COMPARING DRY ELECTRODE MATERIALS FOR LONG-TERM ECG MONITORING

Evaluation of a New Method

Silvester Fuhrhop, Stefan Lamparth, Tobias Seemann, Wilhelm Stork
KIT - Institute for Information Processing Technology, Karlsruhe, Germany

Stephan Heuer, Malte Kirst
FZI Research Center for Information Technology, Haid-und-Neu-Str. 10-14, 76131 Karlsruhe, Germany

Keywords: Dry electrode materials, Signal quality, ECG, Comparison, Long-Term-ECG

Abstract: Studies prove, that ECG monitoring over longer periods of time can significantly improve the diagnosis of heart failure. Dry electrodes are a valuable alternative to conventional wet electrodes, if the monitoring period is longer than one week, because they are more stable and cause less skin irritations. One drawback however is the minor signal quality compared to wet electrodes. As there are different electrode materials for dry electrodes available, a qualitative comparison concerning signal quality is carried out in this work. The signal quality of well known dry-electrode-materials used in fitness-heart belts are compared with metal dry electrodes. All electrodes are assembled in an identical mechanical electrode-setup. A parcours-based field trial with 13 subjects is carried out in two stages. In order to estimate the reproducibility of the parcours, the first stage is used to benchmark the differences in signal quality of consecutive measurements not originating from the electrode material. In the second stage however, the actual measurement takes place. The accuracy of the method is presented and the comparison results are discussed.

1 INTRODUCTION

Longterm ECG monitoring provides a promising approach to face the rising numbers of heart diseases. Established Holter recorders equipped with adhesive wet electrodes feature good signal quality, but show bad wearing comfort and bad usability when looked at from the daily regular use perspective. Recording approaches with textile integrated dry electrodes indeed prevail over these drawbacks (Fuhrhop et al., 2009) (Yoo et al., 2009) (M. Di Rienzo, 2005). Although Gruetzmann et al. state that dry electrodes are more resistant to movement artifacts than adhesive electrodes compared by short-term analysis (A. Grützmann and Müller, 2007) it is shown in (Fuhrhop et al., 2009), that there is a big difference between laboratory measurements and real world measurements where Ag/AgCl electrodes still outperform the dry electrodes in a real 24/7 life scenario. It is for this reason that dry electrode ECG system have failed to establish themselves as alternative for Holter systems with conventional Ag/AgCl electrodes in the medical environment. Multiple sources e. g. (Connolly and Buckley, 2004) (David Ruhlemann and Frosch, 2010) document that conventional Ag/AgCl electrode gels also cause contact dermatitis in multiple cases. As to the knowledge of the authors there are no systems with capacitively coupled electrodes available that can cope with dry electrode systems concerning robustness against movement artifacts. In terms of artifact robustness and long-term usability dry electrodes are the most promising acquisition approach for good signal coverage in long-term ECG monitoring to date.

2 RELATED WORK

The investigations on dry electrodes for ECG monitoring are numerous. (PJ. Xu, 2008) gives a solid overview over this field. Most groups that use dry electrodes have benchmarked their system against a Holter recorder (M. Di Rienzo, 2005) (G. Gargiulo, 2010). This approach is feasible, to compare complete dry electrode systems with each other. However,

Fuhrhop S., Lamparth S., Seemann T., Stork W., Heuer S. and Kirst M..
COMPARING DRY ELECTRODE MATERIALS FOR LONG-TERM ECG MONITORING - Evaluation of a New Method.
DOI: 10.5220/0003165104850488
In *Proceedings of the International Conference on Bio-inspired Systems and Signal Processing* (BIOSIGNALS-2011), pages 485-488
ISBN: 978-989-8425-35-5

