
# Relaxing Patch

## Contract Book

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## Biographies

**Mengyuan Xue** is a first-year master student at Johns Hopkins University, majoring Biomedical Engineering with a focus on imaging and medical device. She is from Shanghai, China and she completed her undergraduate studies at Washington University in St. Louis, where she did two projects focusing on RNA selection for ribosomal protein binding and mice brain vessel segmentation from photoacoustic imaging dataset. She is interested in medical imaging and its application in disease diagnosis and therapy. In her spare time, she loves watching movies, cooking, hiking, and hanging out with friends.

**Yongzhi Sun** is a first-year master student at Johns Hopkins University, majoring Biomedical Engineering with a focus on computational medicine. He is from Beijing, China and he finished his undergraduate study at Southeast University. He has conducted research in areas of flexible electronics and wearable sensors. He has published a SCI paper and has filed a Chinese patent. When he has time, he loves to play soccer and badminton. He also enjoys cooking.

## Abstract

This contract book detailed all essential information for the team's startup 'X-Sun' 'co-founded' by Mengyuan and Yongzhi that focuses on the development of *Relaxing Patch*, which is an ultrasonic patch for reducing hypertension. Relaxing patch is a low-weight product that can be stretched easily and applied on the neck without going to the clinic. Our product revolutionizes the way of hypertension treatment and turns out to be far more superior than our competitors and traditional mainstream therapeutic approach for hypertension. By thorough market research and in-depth analysis of business model, Relaxing Patch has a large market and mainly targets at patients who develop drug tolerance issue for hypertension medication and patients who are older than 60-year-old. Current therapeutic approaches include life-long hypertension control medication and implantable pulse generator for therapeutic purpose, or relief hand-held device that can be applied on carotid artery to reduce the negative effect from hypertension. Thus, the team is convinced that the *Relaxing Patch* has a promising market after commercialized and is expected to go through 510k clearance soon after submitting the application for FDA approval as it would be classified as a Class I medical device that poses low to moderate risk to the patients. The team also designed a proof-of-concept prototype design and completed a patent book by now but will continue to recruit experts on wearable device and material science to further carry on the product design from research phase to commercial phase.

## Introduction

Hypertension is defined with a cutoff point of 80 mmHg in diastolic blood pressure and 130 mmHg in systolic blood pressure, and 90 mmHg/140 mmHg diastolic/systolic blood pressure serves as a cutoff point between Stage 1 and Stage 2 hypertension. Hypertension is one of the most prevalent diseases in the United States currently, approximately 45% (108 million) of the adults in the US have hypertension or are having medication for hypertension. Despite its prevalence, hypertension is actually highly risky for heart disease and stroke. Just in 2018, nearly half a million deaths were associated with hypertension-related diseases.

However, given the high prevalence and severity of the disease, there doesn't turn out to be an effective therapeutic approach up to now. Current mainstream approach is to control hypertension by taking medication, which might cause adverse effects as some patients either develop drug tolerance or cannot tolerate the dose for the medication to be effective. Another adverse effect can be due to physician inertia, which is a kind of behavioral issue for physician to depend on a current treatment plan even though patient parameters show clinically need to change treatment plan. This behavioral phenomenon is relatively common for hypertension diagnosis. Despite the previous issues, it is also mentally challenging for a hypertension patient to take drug lifelong.

Our solution *Relaxing Patch* was based on flexible and stretchable ultrasonic patch that have the characteristics of skin. The ultrasonic patch would be applied on the carotid artery on the neck, and appropriate training needs to be given by physician to make sure the patients can identify the point of application (usually carotid artery). The ultrasonic patch was similar to a conventional ultrasound device that can create stimulation from the carotid artery and subsequently reduce hypertension. Our proposed solution also deploys a wireless communication interface for measurement data onto smart devices or cloud locations so that the data can be stored, displayed, and transmitted, either by user or by medics.

