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Research Article

Novel Yoga Clothing Used in Physical Therapy in the Reduction of Low Back Pain - A Pilot Study

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Abstract

Introduction: Low back pain (LBP) is quite common worldwide. In 2019, there were an estimated 223.5 million cases of LBP. [1] As a result, clinicians are always looking for options in treating this malady. A novel yoga pant, Nadi X, has been developed to help yoga practitioners to more easily attain alignment in 30 yoga positions. It is well known that yoga can be of benefit for low back pain sufferers, and as a result, Nadi X was used in this pilot study to determine if pain can be reduced with the use of these pants to help guide the wearer into the proper pose.

Method: The seven chronic low back pain participants underwent four weekly Physical Therapy low back evaluations and filled out the Oswestry Low Back Pain Scale (Oswestry) and NPRS at each session, in addition to performing a yoga pose three times a day for 21 days.

Results: A decrease in Oswestry scores was found along with an improved sense of pose alignment. This points to the advantage of having haptic guidance and sensor-based posture evaluation to help with proper exercise form.

Conclusion: Further, more rigorous study should be undertaken to confirm these pilot study results, possibly establishing a protocol of yoga exercises specifically targeting chronic low back pain.

Keywords: *Haptics; IMU; Posture; Yoga; Alignment; Wearable Technology*

Abbreviations

PI: Principal Investigator; AROM: Active Range of Motion; IMU: Inertial Measurement Unit; LB: Low Back; LBP: Low Back Pain; NPRS: Numeric Pain Rating Scale; PCB: Printed Circuit Board; BLE: Bluetooth Low Energy; BMI: Body Mass Index

Introduction

The body expands and contracts much the same way a stretchable material does. The stretchable textiles revolutionized the textile industry in 1938 [1], thus enabling the body to move more freely. Designing a stretchable wearables technology platform that easily under-

stands the body's static postures, as well as provides feedback to the wearer, combines a number of various details. These include hardware expertise, textile integration, User Research with expert Yogi's, software evaluation, and machine learning that determines which posture and its level of efficiency. There are additional aesthetic needs of the athleisure category and most importantly, comfort. Being able to move and stretch comfortably is essential for athleisure and fitness apparel. Traditional braces that were often used to restrict movement were often not created with these comfort, aesthetic, and analytical capabilities.

There have been numerous studies demonstrating how yoga can support lower back pain [2]. The results indicate that yoga has an effect on both short term and long-term pain [3]. The Nadi X haptic capabilities and pose validation allow the wearer to take their understanding of how the proprioception of the body works, how it moves, and where it is in space while practicing yoga. This brings more awareness to how the body's range of motion changes. As a result of this increased awareness, proper sustained body positions can lead to stronger core muscles and reduced low back pain. Without proprioception it is difficult to manage recovery and, not only does the practice of yoga assist with this, but also haptic feedback and tactile communication with the body encourage this proprioception development.

The Nadi X pose validation indicates the wearer's binary ability to achieve the therapy pose (aligned posture or not quite aligned posture). This helps the wearer to understand their recovery and development post injury. It demonstrates their better understanding of their body's ability to achieve therapeutic positions, with the goal of allowing the wearer to understand how to more effectively do physical therapy movements for lower back pain recovery. This improved understanding demonstrates how Nadi X supports recovery through pose validation and haptic feedback on the body.

Background and Related Work

Technology integrated into wearables was first documented 1961, when Edward Thorp and Claude Shannon developed a computer small enough to fit into a shoe in order to help cheat a game of roulette [4]. Since then, wearables have been developed to address social activities, music, computing, and health and have largely been accessory based.

Knitwear dates back as early as the mid-13th century [5]. However, it was not until the early 20th century that knits became a staple in mainstream fashion. In 1919, Coco Chanel created a turning point for knitwear with the use of jersey in her line of suits. Jersey, originally only used for men's underwear, revolutionized the fashion world and changed the relationship between women and their bodies [6]. The use of stretch fabrics evolved with cheaper and faster production processes including an effort to make fibers using neoprene, which later resulted in the creation and commercialization of fabrics like spandex [7]. In the early 1990s, stretch fabrics became the norm in sports clothing.

