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Complete List of Authors:	Papi, Enrica; Imperial College London, Department of Surgery and Cancer Belsi, Athina; Imperial College London, Department of Surgery and Cancer McGregor, Alison; Imperial College London, Department of Surgery and Cancer
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Wearable Technology and the Preferences of Patients Living with Osteoarthritis: A qualitative study

Enrica Papi, Athina Belsi, Alison H. McGregor

Department of Surgery and Cancer, Imperial College London, Charing Cross Hospital, W6 8RF, London, UK Enrica Papi research associate Department of Surgery and Cancer, Imperial College London, St Mary's Campus, W2 1BL London, UK Athina Belsi senior teaching fellow Department of Surgery and Cancer, Imperial College London, Charing Cross Hospital, W6 8RF, London, UK Alison H. McGregor professor

Correspondence to: Enrica Papi e.papi@imperial.ac.uk, +44(0)20 3313 8833

Abstract

Objectives: To identify osteoarthritis patients' perspective, in particular design requirements and mode of use, of wearable technology to support the rehabilitation pathway. This study is part of a user-centred design approach adopted to develop a rehabilitation tool for osteoarthritis patients.

Design: Qualitative study via a focus group approach; data management included a thematic analysis of patients' responses.

Participants: Twenty-one osteoarthritis patients (Age range: 45-65 years old) participated to one of four focus groups. Recruitment continued until saturation of data.

Setting: The study was conducted in a University setting.

Results: Main determinants of user acceptance of a wearable technology were appearance and comfort in wearing it. Patients were supportive in the use of wearable technologies during rehabilitation and could recognise their benefit as monitors for their progress, incentives to adhere to exercise, and tools for more informed interaction with clinicians.

Conclusions: This paper should encourage adoption of wearable technology to support rehabilitation of osteoarthritis patients. In doing so, it is pivotal to take into account patients' views. The information obtained from this study should guide the design of new technologies and support their use in clinical practice.

Strengths and limitations of this study

- Focus groups permitted us to have an in-depth insight into patients' views on the use of wearable technology.
- Osteoarthritis patients from diverse socioeconomically background participated in the study.
- This paper presents patients' views of wearable technology which to date have largely been ignored in technology development which accounts for the low uptake of these technologies.

Introduction

Wearable technology enables data gathering, mostly related to health and fitness, over extended periods of time unobtrusively. Recent advancements in miniaturised electronics in parallel with the growing number of technologically adept, amongst our population, have fostered an increased interest in wearable technology and its use for clinical purposes. This also stems by the recognised benefits for patients derived from long term monitoring in real life environments, and alongside rehabilitation with predicted reduction in healthcare costs.[1,2]

Rehabilitation based on exercise therapy is recommended for people living with osteoarthritis (OA).[3] Exercising conveys benefits for patients including reduced pain, enhanced joint function and quality of life.[4] OA patients however are reluctant to adhere to prescribed rehabilitation program over long time periods, compromising and limiting the benefits of this intervention.[5] Adherence increases during supervised exercise sessions but delivery of these is economically resourceful.[6] Among the reasons leading to poor adherence, the majority are related to organisational issues such as time and locations concerns and conflicts with everyday commitments.[6]

Psychosocial issues, poor motivation and lack of understanding of the rehabilitation content and perceived benefits further affect adherence.[6,7]