a direct conclusion about the influence of the used dry-electrode material on the signal quality cannot be drawn, because the mechanical setup of the electrode mounting differs. Lacking the adhesive fixation to the body, the fixture of dry electrodes has great influence on the signal quality. There are multiple methods to compare dry electroconductive electrodes for ECG measurements: Subjective comparison of different electrode types with a reference electrode (Ag/AgCl), the skin-electrode impedance (Hoffmann and Ruff, 2007) (Baek JY, 2008), detectability of ECG waves (Pola and Vanhala, 2007) (Fuhrhop et al., 2009), power spectral density (Scilingo et al., 2005) (Puurtinen et al., 2006). As dry electrode systems have their advantages in long-term applicability, it is very likely that the signal analysis of the recorded data is performed automatically by ECG-waves detection algorithms. That is why the comparison of different electrode materials concerning their signal quality will be accomplished by automated ECG waves detection in this work.

The quality of an ECG signal decreases with rising activity of the subject, because the relative movement between body and electrode induce potentials at the electrode-skin interface that add to the body surface potentials of the heart and reside in the same frequency band. Hence electrodes for long-term applicability need to be robust against potentials at the skin-electrode interface that are induced by movement. For the in vivo comparison of ECG-electrodes it has to be taken into account, that ECG morphology is dependent on the electrode position on the body. Position changes of the electrode can heavily influence the signal morphology. By performing a simultaneous measurement with two electrode-types attached to the subject, the evaluation measurement is not comparable due to the changes in morphology caused by slight differences in electrode position. Therefore the measurements have to be performed consecutively and special care has to be taken, that the measurement is conducted in an identical way.

3 MATERIALS AND METHOD

3.1 Tested Electrode Materials

The five materials compared in this test are presented in the list below. Two dry electrode materials, that are widely used in fitness chest belts and three metal based materials are evaluated:

- Conductive Rubber (www.wacker.com)
- Silver coated Jersey-Textile
- Stainless-steel (14301 alloy)
- Silver (925 sterling silver)
- Stainless-Steel mesh (www.beissermetall.de)

3.2 Measurement Setup

The electrode material is integrated into a rigid carrier that is fixed to the body by a belt. The deployed electrode design ensures that the fixture of each electrode-material-setup is identical hence a relative comparison between the selected electrode materials is possible.

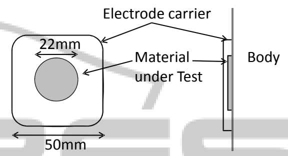

Figure 1: Electrode design.

Two electrodes like the one depicted in figure 1 are mounted in a stretchable belt. The length of the belt is adjusted for each subject individually. A differential measurement setup similar to Einthoven lead I is acquired. Figure 2 shows the configuration of the leads on the left and a subject of the trial with the attached unit (right).

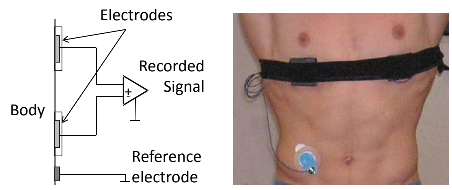

Figure 2: Electrode configuration.

3.3 Field Trial Setup

In order to acquire comparable subsequent measurements a parcours-based field trial with well defined stages was designed. To identify the robustness against movement artifacts, several activities where included in the trial stages. The selected actions occur in the daily routine and induce heavy movements of the thorax and the upper extremities. The list below shows the duration of each activity:

- Sitting in a chair (120s)
- Stirring rice in a jar (60s, 20s break)
- Taking a jar out of a shelf, put it on the floor and back up on a shelf (60s, 20s break)
- Cleaning teeth (60s, 20s break)

- Walking stairs (60 s, 20s break)
- Using a wheelchair (60s, 20s break)
- Walking with cruchtes (60 s, 40s break)
- Fast walking at 6 km/h in a treadmill (180s)

The overall duration of the parcours is 13:20 minutes. No detergent or soap was used for skin preparation but before each run the chest area of each subject was cleaned with tap water and dried with a fresh towel before applying the chest belt. The belt was attached with a tension of 3.5N. Before each measurement, the subject rested with the belt attached for 15 minutes in order to let the dry electrodes reach the equilibrium. The duration of each station in the parcoursis controlled by a timer, so that every activity is done with similar duration for every material. Start and end of each activity is signaled acoustically and by a vibration-motor in the belt. The field trial was divided in two stages. Stage 1: The parcours was conducted four times in a row by each subject with stainless steel electrodes. Between every run, the electrode belt was removed and reapplied in the way described above. Stage 2: In the second stage every subject conducted the parcours once for each electrode material. The trial took place in an air conditioned room, the temperature was between 24 and 25°C, humidity was 50 to 54% rel.

