Here, the case has four slots for buttons and ample front space for the OLED displays. Similarly, the case will have openings for the wires and a power jack for the supply. The casing may not be the best result after the first iteration. Therefore, it is recommended to go for at least three iterations to get the perfect design out of the software. The final draft of the casing can be seen in Figure 6. Here, the openings for the buttons and the wires can be seen, whereas the front essentially has space for the OLEDS.

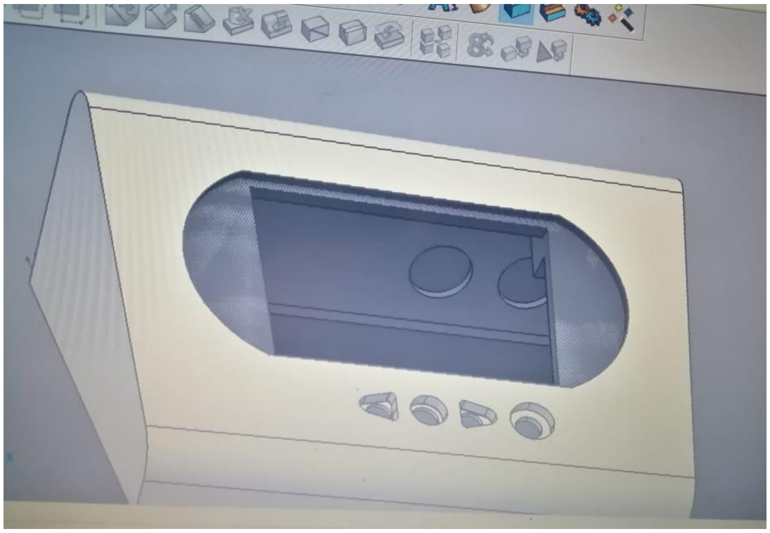

Figure 6. Final Draft of the Case

After the completion of the casing design, the design is then further processed for 3d printing or moulding, in case the 3d print facility is not available.

Results

Results and Discussion

This chapter discusses the hardware implementation of the proposed system and the results of the final assembly.

4.1 Implementation of Circuitry and Hardware

The circuit design of the proposed system is printed on a single circuit board as shown in Figure 7. The PCB comprises the Arduino Nano board, the 2 Monochrome 128x32 I2C OLED graphic displays and a Monochrome 1.3-inch 128x64 OLED graphic display. The headers for the various components, including the boost converter, can be seen on the sides of the board.

Figure 7. Circuitry of the Proposed System

The lower half of the circuit board has buttons for inputs to set the device's various parameters. The digital vernier calliper shows the dimensions of the circuitry's PCB module. The circuit is then tested before being fitted into the casing. Figure 8 shows the OLEDS on the upper half, showing the time, whereas the lower OLED shows the mode of operation for the system.

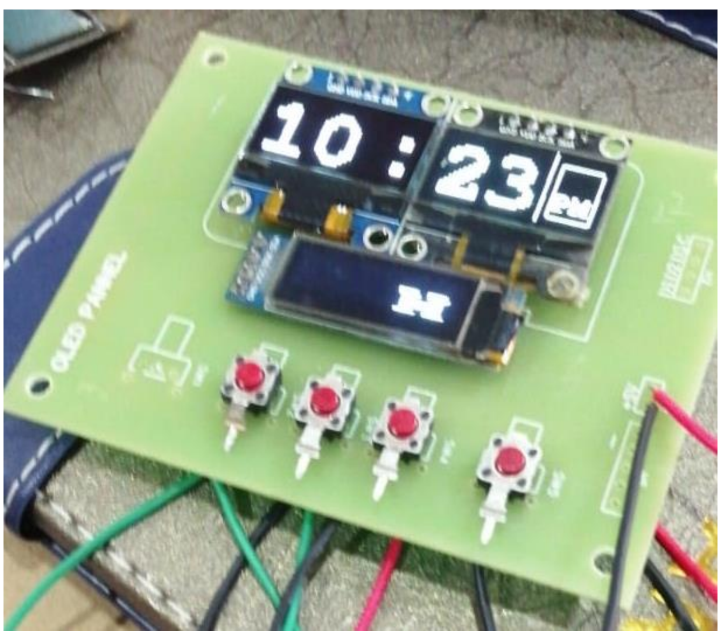

Figure 8 Testing of Circuitry of the Proposed System

Figure 9 shows the circuitry fitting into the casing. It can be seen that the circuitry perfectly fits into the casing for the OLEDS and buttons.

Figure 9. Fitting the circuitry into the casing

Furthermore, Figure 10. shows the operation of the device in the M mode, the time is shown on the top of the OLED, whereas the lower OLED shows the mode of operation of the device.

Figure 10. M-mode operation of the system

Figure 11 shows the operation of the device on L mode. Here, the upper OLED shows the time, whereas the lower OLED shows the device's mode of operation.

Figure 11. L-mode operation of the system

Figure 12. shows the trays for the iontophoresis. Here, the patient will place their hands for the treatment. The trays are connected to the main circuitry using alligator clips.

Figure 12. Trays for the iontophoresis

When the device is powered on, the power is transmitted to the water in the trays, which ionises it, and the same is transmitted to the skin for reliable and effective treatment of palmar and plantar hyperhidrosis with an appropriate technique and period.

4.2 Cost Comparison with other devices

The cost comparison of the various products was performed using the data available online in [25]. Table 4.1 shows the comparison of top iontophoresis machines with the proposed device. The table shows the various variants of the top machines used for the treatment, with most of the devices being powered by outlets and the ones with batteries having expensive batteries. The Hidrex DVP1000 is the costlier device, at $950, and the cheapest among the other devices is Drionic Hand/Foot, at $198.

Table 4.1 Top Iontophoresis Machines Comparison with Proposed System

Model	Current Type	Current Source	Price
Hidrex PSP1000	Direct/Variable Pulse	Main powered	$945
Hidrex DVP1000 (USA equivalent of PSP1000)	Direct/Variable Pulse	Main powered	$950
Hidrex GS400	Direct	Main powered	$699
Hidrex DP 450	Direct/Pulse	Main powered	$695
Idromed 5 PC	Pulse	Main powered	$925
Idromed 5 DC	Direct	Main powered	$725
DermaDry	Direct Current	Main powered	$299 (Total), $279 (Hand/Feet only)
Iontoderma iD-1000	Direct Current	Main powered	$399
Iontex 2	Direct/Pulse	Main powered	$600
Fischer Galvanic Md1a	Direct	Main powered	$ 649 Rent: $ 49 per month
Fischer Galvanic MD-2	Polarity Switching	Main powered	$ 899 Rent: $ 59 per month
Drionic – Hand/Foot	Direct	Expensive batteries	$198
Drionic – Underarm	Direct	Expensive batteries	$208
Iomed	Direct	Standard 9 V Battery	$245
Iontocure	Direct	Main Powered	$249
Proposed Model	Direct	Main Powered	$100

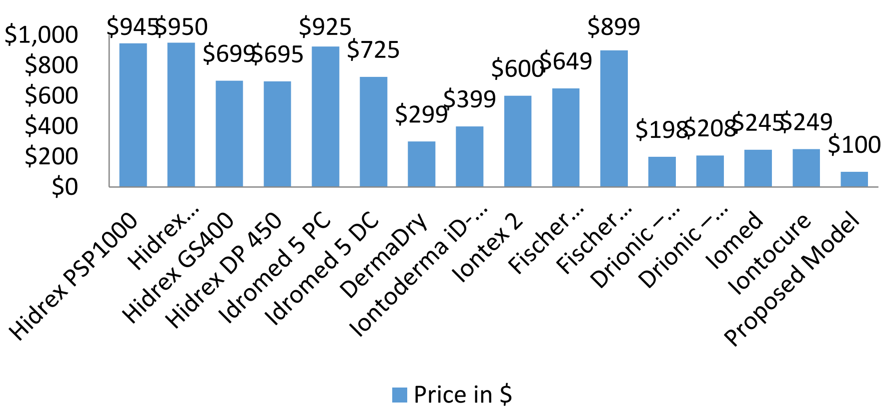

Figure 13. Top Iontophoresis Machines Comparison with Proposed System

There are specific devices that are also available for rent as Fis, such as Fischer Galvanic Md1a, with a price tag of $649, which can be rented for $49 per month. Similarly, the Fischer Galvanic MD-2 has a price tag of $899, but can be rented for $59 per month. Most of the devices are based on DC and

Pulse, with only Fischer Galvanic MD-2 being the one with the operation via Polarity Switching. Figure 13. shows a graphical comparison of the costs of the various iontophoresis machines available on the market. Here, the proposed device shows a significant contribution in proposing a solution within the range of 100$, which is a feasible solution for the patients.