Wearable technology gathering information relating to patients' function could be used to provide feedback on accomplished goals in rehabilitation and inform treatment to maximise the benefit of care to each individual's specific need. Moreover being portable they will allow patient monitoring and guidance during exercise in their chosen environment overcoming organisational barriers to adherence. Despite the numerous wearable systems introduced in research scenarios, clinical adoption remains poor. Most of the studies conducted to date focus on the validation and use of wearable technology in the laboratory environment.[8,9,10] Moreover, the systems were confined to analysis and comparison of movement patterns between healthy and pathological populations with only few using the acquired data for feedback to patients and application in clinical practice.[8] When wearable technology was used to measure complex descriptors of human movement, such as joint kinematics variables, usually acquired with laboratory based equipment,[11,12,13] the complexity of the system was high questioning the usability by non-experts. Researchers have focused mainly on the engineering aspects of the technology whereas users' preferences have not been thoroughly considered in previous studies.[14] This in part explains the mismatch between the number of available technologies and their clinical adoption. Questions like: Are the measures collected and analysed within research practice beyond their mathematical correctness of easy interpretation for clinical use? How can they be employed by patients or clinicians in the management of disabilities? How can additional information change patients' attitude towards rehabilitation regimes? How would they like the extra information being utilised? Which form of feedback is preferred? How long would patients wear a device? How should it be? Most of these questions remain answered. Of the few studies that have explore patients requirements they have identified that patients advocate for systems to be small, with minimal interference with everyday tasks, and easy to use.[14,15,16] Few if any of the technologies developed to date reflect these requirements. Patients' and health professionals' preferences should be an integral part in the design process of the technology for it to progress into clinical practice and ultimately lead to patients' benefit. The questions reported above should be rigorously explored at an early stage of the design process.

We therefore have adopted a user-centred approach while developing a wearable technology to monitor knee functional status in patients affected by OA. The technology, in its prototype form, is characterised by a small flexible polymeric conductive strip embedded into a pair of leggings. Small wearable electronics are connected with the flexible sensor to allow wireless data acquisition. To foresee clinical translation of our technology and finalise its design, we interrogated patients and health professionals' views to guide the final design process. In this paper only patients' preferences are reported. This paper articulates on the requirements for the design process, while a separate paper will be focused on the social implications of the use of the technology in patients' lives. Although, this paper focuses on a particular technology, our custom built wearable system, it also allows generalisation of the findings to be applied to the design of wearable technology for rehabilitation purposes.

Methods

This was a qualitative study using focus groups to investigate patients' perspectives of wearable technology. The study protocol was approved by Imperial College Ethics Research Committee, and all participants provided written informed consent prior to taking part in the study. Patients were recruited from the Imperial College NHS Trust physiotherapy departments and local communities via poster advertisement. Twenty-one adults (19 females, 2 males, age range: 45-65 years old) suffering from osteoarthritis volunteered to take part in this study.

Each patient participated to one of four focus groups, which took place in a quiet room of the Imperial College Charing Cross Campus. The duration of each focus group was between 45 and 60 minutes. Two moderators (AB, EP) facilitated the discussion following a semi-structured topic guide. Table 1 shows the discussion flow stream with some associated questions. Each focus group begun with an introduction clarifying the format of the discussion and assuring the confidentiality of the information exchanged. The aims of the study were thoroughly described and an explanation of what wearable technology is and of the prototype developed was provided. The prototype of the flexible sensor unit and electronics components was shown to the group. The debate could then be articulated following topics in Table 1. Each focus group was audio-recorded and verbatim transcribed to allow subsequent analysis.

A thematic analysis was conducted on each focus group at respondent level using Framework Methodology[17]. Data analysis was conducted separately by the two moderators for cross-validation of the outputs from each focus group before grouping the results. Key themes were identified from which concepts could be developed. These were used for comparison among focus groups and for data mapping and interpretation. Data saturation was reached during analysing the fourth focus group hence recruitment was ceased. Classification of patients' responses in the different themes and concepts identified was done in Microsoft Excel spreadsheets.

Results

Only a few patients were aware of what wearable technology was and could provide valid examples of such systems. Providing a comprehensive explanation of what wearable technology is and by showing them the prototype we developed, allowed us to proceed in the discussion on their views and preferences.

The focus groups revealed recurrent concepts as these were expressed in the participants' views. The findings suggested five overarching themes patients associated with wearable technology, which are linked and intertwined: *practical issues, utility/functionality, patient-doctor communication, social impact and empowerment*. For the aim of this paper, which looks into design requirements for our wearable system, only the first two themes will be discussed in detail. *Practical issues* and *utility/functionality,* along with their associated concepts are presented in Figures 1 and 2.

Where quotes are reported the acronym FG followed by number 1 to 4 is used to indicate the focus groups, and F or M indicate gender, female or male respectively, of the participants at the focus group they attended.

Practical Issues

Patients associated wearable technology with practical issues and the impact of these in their life. The views expressed covered areas around sensor wearability, appearance, when to and how long for to wear the device, comfort and design, but also discreetness and privacy.