3.4 Subject Population

The population of this study is composed of 13 adults, both males and females, with a range of ages from 21 to 26. All of the subjects were healthy and none revealed a past history of any cardiac problems. All subjects were surveyed prior to study inclusion to ensure each met study qualifications.

3.5 Estimation of the Signal Quality by ECG Waves Detection

The applied method, described in (Fuhrhop et al., 2009), uses the detectability of QRS waves. A reference annotation of the ECG signal is created by an expert and a trigger list is computed by a QRS detecting algorithm. This trigger list is compared beat by beat with the reference annotation hence sensitivity (Se) and positive predictive value (pP) of each measurement can be calculated. Those parameters represent the signal quality of the recorded ECG from the QRS detecting algorithms point of view.

3.6 Results

The signal quality of each run was estimated by the beat-by-beat method described above. At first the reproducibility of well defined activities was evaluated: The comparison of successively recorded parcours runs implies that the difference in signal quality between subsequent recordings only originates from the used electrode material. To evaluate if other factors influence the comparability each subject conducted stage 1 (described above). Table 1 shows mean value and standard deviation for Se and pP of 13 subjects. It is clear, that despite of a parcours based trial and a reproducible application of the electrodes, the signal quality of each subject differs between each run significantly. The mean value of the standard deviation for Se is 0.4% and for pP is 1.7%. Hence it is only possible to reliably compare subsequent measurements, if the mean values of the quality indicators for different electrode materials exhibit significant higher differences than the above listed standard deviations.

Table 1: Se and pP of the four subsequent parcours-runs with stainless steel material (stage 1).

Subject	Se [%]		pP [%]	
	mean	std	mean	std
1	98.7	0.4	95.6	0.6
2	98.1	1.6	97.2	1.3
3	99.5	0.5	99.3	0.4
4	99.3	0.3	99.0	0.8
5	99.2	0.2	97.4	1.5
6	99.3	0.5	97.5	0.2
7	99.6	0.1	97.1	2.6
8	99.7	0.1	99.1	0.9
9	99.8	0.1	99.4	0.2
10	99.5	0.5	97.1	3.6
11	99.6	0.5	99.0	1.4
12	98.6	0.5	93.3	2.4
13	99.3	0.7	96.7	6.2
mean	99.3	0.4	97.5	1.7

3.7 Estimation of the ECG Signal Quality for the Electrode Materials

In the succeeding trial stage each subject performed the parcours for each electrode material once. Therefore 13 measurements for each material are available for comparison. Table 2 shows mean values and standard deviation for both pP and Se for all tested materials. Se ranges between 98,91 and 99.29%, pP ranges between 96.94 and 98.25% respectively.

Table 2: Sp an pP for different electrode materials (stage 2).

Material	Se [%]		pP [%]	
	mean	std	mean	std
Silver	99.29	1.2	97.95	1.8
Mesh	98.91	1.4	98.25	1.0
Jersey	99.23	0.6	97.22	2.5
Conductive Rubber	99.06	1.2	96.94	2.6
Stainless Steel	99.27	0.7	97.55	2.8
mean	99.15	1.0	97.57	2.1

4 DISCUSSION

A larger measurement database (both subjects and recording time) could have averaged out outliers, but for the available number of measurements the accuracy of the adopted method ranges at 0.4% for Se and 1.7% for pP. The calculated performance difference of the dry electrode materials of Se and pP reside in the same scale as the accuracy of the method. Due to this fact it is evident that on the given database the applied comparison method is not accurate enough to allow a conclusion, what material is more robust against artifacts.