4.3 Exploration and Analysis of Patient Treatment

The device was tested on 100 patients with the disease on their palms at the Peshawar hospital from January 2024 to August 2024. The patients were treated for their hands with a current of 10-20 mA the hands of the patients were kept in the tray for 10 minutes for a total of 3 sessions and a dataset was generated using the data collected from the patients and the effect of the treatment on these patient figure 14 shows the first few rows of the dataset in google collab below:-

	Patient ID	Age	Gender	Location of Hyperhidrosis	HDSS Description	Duration of Symptoms (Years)	Impact on Quality of Life	Treatment History	Response to Treatment	Family History of Hyperhidrosis	Comorbidities	Session 1 HDSS	Session 2 HDSS	Session 3 HDSS
0	P001	25	Female	Palms	Never noticeable and never interferes with dai...	11.3	Mild	No Treatment	Mild Improvement	No	Hypertension	1	1	1
1	P002	57	Female	Palms	Barely tolerable and frequently interferes wit...	9.0	Mild	Oral medications	No Improvement	Yes	Asthma	3	4	4
2	P003	53	Female	Palms	Never noticeable and never interferes with dai...	14.9	Severe	Oral medications	Significant Improvement	Yes	Hypertension	1	1	2
3	P004	50	Female	Palms	Never noticeable and never interferes with dai...	11.0	Mild	Surgery	Mild Improvement	No	NaN	1	1	1
4	P005	48	Male	Palms	Never noticeable and never interferes with dai...	17.5	Moderate	No Treatment	Significant Improvement	Yes	Hypertension	1	1	1

Figure 14. The first few rows of the patient's dataset in Google Colab

The complete dataset can be found in the annexure; the dataset contains the history of the 100 patients on whom the device was tested. The names of the patients are not included to protect their identities. The dataset comprises the following entities.

Patient ID: This is a sort of identity given to each patient, which helps to track the history and effect of the treatment on the patient after various sessions.

Age and Gender: There are separate columns in the table for patients of both age and gender.

Hyperhidrosis: Hyperhidrosis can occur in various parts of the body. However, as our device is designed for the disease on hands only, this dataset contains only patients with the disease on their palms.

HDSS Description: This column shows the severity of the disease before the treatment on the HDSS scale from 1 to 4. This data will help us to analyze whether the treatment was effective on the patients and how effective this treatment was.

Duration: The duration column shows the patient's data on how long they have been under the influence of the disease. This data is not based on the medical diagnosis but on the patients' reports of when they first felt the symptoms of the disease and for how long they have been experiencing it.

Impact of Qof: The columns show the effects of this disease on the life of patients. This data is also based on the self-reported effect by the patients and on which scale (mild, severe) it affects their daily life and routine work.

Treatment History: This column shows that the patients have experienced some previous treatments to cope with the disease. These mainly include the most common treatment methods, including oral medications, Botox and surgery.

Response to Treatment: This column shows the effect of the treatment on the patient's palms, which is on a scale of mild and significant improvement for the patients.

Family History: This column shows whether there is any history of the disease in the family of the patient, which suggests a possibility of inheriting the disease.

Comorbidities: This column includes the data on any other disease the patient carries.

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HDSS Sessions: There is a column each for the HDSS Session for all three sessions these will indicate the HDSS scale after the patient has attended the session which is on the scale from 1 to 4 where 1 indicates lower level of HDSS means that the treatment was effective whereas the higher number indicates that the disease is severe with low effect of the treatment. The Hyperhidrosis Disease Severity Scale (HDSS) score of the patient was recorded using the table provided by the International Hyperhidrosis Society.

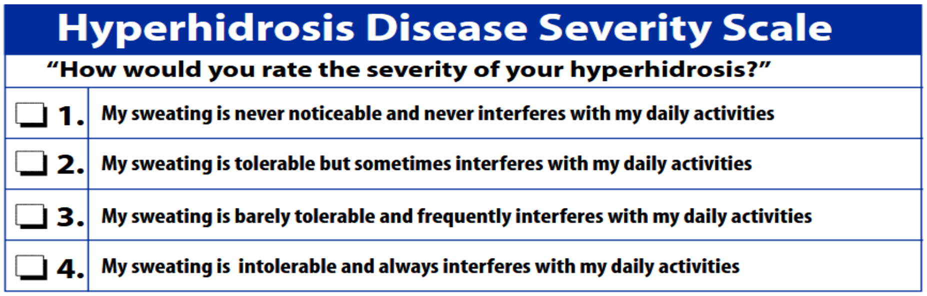

Figure 15. Hyperhidrosis Disease Severity Scale

Table 4.2 shows the age statistics in the dataset. It can be seen that the total count is 100, whereas the mean age is 42.87, which means that most of the patients are in this range. The standard deviation is 13.95 for the age. The minimum age is 19 and the maximum is 65 in this case.

Table 4.2 Statistics of Age

Statistic	count	mean	std	min	25%	50%	75%	max
Value	100	42.87	13.956393	19	31	44	55	65

The histogram of the age is shown in Figure 16. shows the frequency of the disease in the dataset with various age groups. Here, the minimum age of the patient in the dataset is 19, and the maximum age of the patient is 65. The frequency of the disease can be seen highest in the age of 19, 50 and 65, whereas the age of 21 has the minimum frequency in this case. The other ages with high bar graph are 28, 39, and between 53 and 56.

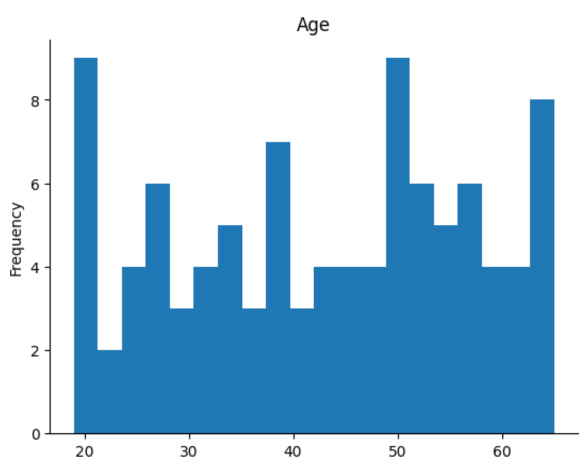

Figure 16. Histogram of Age

The line graph of the age of all the patients is shown in Figure 17. Here, the diverse range of age groups can be seen for all the patients, ranging from 19 to 65. Most of the patients are in the range of 40, as the mean value shows.

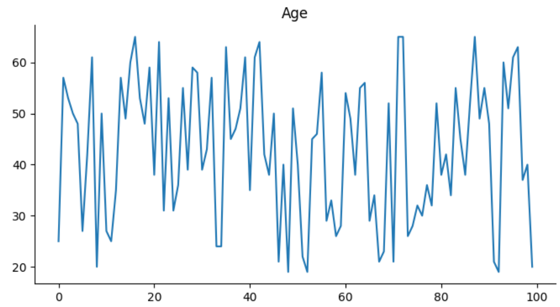

Figure 17. Line graph of Age

Table 4.3 Statistics of Duration of Symptoms

Statistic	count	mean	std	min	25%	50%	75%	max
Value	100	11.097	4.850335	1.7	7.55	10.75	15	19.8

The statistics of the duration of symptoms can be seen in table 4.3 here the count is 100 the mean is at 11.09 whereas the standard deviation is 4.85 with a min duration of 1.7 and max of 19.8 are shown in the table.

