

Patients' perceptions of, and acceptance toward, using wearable sensor technology in wound care

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ABSTRACT

Background

Wearable sensor technologies for wound management have slowly found their way into healthcare systems worldwide. They aim to produce benefits in the reduction of hospitalisation time, facilitate home healthcare, mitigate losses incurred by human error, reductions in clinician and nursing efforts and the prevention of amputations. They have the ability to capture the diurnal and circadian variations of wound parameters, with patients benefitting from continuous long-term monitoring as a part of either a diagnostic procedure or the maintenance of their wounds.

Aim: This study explored the perceptions of those living with chronic wounds of the foot and lower limb toward the concept of a wearable sensor technology for wound management.

Methods

A qualitative description method was employed. Twenty-three semi-structured interviews were conducted in three geographically distinct locations in Ireland. A thematic analysis was also conducted.

Results

Four main themes emerged: the element of personal contact, the medical need for wound diagnostics,

the practicalities of wearable sensor devices and the trialable nature of wearable sensor devices.

Conclusions

Most participants indicated feelings of concern toward accepting wearable sensor technology as a part of wound management and the potential loss of contact with their attending clinician. These findings contribute to understanding technology acceptance in wound patients and aim to open communication channels among users of the technology, researchers and policy and market innovators in wound care.

Key messages

- Wearable sensors have the potential to revolutionise wound management practices, but their acceptance by patients must be considered in advance.
- Researchers and innovators of new sensors should work with patients to develop education tools concerning their use, in order to alleviate fears and increase adoption of the technology.
- Patients value contact with their clinicians and need reassurance that it will be maintained.

INTRODUCTION

Chronic wounds are considered a silent epidemic -

and are an under-recognised issue, both nationally in Ireland and internationally. They are under-considered, in terms of research and education, with poor financial incentives for investment and public policy compared to other chronic conditions. This indifference is unjustified, given the associated diseases and economic burden of chronic wounds globally.

Current research considers the rapid rise of the elderly population, coupled with modern lifestyle changes, as having had a significant effect on the associated costs and prevalence of chronic wounds worldwide.¹⁻³ It is estimated that, globally, more than 700 million people are living with a chronic wound^{1,4}, and in Western countries, up to 4% of total healthcare expenditures are spent on wound care.⁴ Additional and often unseen costs include losses of income, unemployment, transportation issues and the cost of support for adaptive housing for these patients.⁵

Irrespective of the financial burden, chronic wounds have great societal and economic impacts in the form of increased hospitalisation rates, leading to reduced capacities among both patients and health care providers.⁶ The ongoing nature and prolonged healing times of chronic wounds create a cycle of pain that can affect individuals emotionally, impairing their mobility and leading to anxiety, social isolation and a poor quality of life.

Early and effective interventions have been found to be crucial for maintaining the autonomy and quality of life of patients with chronic wounds.^{1,7} Research has noted the potential impact of sensor innovation on wound care costs, clinical practice, patient outcomes and economic policies.⁸⁻¹¹ Regarding wound care specifically, there is now substantial evidence to suggest that this field is on the verge of new significant advances, and wearable sensors will be used as diagnostic tools and become an integral part of routine clinical practice.^{11,12}

The concept of a wearable sensor technology that uses devices embedded within dressings or as a point of care technique for the instant and continual management of wounds is growing rapidly, with increased potential for applying its use to both acute and chronic wounds as a matter of routine.¹¹ The types of wounds suggested as the most likely to benefit from sensor technology are chronic wounds, followed by infected wounds and full thickness burns.¹¹⁻¹³

Wearable sensors for wound care are aimed at generating readable outputs that have both diagnostic and theragnostic value.¹¹ A signal processing system will likely serve as the system's central node, providing temporary data storage of appropriate parameters, while communication systems aim to transmit raw data to remote sites for long-term storage and consideration by health professionals.^{11,14,15} The data sets stored and recorded using wearable sensor systems may be used to detect events predictive of the possible worsening of the patient's clinical situation, or may be explored to assess the impact of clinical interventions.^{11,16}

One area of growing research within the realm of wound care and wearable sensor technology has been the concept of 'smart dressings'. Their purpose is emphasised as a means of continuously sensing the wound milieu, such as temperature, moisture, the pH of wound fluid and bacterial load from within wound dressings, in hope of reducing unnecessary medical tests, diminishing medical errors, decreasing clinician and nursing efforts, enabling outpatient care and improving clinical decision making.^{17,18}

While the integration of wearable sensor technology has many potential benefits, potential challenges have also been noted, including: the enabling of the secure transmission of all collected private data; compatibility with and safety of biological tissues, such as wounds or open lesions on the skin; the ability to engage in daily activities such as swimming and showering; and the prevention of electromagnetic interference among various other electronic, wireless devices.¹⁹ Most notably, the concept of wound patients accepting the potential of this type of technology as part of their wound care management has been rendered a challenge of high priority.²⁰

Wearable sensor technologies as point of care wound assessments have the potential to ensure the effective management of wounds based on objective biochemical information that can be administered without delay, rather than after the fact.¹¹ The ability to not just monitor wound healing but to potentially predict complexities within the wound healing process could ensure that potentially problematic wounds receive the correct and most effective attention at the earliest possible stage in the healing process.