## Patent Survey

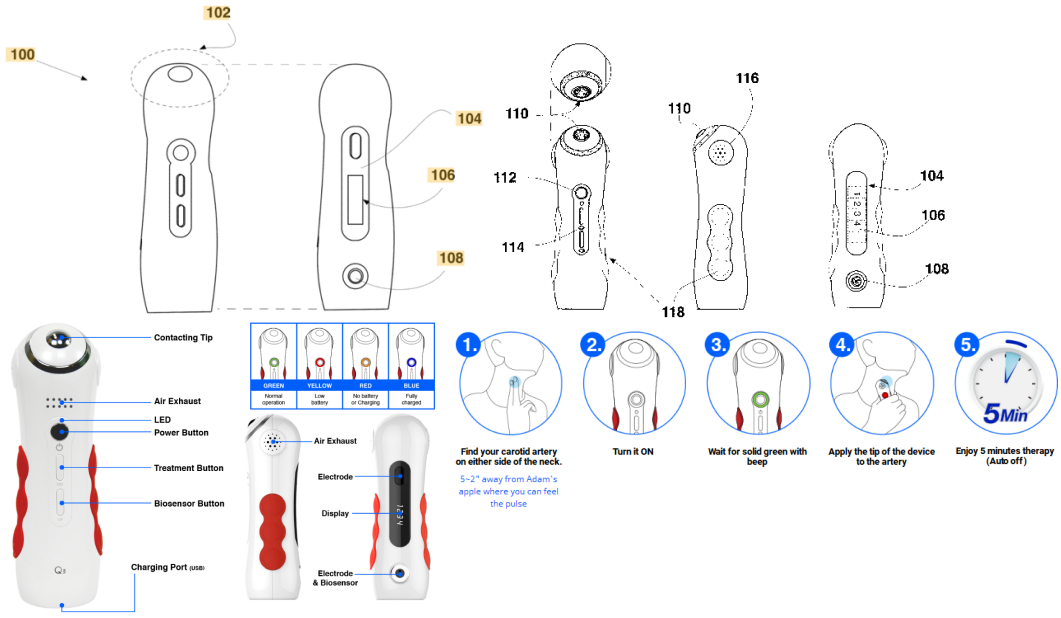


**Figure 1:** PhysioCue Patent Illustration Figure

This patent utilizes simulation of the carotid baroreceptors to lower blood pressure the product has already been commercialized with a brand name of PhysioCue. With the carotid baroceptors simulation, patients' blood pressure can be reduced through noninvasive means. PhysioCue is a hypothermia therapy device, and one end of the system is temperature-controlled hypothermic with a circular shape that can be applied to the carotid sinus of a patient for a designated duration. The hypothermic end creates a low-temperature stimulation that induces a baroreflex activation within the human body and reduces the patient's blood pressure consequently.

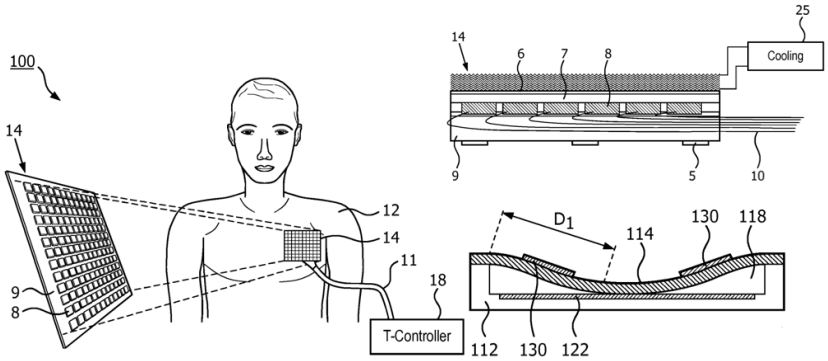


**Figure 2:** *An ultrasound patch for ultrasound hyperthermia and imaging* illustration

This patent is an ultrasound therapeutic system for both ablation and hyperthermia by applying an ultrasound patch on the patient. The patch is a two-dimensional array of ultrasonic transducers that utilizes CMUTs as the major material and can be operated in a variable frequency range. The system also has a transducer controller that permits continuously varying the frequencies, at which the transducers in the array can be operated. The transducer controller may activate the transducers operating at different frequencies either simultaneously or in a predefined sequence, which has clinical application for human diseases.

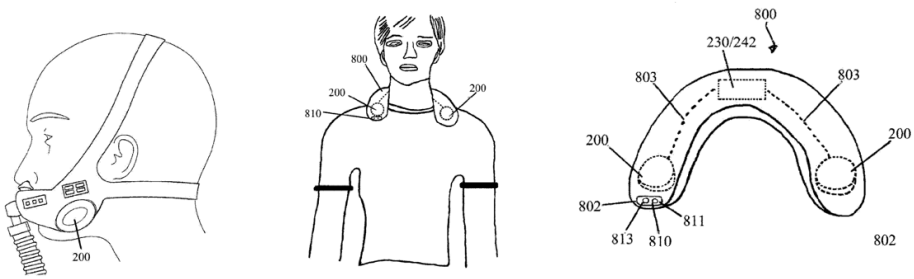


**Figure 3:** *Methods and Devices for Treating Hypertension* illustration

This system uses the activation of baroreceptors to treat hypertension and the adhesive baroreceptor activation device or other sensory activation device is positioned near a dermal bone to provide the treatment. When baroreceptors and nerves are activated, the sympathetic nervous system is induced by reducing the blood pressure, which can minimize the negative effects on heart and vasculature system from hypertension.

## Market Research

Hypertension is a highly prevalent disease in the United States with nearly half a million deaths including hypertension as a primary or contributing cause in 2018. Despite its prevalence, nearly 45% of adults in the US have hypertension or are taking medication for hypertension, and only 1 in 4 adults with hypertension have their condition under control. Therefore, there has been an increasing demand of controlling hypertension with the increasing prevalence of hypertension among people in the United States, or globally. According to a recent age-stratified survey, hypertension is also very prevalent in people older than 60-year-old: nearly 75% of the people in the age group suffer from hypertension, and our most focused audience group would be the aged ones. Globally, approximately 26% of the population in the world have hypertension and the number is expected to increase to 29% by 2025.

Current mainstream therapeutic approach is to control hypertension by taking medication, which might cause adverse effects as some patients either develop drug tolerance or cannot tolerate the dose for the medication to be effective. Another adverse effect can be due to physician inertia, which is a kind of behavioral issue for physician to depend on a current treatment plan even though patient parameters show clinically need to change treatment plan. This behavioral phenomenon is relatively common for hypertension diagnosis. Despite the previous issues, it is also mentally challenging for a hypertension patient to take drug lifelong.

Thus, given the large group of patients who are in need of effective hypertension control, we believe there will be a large market for *Relaxing Patch*, which is a safe, efficient, and light-weight patch that can be used at home without regular help from physicians. Moreover, we anticipate the market to grow, as one in five Americans would be older than 65-year-old by the time of 2030.

