Original Article

Fabrication of a low-cost strap for holding precordial electrodes on the hirsute chest

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Abstract

Background: Reusable suction-cup electrodes are used for recording a 12-lead electrocardiogram (ECG) in resource-limited settings. These electrodes may easily detach if those are attached on a hirsute chest. Additionally, the suction pressure may cause erythema and pain. **Aim:** The aim of this study was to develop a low-cost strap for holding the suction-cup-based precordial electrodes and to test its applicability to the recording of ECG. **Materials and Methods:** A scrap rubber tube was cut in size so that it can cover all the precordial electrode positions. Slit openings (electrodes can be inserted through these opening) were made on this rubber strap. A cloth and a hook-and-loop fastener were used to make an adjustable fastener. ECG was recorded first on 16 non-hairy males with electrodes placed on the chest with the strap and then with electrodes attached by suction. After that, ECG was recorded on 16 males with hirsute chest first with the electrodes placed with the help of the strap and then with suction (without strap) on the shaved chest. **Results:** The outcome of this study is a low-cost ECG chest strap for a hirsute chest. Both the negative and positive QRS voltages in six precordial leads recorded with electrodes placed with the strap were similar to that of suction-attached electrodes in both non-hairy and hirsute chest. **Conclusion:** Developed rubber chest strap can be made with minimal cost and expertise in any resource-limited settings. This would help in recording the ECG of a patient with a hirsute chest. This prototype strap has scope for further improvement.

Keywords: Chest lead, ECG strap, EKG, electrocardiography, electrodes, erythema, innovation

Introduction

For a standard 12-lead electrocardiogram (ECG), four electrodes are attached to four limbs and precordial electrodes are attached to the chest.[1] There are mainly three types of surface electrodes which are used for precordial leads—suction-cup, metal wet electrodes, and dry electrodes.[2,3] Further, the electrodes may be either reusable or disposable. The usage of disposable electrodes may help reducing infection rates sourced from the electrodes.[4] However, in resource-poor settings, the adoption of disposable electrodes may not be feasible. For those settings, reusable electrodes are economical and effective for recording the ECG.

Reusable suction-cup-based electrodes have a metallic cup that is attached with a rubber bulb which can create a vacuum when the cup is attached against the skin surface. However, the vacuum may cause erythema on the skin. Figures 1a and b show the skin of two persons with erythema caused after 1 min of attachment of the suction-cup electrodes. This erythema even needs 2–3 days

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for the disappearance. Along with the erythema, mild pain or stinging sensation is also felt by the patients. A major problem of this suction-cup is an attachment on any hirsute chest. As there is hair on the skin-metal interface, maintenance of suction is inadequate and the electrodes frequently get detached from its position, even in midst of a recording. In our setting, we frequently face this challenge while recording ECG of a subject with a hirsute chest. And if the electrodes get detached during the acquisition of voltages, this causes loss of ECG paper, time, and effort of both the operator and the patient. To overcome this difficulty, shaving the chest hairs is the current preferred solution.[5] However, this also requires additional time and manpower. Hence, we were searching for a chest strap that can be used to hold the electrodes on the chest.

There are chest straps available for continuous electrocardiography during a span of time, especially in exercise. These straps are loaded with electrodes and a final connecting wire gives the output connection to electrocardiograph or the signal is sent to other devices via wireless technology like Bluetooth or Wi-Fi.[6] These straps are costly and cannot be used for electrocardiography with ordinary suction-cup electrodes. A low-cost chest strap has been developed by Yadav *et al*. which can hold the electrodes on the chest.[7] This may be potentially used for the hirsute chest. However, the device has not been tested for the same. Furthermore, the electrodes are attached to the strap and there is no provision for using regular suction-cup-based electrodes.

With this background, the aim of this study was to develop a low-cost chest strap for resource-limited settings which can firmly keep the precordial electrodes on the chest without the need for any suction. This device would have the potential to solve three current problems faced with suction-based electrodes—the problem of attachment on hirsute skin, erythema, and pain. We also aimed to check the feasibility of the usage of the strap in electrocardiography.