The use and acceptance of these smart dressings are likely to differ based on individual psychographic

characteristics.²¹ While significant for addressing issues of wound management, there are no reports to date investigating the potential acceptance of wound care patients of the use of wearable sensor technology in the management of their wounds.

User technology acceptance has been described as an increasingly critical technology implementation and management issue, as, regardless of its potential technological merits, an unused or underused technology cannot be effective.⁹ The phenomenon of user acceptance attempts to understand the determinants of user acceptance of technology, in order to apply these factors to increase the usability and success of health IT to create positive patient experiences and outcomes.

Gains from investments in technology are, to a large extent, dependant on the number of users contemplating the adoption of a technology and, more inherently, the specific attitudes of users toward that type of technological application.²¹ The acceptance of health IT systems is only prompted if the factors that influence the acceptance of technology are known. Herein, this can only be done by examining the perceptions of users concerning the use of the technology.⁹

The aim of this study was to investigate patients' perceptions and potential acceptance of wearable sensor technology for wound care.

METHODS

Conceptual framework

Qualitative description was the most appropriate conceptual framework approach for addressing the research question and study aims. A conceptual framework draws on concepts from theories or research findings and guides decision-making and the interpretation of data.^{22,23} It has been described as a 'non-categorical alternative' for inquiry in which the approach firmly exists.²² This, as a framework and method, allows the researcher to stay closer to their data and the participants' points of view, compared to other methods.²⁴ Qualitative description is a flexible approach to qualitative research, offering a comprehensive summary of events or experiences of those being investigated and is seen as a particularly relevant method in health services research for answering research questions where patients, relatives or professionals' perspectives are the main aim of the research.^{22,24} Qualitative description is, simply put, a

method of gathering rich, but surface-level, descriptions of participants' experiences in a language similar to the participants' own, involving a low degree of inference for data interpretation, thus limiting what can be learned from the meaning of participants' responses.²² However, as with any other qualitative approach, qualitative description may be inspired by other qualitative methods and acquire phenomenological or narrative overtones^{22,25}, as is the case for this study. This phenomenological texture added to the qualitative description approach and method does not aim to provide definitive explanations of the data; rather, it strives to develop and increase insight about the phenomena being investigated.²⁶

Research design

This study was guided by a prospective, qualitative description research design. This method is appropriate for answering the research question and illuminating an under-researched area. The study is prospective in design, due to the subset of the population of wound care patients being investigated at only one point in time, and the nature of the study exploring the 'potential' acceptance of wearable sensor technology in wound management for the future, in hopes of informing technology research in a variety of ways.

Inclusion and exclusion criteria

Any person over the age of 18 years able to provide consent and who currently has or previously had a wound of the foot, lower limb and/or leg within the last six months, in order to obtain data on more recent experiences rather than a retrospective view of the research topic, was considered eligible to participate in this study.

Those who did not have an active wound within the last six months or who were under the age of 18 years were excluded from participating in the study.

Sample size

Purposeful sampling of a homogenous group of wound care patients in Ireland was used to maximise the depth and richness of the data collected to address the research question in a homogenous group of wound care patients in Ireland.²⁷ In keeping with the qualitative research design, no sample size limit was set; rather, recruitment was allowed to continue until the point of data saturation.

Study setting and recruitment

This was a multi-site study. Three outpatient wound

clinics across Ireland treating patients with a range of chronic wounds were included. The advantage of multi-site studies is their ability to provide larger, more diverse sample sizes than those of single-institution studies.²⁸ Clinicians at each clinic acted as gatekeepers to the research and throughout the recruitment process.

Informed consent

Informed written consent was obtained from all participants prior to the commencement of data collection. Following the dissemination of participant information leaflets in each clinic, each participant had until their next appointment to consider whether or not they would like to participate in the study.

Data collection

Semi-structured, face-to-face, one-on-one interviews took place in a private room at each clinic site. Each interview was recorded using a voice recorder, and handwritten notes were taken during the interview process.

Semi-structured interviews were conducted on the basis of a loose structure consisting of open-ended questions that defined the topics of technology and wound care. The interviews initially adhered to pre-formulated questions, starting with the question 'Do you own any technology at the moment, like a mobile phone or computer?' However, the flexibility of semi-structured interviews allowed the researcher the freedom to ask additional questions to seek clarification or to uncover new perspectives as they arose.

'Data saturation' is a concept in qualitative research that explains the instance when the collection of new data does not contribute to exploring the topic further, where there is enough information to replicate the study.²⁹ In this study, we determined that an adequate sample size had been reached when no new information was derived from interviews. Participants were invited for interviews until the point of data saturation.