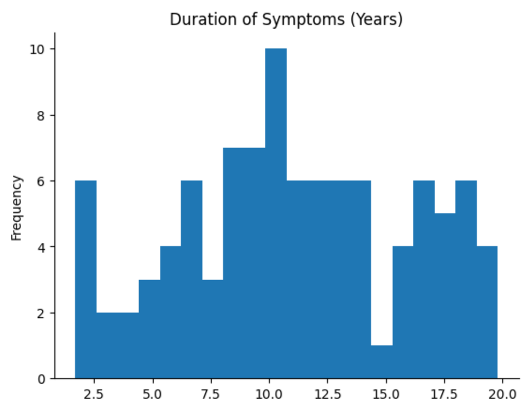

Figure 18. Histogram of Duration of Symptoms

The figure 18. shows the histogram of the duration of symptoms and the frequency in the dataset as per the graph we can the maximum frequency is 10 for the duration of 10 years whereas the min is 1.7 for the years 14 and 15 other than that the duration between 2.5 and 5 have low values and similar is the case with the 7 .5 to 8 all other duration have somewhat high frequency of the disease.

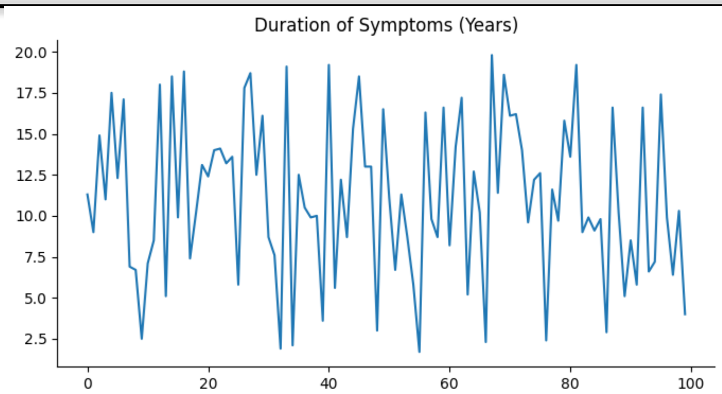

Figure 19. Line graph of Duration of Symptoms

The line graph for the duration of symptoms for all the patients can be seen in figure 19. the range of duration is the years for which the patients have suffered this condition. The min duration is 1.7 years and the max is 19.8 the mean of 11.09 shows that most of the patients are in this range.

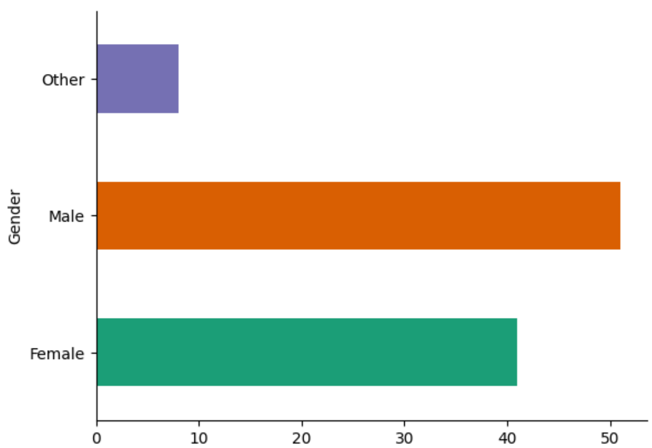

Figure 20. Bar plot of Gender

The figure 20. shows the bar plot of the gender of the patients in the dataset here the data shows the number of male, female and other. There are a total number of 41 female patients, also there are 8 patients other than male female.

Table 4.4 Statistics of Gender vs Age

Gender	count	mean	std	min	25%	50%	75%	max
Female	41	42.853659	13.979558	19	31	42	55	65
Male	51	43.784314	13.714684	19	33.5	48	54	65
Other	8	37.125	15.833396	19	23.75	35.5	48	60

Table 4.4 shows the comparison of gender vs age for the patients in the dataset. Here the female patients with a count of 41 have a mean age of 42.85 with a standard deviation of 13.97 the min age of female patients is 19 whereas the max is 65. Similarly for male patients the patient count is 51 with a mean of

43.78 and a standard deviation of 13.71 with the min age of 19 and max of 65 similar to that of female patients. The others category has only 8 patients with a mean age of 37.12 and standard deviation of 15.83 with min age of 19 and max of 60.

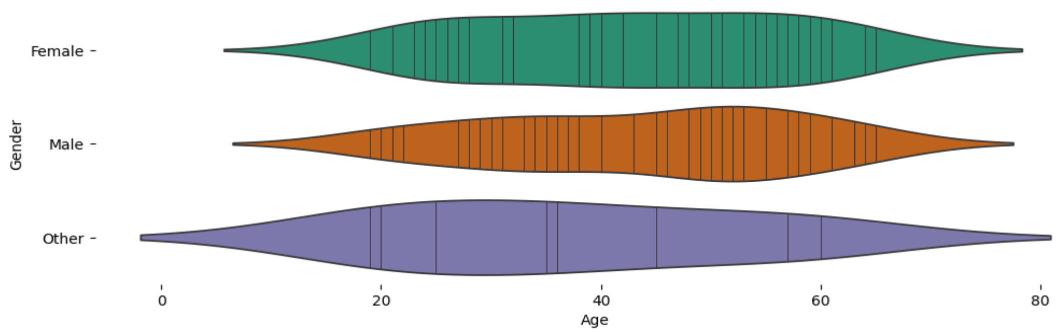

Figure 21. Violin plot of Gender vs Age

The figure 21. shows the violin plots for all genders vs age for female patients we can see a higher density around age 40 and 60 whereas for male it 43 to 60 for others the higher density is from 37 to 40 age.

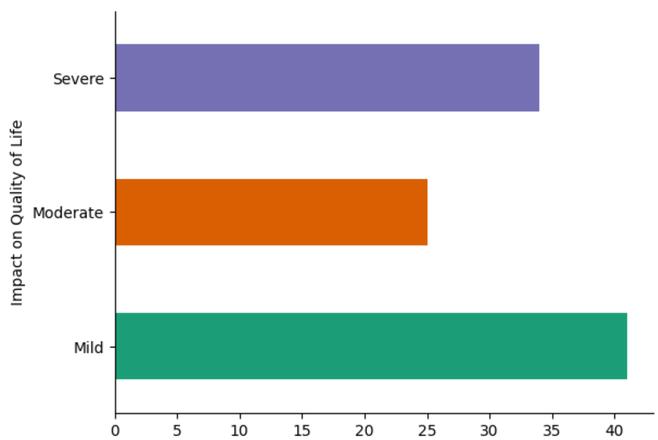

Figure 22. Bar plot of Impact on Quality of Life

Figure 22. shows the bar plot of the impact of the disease on the quality of life of the patients in the dataset. The patients were asked to rate the impact on the range of mild, moderate and severe in this case. Around 25 patients said that the disease had a moderate impact on their lives whereas 25 patients have a moderate impact of the disease in their lives and the 34 patients had a severe impact of the disease in their lives as per the dataset.

Table 4.5 Impact on Quality of Life vs Age

Impact on Quality of Life	count	mean	std	min	25%	50%	75%	max
Mild	41	45.0976	12.3992	19	37	46	55	65
Moderate	25	41.16	14.5765	19	29	39	52	65
Severe	34	41.4412	15.2637	19	27.25	40	55.25	65

Table 4.5 shows the impact of the disease on the quality of life vs age for mild, moderate and severe conditions. The min age for all the cases is 19 and the max age is 65. The count for mild is 41 patients with mean at 45.09 and a standard deviation of 12.39 , for moderate the count is 25 with a mean of 41.16 and standard deviation of 14.57, similarly a total of 34 patients had severe condition with a mean of 41.44 and standard deviation of 15.26 for this case.