The benefits of using a stretch textile include the construction flexibility, with the ability to allow any materials in the knit to be close to and move with the body. The construction of a knit allows for air and movement between each fiber, as well as the introduction of textile technologies such as anti-bacterial and water wicking properties. Additionally, knits eliminate many uses for additional hardware such as zippers, buttons and snaps. Stretchware is unanimously used in the fitness and wellness industry because of the aforementioned capabilities. The construction of the Nadi X haptic platform into a stretch textile, spandex, allowed for mobility, expandability, and easy adoption by the yoga and fitness communities.

Vibration therapy has been shown to have positive effects on muscle and neuropathic pain [8]. Localized vibration therapy has had positive effects on patients and is noted to be safer than full body vibrational therapy [9]. Additionally, the expanding and contracting capabilities of a knit or stretchable cut and sew construction allow for softer encapsulation and integration strategies with hardware. Softer encapsulation refers to how the electronics are embedded into the garment to ensure the comfort of the wearer. Integrating electronics directly into the yarn and knitted through a knitwear machine has been actively explored by companies like Shima Seiki [10]. Many com-

panies still separate the hard electronics from the sensor itself and this is actively being explored for the healthcare market [11] but not for physical therapy or with haptic feedback.

Exploring haptics in relation to the body has been an ongoing area of research including the encapsulation of such hardware in textiles [12-14]. The way that one perceives their body's appearance and physical capabilities changes continuously in response to sensory signals related to one's body. Recent neuroscientific studies have also shown that sensory feedback related to one's body can be used to alter body-perceptions [15].

Nadi X is a modular, expandable solution including stretchable electronic platform. By using this patented technology [16] Nadi X has been consumer validated as an efficient tool in the yoga industry. While the use of smart garments is continuously being explored for recovery, studies have shown strong correlation between yoga and recovery for lower back pain [17,18].

Novel wearable sensors and haptics: Nadi X

The basic principle of the Novel Nadi X platform is that the wearer needs to know where the parts of the body are to be able to focus on those muscles, this is provided through the haptic on-body guidance, produced through 10 haptic motors embedded in the garment that are paired with audio instructions and pose evaluation. The real-time pose validation performed by the integrated IMU's paired via bluetooth with the custom Nadi X App (available in the app store) ensure that the wearer gets a clear audio/visual/tactile indication of how to move into each pose and feedback on the success of their posture i.e. Chair Pose.

Nadi X [19] (Figure 1-4) system is the novel smart textile based wearable technology platform that measures static postures, such as yoga poses and provides haptic (vibration/tactile) feedback as guidance to the wearer. This guidance shows the wearer where to focus while moving into each pose. There are 10 haptic motors built into a module with an IMU that are joined via stretchable conductive pathways. There are three IMU module locations, one at the hip, behind both knees and at each ankle. Behind the left knee, in the popliteal fossa, the wearer clips in the battery module, known as the pulse. This contains the PCB, battery, and BLE chip. At the end of each pose sequence the IMU modules in the hips, knees, and ankles communicate back to the custom Nadi X app that determines whether the wearer has made it into the selected pose or whether they should try again. This novel system accurately measures static motion rather than repetitive motion, like many traditional wearables. The Nadi X system drastically simplifies smart sensing and can integrate into stretchable textiles that are washed regularly. Understanding static motion and guiding the wearer via haptics allows for exciting new use cases in Physical Therapy, posture management, and reducing lower back pain.