Research on technology acceptance has been examined across various user populations and information technologies, while developing empirical support for respective theories or models that incorporate factors and phases for predicting technology acceptance.^{30,31} Technology acceptance in wound care populations has received little to no attention, and as such no model currently exists to examine the factors influ-

encing technology acceptance. A literature review yielded a set of acceptance factors and interlinked questions based on the Technology Acceptance Model, Theory of Reasoned Action^{32,33} and the Theory of Planned Behaviour.³⁴ These were used to develop the interview guide.

Data analysis

Thematic analysis was used for this research. The structure and format of thematic analysis are based on Braun and Clarke's six-stage process by generating initial codes for the data followed by the development of themes. The technique used to code the data was known as 'open coding', which meant the researcher did not use pre-set codes, but instead developed and modified codes throughout this aspect of analysis of the initial codes. This included techniques such as recognising repetition in the data³⁵, metaphors and analogues, transitions and naturally occurring shifts in the content or similarities and differences in expressions among participants.³⁶ NVivo was used at a later stage in the analysis process. This data analysis software program is designed to aid analysis while allowing the researcher to remain creative and in control throughout the analytical stages of the research.³⁷

Data protection and confidentiality

All data collected were pseudonymised and coded. All participants were assigned a non-identifiable code upon entering the study. Raw data and coded data were never stored in the same place, to protect each participant involved in the study.³⁸

Ethical Considerations and Issues in the Study

Due to this being a multi-site research study, ethical approval was sought from both the Galway Clinical Research Ethics Committee and the HSE North East Area Research Ethics Committee. This study was conducted in full accordance with ethical principles outlined by the Declaration of Helsinki.

RESULTS

Population profile

Twenty-three interviews were conducted over four months, between May and September 2018. Four themes emerged from the analysis of the data, as guided by Braun and Clarke³⁵, within which sub-themes emerged to highlight the key elements of the participants' perceptions of wearable sensor technology in wound care.

The four themes and subthemes that emerged are presented here with anonymised quotes from participants.



Figure 1:
Thematic map of the four themes of the study

Theme 1:

The element of personal contact

Frequency of wound care appointments

More than half of all participants (n=12, 52%) expressed concerns regarding the potential for a decrease in weekly wound care appointments and the consequent loss of regular social interaction, personal contact, reassurance from their clinician, alleviation of fears associated with the wound and the security of being looked after that clinic visits bring.

The biggest thing (would be) the attention I get. It is absolutely wonderful. I'd miss that. Erm, I think you feel more secure and safe (knowing) that somebody is checking it and you know you have that someone there, you know. Yeah, so erm, I'd miss that (P- 20) Almost one-third of participants (n=7, 30%) believed that less-frequent attendance, and therefore less personal contact at wound care appointments, were good. Less-frequent dressing changes were perceived to be less likely to disturb the natural wound-healing process. Patients were also mindful of the subjective nature of wound management and particularly the subjectivity of the frequency of wound dressing changes, which may vary among wound clinics or wound care clinicians. Therefore, wearable sensors would make this process more objective.

Some participants (n=6, 26%) spoke of the effort and expense that attending regular wound care appointments entails, and thus less-frequent appointments were a positive for some. Participants reflected on

their reliance on others to bring them to scheduled appointments, the monetary cost of travel and the distance travelled weekly as part of their wound management. Additionally, frequent appointments affected work obligations and thus any intervention to improve this would be valuable.

It is costing me money to be here every week. I have to pay my driver. (P – 19)

However, in conjunction with highlighting the cost and time concerns of chronic wound management, one participant also noted how work obligations are affected by the frequency of wound care appointments. It was also believed that their less-frequent attendance at appointments would enhance care for others:

It (could) also mean you (clinicians) could probably give longer time between patients? Because you would be able to monitor it, away from it (the clinic)? (P – 10)

Comfort and aesthetics of wound dressings

Specifically, concerns over the quality of wound dressings were raised. Particular concerns were raised related to the potential of 'oozing', 'exudate' and odour from wound dressings if left for longer periods, and queries were made on the ability of the dressings to stay in place for longer periods. Current experiences of participants in relation to wound dressings being on 'too long' and the issues this already causes for wound care patients and their families were also discussed.

They should really be done (changed) twice a week. My sister tried to cut them (compression bandages) off and they were like, they would be gone green, you know? So, really they do need to be changed and dressed twice a week. (P – 2)

Feelings of anxiousness were re-iterated, with repeated queries from participants such as:

I would be worried, would they (clinicians) be checking on it? (P– 6)

Chronic disease as a consideration

Participants commented on the idea of less personal contact as practically impossible in their cases, due to other chronic and concerning issues related to their foot and lower limb care.