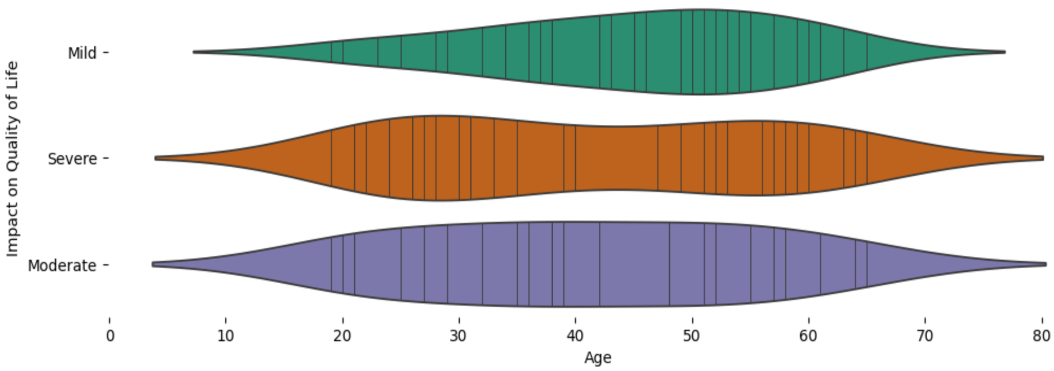

Figure 23. Violin plot of Impact on Quality of Life vs Age

Figure 23. shows the violin plot for the impact on the quality of life vs age. Here the mild conditions have high density from 45 to 50 age, the severe conditions have high density at 25 and 30 whereas for the moderate the ages 30 to 50 seems critical.

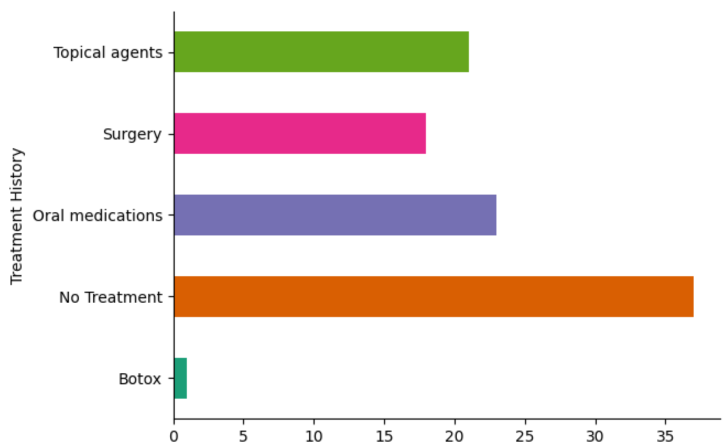

Figure 24. Bar plot of Treatment History

The bar plot of the treatment history of the patients can be seen in figure 24 here it is visible that most of the patients to be exact 37 have never opted for any treatment at all, 23 have relied on oral medication either prescribed or on advise of someone who has suffered the disease before. There are 18 number of patients who claim a minor surgery before this treatment and one patient also claimed to have botox treatment for the disease.

Table 4.6 Treatment History vs Age

Treatment History	count	mean	std	min	25%	50%	75%	max
Botox	1	50	NaN	50	50	50	50	50
No Treatment	37	42.1622	14.5077	19	30	45	52	65

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Oral medications	23	44.3913	13.6473	19	33.5	45	57	65
Surgery	18	38.0556	14.941	19	25.25	35.5	51.5	61
Topical agents	21	46.2381	12.3203	27	36	46	55	65

Table 4.6 shows the treatment history vs. age statistics here. The highest count of 37 is for the patients with no treatment history at all, with a mean of 42.16 and a standard deviation of 14.60. The minimum age for this case is 19, and the maximum age is 65. This is also the case for patients with a history of oral medications, who have a count of 23, with a mean of 44.39 and a standard deviation of 14.94.

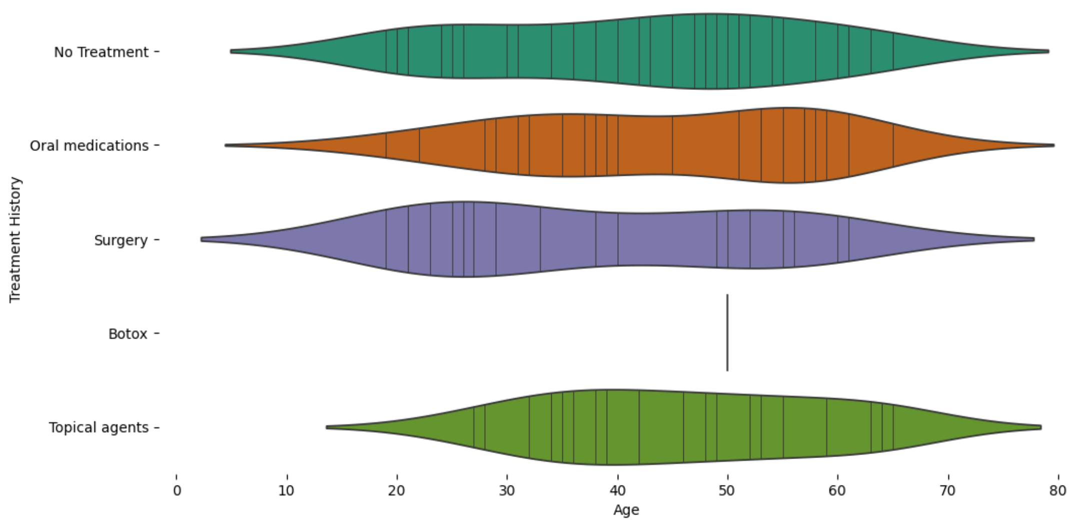

Figure 25. Violin plot of Treatment History vs Age

The topical agents have a count of 21, with a mean of 46.23 and a standard deviation of 12.32, with a minimum age of 27 and a maximum of 65. The patients with surgery in the past treatment history have a low count of 18 and a mean of 38.05 with a standard deviation of 38.05. The minimum age is 19, and the maximum age is 61 for this case. There is only one patient for the Botox treatment, aged 50. Figure 25 shows the Violin plot of Treatment History vs Age. The Botox treatment can be seen with only one value at 50. The patients with no treatment can be seen having a plot with a high density of patients aged between 40 and 50. The patients aged 40 to 55 have high density in the violin plot of oral medications. The surgical treatment in history has a high density from 25 to 38 years. Patients with a history of treatment with topical agents have higher densities from ages 40 to 55, as shown in the violin plot.

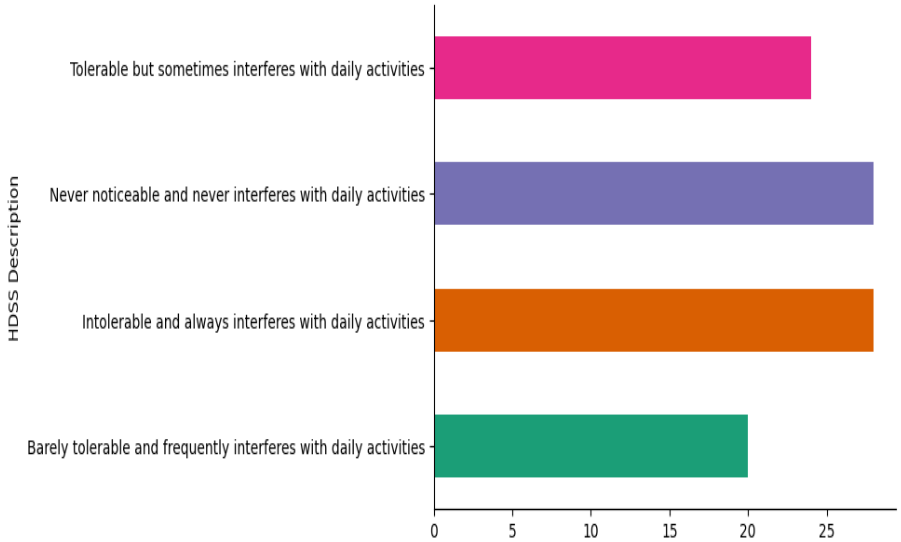

Figure 26. Bar plot of HDSS Description

The bar plot of the HDSS description is depicted in Figure 26. The data includes barely tolerable numbers of 20, which claim to be interfering with daily activities on frequent occasions. Then there are 28 patients with intolerable HDSS, which always interfere with the daily activities of the patient. The 28 patients claimed that the HDSS was never noticeable, nor did it interfere with the daily life of these patients. 24 of the patients claimed that the HDSS was tolerable, but sometimes interfered with their daily activities.