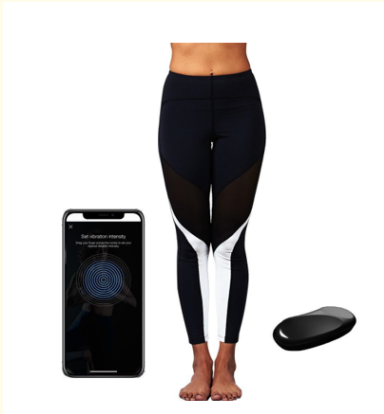

Figure 1

Figure 2

Figure 3

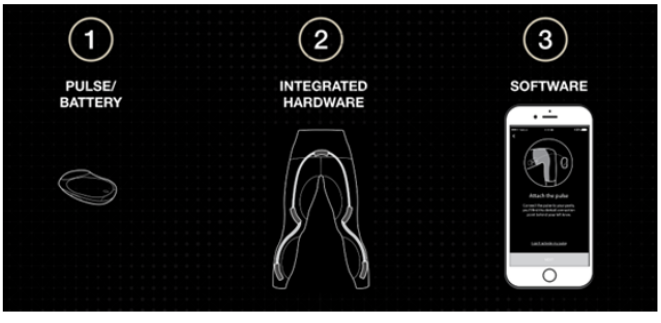

Figure 4

To understand the yoga postures of many different body types and forms, data collection was performed with 50 - 100 yogi's performing a variety of poses where postures are classified both "successfully" and "less successfully". This data was collected on sizes from XS, S, M, L, XL - with pants on properly and slightly twisted. The XYZ values from the IMU sensors are used to process the postures' likelihood of correctness.

To accurately measure specific static postures, the sensor location or placement is crucial. This means that measuring such static poses would be inaccurate if the sensor was not placed in the hips, knees, and ankles of the pants. The location of these sensors was determined by its accuracy of the measurements and the comfort for the wearer. The novelty of this system is not only because of the location of the IMU sensors in the hips, knees, and ankles, but also because of its integration into clothing and pairing with haptics. In comparison to traditional wrist-based activity trackers, the Nadi X system has a high degree of accuracy in measuring these static poses that are necessary for measuring parts of physical therapy.

Methods

The pilot study was performed in collaboration with Spectrum Ergonomics at their clinic. This pilot study was a within subject design with 8 participants self-identified as having low back pain, with 7 (5 females and 2 males) completing the study. They were recruited by advertising in various printed and electronic forums. The Principal Investigator performed a physical screening over the telephone to screen out those who may have frank neurological symptoms. Once the participants came in for their first Physical Therapy evaluations, they were screened for frank neurological signs and given the proper instructions on how to perform the Chair Pose with the technology as guidance. At this first session they were also given personal instructions by the Research Assistant in the use of the app and placement of the pulse. These procedures were beneficial to ensure that participants were confident in using the Nadi X.

Participants	Gender	Age Range	Weight Range	Height Range
	M	56 - 65	(91 - 102 kg)	(1.81 - 1.9m)
	F	56 - 65	(69 - 79 kg)	(1.66 - 1.8m)
	F	46 - 55	(57 - 68 kg)	(1.6 -1.65m)
	F	66 - 75	(57 - 68 kg)	(1.6 -1.65m)
	M	66 - 75	(69 - 79 kg)	(1.66 - 1.8m)
	F	66 - 75	(45 - 56 kg)	(< 1.5m)
	F	36 - 45	(45 - 56 kg)	(1.6 - 1.65m)

Table 1: *Self-reported anthropometric data.*

Gender	Body Mass Index
Males	Median (n = 2) 29.25 (overweight)
Females	Median (n = 5) 22.04 (normal weight)
All Participants	Mean BMI of all participants 24.1 (normal weight)

Table 2: *Participants' body mass index as measured during in-person sessions and averaged.*

Signed informed consents were obtained from each of the participants and each was given a pilot study Notice of Privacy Practice. Onboarding of each participant with Nadi X was successfully performed by the Research Assistant by walking them through how to use

Nadi X step by step on this first session prior to their evaluation by the PI. Any subsequent problems with the Nadi X system were handled by the Research Assistant. Each participant was compensated for their participation by being given their Nadi X yoga pants used in the study and offered a free home exercise instruction session with the PI upon completion of the study. The pilot study consisted of 4 weeks of medical data derived from once-a-week Physical Therapy evaluations and 3 weeks of participants performing Chair Pose with Nadi X, 3 times per day. At the end of each day, the participants would complete a perception form. The PI kept all medical data separate (to be in compliance with HIPPA) from the subjective data inputted daily by the participants and was not shared with the Nadi X team until completion of the pilot study. This medical data was used for statistical purposes only and no participant identity was revealed.

Pilot study protocol

Participants were sent a form daily to assess their Numeric Pain Rating Scale [20,21] (NPRS, 0-10/10), trunk active range of motion, and gather binary posture (either attaining Chair pose or not) results from the Nadi X system.