Although chronic wounds are a major concerning and high-risk condition, so are the additional conditions or ailments that coincide with chronic disease, such as involuted nails, the development of anhidrotic (dry) skin and callus (hard skin) formation. While all participants aspired to better healing outcomes, 'If I thought it would heal it quicker, I would consider it, yes. But ...', they were also very clear that the potential for less personal contact with wound care clinicians would be a huge consideration in their acceptance of wearable sensor technology for many reasons, 'If it was still oozing, I wouldn't like to leave the dressing on too long' (P – 4).

Theme 2:

Medical needs for wound diagnostics

Early detection

There was considerable agreement amongst all participants regarding the need to improve processes aimed at detecting complications within chronic wound care at an earlier stage. The idea of wound care clinicians having knowledge of how wounds are progressing, or indeed digressing, between wound care appointments was a positive aspect. This, in some cases, was compounded by the reality of participants' previous experiences with delays in the detection of wound complications.

I wouldn't mind the (monitoring) at all. At least then (they) would know what the problem is rather than (me) being an anti-Christ when I am going to see the doctor or the nurse! The reason is because the device would be there and at least I would know what the problem is (too). (P – 9)

Perceptions of early detection as a potentially desirable function emerged, and some noted the prospect of not having to visit a doctor as often for antibiotics due to the complication of infection in their wounds as a positive.

Well, it would save you. I mean, it might even save you having to go to the doctors every second day. (P – 13)

There was a desire for wound care patients to enable both themselves and their wound care clinicians to have every opportunity to detect complications at the earliest stage possible:

I suppose first of all, the fact that it (the wound) is being monitored, that fact that if there is a problem it

will potentially be spotted early. I won't have to wait for two weeks to have the dressings off before somebody says that it is not good. So, it is the immediacy of information is what would be important. (P – 23)

This deep desire for the earliest possible detection of complications appeared to stem from the fear and knowledge of the common, yet often preventable, adverse events that can occur due to complications associated with chronic wounds if they are not detected and dealt with at an early stage.

Adverse event prevention

Mentioned throughout the data collection process was the challenging nature of preventing amputation and hospital admissions due to complications; in particular, infection was most often discussed. References were made to how the prospect of wearable sensor devices could have previously helped prevent, or could potentially help prevent, future similar events: ...at least I would know what the problem is. I would be worried about losing the leg! (P9)

I think all (of) these things (technology) are a good thing because, erm, it could prevent amputations and all (of) that I am sure? (P– 13)

Participant 10 also added that a wearable sensor device for wound management could be the equivalent of the body letting you know when something is needed to survive:

I mean the biggest thing with technology there is, I mean, the things that monitor you. You (know), you have an issue before it even feels like you have one. You know, your body tells you, you know it is time to eat something now or whatever, you know? (P – 10)

Monitoring and reassurance

Participants also expressed how technology could potentially bring about feelings of security and reassurance in the management of their wounds. When asked how a wearable sensor device could make an impact on their wound care, one response was:

I think I would feel more secure knowing it was there ...there is a security element in it, you know? (P– 16) Another reference was made on the idea of being 'looked after' in terms of the participants' expectations for their wound care and wound management plan:

...I would know I was being looked after ... At least if

there was something going on, you (clinicians) would get it and be able to do something about it. Rather than the likes of me, I just wait until my next appointment. (P – 22)

The feeling of reassurance was illustrated in terms of the availability of wound care appointments. This reassurance was expressed by the knowledge that participants could potentially have a wearable sensor device monitoring their wounds, even if a situation arose where they would have to cancel or miss their wound care appointment, or if there were none available to them within their usual timeframe.

Participants further discussed their reassurance in terms of the knowledge that incorporating a wearable sensor device could bring to them by knowing their wound status information was being sent and assessed remotely by a wound care professional:

...I don't think there is anything else, other than the comfort in knowing someone is looking at it (remotely) and saying 'Something is going wrong here. I better ring this guy and get him in here'. And surely that, for a month or two, has got to be worth it? (P – 21)

Throughout this theme, the idea that wearable sensor technology has a place in wound care and medical diagnostics was discussed in a positive light by 52% (n=12) of participants. The optimism concerning the potential of enhanced wound management strategies was noted throughout data analysis.

Theme 3:

Practicalities of a wearable sensor device *Bathing concerns and charging practicalities of a wearable sensor device*

Struggles with showering and trying to protect wound dressings were raised as concerns of chronic wound patients. Some expressed suggestions regarding the design of the device they would prefer and asked if it would be necessary to bathe while wearing the sensor device, considering it would be an electrical appliance potentially embedded within a dressing:

Having a bath, would that be a problem? It wouldn't make me nervous, you know, I would hope it is only a battery-operated thing? As long as there is no electrical current going into it or anything, you are not plugged into the mains or anything, no? (P– 21)

The perceptions of the ease of use of wearable sensor devices, and the concept of potentially having to charge the device, were important topics of discussion by many. In particular, patients raised concerns about perceptions of their ability to use the device with ease. The idea that participants would not feel comfortable if responsible for charging the device was echoed throughout discussions on the possibilities of the same. One participant noted how he would simply 'rebel' against doing so, if it was a necessary element of any wearable sensor device.

