POLYMERIC MICRONEEDLE-BASED 'DRY' ELECTRODES FOR WEARABLE CARDIAC MONITORING

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Background: Microneedles (MNs) are minimally invasive devices consisting of single, or multiple micron-sized needles. Originally conceptualized and patented in the 1970s, MNs were considered a novel approach to transdermal drug delivery. Over the years, MNs have become more versatile and are now utilised in many fields, including physiological signal monitoring. Electrocardiography (ECG) is a clinical procedure used to help diagnose and monitor cardiovascular conditions. Wet electrodes used during ECG contain conductive gels to maintain a low impedance skin-electrode contact. Whilst effective in the short-term, dehydration of these gels can reduce the quality of recorded signals. MN-based 'dry' electrodes appear to be a promising alternative as they negate the need for conductive gels but also offer the potential to improve the signal fidelity of ECGs. We aim to use ECG signal acquisition, as an exemplar, to assess the wearability and performance aspects of MN electrodes for remote cardiac monitoring.

Methods: To assess MN electrodes and define those parameters which influence performance, a suitable ex-vivo skin model was developed. To account for signal loss resulting from the setup, simulated ECG signals were recorded at multiple stages of the model. Following data normalisation, the signal-to-noise ratio (SNR) and Pearson's correlation coefficient were calculated with respect to the original emitted signal. Following MN removal, penetration was assessed using methylene blue staining, optical coherence tomography (OCT) and histology. A subsequent study compared results in our model with in-vivo ECGs. Following ethical approval, both wet and MN electrodes were applied to the torso of healthy volunteers. ECGs were recorded simultaneously from both types of electrode, at the same sampling frequency, in a lead II configuration over three minutes.

Results: Correlation coefficients and SNR values were determined by analysing fifteen different simulated ECG waveforms recorded over three minutes. Overall, as the signal travelled from its source through to individual electrodes, correlation and SNR values declined, whilst the level of powerline interference increased. Interference was found to be present in substantial amounts at 50Hz. Following the application of a digital notch filter, results improved with the initial output signal achieving a near perfect recreation with an average correlation of 99.9% and SNR of 31.7dB. MN electrodes were comparable with wet electrodes producing SNR values of 27.48dB and 27.57dB respectively post filtering. Upon removal of MN electrodes from ex-vivo skin, application of methylene blue dye suggested MN penetration, which was subsequently corroborated with OCT. Visual analysis of the in-vivo ECGs highlighted that wet electrodes were less susceptible to motion artefacts when compared to the 'dry' MN electrodes.

Conclusions: Our ex-vivo model was successful at generating and acquiring simulated ECG signals through ex-vivo skin. This model can now be utilised for data simulations to assess parameters which affect MN electrode performance. Recording ECGs from healthy volunteers not only helped inform the development of the model, but importantly highlighted both the promise and limitations of our current microneedle design. We are now testing an adapted electrode containing a mechanism to improve MN retention in skin.