Table 4.7 HDSS Description vs Age

HDSS Description	count	mean	std	min	25%	50%	75%	max
Barely tolerable and frequently interferes with daily activities	20	41.95	13.945288	19	35.5	40.5	52	65
Intolerable and always interferes with daily activities	28	42.392857	13.798388	21	31	40	55.5	63
Never noticeable and never interferes with daily activities	28	44.75	14.122808	19	35.75	48.5	52.25	65
Tolerable, but sometimes interferes with daily activities	24	42	14.628739	19	29.5	42.5	54.25	65

Table 4.7 shows the statistics of HDSS description vs age. The minimum age is 19, and the maximum age is 65 for all cases other than Intolerable. It always interferes with daily activities, which has a minimum age of 21 and a maximum age of 63. The count is 28, with a mean of 42.39 and a standard deviation of 13.79. The Never noticeable and never interferes with daily activities has also a count of 28 with a mean of 44.75 and a standard deviation of 14.12. The Tolerance, but sometimes interferes with daily activities, has a count of 24 and a mean of 42, with a standard deviation of 14.62. The lowest count is 20 for Barely tolerable and frequently interferes with daily activities, with a mean of 41.95 and a standard deviation of 13.94 for the case.

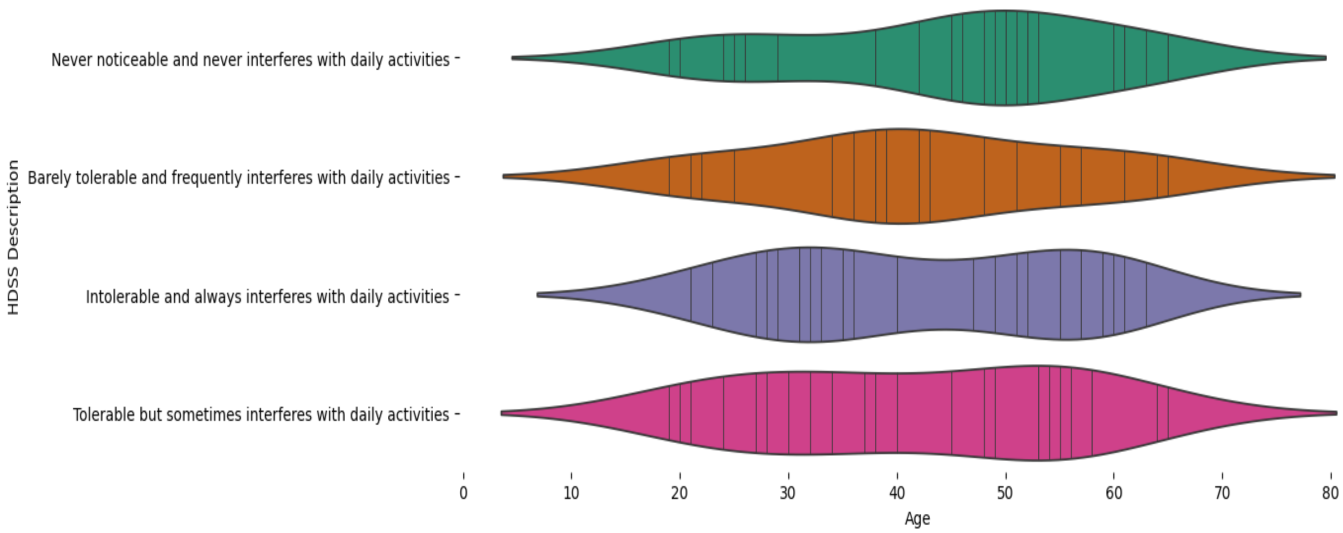

Figure 27. Violin plot of HDSS Description vs Age

The violin plot of the HDSS description vs age, the barely tolerable and frequently interferes with daily activities has more intensity from the age of 40 to 55, and the intolerable and always interferes with daily activities has higher intensity from age 35 to 45. The Never noticeable and never interferes with daily activities have higher intensity from age 25 to 55. Tolerable but sometimes interferes with daily activities, has high intensity over the range of 20 to 55 years.

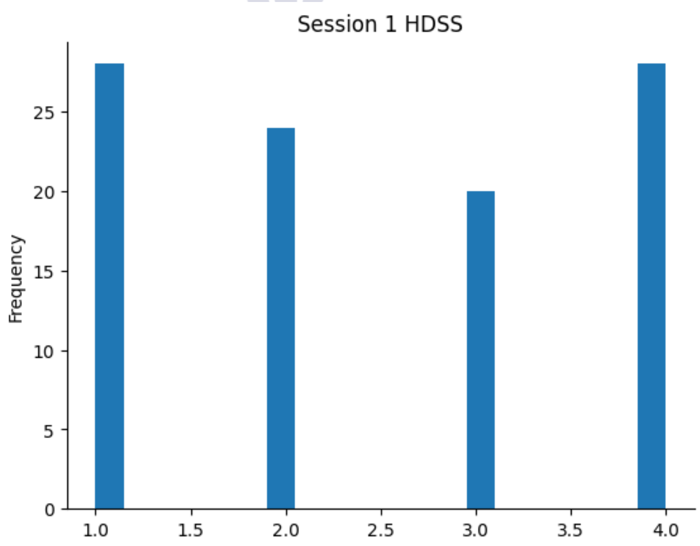

Figure 28. Histogram of Session 1 HDSS Score

The histogram for session 1 of the HDSS Score can be seen in Figure 28. Here, the scores of various patients during the first session of HDSS can be seen. The bar graphs are on the scale from 1 to 4. Table 4.7 shows the statistics of the session 1 HDSS score, with a total count of 100. The mean is at 2.48 with a standard deviation of 1.17; the minimum score is 1, which shows a significant improvement in the HDSS, whereas the maximum score is 4, which shows no improvement for the patient after the first session.

Table 4.8 Statistics of Session 1 HDSS score

count	mean	std	min	25%	50%	75%	max
100	2.48	1.176195	1	1	2	4	4

The statistics of session 1 HDSS scores are shown in Table 4.8. The count is 100, with a mean of 2.48 and a standard deviation of 1.17. The minimum HDSS score is 1, and the maximum is 4.

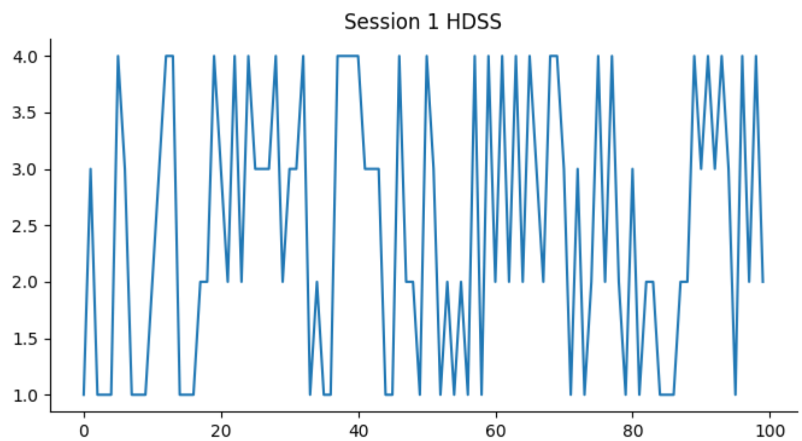

Figure 29. Line graph of Session 1 HDSS Score

Figure 29 shows the line graph of the session HDSS score. The graph shows the variation of the HDSS score over the 100 patients. The scores are diverse for the number of patients, with most of the patients having high HDSS scores, as it is the very first session for all the patients.