All patients expressed a positive attitude towards wearing our wearable technology, although different views emerged on how long for they would be willing to wear it. For instance, some participants were willing to wear it only for few hours per day and particularly when exercising:

'*I could envisage wearing it for a few hours a day, like when I was specifically doing exercises or something that was giving a lot of feedback either to me or to the clinician, but I'm not sure that I would be happy wearing it all day everyday*' (FG2, F1),

but some would also wear it over prolonged periods, as they acknowledged the advantage of a real situation monitoring:

'*It would be good information for the clinical team to get that [data collection], even when we're just walking down the street or whatever* ' (FG3, M1),

'*It's when you're actually out, trying to get on the bus or trying to get off the bus, that you really find that your weakest bits are going and so that would be able to identify some of those. So yes indeed, I would, is the answer to that*' (FG3, F1).

While wearing preferences during the day varied, all patients agreed that they would not wear the device at night and when relaxing.

Patients also discussed their preferences in the way wearable technology could be embedded in clothing. An issue patients noted with the current prototype was related to the integration of the sensor onto a pair of leggings and the unlikelihood of wearing leggings throughout a day. Rather, they stated the preference of having the sensor integrated into a band to be positioned around the knee:

'*I would prefer a band, something that's simple, just put it on quickly, take it off quickly, and get on with it*'. (FG4, M1).

Different design options which would accommodate and fit better with their lifestyle were also discussed*:*

'Do you think a distinction should be made between something you wear for exercise as opposed to something you'd wear all day because you're going on a walk? I guess people would be willing to put certain things on as part of exercising as opposed to day to day, all day' (FG1, F4).

Other patient preferences however had to do with skin colour and having the option for wearable technology to match it, so that it would be less visible and more discreet:

'*Personally I don't see it as a feature so I would want mine to be a nude colour. I'm not wearing it because I want it to be seen. I'm wearing it because I want to know how my knee's doing*' (FG4, F2).

The older participants were not concerned on the appearance of the technology, a finding which suggests that age played a role in their views:

'*I don't think in our ages orange fluorescent or spotted or striped will make a difference we don't need a fashion item'* (FG1, F4).

When discussing day-by-day use of the technology among the factors that would discourage patients to wear it would be if the system is '*uncomfortable*', '*itchy*', 'hot' and if it '*buckles up'*, '*bulges out'* and '*moves around'*, suggesting that a small size and weight would also facilitate acceptance:

'I think weight would be a major factor as to whether, how long you could cope with it' (FG2, F3);

'*If it's something small you're much more likely to wear it all day'* (FG4, F2).

Flexibility in the choice of clothing was another important issue highlighted in patients' views, as they would prefer to have a choice in what they wear, rather than having to put on a specific clothing item just because the sensor would be attached to it. For this reason, having the sensor embedded in leggings was not preferred.

'*I wouldn't want it in a pair of leggings because I wouldn't want you determining what I wore. I would want it as a band and then I'd wear what I want. It gives you flexibility as to what you wear it'* (FG4, F2).

Even more so when having specific clothing was associated with 'patient clothing', thus bringing in concerns of being 'labelled as patients'. Identity intrusion seemed to be an important demotivator:

'*I think if it's in a pair of leggings automatically you have become a patient. Do you know what I mean? You've become medicalised, whereas if you're just wearing a band then you're you with a band. It's a different thing and you keep your identity with the band*' (FG4, F3).

Likewise discreteness and maintaining one's privacy were therefore a major concern in the decision to wear a technology or not:

'*If you have something that draws everybody's attention to it you're going to be questioned about it and, to be honest with you, I don't really want to go through my medical history with the world*' (FG4, F1),

and particularly the appearance could bias their appreciation of the system '*if it looked too medical I would be less happy wearing it*'(FG2,F1).

Patients, hence, suggested paying attention on to the design to avoid the stereotype of a medical item but without looking '*too out of the ordinary*',

'*If it looked quite nice, it is a piece of clothing, I'd be much happier wearing it than if it looked like a kind of medical thing* '(FG2, F1).