Materials and Methods

Ethical statement

This study was divided into two parts—the development of the chest strap and piloting its validity in the measurement of ECG. The device was conceived and developed by the first and third authors. Adult male research participants (age >18 years) with and without hirsute chests were recruited after taking written consent. The study protocol was approved by the Institutional Ethics Committee (No. 19/IEC, Dated 7th November 2019). Furthermore, we declare that all the procedure of this study was done with full compliance with the Declaration of the Helsinki.

Materials used

Household materials were used to develop the device. A punctured scrap tube of a scooter was the major component. A piece of cloth was taken from a scrap bed sheet. An unused hook-and-loop was used for making a fastener. Readily available needle, thread, and shaving blade were the instruments.

For the recording of ECG, an automatic ECG machine (BPL Cardiart 9108, BPL Medical Technologies Private Limited, Kerala, India) was used.

Fabrication of the strap

First, the chest of the first author was measured for the length between the right 4th intercostal space near the sternum and left mid-axillary line at the level of 5th intercostal space. Then the breath was measured from the upper border of the 4th intercostal space to the lower border of the 5th intercostal space. The length was 26 cm and breadth was 5 cm. A piece of rubber tube was cut with a minimum of 2 cm excess in all directions in comparison to the measurement [Figure 2a]. The positions of the chest electrodes were marked and the corresponding point on the rubber sheet was marked. Vertical slit openings were made on the point of the lead positions [Figure 2b]. A piece of cloth (which can encircle the body to reach the right edge of the strap) was stitched on the left edge of the strap [Figure 2c]. The right edge of the cloth was attached with the hook part of the hook-and-loop fastener. The loop part of the fastener was stitched on the right side of the strap [Figure 2d].

Recording of ECG

First, we checked if electrodes placed with the help of the strap can give us the same voltage in the QRS complex as that of a common recording on a subject with a hairless chest. To check this, we recorded 12-lead ECG (0.67–100 Hz AC50, paper speed 25 mm/s, 10 mm/mV) on 16 male research participants with a hairless chest with precordial electrodes placed (without suction) on the chest with help of the newly developed strap. Then, we recorded 12-leads ECG on the same sample with the electrodes attached (with suction) on the chest.

Then, we checked if leads placed on the chest with help of the strap can record the same voltage in the QRS complex as that of recording with a shaved chest. To check this, we recorded 12-leads ECG (0.67–100 Hz AC50, paper speed 25 mm/s, 10 mm/mV) on 16 research participants with a hairy chest with the electrodes placed (without suction) with help of the strap. Then, we shaved the hair of the chest and recorded 12-leads ECG with attached electrodes (with suction) on the chest.

All the ECG was recorded by a single operator. The time for obtaining ECG was recorded in a stopwatch. For all the cases, subjects' data entry on the device, undressing of the upper part of the body, and proper positioning of the subjects on the couch were excluded. The stopwatch was started from the application of cardiac jelly to get the printed ECG report. For the subjects with hirsute chest, the time for recording ECG includes the time for a quick shaving of the area of the chest required for attachment of the electrodes.

Statistical analysis

From a 12-lead ECG, the highest positive and negative voltage of each chest leads (V1–V6) was considered final and it was stored for analysis. Data of 16 research participants were expressed in mean and standard deviation. We tested the data with paired *t*-test and Pearson's correlation coefficient. A $P < 0.05$ was considered statistically significant. The statistical analysis was carried out in GraphPad Prism 6.01 (GraphPad Software, CA, USA).

Results

The developed strap placed on a chest with the electrodes is shown in Figure 3a and the position of the suction cup is shown in Figure 3b.