Participants came into the Spectrum Ergonomics office once a week for 4 consecutive weeks and were evaluated by the PI. The participants completed the Oswestry Low Back Pain Scale (Oswestry) and the NPRS at each of the four weekly Physical Therapy evaluations. They were evaluated in person to ascertain if there was any regression or improvement in physiological signs/symptoms and or subjective symptoms. If the participant showed any worsening physiological signs or symptoms or did not want to continue in the pilot study, they would be removed from the study and had the option to notify their Primary Care Provider or preferred specialist. No participants were removed due to worsening physiological signs/symptoms, however, one did not want to continue to perform Chair pose as per the prescribed amount and frequency. This participant was voluntarily removed from the pilot study after a Physical Therapy evaluation was done to assess if any worsening physiological signs/symptoms had occurred as a result of participation in the pilot study. At the end of the pilot study, retrospective data was electronically collected via a Google form to reflect on their experience and give feedback on Nadi X as a tool for lower back pain.

Participants performed Chair Pose 3 times per day on the days where they were not evaluated by the PI and answered a series of Likert scale questions about their pain levels, range of motion, and lifestyle questions. There was daily data collected on personal perceived pose accuracy and this was compared against the Nadi X system pose confirmation.

Wearable X and Spectrum Ergonomics aligned on Chair Pose as the daily exercise because this is a pose that activates the core muscles and does not require much lumbar spine mobility. The PI states: "The Chair Pose, in utilizing the core muscles, can also help with static balance as the core muscles surround the body's center of gravity (COG). Since humans are moving quite frequently, the COG does change and the stronger the core muscles the more control we have over larger fluctuations in our COG, thus better balance with a more stable lumbar (low back) spine".

Results

Posture classification results

Participants were given a binary response through the app audio and visual after the completion of each Chair Pose from the Nadi X system. The response was either "Pose Complete" or "Almost there, go back and try again". The evaluation from the Nadi X system was compared to perceived daily pose accuracy. Participants were prompted with the question, "How accurately do you feel like you did Chair Pose today?" as well as were asked to respond on a scale from 0 (not well) -10 (perfect) in their daily Google form (Figure 5). Participants received "pose complete" 100% of the time when they rated their daily perceived pose accuracy a 10 (perfect). Participants received "pose complete" an average of 77% of the time when they rated their daily perceived pose accuracy a 9/10 (perfect). The average pose accuracy score over the course of the study was 8.19/10 across all 7 participants. The hypothesis is that participants who perceived higher accuracy on their pose will receive "Pose complete" from the Nadi X system. This validates the technology as a tool that allows wearers to understand their posture and improve their form.

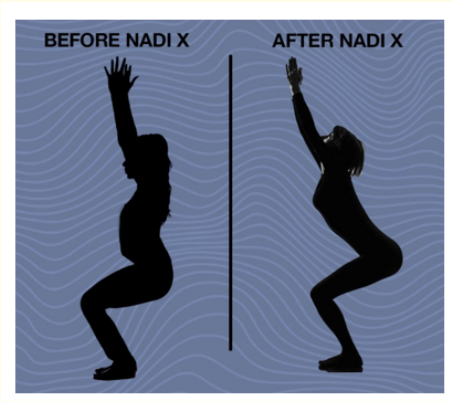

Figure 5

Comparison of perception results and Oswestry

The results of the pilot study showed a willingness to perform Chair Pose daily, as seen in retrospective responses asked at the end of the study and an average Oswestry score decrease of 16% from session 1 to session 4 (Physical therapy evaluation sessions with the PI).

Participants were asked daily if they felt their range of motion increased or decreased from the previous day on a scale of 0 (smaller range of motion)- 10 (larger range of motion). 43% of participants reported an increase in range of motion from day 1 to day 21, with all three of these participants falling in the age range 66- 75. The average difference in range of motion from day 1 to day 21 was 0.43.

The relationship of daily perceived pain levels (Figure 6) and perceived pose accuracy, which was taken from the Google daily form, was evaluated and the resulting Pearson Correlation Coefficient was insignificant at -0.045.