The idea of 'hassle' and 'age' were also mentioned in relation to potentially being responsible for charging a wearable sensor device:

Erm, the hassle would be plugging it (the device) in every 2 days. That would be (a) hassle ... I mean, if it was something that you could stick on top of the bandages (to charge), that wouldn't bother me in the least. I would much prefer that. It's time out of short time, if you know what I mean. It's my age, it's my age. (P – 23)

References were also made to concerns of whether or not the device would charge properly, and what the implications would be when in company or out socially if the battery were to run low or the device were to 'lose signal'. (P - 10)

Footwear, clothing and mobility restrictions

Many participants highlighted their concerns regarding footwear and clothing restrictions. The consensus among most participants (n=20, 87%) seemed to be that their footwear restrictions have already been considered, in terms of bespoke footwear to accommodate the presence of chronic wounds and their wound dressings; therefore, footwear would not pose as a concern in this instance. However, the idea that the addition of a wearable sensor device to an aspect of wound care that already required a great deal of thought and precision regarding footwear and clothing considerations raised concerns with some.

The ease of use of a wearable sensor device and clothing restrictions was also discussed. Many described their current struggles with clothing and wound dressings, particularly those who suffer with chronic leg ulcers, which then led to queries and concerns of the same if a wearable sensor device were to be considered in the future:

I probably would be a bit conscious about clothing restrictions. (P – 8)

Several participants, particularly those with chronic leg wounds, had queries as to where the wearable sensor device would be situated on the leg:

It is not very big is it? My bandages are big enough. (P – 7)

Mentioned throughout the interviews were concerns about mobility and whether the addition of a wearable sensor device would hinder or limit the normal ambulation of participants, 'If I could get about, I wouldn't mind' (P – 5). The main concern that arose dealt with whether a device would make participants totally immobile:

I probably wouldn't mind it, as long as it wasn't hurting me or doing anything to my wounds, you know? But, erm, as long as it wouldn't make me un-mobile [sic]. (Participant – 8)

Fears of putting on shoes to walk and potentially damaging the device were also discussed:

I wonder how much you would feel it? Like, what is the size of it? (P – 20)

Discussions also revolved around concerns of physically having to use the wearable sensor device. Most participants who spoke to this issue discussed how they might physically struggle to deal with the device if this was a necessary element to them:

I think it would be awkward for me, where it is. I wouldn't be able to, well, I feel I wouldn't be able to get the dressing back properly doing it myself, you know? Doing it myself. (P – 16)

Noise: sleep and social concerns

Almost half of all participants (47%, n=11) reported concerns in relation to noise, including concerns over both sleep disturbances to themselves and their partner, noise when in social settings and regarding the inconvenience noise might cause to friends, which could consequently lead to isolation from visiting and socialising with friends if it became an issue.

Would it (device) keep me awake at night? I wouldn't mind it, as long as it wasn't keeping me awake. I have

enough things keeping me awake at the moment. (P – 1)

If I were in company, I would not (like) it. (P – 4)
Would it be a loud noise? (P – 6)

Noise was a common topic of discussion. Notably, what became apparent was that the mere mention of noise from a wearable sensor device seemed to cause much unease and distress in many participants.

Others described how noise was, in general, an undesirable aspect of the concept of wearable sensor technology and would be something they would prefer to avoid in their daily lives:

I don't like anything ticking at all! (P – 3)

Theme 4:

Trialability nature of a wearable sensor device

Length of wear time

The uncertainty over the length of time the wearable sensor device would be worn was a concern for some participants. This is also linked to the first theme, which considers the potential loss of frequent, weekly wound care appointments to allow for adequate monitoring of the wounds and, as such, fewer wound dressing changes. However, the concerns raised in this instance were feelings of unease over the uncertainty concerning the length of wear time for the device, specifically due to its novel status in wound management.

I feel a bit of a guinea pig... Well, I would have a fair amount of worries with it (the sensor device), you know? The safety of it. I wouldn't be worried if you could reassure me that nothing is going to happen? In the first instance, I would be afraid of it going wrong. Of anything going wrong. (P – 12)

Pain and irritation concerns

It became evident that participants were eager to learn more about the implications of wearable sensor devices. Specifically, participants grew increasingly curious as to whether a wearable sensor device would suit their particular wounds; 'Would it be any good for me like?' (P – 13), and whether there would be implications if they adopted it or not: 'I assume you wouldn't make them any worse? It shouldn't, should it?' (P – 20). Some expressed worry about the comfort of the devices, while others appeared concerned about the devices' long-term implications.

A primary cause for concern arose from worries of additional pain and unanticipated or unnecessary damage to healthy skin due to the addition of a wearable sensor device.