The QRS voltages from the ECG of hairless research participants are shown in Table 1. There was no statistically significant difference in voltages in the QRS complex in recording with suction and without suction (placed with help of the strap). There was a significant positive correlation of voltages in two measurements. The required time for recording ECG with strap and without strap was 87.25 ± 9.43 s and 94.13 ± 12.56 s (*t*-test $P = 0.09$), respectively.

The QRS voltages from the ECG of hirsute research participants are shown in Table 2. There was no statistically significant difference in voltages in the QRS complex in recording without suction (placed with the help of strap) and without suction on the shaved chest. In this case, also, we found a significant positive correlation of voltages in two measurements. The required time for recording ECG with strap and without a strap (including time for shaving required area for attachment of electrodes) was 89.88 ± 10.22 s and 194.31 ± 47.15 s (*t*-test $P < 0.0001$), respectively.

Discussion

What we already have?

Different types of ECG straps are available in the market. The majority of them are for keeping the electrodes in place during an exercise tolerance test.[6] The cost of the devices is the first hindrance to the usage of such straps in electrocardiography in resource-limited settings. Additionally, these are specially designed straps for particular proprietary devices. Some of the straps hold the precordial electrodes; however, those are compatible with only disposable electrodes (e.g. V-Quick patch).[8] And, these straps are designed for a hairless or shaved chest.

What this study adds?

This study adds an ultra-low-cost ECG strap in the literature of electrocardiography. This strap may help during any emergency situation where a shaving facility is not available but recording ECG is necessary. In outdoor patient departments where a huge number of patients are catered by a single electrocardiograph, the operator may use this device and record ECG with patients with a hairy chest. Shaving the chest hair in many outdoor settings may be embarrassing for a male patient. A little erythema on the skin at the contact point with the electrode helps in the

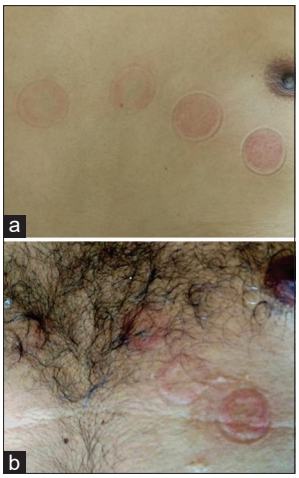

Figure 1: Erythema on the chest after attachment of suction-cup based-precordial electrodes for 1 min

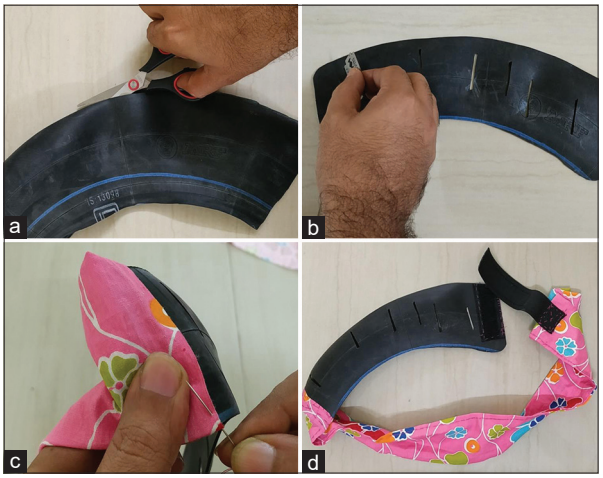

Figure 2: Development of chest strap (a) cutting a portion of rubber sheet from a motorcycle tube (b) making a slit opening (c) stitching cloth (d) the final chest strap