Table 4.9 Statistics of Session 2 HDSS score

count	mean	std	min	25%	50%	75%	max
100	2.39	1.144993	1	1	2	3	4

The statistics of the session 2 HDSS score are shown in Table 4.9. The count is at 100, with the mean HDSS score of 2.39 and standard deviation of 1.14, with a min value of 1 and max of 4. Figure 29. shows the histogram for the HDSS scores of the second session. The values are at 1, 2,3, and 4. The total count of the patients is 100, which can be seen in Table 4.8 with a minimum score of 1 and a maximum score of 4. The mean at this is 2.39 for this session, which shows better results as compared to those of session 1. This means that the patient's condition improves after two sessions.

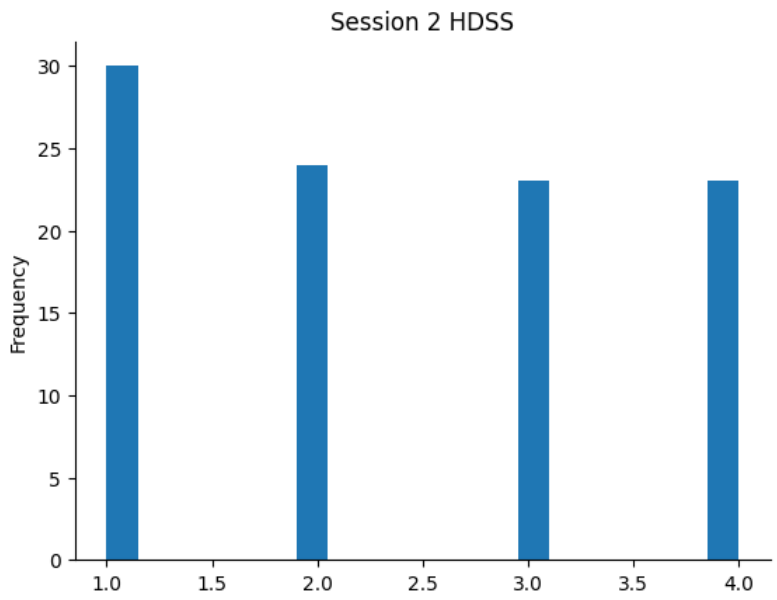

Figure 30. Histogram of Session 2 HDSS Score

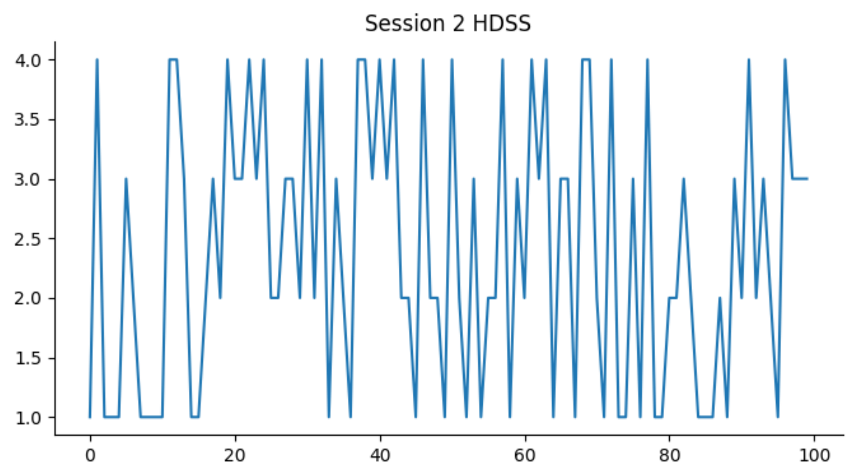

Figure 31. Line graph of Session 2 HDSS Score

Figure 31 shows the line graph for the HDSS score of session 2. Here, the patients at 100 count have a diverse range of scores. Looking at all the scores of the patients, the results seem to improve for most of the patients after the second session of the treatment.

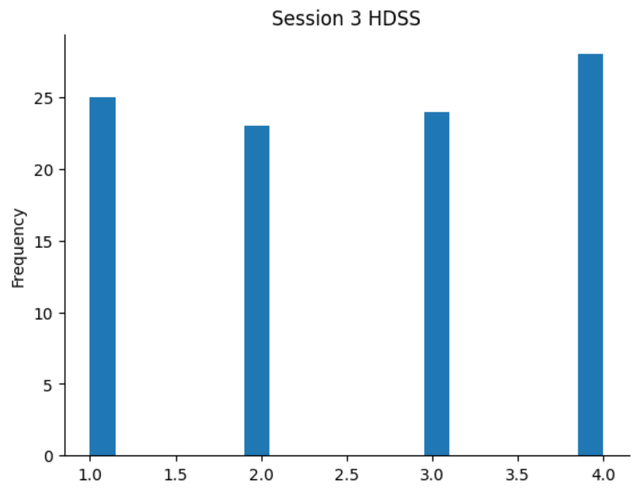

Figure 32. Histogram of Session 3 HDSS Score

The score for the third session of HDSS is shown in the histogram in Figure 32. The range of the score is from 1 to 4. Similarly, the scores are shown in Table 4.8. The statistics show a count of 100 with a mean of 2.55 and a standard deviation of 1.14, showing a much better improvement in the HDSS score. However, there are still some patients with high HDSS scores even after three sessions.

Table 4.9 Statistics of Session 3 HDSS score

count	mean	std	min	25%	50%	75%	max
100	2.55	1.14922	1	1.75	4	4	4

Table 4.9 shows the statistics of session 3 HDSS scores. The count is 100, and the mean is 2.56, with a standard deviation of 1.14, a minimum score of 1, and a maximum score of 4.

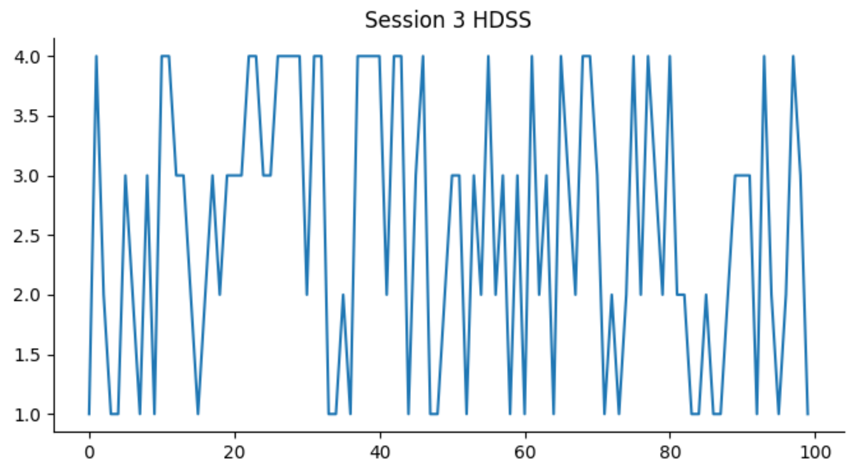

Figure 33. Line graph of Session 3 HDSS Score

Figure 33 shows the line graph for the HDSS score of all 100 patients. The scores are variable for all the patients, but compared to the first two sessions, the results are much better for most of the patients. Many of the patients who had higher HDSS scores are not down at the score of 1, which shows improvement in their conditions.