As for the traditional hypertensive drug market, there are some predominant competitors globally. Some dominant companies include:

- **North America:**
  - US: Pfizer, Johnson & Johnson, Merck, Bayer HealthCare
  - Canada: Valeant Pharmaceuticals, Northern Therapeutics

- **Europe:**
  - France: Sanofi
  - Switzerland: Novartis, Actelion Pharmaceuticals
  - Germany: Boehringer Ingelheim
- **Asia:**
  - Japan: Daiichi Sankyo, Takeda Pharmaceuticals, Ono Pharmaceutical
  - Korea: Dong-A ST, LG HealthCare, Yuhan

Current competitors that exist can mainly be divided into two types: therapeutic type and relief type. Some representatives of the first kind include Mobius HD and Barostim NEO, which is an implantable pulse generator placed into one's body invasively by a surgeon, whereas PhysioCue is one of the representatives of the second type and is a device that uses hypothermia therapy to mitigate hypertension condition. Mobius HD device and Barostim are both implantable devices that need to be placed via a catheter into a patient' s body, and is only possible by the order of a physician. Also, the two devices were still undergoing extensive clinical trials to assure its safety and effectiveness. Physiocue has already finished clinical trial and has filed an FDA class II 510k clearance, so this one is the only similar commercially available product, but one point of note is that is can only relieve the negative effects from hypertension without truly curing hypertension.

**Table 1** entails the detailed SWOT analysis of our product *Relaxing Patch*.

| **Strengths:** | **Weaknesses:** |
|---|---|
| 1. Current members have relative expertise on the subjects related to the product.<br>2. The product is well-supported by biomedical theory and is expected to be effective. | 1. Lack of funding for hardware and salary needed for the technicians.<br>2. Lack of enough experts that can devote full-time on the product.<br>3. High price of the product in the initial phase. |
| **Opportunities:** | **Threats:** |
| 1. No effective therapeutic approach is available till now that can completely cure hypertension.<br>2. A large group of people suffer from hypertension, which causes restrictions on life and diet.<br>3. Current solutions other than medication are invasive and not home applicable. | 1. There have been multiple research labs focusing on similar development of wearable device and creating simulation on application of human disease therapy.<br>2. The development cycle for the product is relatively long, and unknown development or idea might occur during the years. |

**Table 1:** SWOT Analysis for *Relaxing Patch*.

## Current Solution

As the product *Relaxing Patch* is still in active research phase and based on technical knowledge, this section will introduce the overall science behind the product in a way relatively easy to understand.

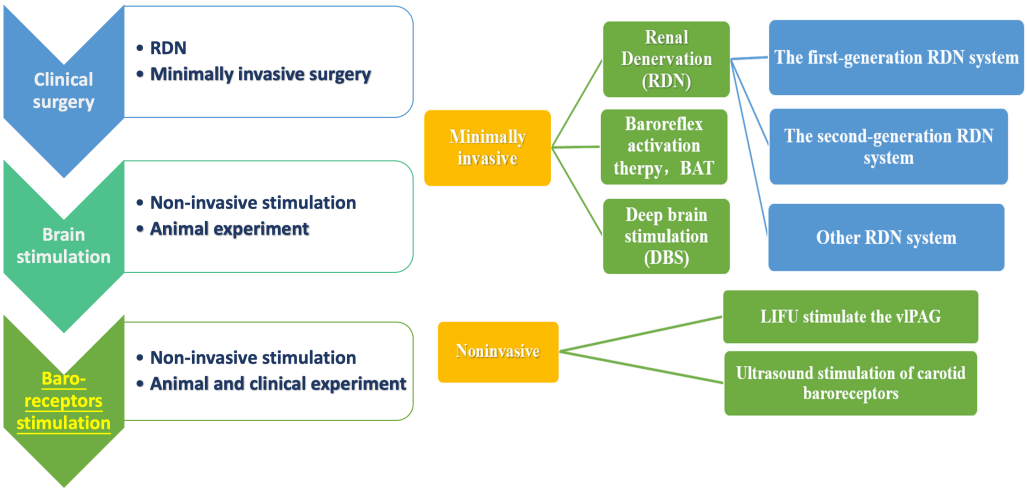


**Figure 1:** Flow chart of current and potential therapeutic approach for hypertension

**Figure 1** listed several current and potential therapeutic approaches for hypertension, and several categories of minimally invasive/noninvasive methods were included. The most direct and reliable method is by clinical surgery, RDN, which is a minimally invasive surgery. RDN is a good method of altering sympathetic tone, and surgical RDN has been shown to reduce BP. The relevant mechanism has been proved. Firstly, Activation of renal sympathetic efferent nerves can decrease renal blood flow. Secondly, it can decrease urinary excretion of salt and water. Additionally, it can increase renin release from the kidney. Furthermore, RDN interrupts sensory afferents as well as sympathetic efferent, and afferent denervation may be just as important as efferent denervation in reducing BP. Activation of renal afferent nerves can increase systemic sympathetic activity through a central action. Hence, RDN might lower BP through reversing these mechanisms

As for noninvasive stimulation method, low intensity focused ultrasound (LIFU) stimulates the ventrolateral periaqueductal gray (vlPAG) in spontaneously hypertensive rats (SHRs) model experiments were conducted, and the results support that it could relieve hypertension in SHRs, which shows that the LIFU stimulation of the vlPAG could be an alternative non-invasive therapy for hypertension. However, the disadvantages are also obvious as it's for animal experiments only and its non-wearable and bulky feature.