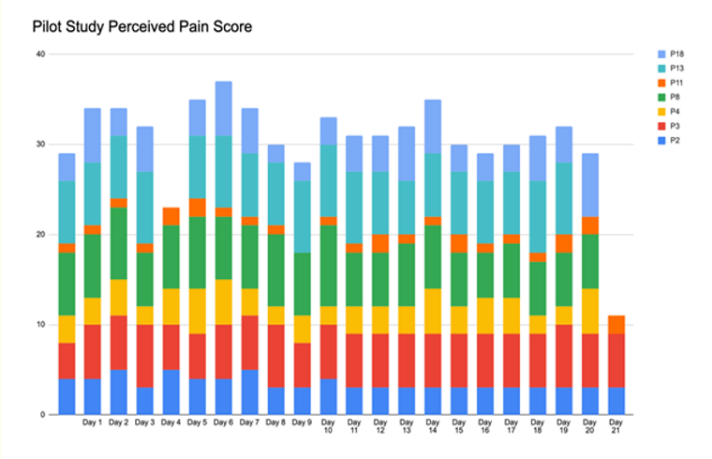

Figure 6

Oswestry results

Participants were asked to fill out the Oswestry at each physical therapy evaluation session. 86% of participants showed a decrease in their Oswestry score when comparing day 1 (first physical therapy evaluation session) to day 21 (last physical therapy evaluation session). There was a 16% average decrease in scores in the pilot study from session 1 to session 4. The largest decrease in score was observed from sessions 1-2, with an average 18.09% decrease.

Oswestry section specific results

The average decrease in scores amongst all participants was 9.5% in the social life section and 35.7% for the sleeping section.

Five participants reported that they worked out 6 times a week, one participant reported 4 times, and one reported 2 times per week. There was no correlation between the number of times participants worked out and changes in the Oswestry, perceived pain level, perceived pose accuracy, or NPRS.

Results by demographics

The data was further evaluated to understand patterns between age range, weight range, and gender. There were no correlations found with age range, height range, weight range, and gender on Oswestry scores for these participants.

Results by age group

All participants ages 56 - 65 experienced a 14% decrease in Oswestry score from sessions 1 to 4. All participants under the age of 55 experienced a 30% decrease in Oswestry scores from session 1 to 4.

Results by gender

80% of female participants showed an average decrease in their Oswestry score of 20% from sessions 1 to 4, while all male participants showed a 17% decrease in their Oswestry score from sessions 1-4.

Results by height range

There were no correlations in average Oswestry scores with participants in different height ranges, however, participants with a height above 145 cm. experienced a 14% or higher decrease in Oswestry score from session 1 to session 4.

Physical therapy evaluation data

Participants received a physical therapy evaluation in each of their four, in-person physical therapy sessions (Sessions 1, 2, 3, 4) to measure changes in trunk range of motion, neurological status, low back muscle tone, and more. There were no significant findings in comparing Oswestry scores to ROM, muscle tone, or neurological changes.

Discussion

Advantages and limitations of Nadi X pilot study

Nadi X technology allows people to practice yoga on their own schedule and 100% of the participants said that they enjoyed choosing when they could practice Chair pose throughout the day. The advantage of a remote recovery system is the self-motivation and guidance of performing recovery exercises outside of the physical therapist's office. We observed a lower fluctuation in perceived accuracy, pain levels, and range of motion throughout the study as seen on the participants' Daily Forms. Nadi X customers have noted that after getting onboarded the system is easy to use at home. Additionally, because of the limited yoga pant size range available, recruiting participants for this study was smaller than planned initially. Onboarding of Nadi X was done on their first physical therapy evaluation session to account for a threshold period for participants to get used to the technology and to assist participants with their first-time using Nadi X.

We asked participants retrospective questions (one participant did not respond) regarding their experience in the Nadi X Pilot Study. When asked "How did you find the length of time you had to hold Chair Pose?" on a scale of 0 (difficult) - 10 (easy), one participant reported 5, while the 5 remaining participants reported 9 or higher. One participant noted that "Once the pants lost their newness they were easier to get on and off. Getting the connection was easy and using the app was simple". 50% of participants said that they would continue to use Nadi X if the technology were shown to help them with lower back pain.

Use cases and applications

The initial use case for this technology was yoga, due to the specific ability to measure static motion and the importance of haptic vibration as part of the instructional experience. This pilot study explored the application of this technology into remote physical therapy for the support of lower back pain treatment. This technology has also been explored in the upper body (Figure 3). The combination of IMU sensors and haptic instructions on the body need to be placed with attention to the kinematics that it is trying to understand and impact. For example, it is less effective to have IMU's placed on the wrist when the body part that the garment is trying to measure relates to shoulder and hip orientation. Additionally, if the haptic motors or sensors are floating on a part of the body it makes it more difficult for the wearer to understand the vibrational language. There has been active exploration into a bra form factor for posture management as well as tight fitting t-shirts for back and shoulder alignment. The application is to further develop the yoga pose library as well as the physical therapy movements that are necessary to support recovery.