I probably wouldn't mind it (a sensor device), as long as it wasn't hurting me or doing anything like that to my wounds, you know. (P- 8)

It became clear that participants had additional worries, not only concerning additional pain on top of what they already experience, but about the potential for wearable sensor devices causing irritation resulting in further damage to surrounding healthy skin and the development and burden of new chronic wounds.

It wouldn't be anything like vibrating the leg would it? (P- 7)

Worries about the unknown implications of wearable sensor devices involving the unknowns of the length of wear time and pain and irritation concerns were discussed among 35% (n=8) of participants.

Malfunctions - confidentiality and privacy of information concerns

Discussions arose over the daily functions of wearable sensor devices and the concerns of whether they had the potential to malfunction or stop working while the patient was away from a clinical site or clinician who could intervene. Interviewees were concerned that the device might not complete its task of monitoring and relaying information to the appropriate health professionals.

No (issues), unless it (the sensor device) started playing up on me ...I would be afraid of it going wrong, of anything going wrong. (P- 12)

One of the younger participants, in the 41–55 years age group, made an interesting point in wondering whether a wearable sensor device could interfere with other technical devices he had in his home and uses regularly, potentially leading to the wearable sensor device not performing efficiently:

But that (the sensor device) wouldn't affect the mobile now, or anything like that now? Or the TV? I wouldn't like to be on the tablet now and all of a sudden, this alarm goes off? (P- 9)

Amid concerns of whether the day-to-day functions of wearable sensor devices would successfully relay information to clinicians, discussions arose over the confidentiality and privacy of the information sent.

While some were not concerned with this, saying, 'I don't see that as an invasion of privacy' (P- 23), others expressed the opposite opinion:

I probably would ask (about confidentiality), yes. I would ask. (P- 8)

One participant commented that this is a concept that she would have to take some time to understand before she would feel comfortable with it.

Another participant expressed his suspicion regarding the type of information that could be picked up using a wearable sensor as a monitoring device and the risk of invasion of his privacy:

As long as it wouldn't pick up your tongue? ...As long as it wouldn't pick up on what you be talking about. (P- 19)

The cost factor

Cost considerations of wearable sensor devices and the uncertainty at the time of this research whether this would be a consideration for wound patients contemplating adopting wearable sensor devices as part of their wound management plans, and their perceptions of this, were common. This was noted as a negative aspect of wearable sensor devices by 35% (n=8) of participants.

Through discussions of the potential cost factor associated with the adoption of wearable sensor devices, the element of 'living on a pension' emerged. Considering the age distribution of participants involved in the study, where the majority were between the ages of 66 and 75 years, it became evident that the thought of having to factor in a new payment for wound care would be an issue. Most participants referred at some point to their weekly income and the aspect of living on a pension as their main concern.

I have enough paying out. I sometimes struggle. I am on my own you know. (Participant - 12)

Considering the participants interviewed during this study were all (n=23) under the care of outpatient wound clinics, the feeling was that they were not in

favour of potentially having to pay for wearable sensor devices, especially after taking into consideration that, at the time of the study, they were receiving their care free of charge within the realms of the clinics they attended.

DISCUSSION

This study set out to explore the views, perceptions and potential acceptance of patients with chronic wounds toward wearable sensor devices. This work takes advantage of the fact that participants had no prior knowledge or experience with wearable sensor devices for wound monitoring; as such, they were able to discuss any perceived concerns about the devices freely, without any preconceptions.

Social and functional support

The potential loss of regular interactions with their wound care clinician, and how this could affect participants emotionally, was obvious throughout more than half of the interview discussions (52%). Participants expressed concerns about the concept of potentially decreasing the amount of patient–clinician interaction that could come with the implementation of wearable sensor devices in terms of missing personal contact and the comradery element of regular appointments.

Previous research has noted the importance of regular interactions between healthcare professionals and patients with long-term, chronic diseases for two main reasons; the first is the importance of success for overall healthcare outcomes, and second is the emotional disclosure and psychological outlet these contacts bring to patients with long-term illness, such as chronic wounds.^{9–41} Regular interactions between patients and clinicians play a key role in the success of healthcare provision, including person-centred care, and is a significant contributor to both patient outcomes, including adherence to treatment, rapport, trust and patient satisfaction, and healthcare outcomes in terms of diagnostic accuracy.^{40–43} However, the psychological implications and the availability of a health professional to provide guidance and emotional support for patients on a regular basis has been found to protect patients from experiencing the negative consequences of chronic disease in terms of their functional support and emotional well-being.^{39, 41} Fewer social interactions between patients and clinicians often lead to patients withholding information, thus delaying wound healing as a result of retaining potentially critical information that could alter fu-

ture management plans.^{44–46} The perception of fewer instances of personal contact also raises the issue of whether wearable sensor devices, and the prospect of potentially lower levels of personal contact in a bid to decrease nursing and clinician efforts, could lead to unanticipated consequences. This, ultimately, could deter patients from accepting this type of technology as a part of a wound management regimen.