As for baroreceptors stimulation, current approach is to electrically activate the baroreflex, the body's main cardiovascular reflex, signaling the brain to regulate cardiovascular function. It activates baroreceptors in the wall of the carotid artery and stimulates the afferent and efferent pathways of the autonomic nervous system. Through treatment, the brain responds to the therapy by modulating efferent pathways, relaxing blood vessels, slowing the heart rate and reducing fluid in the body via improved renal function. However, the electrical stimulation has obvious disadvantages. Firstly, it is hard to control the magnitude of pressure reduction. Secondly, the safety of long-term implantation cannot be guaranteed. Lastly, implants are invasive, battery life and the cost of long-term treatment are also problems that exist.

Compared with electrical pulses, ultrasound, as a mechanical wave, is more easily received and sensed by pressure receptors than electrical stimulation as the receptors are mechanical sensors that sense the physical changes of the blood vessel wall. According to a published research, ultrasonic stimulation can effectively reduce the blood pressure of hypertension patients, as shown in **Figure 2.**

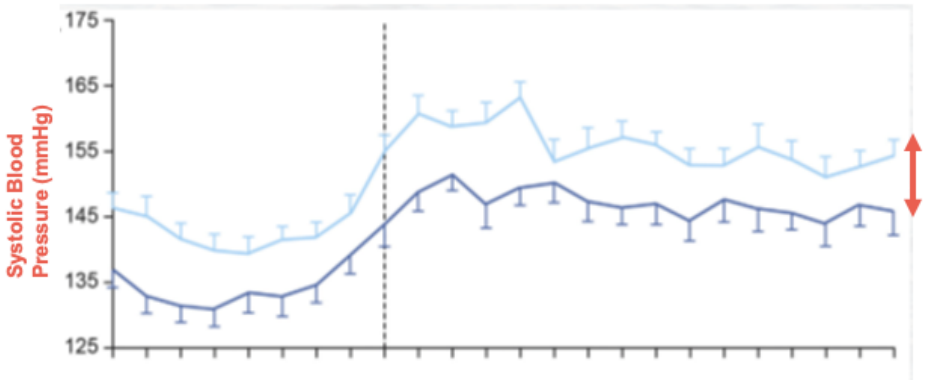


**Figure 2:** Blood pressure reduction effect by ultrasound stimulation

Therefore, among the approaches shown in **Figure 1,** the stimulation of carotid baroreceptors is very suitable for our products and ultrasound stimulation on baroreceptors is more optimal to control hypertension and reduce blood pressure for wearable devices.

## Prototype Design

We've conceived the design of a portable, automatic blood pressure regulation system with a non-invasive and wearable ultrasonic patch to regulate blood pressure, which uses a co-mounted ultrasound probe and fast ultrasound imaging technology to measure the real-time carotid blood pressure waveform. Low-power ultrasound focusing pulses are emitted targeting the pressure receptors on the carotid sinus for the purpose of blood pressure regulation. The system consists of three parts: a wearable ultrasound imaging device, a flexible ultrasound array and a wireless transmission device. **Figure 3** indicates our design scheme that we conceive of, where both a wearable ultrasonic patch feature and a wireless transmission device feature are included. **Figure 4 and Figure 5** indicate a similar wearable ultrasonic patch (**Figure 4**: Illustration of component parts; **Figure 5**: Illustration of the patch) from a research group, since due to the time and scope limitation, there hasn't been a real prototype owned by the team.

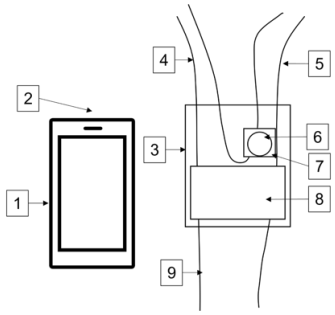


**Figure 3:** Illustration of the design

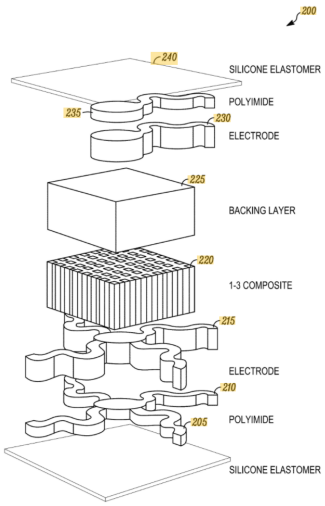


**Figure 4:** Illustration of the component parts

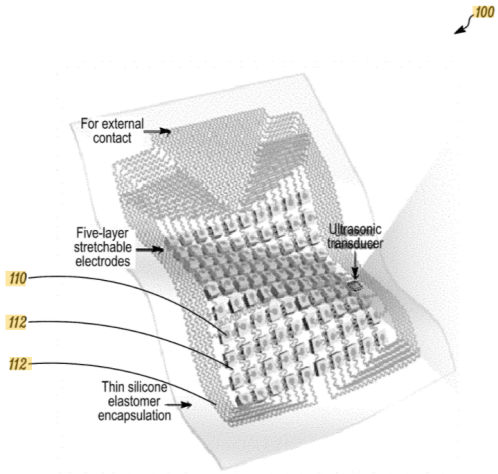


**Figure 5:** Illustration of the patch

We hope the product can have the following features, as specified in **Table 2**.

| Device Features | Description |
|---|---|
| Size | Wearable, portable and non-invasive. |
| Work Scheme | A blood pressure regulation device that uses ultrasound pulses to irradiate baroreceptors on the carotid sinus. |
| Purpose | Reduce blood pressure for hypertension patients. |
| Components | A wearable ultrasound imaging device, a flexible ultrasound array and a wireless transmission device. |
| Usage of flexible ultrasound array | Equip with an ultrasound probe for emitting low-power ultrasound pulse and detecting common carotid artery and waveform for calculating systolic/diastolic pressure. |
| Usage of transmission device | Transfer data from the operation of the flexible ultrasound array and imaging device. |
| Usage of ultrasound imaging device | Obtain B-mode grayscale ultrasound image of common carotid artery. |
| Additional Features | Automatic adjustment of the focus position of the low-power focused ultrasound pulse. |
| | Periodic pulse wave velocity measurement of the common carotid artery. |
| | Continuous carotid artery blood pressure waveform measurement. |
| | Automatic detection of the ultrasound probe movement. |
| | Automatic optimization of the emitted ultrasound pulse (frequency, duty cycle, power etc.). |