Table 4.10 Comparison of Statistics of HDSS Scores

Variable	Count	Mean	Std Dev	Min	25%	50%	75%	Max
Session 1 HDSS	100	2.48	1.176195	1	1	2	4	4
Session 2 HDSS	100	2.39	1.144993	1	1	2	3	4
Session 3 HDSS	100	2.55	1.14922	1	1.75	3	4	4

Table 4.10 shows the comparison of HDSS Scores for Sessions 1, 2, and 3; the count for all the sessions is 100. Session 2 has the lowest mean value of 2.39 for the HDSS score, which means that most of the patients had a low score on the HDSS, proving improvement in the condition of the patients. Session 1 has a 2.48 score, better than session three, which means that in case of some patients, the HDSS score has again risen. This means that the two HDSS sessions will work for most of the patients.

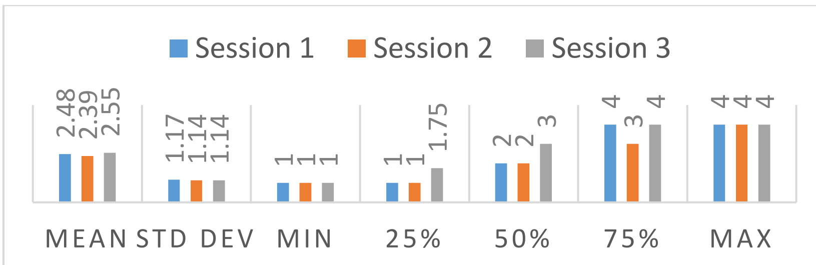

Figure 34. Histogram of Comparison of Statistics of HDSS Scores

Table 4.11 shows the Statistics of Treatment History vs. Response to Treatment. Twenty-seven patients did not show any improvement in their HDSS scores after the treatment. A total of 38 patients showed mild enhancements, with the highest number of 14 patients who had no previous treatment. Overall, 35 patients showed significant improvement in their HDSS scores, with the largest number of 15 for the patients with no treatment before these sessions.

Table 4.11 Statistics of Treatment History vs Response to Treatment

Treatment History	Mild Improvement	No Improvement	Significant Improvement	Total
Botox	1	0	0	1
No Treatment	14	8	15	37
Oral medications	8	9	6	23
Surgery	7	5	6	18
Topical agents	8	5	8	21
Total	38	27	35	100

These improvements are also evident in Figure 34, which shows the heat map of the Treatment History vs Response to Treatment with the previous treatments opted by the patients on the x-axis and the other axis with the response to treatment. Only a single patient opted for Botox, which has mild improvement; therefore, the heat map is empty for other enhancements in this case. The heat map of patients with no prior treatment shows the highest density at significant and mild enhancements. The columns with patients with oral medications show a similar heat map for all three improvements, and the same is the case with the patients with surgery prior to this treatment. The patients with prior treatment with topical agents also show a similar heat map for all three responses after the treatment.

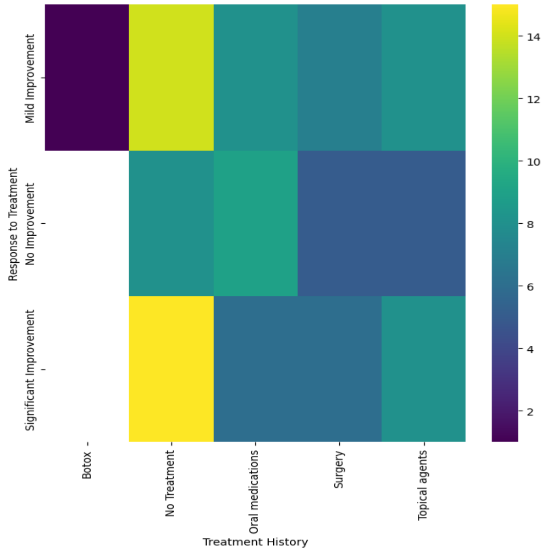

Figure 35. Heat map of Treatment History vs Response to Treatment

Table 4.12 shows the statistics on the impact of quality of life vs. treatment history. Here, 41 patients had mild impacts on their quality of life, 25 had moderate impacts, and 34 had severe consequences. The patients with no treatment prior to these sessions are the most numerous when it comes to mild, moderate, and severe effects on the quality of life, as can be seen in the table.

Table 4.12 Statistics of Impact on Quality of Life vs Treatment History

Treatment History	Mild	Moderate	Severe	Total
Botox	1	0	0	1
No Treatment	14	10	13	37
Oral medications	8	4	11	23
Surgery	10	2	6	18
Topical agents	8	9	4	21
Total	41	25	34	100

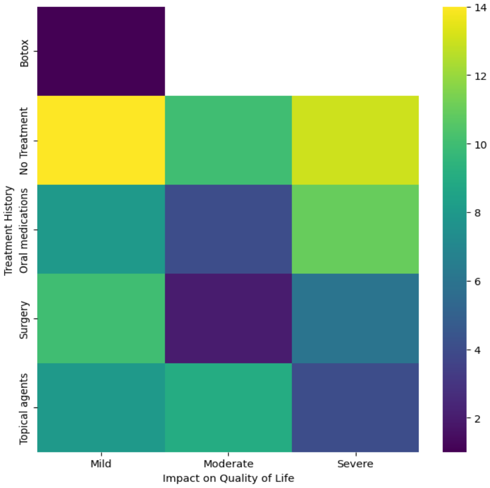

Figure 36. Heat map of Impact on Quality-of-Life vs Treatment History

Figure 36 shows the Statistics of Impact on quality of life vs. Treatment History, showing the mild, moderate, and severe impacts. For the mild impacts, the patients with no treatment prior to these sessions show the highest value in the heat map. The moderate impacts column shows that the topical agents and the no-treatment patients have more numbers than the others. The severe impact column also indicates the significant number of patients with no treatment before the sessions.

Table 4.13 Statistics of HDSS Description vs Impact on Quality of Life

HDSS Description	Impact on Quality of Life		
	Mild	Moderate	Severe
Barely tolerable and frequently interferes with daily activities	9	7	4
Intolerable and always interferes with daily activities	10	6	12
Never noticeable and never interferes with daily activities	16	4	8
Tolerable, but sometimes interferes with daily activities	6	8	10

Table 4.13 shows the Statistics of HDSS Description vs Impact on Quality of Life. Here, the 41 patients had mild impacts on the quality of life, with those whose HDSS was never noticeable and never interfered with daily activities being the most at 16. The Tolerable, but sometimes interferes with daily activities, with eight patients having a moderate impact, and the Intolerable, which always interferes with daily activities, is highest, with 12 patients having the most numbers in this case. Figure 37. shows the Heat map of HDSS Description vs Impact on Quality of Life.

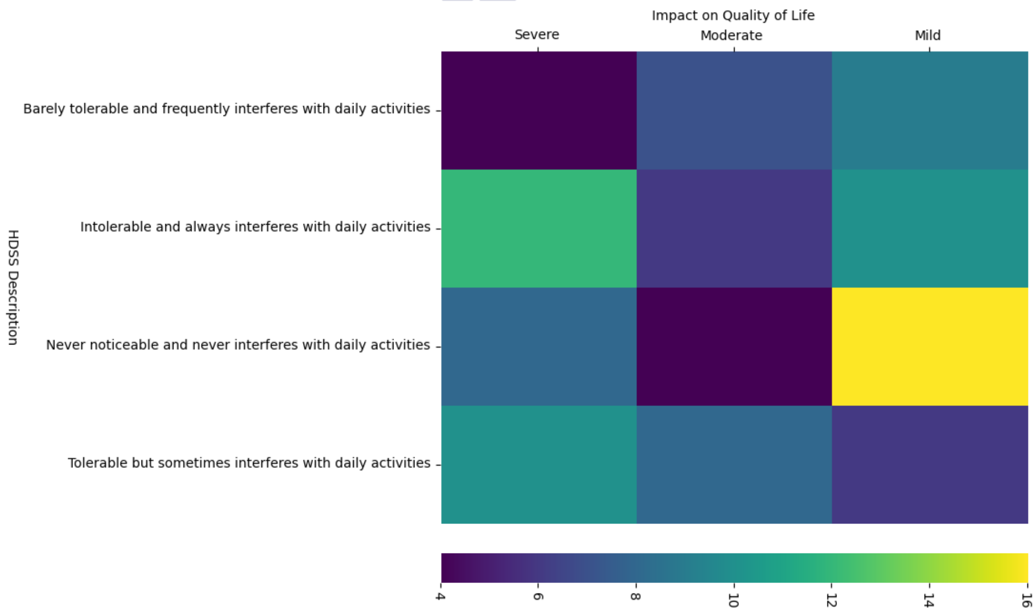

Figure 37. Heat map of HDSS Description vs Impact on Quality of Life

Table 4.14 Statistics of Gender vs HDSS Description

HDSS Description	Female	Male	Other	Total
Barely tolerable and frequently interferes with daily activities	12	6	2	20
Intolerable and always interferes with daily activities	9	17	2	28