There were also suggestions that the sensor should provide haptic feedback in the form of vibration or little impulse '*as a little reminder to telling you you're not walking in the correct way, come on, get it right, you'll find it easier in the long run'* (FG2, F3). However in doing so it should remain '*silent*' to not '*draw attention to yourself in anyway*' and hence be discreet.

Utility/Functionality

The majority of participants recognised the benefits of being monitored to obtain objective data on their joint functional status and it was acknowledged that this would be useful for themselves as well as for their clinicians. Their responses connected the use of wearable technology with issues such as the advantages of constant and objective monitoring, the impact that using this data would have on adherence and compliance, as well as managing their condition and reducing the relevant costs. These issues are developed below.

In terms of using themselves the data gathered with the use of wearable technology, patients were positively keen in obtaining more information on their condition so that they could too, observe their progress, monitor their status and guide their actions:

'*It would be very nice to have something which could actually inform you as to what you might be doing, how you might be moving incorrectly and how to correct that problem to really stop it before it becomes an issue*' (FG4, F3).

Interestingly, it was perceived that having clearer information about their health would motivate them to comply in a consistent way to treatment and improve their condition:

'*The thing is if we know we're doing something right, we're going to progress so much better, aren't we?*' (FG2, F3).

The participants also talked about adherence, as there were some who more directly saw the device as a way to adhere more with exercise regimes, once supervised sessions ceased, also facilitated by the ability to perform exercise at home:

'*I do them [the exercise], only because over the years I have now learnt that if I don't it gets very much worse. If I'd had something like that to prompt me ten years ago when I didn't do my exercises, I probably would have done them more and it would have been better. I may not have, but I have now become quite diligent, so that's OK, but I think it might have helped to have had something like that when I was less diligent*' (FG2, F1);

'*So we can do it at home. We can do it by ourselves really*' (FG3, F2).

The technology was further seen as an alternative way to provide supervision when away from a clinical setting to '*reinforce what you learn and helping you to remember how to do it'* and hence maintain achieved benefits without *slip back into bad habits* ':

'*The physio tells me that I'm walking too much on one side or the other side of my foot, and I do that, but I'm simply myself not aware of it, so if there was something that was just reminding me, that would be brilliant'* (FG2, F1).

Patients also discussed the advantages of having an ongoing data gathering of their function, especially when they would be away from their clinicians, and how this could prove beneficial in their subsequent visits in terms of management and planning ahead:

'*I mean it's like having a physiotherapist by your side so when you do go and see her, him or her, they've got all this, they've been there with you and so they can say, well, this is what you were doing, I was there. Not really, but sort of, because of the machine.*' (FG3, F1).

In relation to how participants perceived the usefulness of objective data in the treatment decision-making process, it was felt that objective information would help them during the consultation by providing a clear explanation of their current status beyond their subjective description:

'*So having something which can be more precise rather than you trying to explain is I think a very attractive step forward really because it gives proper data rather than your understanding of what it is you're doing*' (FG4, F3),

and would also provide clinicians with extra information to tailor treatment to each patient:

'*Help the physio to give you the best exercises which are geared just for your needs*' (FG1, F1).

On a more personal level, there were also thoughts that the use of the technology could help patients to make a more effective use of their time during the rehabilitation process:

'*I think it could also save the need to attend a hospital, doctor or physio appointment, if the data could be transmitted using the internet, downloaded and transmitted that way, because I know they do it for, particularly in remote communities. They do ECGs and all that remotely. The data could be sent to your healthcare professional, and they could say, yeah, that's fine, we don't need to see you or I think perhaps we'd better have a, you'd better come and see us*' (FG2, F3).

Analogously the accessibility of objective information on function could speed up the assessment process:

'*A quicker, less pain, hopefully, at the end you will have more information, your problem will be sorted out quicker, whereas if you're going the traditional route you're talking about months sometimes.*'(FG4, F3).

Participants also highlighted how the use of technology could, in addition to saving time, reduce costs for themselves:

'*I'd say cost and/or time because, time is a personal cost and you can spend hours waiting for X-rays, waiting, going to see physios, waiting, going to see your GP who spends ages for his letter before it gets to the consultant who's away for three* *months who when you finally, all of that is time and it's tedious and it's phone calls and it's, so I think time and cost*.' (FG4, F2);

as well as for the healthcare system:

'*If a patient, I don't know what it costs, is it £600 a visit or something? Well, that's a lot of money saved (by healthcare system) if you're just cutting out a few visits, money that could be used for everybody's benefit'* (FG2, F3).