**Table 2:** Desired design specifications of *Relaxing Patch*.

## Regulation Issues

According to the FDA database and similar product research in the database, our *Relaxing Patch* product can be classified as a Class I medical device after exploring products in the same category. Thus, to have FDA approval, the team plan to submit a 510(k) for clearance first, then go through a de novo pathway. After the 510(k) is cleared for 'no substantially equivalent' approval, the team will submit documents necessary for the de novo pathway application as we believe the *Relaxing Patch* poses low risk to patients. Additionally, the team plan to apply for patent and register trademarks of company through USPTO (US Patent Trademark Office) so that our intellectual property for Relaxing Patch and related technology can be protected in a legal approach.

## Business Strategy

As a company based on products that are in active research and development process, the team plan to test and sell the product first internally with partners in several affiliated hospitals of the institution, which some collaborative funding between the team and other investigators might exist. The collaborative funding can address the initial high cost of a single product (as reducing the cost would be a long-term goal that needs to be addressed), and it is known by the team that the price of the product would be relatively high given the manufacturing cost and research cost to assembly an effective product. After the product cost can be reduced for the public to afford (which might take years to achieve), the major sales platform would be through hospital collaboration given the therapeutic nature of the product. The EHR system would be utilized, and the data related to patient's demographics, health situation would be gathered through the EHR system for further data analysis use. The product will be patented, and no third-party sales platform or online sales will be initialized. The team will not pursue sales revenue on top of patient safety and technology level, and thus the team also set up exit strategy if the company must exit the market. The hardware and devices will be utilized in the research lab that the team belongs to, and the personnel will be either included into the lab or recommended to the industry based on the individual needs.

As our team is closely related to research lab in an academic institution, the team will intend to recruit students (all levels: Undergraduates, Masters and PhDs) and other experts in related field through recruitment platform. To increase its advertising breadth, the team plan to post the application link on multiple professional social media (Indeed, LinkedIn, Handshake etc.). The team will provide competitive salary to intern students and full-time technicians to attract more experts to the team. As far as current funding allows, the team can recruit up to three full-time technicians, though might also be able to include students who wish to conduct project related to the product.

## Reimbursement Strategy

The team hope to make the ultrasonic patch highly affordable for patients, even for those people without medical insurance. Though, the team still hope to apply for CPT codes or categorize *Relaxing Patch* under one of the current CPT codes. As *Relaxing Patch* is mostly a home-treatment service without much need of physicians, the team hope to categorize the product under 'Home Health Procedures and Services' (99500-99602) or 'Medication Therapy Management Services' (99605-99607). The team also hope to apply for new CPT codes that focus on self-use device and tele-health component, as our *Relaxing Patch* does. With the help of the reimbursement strategy, physicians should be more encouraged to prescribe the device and guide the patients to correctly apply the patch on the carotid artery, whereas patients would be less reluctant to purchase the product due to its low cost and high acceptability from the health insurance company.

## Proposed Budget

**Table 2** provided an overview of the proposed budget that needs to be funded for the first four years. As the product is still in its research phase, the incurred cost will be mostly based in the setting of a research lab. An estimate of three technicians would be needed additionally for the first four years, and each technician will be paid a yearly salary of $60,000. It is estimated that the hardware materials needed for researching and assembling prototypes would cost approximately $50,000 at the first year and decrease in later years. As some of the devices can be used in an existing lab, only additional materials and incurred cost has been included in the table. Another two additional expenses including the ones for business/academic meetings (flight, hotels etc.) and the ones for doing marketing and advertising related to the technology and the product. There has been a overestimate in the numbers for contingency and has already been included in the numbers. In total, the incurred cost for the first four years is around $1,000,000.

| | Year 1 | Year 2 | Year 3 | Year 4 |
|---|---|---|---|---|
| Salary for Technicians | $180,000 | $180,000 | $180,000 | $180,000 |
| Hardware Parts | $50,000 | $30,000 | $20,000 | $20,000 |
| Trips/Meetings Expenses | $20,000 | $20,000 | $20,000 | $20,000 |
| Marketing Expenses | $15,000 | $10,000 | $10,000 | $10,000 |
| Total | $265,000 | $240,000 | $230,000 | $230,000 |

**Table 2:** Overview of the proposed budget for the first four years

**Pitch**

Good afternoon, everyone, my name is Mengyuan Xue and I'm one of the co-CEO of our company X-sun with my partner Yongzhi Sun, and we are a company that makes it easy for people to control blood pressure.

Think about your parents, your grandparents or some of your aged relatives, how many of them have hypertension, and think about how painful it is to have different kinds of medication everyday, not to say some of them even develop drug tolerance during this process; and think about the restrictions on their life and diet. That's why we're developing the relaxing patch, which is a low-weight product that can be stretched easily and applied on the neck without going to the clinic.