Never noticeable and never interferes with daily activities	13	13	2	28
Tolerable, but sometimes interferes with daily activities	7	15	2	24
Total	41	51	8	100

Table 4.14 shows the Statistics of Gender vs. HDSS Description. The barely tolerable and frequently interfering with daily activities have a high number of female patients, i.e., 12. The Intolerable and always interferes with daily activities have a high number of male patients, with a count of 17.

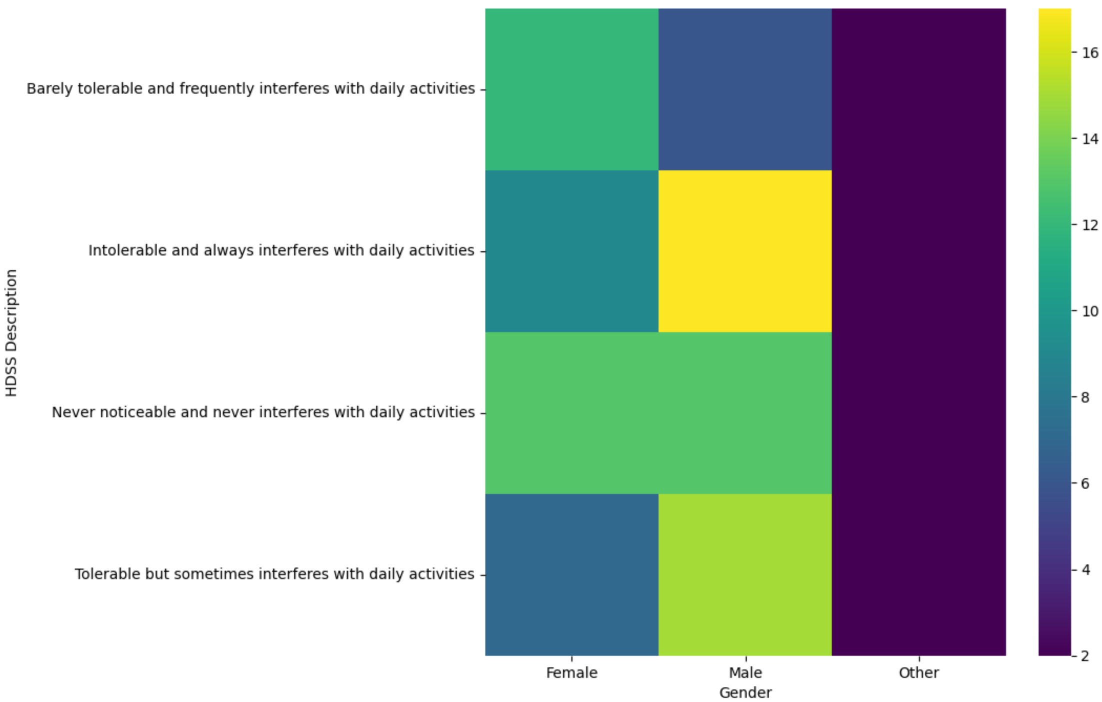

Figure 38. Heat map of Gender vs HDSS Description

The Never noticeable and never interferes with daily activities are the same, 13 each for both male and female. The Tolerable but sometimes interferes with daily activities also has males with the most numbers, i.e 15 for the category. The number of others is 2 for each case. The heatmap of Gender vs HDSS Description can also be seen in Figure 38. The heat map has a column for each attribute and shows the statistics shown in Table 4.15 with a heat map. The Intolerable and always interferes with daily activities is highest for males in the heat map. The barely tolerable and frequently interferes with daily activities, and is never noticeable and never interferes with daily activities, have a high value for female patients in this case.

Conclusion

This thesis explores the development and Implementation of a Hyperhidrosis treatment device using the water Iontophoresis technique. The device is developed using discrete components that are readily available, including Arduino nano, h-bridge module, and OLED panels for monitoring and display. The overall cost of the device is as low as 100$, which makes it a cost-effective solution for the patients of third-world countries. The trials of the device are then performed on 100 patients from January 2024 to August 2024 at Peshawar. The history of these patients was obtained, and then a total of 3 HDSS treatment sessions using the device were performed on these patients. The history included Patient ID, Age and Gender, Location of Hyperhidrosis, HDSS Description, Duration, Impact on Quality of Life, Treatment History, Response to

Treatment, Family History and Comorbidities. The data is then analysed using Python in Google Colab. The patients have a mean value of 41.87, with a minimum age of 19 and a maximum age of 65. The mean for the years of symptoms was 11.097, which shows that the disease can have an impact on the patients for many years or throughout life for some patients. A total count of Female patients was found to be 41, with a mean age of 42.85. For Male patients, the count is 51, with a mean age of 43.78, and others were counted at 8, with a mean age of 37.12. The impact on the life of patients was Mild for 41 patients with a mean age of 45.09, Moderate for 25 patients with a mean age of 41.16, whereas 34 patients had the severe impact of the disease in their lives with a mean age of 41.44, which shows that the effects of the disease is reduced with ageing. The analysis of the dataset also reveals about the past treatments patients had with, the patients with no treatment has a count of 37 with a mean age of 42.16, for oral medication has count of 23 with mean age of 44.39, 18 patients had surgery with mean age of 38 and topical agents having 21 count with mean of 46.23 which shows that most of the patients don't even consider this as a disease and don't opt for any treatment and those who opt for treatment generally opt for oral medications. The HDSS scores for session one show a mean of 2.48, which decreases to 2.39 after the second session and increases to 2.55 again after the third session, which shows that two sessions of the treatment are enough for the patients, as it reduces the HDSS scale up to 2.39 for most of the patients. The negative correlation between age and HDSS scores, ranging from -0.06 to -0.10, shows a reduction in HDSS scores with an increase in age, which is an essential factor. Lastly, the HDSS scores of these 100 patients are trained using AI/ML models, including Linear Regression, Decision Trees, SVR and Random Forest. The Linear Regression model shows best results for sessions 1 and 2, whereas all the models struggle to achieve high precision and accuracy for the session, as the HDSS scores start to increase again. The Random Forest technique shows acceptable results, with the SVR model being consistent throughout. Therefore, it can be concluded that the Linear Regression model is the best for sessions 1 and 2 and is recommended for high accuracy. If there is a need for a less accurate but consistent model, then SVR can be used to train the model for such a diverse type of dataset.

Future Work

The recommended future work for the project in terms of hardware implementation is to convert the tabletop device to a portable device that patients can easily carry. A handheld device will enable the patients to use the equipment more frequently while they are walking, travelling by bus, using a self-driving car, or jogging. The HDSS levels can also be reduced by implementing new techniques to provide variable current during the treatment as per the condition of the patients, which can only be achieved when the device is Iot-ready. In terms of analysis and training models, the data set is minimal; therefore, a large dataset of multiple localities will be helpful to train high-performing AI/ML models.

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