Conclusion

Smart textiles and novel wearable sensors paired with haptic vibration have considerable opportunity to solve specific problems as state-of-the-art rehabilitation science continues to evolve. There are many factors that contribute to the data that has been captured through this pilot study. It is important to note that with perception data often participants can forget what their earlier daily responses were, this being a natural part of a study that takes place over several weeks. Additionally, there are many parts of the participant's day that are not captured through the current data analysis, such as lifting or carrying heavy loads the day of their physical therapy evaluations. Activities such as these can contribute to changes in the physical therapy evaluation findings.

The Chair pose was chosen for this study to help understand the effect of the haptic feedback in helping to gain postural muscle control and its effect on pain reduction. Since this pose does not involve low back movements beyond a spine neutral position, there was no opportunity to see the effects of improving low back active range of motion.

This Pilot Study demonstrated a reduction in Oswestry Low Back Pain Scale scores and the participants' improved perception of attaining the assigned Chair pose, this established a connection between the internal technology of the Nadi X, as witnessed by the participants' improved ability to self-report attainment of Chair pose. This finding in combination with the lower Oswestry scores suggests the usefulness of this haptic feedback and posture analysis in a Physical Therapy regimen to help reduce LBP.

Suggestions for Future Study

The next phase of this research is a further study to include more participants and to understand broader parts of the participants' daily lives, thus giving us a chance to look at more variables. Variables such as levels of pain, lifestyle, age, and stage of pain development. This would help to gain an understanding of what is contributing to the changes in data. Other follow-up efforts could include a double-blind randomized control study to more clearly demonstrate the benefits of Nadi X.

The onboarding of the participants to the Nadi X technology could be changed to include the experience with the Physical Therapist. This could help the participants understand the exact technology experience and how it assists with their therapy. The selection of one or more yoga poses could include a pose or poses that has some low back motion in one or more directions to see the effect on LB AROM during the Physical Therapy evaluations. Additionally, collecting data for a longer period of time will be useful as LB pain, especially

chronic pain, usually takes longer than 4 weeks to begin showing signs of significant decrease. Knowing this and yet seeing a reduction in Oswestry scores in our short-term pilot study was very encouraging!

The development of haptic polymers will allow for the vibrations to become more minute and thus observe if some variables such as perceptions of pose attainment will improve at a more rapid pace than with this pilot study.

Conflict of Interest

This pilot study was funded by Wearable X. The PI (co-author) is an independent contractor and as a result, there is no conflict of interest. The other co-author states that there may be a potential conflict of interest

Appendix 1

Nadi X Pilot Study LB Evaluation Form

Participant ID# Height in Weight # Date

Posture Observations: Chair Pose technique- Properly done without pain increase Y N

Integumentary Observations:

Trunk AROM

Flexion-FTF cm Extension- deg Sidebending-FTF R cm L cm Rotation-deg R L

Neurological Testing:

Reflexes: L3 L4 L5 S1 Sitting Dural Stretch

Babinski: Present Not Present Clonus (calf): R beat L beat

Myotomes: L2 L3 L4 L5 S1

Dermatomes: L1 L2 L3 L4 L5 S1 I (Intact) D (Diminished) A (Absent)

Sacroiliac Joint Testing: + or -

Gapping R L Compression R L Torsion R L

Vertebral Testing: + or – and vertebral level

P/A glides Rotational glides

Myofascial Palpation:

Appropriate to continue with study: Y N (Reason and further action to be taken):

Appendix 2

Medical History Screening for Inclusion to Nadi X Pilot Study

Participant ID # Name Waist Size Date

What other medical conditions do you have and any medicines you are currently taking for it.

Where is your back pain located?

Does it radiate and if so, from what area to what area?

Do you have numbness or tingling or both in your legs and if so where is it?

What makes the pain worse?

What makes it better?

Do you have any joint problems? If so, where?

Have you had a fracture in your low back or legs? If so, where and when?

Have you had any surgeries? If so, what and when?

Do you have any skin conditions or sensitivities? If so, what?

Do you have a heart condition? If so, what?

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