Our product is revolutionary as current solutions are all invasive or bulky, current solution can either be an in-body pulse generator or a hand-held device. Also there has been research upon the effectiveness of such ultrasonic patch that we are proposing, as you can see in the figure, the patients who received the treatment will have their blood pressure reduced by about 10 millimeters of mercury. Despite the effectiveness, we expect to have a huge market, as in 2018, half a million deaths were largely contributed by hypertension and nearly 45% of adults in the states are taking medication for controlling hypertension.

We're pitching this product to you as we want to have patients from the hospital to start with the effectiveness trial of the product and, we want to request some funding so that we can smoothly carry on the project. We are convinced that the product would be promising, not only due to the large market, but also due to our team's expertise on this field. My partner and I both had extensive project experience on device instrumentation, wearable device and data analysis and we also hope to recruit fellows having similar expertise to work on the product, and we are sure this product that gather the five features can pay off the money and resources that you invest.

That's all for our pitch and thanks so much for your attention to our pitch!

## Future Work

The future work is hypothesized given all plans and results will be finished in the time span of four years. By that time, the team should have the (at least) first prototype available for human effectiveness trial. We hope to conduct clinical trial and gather data for *Relaxing Patch*'s effectiveness of reducing hypertension and conduct further research given the data and the prototype we have at that time. Hopefully the prototype can go through mass production phase and the team hope to reduce the production cost of the ultrasonic patch so that patients can afford it even without the reimbursement from the insurance company. Still, with a low production cost, the team hope to make the product safe, effective, and convenient for human use. As a company, the team hope to keep it profitable even without the initial-phase funding from third-party agencies. The team wish to fill the gap of hypertension therapy with the advance of such ultrasonic patch and revolutionize the traditional medication approach of controlling hypertension.

## Summary

As more and more people are developing hypertension around the world, with current medication therapeutic approach ineffective and not adaptable for some of the patients. Our Relaxing Patch has a solid technology background and can help patients to reduce and control patients' blood pressure by applying the patch on the carotid artery. It is believed that the current medication therapeutic approach will be gradually replaced by therapeutic approach like the *Relaxing Patch* we have, and we are confident that our promising and special product can completely revolutionize the world.

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US 20216666666A1

# United States
# Patent Application Publication

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SUN et al.

Pub. Date: Nov. 25, 2021

## PORTABLE, AUTOMATIC BLOOD PRESSURE REGULATION SYSTEM BASED ON ULTRASOUND STIMULATION OF CAROTID PRESSURE RECEPTORS

Inventors: **Yongzhi SUN**, Baltimore, MD (US), **Mengyuan XUE,** Baltimore, MD (US)

Appl. No: **21/666,666**

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**Int. CI.**
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***A61B 8/08***
***H01L 41/18***

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**ABSTRACT**

A portable, automatic blood pressure regulation system with a non-invasive and wearable ultrasonic patch was invented to regulate blood pressure, which uses a co-mounted ultrasound probe and fast ultrasound imaging technology to measure the real-time carotid blood pressure waveform. Low-power ultrasound focusing pulses are emitted targeting the pressure receptors on the carotid sinus for the purpose of blood pressure regulation. The system consists of three parts: a wearable ultrasound imaging device, a flexible ultrasound array and a wireless transmission device.