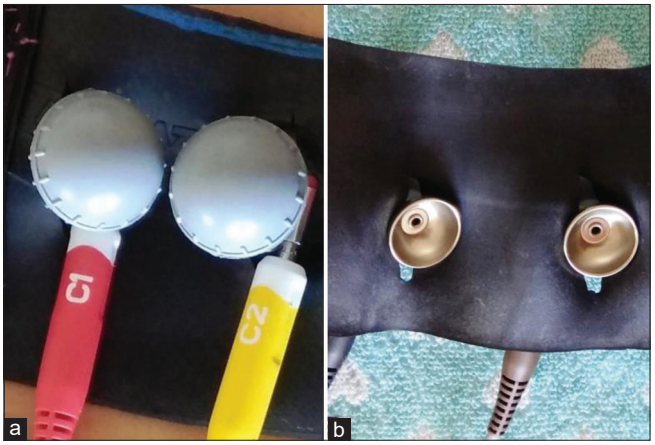

Figure 3: Precordial electrodes fitted with the chest strap—(a) placed on the chest (b) suction cups seen from the opposite side

Table 1: QRS voltage of ECG on subjects with hairless chest

Precordial leads	Direction from isoelectric line	Electrodes placed with strap	Electrodes attached with suction	*t*-test *P*	*r*
V1	Positive	2.81±1.22	2.81±1.24	>0.99	0.97
	Negative	9±2.94	9.13±2.64	0.48	0.97
V2	Positive	4.23±1.69	4.28±2.29	0.79	0.92
	Negative	11.59±3.67	11.41±3.16	0.57	0.93
V3	Positive	7.53±2.72	7.72±2.61	0.35	0.95
	Negative	9.38±2.82	9.31±2.94	0.54	0.99
V4	Positive	11.97±3.89	12±3.76	0.82	0.98
	Negative	4.97±2.19	4.94±2.18	0.84	0.95
V5	Positive	12.13±4.42	11.91±4.16	0.32	0.98
	Negative	1.66±0.79	1.69±1.01	0.77	0.91
V6	Positive	9.66±3.27	9.75±3.02	0.66	0.96
	Negative	0.91±0.66	0.89±0.85	0.71	0.92

V1-V6: Standard chest lead 1-6, *r*=Pearson's correlation coefficient (all *P*-value of Pearson's correlation was <0.001)

Table 2: QRS voltage of ECG on subjects with hirsute chest

Precordial leads	Direction from isoelectric line	Electrodes placed with strap	Electrodes attached with suction	*t*-test *P*	*r*
V1	Positive	4.13±2	4.19±1.82	0.72	0.93
	Negative	9.19±2.41	9.38±2.09	0.34	0.94
V2	Positive	5.19±2.12	5.03±2.05	0.2	0.97
	Negative	13.38±4.26	13.59±3.74	0.47	0.96
V3	Positive	6.63±2.76	6.44±2.42	0.43	0.94
	Negative	10.38±2.99	11.03±2.93	0.01*	0.94
V4	Positive	11.69±4.21	11.63±3.73	0.86	0.94
	Negative	4.16±2.23	3.78±2.04	0.08	0.93
V5	Positive	11.13±4.58	11.22±4.11	0.71	0.97
	Negative	1.53±0.92	1.59±1.02	0.68	0.81
V6	Positive	8.88±3.51	9.09±3.64	0.35	0.96
	Negative	0.91±0.66	0.84±0.7	0.54	0.82

V1-V6: Standard chest lead 1-6, *r*=Pearson's correlation coefficient (all *P*-value of Pearson's correlation was <0.001), *Statistically significant *P*

optimum transmission of the electrical signals from the skin to electrodes. However, erythema caused by a suction-cup vacuum is an unnecessary side effect. In addition to the erythema, many patients feel uncomfortable (e.g. stinging or pain) with the vacuum attached electrodes. Hence, the newly developed strap can be a potential solution for hirsute skin, for reducing erythema, and for avoiding patients' discomfort.

Cost and expertise required

Anyone with minimum expertise and minimum instruments can develop straps based on this prototype. We did not invest any money for the device. However, those who need to procure the raw materials can make the device by spending only ₹50–60 (equivalent to $0.71–0.85) for a scrap tube, hook-and-loop fastener, and a piece of cloth.