The majority of participants in this study ($n=13$, 57%) were between the ages of 66 and 75 years. Studies on the therapeutic effects of clinician–older patient relationships have found that, alongside changes associated with aging such as physical, psychological, social, economic and lifestyle changes, comes greater reliance on the support and encouragement of their relationship with their attending clinician.^{41,47} The social challenges of ageing, such as the size of social networks and the amount of social support received, can drastically change as individuals age, which can lead to cognitive and psychological challenges, creating this reliance.^{41,48} Frequent visits between clinicians and patients are considered a therapeutic agent that can often negate these emotional effects in ageing patients.^{41,49} Regular interactions and good relationships with attending clinicians have been found to have positive effects on older patients' views of their own physical and mental health status, and particularly their adherence to treatment and satisfaction with care.^{41,50}

Several studies have been conducted on the challenges of integrating technology with healthcare, and particularly how technology can alter patient–clinician interactions and the effects of this.^{42,48} Studies of this nature have found that, with changes in clinician–patient interactions that are a result of technology integration, patients begin to feel disengaged, or that their clinicians are less attentive, with patients becoming dissatisfied with their level of care over time.^{42,47,48} With the integration of health information technology, in order to avoid negatively affecting patient-centred practices in terms of diminishing dialogue within the psychosocial and emotional realms, one must consider the potential disruptive nature of technology to psychosocial inquiry and emotional responsiveness if patient–clinician interactions are reduced or altered.^{42,47,48}

It must be noted that this outlook was not equal among all participants of the study. Some participants ($n=6$, 26%) voiced the opinion that fewer wound care

appointments would be a positive aspect of wearable sensor devices, in terms of requiring less effort and their desire to attend hospital settings less often for wound care appointments. Pain during dressing changes and treatment regimens were also factors noted in wound care research that could stimulate participants' desire to decrease the frequency of appointments. Anxiety about anticipated pain during dressing changes is also thought to lead to failures to adhere to treatment regimens and patients missing regular appointments.⁴⁴

Malodour and exudate are common symptoms of chronic wounds.⁵¹ Both symptoms have been linked to depression, anxiety and negative body image, with profound negative implications on quality of life.⁵² The potential decrease in weekly wound care appointments raised concerns about the implications for their wounds, in terms of comfort and aesthetics, particularly exudate and malodour, and pain and irritation, with the worries of 'oozing' and 'weeping' expressed most often.

The implementation of wearable sensor devices was discussed in a positive light, in terms of potentially relieving some reliance on others and reclaiming some of patients' independence with less-frequent wound care appointments. Where individuals perceive technology to potentially prolong independence or to have a perceived usefulness relative to their quality of life, individuals are more inclined to accept such technologies as a part of their care, particularly in older patients.⁵³

Chronic disease and advancing age

Participants of this study expressed that they rely on others, including family, friends and taxis, to bring them to and from scheduled weekly wound care appointments, and they noted the burden this places on them emotionally and financially. As such, the implementation of wearable sensor devices was discussed in a positive light, in terms of potentially relieving some of this reliance on others and reclaiming some of their independence with less frequent wound care appointments. This perception is supported by literature, such that, where individuals perceive technology to potentially prolong independence or to have a perceived usefulness relative to quality of life, individuals are more inclined to accept these technologies as part of their care, particularly in older patients.^{53, 54}

Financial status, particularly for elderly patients, af-

fects perceptions and the willingness to use technology as a part of care.⁵³ Studies on elderly persons' perceptions and acceptance of using smart and wireless technology have found cost to be the most critical determinant in determining an elderly person's acceptance. Technologies will be rejected and not be accepted if they are not affordable.^{53,54} Based on the results of this study and the probable relationship with the current literature, participants viewed wearable sensor devices as an elective option to their care, one that did not rank necessarily high on their financial agenda. Imposing a cost factor for wearable sensor technology for wound management may act as a barrier to the acceptance of such technology for wound patients, in terms of adding a burden to their already-limited incomes.

System Functionality

The lack of current knowledge concerning the reliability of wearable sensor devices, in terms of whether they have the potential to malfunction or stop working once integrated into patients' wound management plans, was a concern. This finding is in line with other studies that identified the reliability and predictability of technologies as important for all users, but perhaps most critical to those who are elderly, more vulnerable and who may be less resilient when managing their condition, compared to younger patients.⁵⁴

In spite of this finding, other studies have revealed that it is less often the reliability, and more often the accuracy, of the technology that is concerning to patient.⁵³ Participants in this study questioned whether the device would accurately complete its task of monitoring and relaying information to the appropriate health professional. Similar to other studies, concerns of whether the system could accurately determine the patients' needs at the same level as a wound care clinician were also expressed.⁵⁴