**10 Claims, 2 drawings**

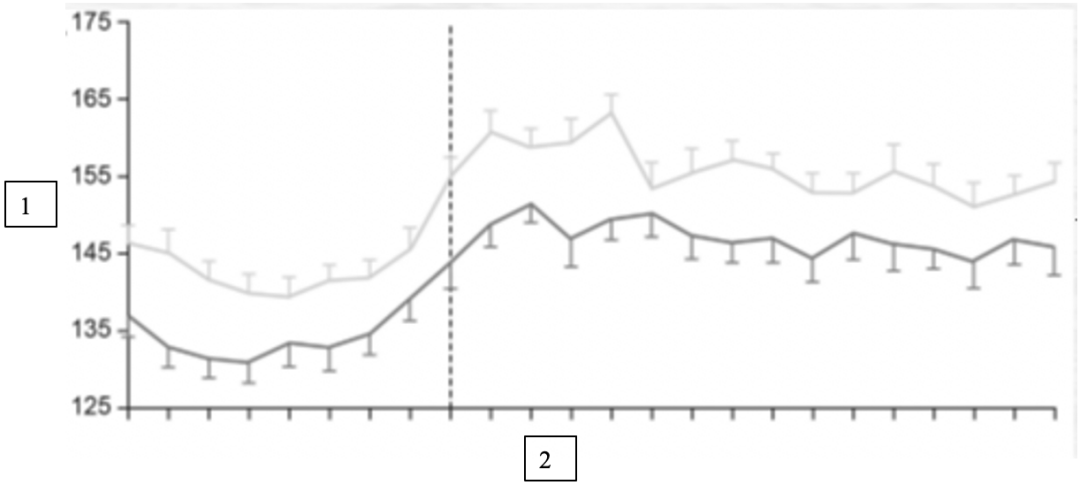


**FIGURE 1**

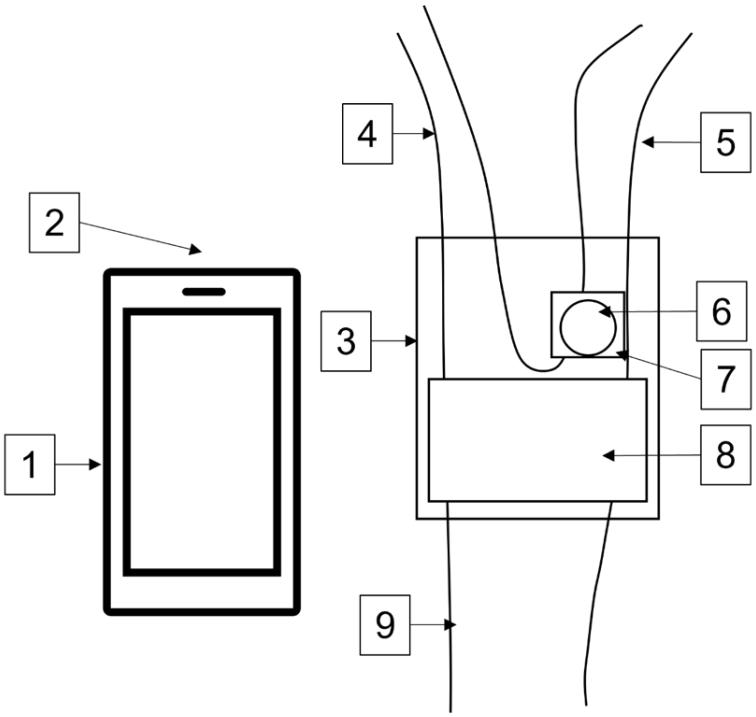


**FIGURE 2**

## FIELD OF THE INVENTION

The invention is a non-invasive, portable, and intelligent blood pressure regulation system that performs rapid ultrasound imaging of the carotid artery, detects the carotid blood pressure waveform, and emits appropriate low-power ultrasound focusing pulses on the pressure receptors of the carotid sinus for the purpose of blood pressure regulation. It is a personalized home-based blood pressure control system, and it is an interdisciplinary invention in the field of biomedical and electrical engineering.

## SUMMARY OF THE INVENTION

The device is a non-invasive, wearable blood pressure regulation device that uses ultrasound pulses to irradiate baroreceptors on the carotid sinus for the purpose of lowering blood pressure.

The device uses a wearable imaging device to deploy the flexible ultrasound array for transmitting and receiving ultrasound signals. The device uses an ultrasound array near the carotid artery to control blood pressure by emitting low power focused ultrasound and stimulate pressure receptor

The device attaches a portable probe on the ultrasound array near the common carotid artery for imaging and calculate the blood pressure.

The device uses a wireless transmission device to transmit data obtained from human body.

The device automatically recognizes pressure receptors near the carotid sinus, emits optimized low-power focused ultrasound pulse and measures the pulse wave velocity for calculating blood pressure.

The device automatically emits ultrasound to prevent patients' hypertension based on the regular calculation of blood pressure.

## BACKGROUND OF THE INVENTION

With the advanced knowledge of pressure reflex and soft electronics, it is now possible to cure hypertension by baroreceptor activating therapy, which is similar to cardiac pacing technology that consists of an electrical stimulation system and pacing electrodes implanted near the clavicle. However, carotid sinus electrical stimulation is an invasive operation with many adverse effects, such as postoperative infection, electrode displacement and stroke etc., limiting the application of this technique. In addition, the high cost of the equipment is also an important reason that hinders the prevalent application of the technology.

Compared with electrical pulses, ultrasound, as a mechanical wave, is more easily received and sensed by pressure receptors than electrical stimulation as the receptors are mechanical sensors that sense the physical changes of the blood vessel wall. According to a published research, ultrasonic stimulation can effectively reduce the blood pressure of hypertension patients, as shown in Figure 1.

Though ultrasonic stimulation has been proved to be effective in reducing hypertension, the devices have been bulky and impossible for attachment on human body and portable out of the clinics. Recent advances in soft electronics and flexible patch-type device enable such ultrasonic patch to be attachable to human body and emits non-invasive ultrasonic stimulation that subsequently makes long-term ultrasonic therapy possible.

Two research groups (Li, Cui et al and Yen, Chen et al) subsequently attempted to use ultrasound stimulation to reduce blood pressure, but both of them only obtained the data from animal experiments, not to say the ultrasound stimulation device is bulky and the effectiveness is limited.

Therefore, with technology advances, it provides solid foundation and present great needs upon our development of an effective and portable ultrasonic patch that emits focused ultrasound stimulation for reducing blood pressure, which is a convenient and non-invasive portable device that can be attached to human body.

## BRIEF DESCRIPTION OF THE FIGURES

Figure 1 Plot of ultrasound irradiated pressure receptor time vs. blood pressure: 1 - systolic blood pressure (mmHg) 2 – time (s)

Figure 2 Portable automatic blood pressure regulation system based on ultrasound stimulation of carotid pressure receptors: 1 - ultrasound imaging and control host (cell phone); 2-Signal transmission and host interface; 3-integrated patch; 4-internal carotid artery; 5-external carotid artery; 6-carotid sinus (pressure receptor); 7-pressure receptor flexible probe array; 8-common carotid artery flexible probe array; 9-common carotid artery

## DESCRIPTION OF THE INVENTION

We have invented a non-invasive, wearable and automatic blood pressure regulation technology that uses ultrasound pulses instead of electrical pulses in BAT to irradiate pressure receptors on the carotid sinus for the purpose of lowering blood pressure. The illustration of the blood pressure regulation system is shown in Figure 2.

The device is a wearable ultrasound imaging device, with a sufficient number of physical channels to support multi-channel ultrasound data transmission, echo signal reception, signal analysis and processing, and image reconstruction.

The device has a large array of patch-type flexible ultrasound probes covering the pressure receptors, one part of the probes is for detecting pulses from the common carotid artery and calculating continuous waveform and systolic/diastolic pressure, and the other part is to locate the pressure receptors based on the ultrasound imaging results of the common carotid artery.

The device can emit low-power focused ultrasound to stimulate the pressure receptors for reducing blood pressure.