5 CONCLUSIONS AND OUTLOOK

A comparison between dry electrode-materials used in fitness belts that feature a low prize and easy textile integrability and metal dry electrode-materials has been carried out. The accuracy of the method used for comparison was evaluated. It could be proven that even during a well defined reproducible parcours based study the signal quality of each run significantly differs due to other factors than the electrode material. The fact that the number of subjects was limited and the recording duration was short reduced the accuracy of the applied method. The comparison between the selected materials revealed, that the identified performance differences range in the measuring inaccuracy, hence no conclusion about the influence of the material can be drawn. The method must be adapted in such a way, that either the amount of recorded data is enlarged or the measurements of the different materials are taken simultaneously. In this case the effect of different electrode positions must be taken into account. Because all electrode materials are attached mechanical identically in this evaluation, it is also possible that the electrode mounting of dry electrodes is more relevant for movement artifacts than the electrode material itself. In the ongoing work the presented method will be adapted to allow a more accurate conclusion about the influence of dry electrode material on signal quality and the effects of the mechanical fixture on the signal quality will be analyzed.

REFERENCES

A. Grützmann, S. H. and Müller, J. (2007). Novel dry electrodes for ecg monitoring. *Physiological Measurement*, 28.

Baek JY, An JH, C. J. e. a. (2008). Flexible polymeric dry electrodes for the long-term monitoring of ecg. In *Sensors and Actuators A: Physical*. Elsevier.

Connolly, M. and Buckley, D. A. (2004). *Contact dermatitis from propylene glycol in ECG electrodes, complicated by medicament allergy*, volume 50 of *Contact Dermatitis*. Wiley-Blackwell.

David Ruhlemann, Katrin Kuegler, B. M. and Frosch, P. J. (2010). *Contact dermatitis to self-adhesive ECG electrodes*, volume 62 of *Contact Dermatitis*. Wiley-Blackwell.

Fuhrhop, S., Lamparth, S., and et al, K. (2009). Ambulant ecg recording with wet and dry electrodes. In *World Congress on Medical Physics and Biomedical Engineering*, volume 25/5 of *IFMBE Proceedings*. Springer.

G. Gargiulo, P. Bifulco, M. C. e. a. (2010). An ultra-high input impedance ecg amplifier for long-term monitoring of athletes. In *Medical Devices: Evidence and Research*. Dove Press.

Hoffmann, K.-P. and Ruff, R. (2007). Flexible dry surface-electrodes for ecg long-term monitoring. In *Engineering in Medicine and Biology Society, 2007. EMBS 2007*.

M. Di Rienzo, F. Rizzo, G. P. e. a. (2005). Magic system: a new textile-based wearable device for biological signal monitoring. In *Engineering in Medicine and Biology Society, 2005. IEEE-EMBS 2005*.

PJ. Xu, H. Zhang, X. T. (2008). *Textile-structured electrodes for electrocardiogram*. Textile Progress.

Pola, T. and Vanhala, J. (2007). Textile electrodes in ecg measurement.

Puurtinen, M., Komulainen, S., Kauppinen, P., Malmivuo, J., and Hyttinen, J. (2006). Measurement of noise and impedance of dry and wet textile electrodes, and textile electrodes with hydrogel. In *Engineering in Medicine and Biology Society, 2006. EMBS '06*.

Scilingo, E. P., Gemignani, A., Paradiso, R., Taccini, N., Ghelarducci, B., and De Rossi, D. (2005). Performance evaluation of sensing fabrics for monitoring physiological and biomechanical variables. *Information Technology in Biomedicine, IEEE Transactions on*, 9(3).

Yoo, J., Yan, L., Lee, S., Kim, H., and Yoo, H.-J. (2009). A wearable ecg acquisition system with compact planar-fashionable circuit board-based shirt. *Information Technology in Biomedicine, IEEE Transactions on*, 13(6).