Elements such as uncertainty about the confidentiality and privacy of participant data were also of concern. What type of information would be recorded and who would receive it were the most commonly raised issues. One study on older adults' perceptions of wireless smart home technologies revealed that participants worried that data recorded and collected to monitor the progress of their health could possibly be used by their health care provider or health insurer to penalise them for not complying with prescribed health regimens.⁵⁴ Interestingly, there are conflict-

ing reports on this matter. Research has found that, apart from objections to the use of a camera when implementing wireless technology, most patients do not see their medical data as a target for an invasion of privacy or an element of concern.⁵³

Participants described bathing as an already difficult task in their daily lives, describing their profound efforts to keep wound dressings dry and intact. Concerns arose over whether the addition of a wearable sensor device would add to this difficulty, and specifically whether showering and potentially getting the device wet could impede its ability to function. Recent suggestions that changes in skin conductivity as a result of perspiration or water from showering or swimming may alter the signal quality of wearable, wireless sensor devices, while also affecting the adhesive nature of the device, may be a cause for concern in the design of such technologies and a plausible explanation for the participants' concerns.^{19,55}

The concept of having to interact with the technology was not viewed positively, despite most participants indicating a desire to have some means of remote monitoring made available to them during the management of their wounds. Most participants desired a simple, easy to understand device, with minimal interaction. Participants grew particularly concerned about the potential responsibility of having to charge the device, with most indicating that their 'age' must be considered and that they would absolutely 'need assistance' with this aspect of technology. A plausible explanation for this perception may be that other studies have indicated that patients, and particularly elderly patients, prefer minimal interaction with sensor devices for healthcare monitoring, in order to avoid memory issues and obtrusiveness into their daily routines, and given the fact that most elderly people demonstrate low technology self-efficacy. In other words, they have a low self-belief in their ability to engage with technology; this appears to be the case with participants of this study as well.^{20,53,56} According to technology acceptance literature, feelings of low technology self-efficacy can be negatively associated with perceived ease of use, thus influencing technology acceptance.²⁰ The extent of these feelings is often related to an individual's previous experience with technology, verbal persuasion from others and affective arousal.^{20,53,56} Considering the age of participants in this study and their varying degrees of disability due to chronic disease, they may have difficulty memorising what functions various aspects

of the device hold, or they may require specific design requirements, compared to the average user, due to their diverse abilities, such as difficulty bending or visual impairments.⁵³

Social factors have played a prominent predictive role in technology acceptance research.²⁰ Individuals may be more or less inclined to accept technology depending on the extent to which it may affect their relationships with others or to which their children, grandchildren, friends or clinicians urge them to use it.^{20,56}

Moreover, the adoption of wearable sensor technology, particularly if its presence is known either visibly or audibly, may be a stigma in patients' views, further highlighting their current ailments and more symbolic of their frailty than of their supported independence and health.⁵³ Ebbeskog and Ekman⁵⁷ referred to the social disengagement of patients with chronic venous leg ulcers, noting that patients consciously isolated themselves from immediate friends and family to avoid subjecting them to the symptoms of their wounds. People often feel ashamed when they feel different, or when they think others notice they are different. A stigmatised person, therefore, is likely to socially isolate themselves, not only to avoid embarrassment but also to avoid embarrassing friends and family.⁵²

In summary, the importance of examining the perceptions and acceptance of chronic wound patients marries calls in the health informatics literature for increased knowledge and research on wearable sensor technology among chronic wound patients of the foot and lower limb, to facilitate the implementation and design efforts necessary for ultimate success.

RECOMMENDATIONS

It is recommended that manufacturers of 'smart' wound care devices discuss and adapt their products' designs with patients, so as to ensure that those for whom they are designed are accepting of them. In addition, manufacturers and researchers of wearable sensors and smart dressings should develop information and education materials to alleviate potential concerns, and thus potential stress, caused by underlying concerns.

CONCLUSION

This research has highlighted that, despite their potential advantages, patients with chronic wounds are

not necessarily open to certain aspects of wearable sensor technology designed for use with wound management. A continuous, ambulatory, portable monitoring system is critical, one that can be used comfortably by wound patients without affecting their daily lives. At the same time, and more importantly, the research revealed that even the most advanced technology will never fully replace the peace of mind and reassurance that physically interacting with their attending wound clinician brings to these patients' level of care. The implementation of wearable sensor devices in wound management would likely be accepted and prove beneficial, once the practical issues and psychological implications are resolved and adequately addressed. Failure to engage with and understand chronic wound patients' perceptions of wearable sensor technology for future wound man-

agement will impede the evolution of such innovative technologies as a public health resource, ultimately preventing populations from realising their potential health benefits.

IMPLICATIONS FOR FUTURE RESEARCH

The findings of this research aim to promote awareness among all healthcare forums and those involved in technology acceptance, integration and development. The findings hope to spur health professionals, policy makers, researchers and market innovators on the opinions, both positive and negative, of patients with chronic wounds toward wearable sensor technology, enabling them to provide a more responsive and holistic view of care with the implementation of wearable sensor devices for wound management.

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