The ultrasound imaging core of the device obtains B-mode grayscale imaging and subsequently enables the probe to be placed on pressure receptors and common carotid arteries near the carotid sinus.

The device has a low power focused ultrasound pulse emission function, which emits low power focused ultrasound irradiating pressure receptors.

The device has an automatic adjustment function of the focus position of the low-power focused ultrasound pulse.

The device has an automatic optimization function of the emitted low-power focused ultrasound wave, which automatically optimizes the focal position, frequency, power, duty cycle according to the real-time measured blood pressure.

The device has a pulse wave velocity measurement function of the common carotid artery, which measures the pulse wave velocity periodically (e.g., once every minute).

The device has a continuous waveform measurement function of carotid artery blood pressure, periodically measuring the waveform of the blood pressure of the common carotid artery during one cardiac cycle.

The device has an automatic detection function of the position movement of the ultrasound probe, which detects the position of the probe periodically (e.g., once every 10 minutes).

The device has a multi-layered structure to achieve flexibility and wearability of rigid devices. The entire device is wrapped in silicone

resin elastomer, and each ultrasound unit is connected by a stretchable circuit, which has a spring-like shape through a rational mechanical design.

## DESCRIPTION OF THE PREFERRED EMBODIMENT

1. *Portable ultrasound probe array for B-mode imaging sweep.*
   The flexible patch should be attached near the patient's carotid sinus and the probe to be attached to the common carotid artery. Pressure receptors should be located directly below the center of the flexible patch ultrasound probe array to facilitate energy focusing. Previously tested AI-based model automatically identifies the location of the pressure receptor to help the probe locate accurately on the carotid artery.
2. The ultrasound is focused on the pressure receptor, and the probe emits a low-power focused ultrasound pulse to irradiate the pressure receptor.
3. During the non-imaging mode of the probe, the pulse wave velocity of the carotid artery is measured periodically (e.g., once per minute) and stored. The velocity data is used to calculate the change in the internal diameter D of the carotid artery, which subsequently is used to calculate the changing waveform of the carotid artery pressure within one cardiac cycle.
4. If the patch-type probe occurs a serious (greater than a set value) position shift, an audible alarm is issued to indicate the need to reposition the patch ultrasound probe.
5. *Local vascular PWV measurement technique*
   To measure continuous blood pressure waveform, the ultrasound imaging device must have a high imaging frame rate (typically requiring an imaging frame rate of thousands of Hz) to provide a high enough temporal resolution to image the transverse vibration of the vessel wall caused by the wave propagation along the longitudinal axis of the vessel. Since it is a wearable ultrasound device, computational power is relatively limited, so the priority is given to reducing the density of swept A-lines to increase the frame rate of imaging.
6. *Ultrasound-based blood pressure measurement techniques*
   The main function of the blood pressure measurement module is to achieve continuous measurement of the carotid blood pressure beat waveform based on a portable ultrasound device and a patch-type ultrasound probe, and we use the superficial carotid artery as a target for blood pressure regulation.
7. *Optimization and adjustment of the parameters of the low-power ultrasound pulse*
   Based on the real-time carotid blood pressure parameters (systolic/diastolic blood pressure), the predicted parameters will be adjusted according to the pre-trained computational model. Some of the parameters that are automatically adjusted include power, duty cycle, and irradiation frequency etc.
8. There are many ways to transmit the signal, either wireless or wired transmission, the actual application can be adjusted according to the needs of the scene, wireless transmission to Bluetooth transmission is preferred.

## CLAIMS

1. A portable blood pressure regulation system based on wearable patch with ultrasonic stimulation of carotid pressure receptors, for non-invasive, automatically regulate blood pressure regulation. The system uses a co-mounted ultrasound probe as well as fast

ultrasound imaging technology to measure real-time carotid blood pressure.

2. Claim 1 of the system consists of three parts: a wearable ultrasound imaging device for controlling the flexible ultrasound array; a flexible ultrasound array; and a wireless transmission device connecting the main unit to the ultrasound probe.
3. Claim 2 of the system, is a large array of patch-type flexible ultrasound probes covering the pressure receptors, containing one part for detecting pulses from the common carotid artery and calculating continuous waveform and systolic/diastolic pressure, and the other part for locating the pressure receptors based on the ultrasound imaging results of the common carotid artery.
4. Claim 3 of the system, ultrasound imaging device and flexible electrodes, has the following main functions: ultrasound imaging, automatic identification of pressure receptors near the carotid sinus, low-power focused ultrasound pulse emission, automatic optimization of the emitted ultrasound pulse, common carotid artery pulse wave velocity measurement.
5. Claim 4 of the system, the ultrasound imaging function, deploys primarily B-mode grayscale imaging.
6. Claim 4 of the system, the automatic identification of pressure receptors near the carotid sinus, directs the flexible patch ultrasound probe array to be placed on the pressure receptor near the carotid sinus .
7. Claim 4 of the system, a low power focused ultrasound pulse emission function, emits low power focused ultrasound irradiating the pressure receptors.
8. Claim 4 of the system, the automatic optimization function of the low power focused ultrasound pulse emission, automatically optimizes the focal position, frequency, power, duty cycle, of the emission pulse based on the real-time carotid blood pressure measurements.
9. Claim 4 of the system, PWV (pulse wave velocity) measurement for the blood pressure of common carotid artery, is measured periodically (e.g. every minute).
10. Claim 4 of the system, the continuous waveform measurement function of carotid blood pressure, periodically measures the waveform of the systolic/diastolic blood pressure of the common carotid artery (e.g. once per minute).