Disinfection of the strap: A limitation

On one hand, this reusable strap can be used for a huge number of patients with a hairy chest. Hence, the cost per patient is virtually zero. In another hand, using the same strap for a number of patients can potentially transmit pathogenic organisms and skin commensals. However, this is a common limitation of using reusable electrodes for ECG.[9] Hence, proper disinfection after each use is recommended. However, the presence of cloth limits the disinfection process in the current device.

Validity of the strap

The strap was successfully used to record ECG on both non-hairy and hirsute chest. The QRS voltages were similar to the placed electrodes and suction-attached electrodes on hairless chests [Table 1]. Hence, we can avoid unnecessary suction pressure on the skin with this strap while recording ECG on patients with the hairless chests. This would reduce the erythema and stinging sensation.

There was no voltage difference in the QRS complex when ECG recorded on subjects with the hirsute chest (placed electrodes with the help of the strap) and shaved chest [Table 2]. Hence, usage of the straps can help us to avoid shaving chest hair for accurate measurement of ECG, especially the voltages of chest leads.

This strap may serve as an added accessory for electrocardiography for patients with the both hairless and hirsute chest.

Application in primary health care

Electrocardiography in a primary health care setting is an effective tool which reduces the number of referral to specialist doctors.[10,11] Hence, in primary health care, similar straps can be made to overcome the difficulty of recording ECG on the hirsute

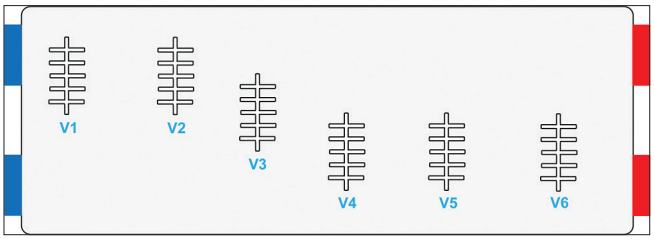

Figure 4: A sketch of a transparent chest strap with vertical and horizontal navigation option for precordial suction-cup based electrodes (red and blue indicate fastener attachment point on the left and right edge, respectively)

chest and to avoid erythema on the site of electrode attachment. Precautionary, this strap can be used in known dermatographism patients to limit the exacerbation of symptoms due to application of suction-cup electrodes.[12]

Future directives

This is a report of only the prototype. In the future, the device would be made more operator-friendly. Following are the future plan:

1. Usage of transparent rubber. This would eliminate the current problem of confirmation of proper placement of the electrodes.
2. Enhancement of the design of the navigation slit. It would be designed as shown in Figure 4. This will allow both horizontal and vertical maneuvers. Hence, the strap can be used for a wide range of chest circumference as there is the provision of horizontal movement of the electrodes. Further, there is also provision for vertical movement of the electrodes which enables the device for a wide range of chest height.
3. Usage of rubber instead of cloth for ease of disinfection and sterilization.
4. Addition of fastener number. Currently, one fastener is used. In the improved version, two fasteners with a gap would be used which would help in the better attachment.

Declaration

The design of the devices (both the version described in Figures 2 and 4) is open-source and can be used by any interested person for the development of similar straps.

Conclusion

A simple and low-cost chest strap helps in reducing the necessity of shaving chest hair for recording ECG on a hirsute chest. It also helps in reducing erythema and irritation caused by the vacuum of the suction-cup-based electrodes for both hirsute and hairless chest. A similar chest strap can be made in any resource-limited settings based on this prototype. Further modification and experiments would enrich the chest strap.

Declaration of patient consent

The authors certify that they have obtained all appropriate patient consent forms. In the form, the patient (s) has/have given his/her/their consent for his/her/their images and other clinical information to be reported in the journal. The patients understand that their names and initials will not be published and due efforts will be made to conceal their identity, but anonymity cannot be guaranteed.

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Nil.

Conflicts of interest

The first author of this article has a hairy chest and faced stinging sensation and detachment of electrodes during the recording of ECG and erythema on the skin after the recording.

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