The cost of the actual system, although with suggestions to be reasonably inexpensive, was not seen as a limitation to its adoption:

'Well if it's going to help me I don't care what it costs, to be honest. It's to my benefit. What's my health worth to me?' (FG3, M1).

Discussion

This study investigated patients' preferences in relation to wearable technology and how they envisaged its optimal design in relation to use. Overall patients showed a positive response towards the use of technology within a rehabilitation context and recognised the benefits that they could obtain from its use.

The main determinants for acceptance of a wearable system were identified in its appearance and comfort in wearing it. Design requirements were discussed in detail. Among these, patients expressed the necessity for a wearable system to be small, stable, lightweight, and discrete to enable them to wear their usual outfit with no constraints and avoid identity intrusion. In this regard, integration into a pair of leggings for daily use was discouraged. As for how long to wear it, all patients agreed to not wearing the system over night and most advocated its use during exercising. However, a few patients recognised the benefits of wearing it whilst out and about. This is in line with clinicians' and researchers' beliefs of the importance of data in real life scenarios of daily activities and most of all the need of objective data over self-reported measures of function to tailor and optimise treatment provision.[1,18] When patients will wear the system is key in identifying the functional variables (e.g. knee range of motion, distance, step numbers) that could be acquired over the defined period that will be useful for clinical applications, encompassing patients and clinicians use. Health professionals were also interviewed but their requirements will be discussed in a separate paper. Having both views and integrating them during the final design stage of our system will maximise the chance of clinical uptake.

As for how to use the wearable technology participants recognised the benefits of using the device as a system for supporting themselves over their rehabilitative course. In particular, they indicated the usefulness of the system in monitoring their function, encouraging and motivating them exercising, providing virtual supervision, correcting their movement and as a new mean of communication with health professionals. They could also envisage a more effective use of their time and money derived by the additional information available from the system.

The design requirements identified, agree with that described in the current literature however, there was a need identified to explore patients preferences in relation to wearable technology as a need in this area has been highlighted.[14] Previous studies reported on health-related information acquisition via portable devices or home sensors rather than functional monitoring,[14,19,20, 21] considered a population other than osteoarthritis,[14,20, 22,23] identified design requirements without asking patients for their preference,[16] or used a questionnaire approach rather than an open debate. It is known that focus groups permit a deeper investigation of participants' views.[14,15] There have been brief reports on patients' experience after using a particular device but this focused more on technical aspects.[24] In contrast to previous studies, the cost of the system itself was not seen as a factor to limit adoption since it was perceived that the benefits outweighed the costs. [14,25] Our patients could foresee a long-term advantage in using the device as a way to employ NHS resources more effectively for '*everybody's benefit'*. Moreover, beyond the design requirements of the device, we also asked different questions from previous studies, including how patients felt about the use of a wearable system for their condition and how they would fit it in their routine and use it for their benefits.

The fact that participants perceived the use of technology as an incentive to adhere to rehabilitation regimes supports current trends of finding effective approaches to motivate patients exercising and ensure continuity of rehabilitation in the long term to maximise its success.[26,27,28] The use of wearable technology could offer a novel way to deliver rehabilitation for OA patients when away from the clinic whilst ensuring virtual supervision via aerial data sharing with clinicians. This, however, is only possible if new developed systems align with users' preferences.

The next step will be therefore to finalise the design of our system in accordance with the outputs of this study and health professionals interviews. Secondly, clinical trials will be conducted to prove the effectiveness of this technology in OA patient's management.

There were no restrictions in participants' recruitment with regards to their background, financial capacity and ethnicity to provide a general view of our population. However, participants were only recruited within the London area and this could represent a limitation of the study.

In conclusion, this paper presents a qualitative study aimed to investigate patients' preferences of the design and usage of wearable technology. Outputs from this study should guide the design of wearable technology to maximise user acceptance. Participants were positive and supportive for the use of technology as a rehabilitation aid that should be taken into account in the clinical environment. This should encourage developer and researcher to address patients requirements to accelerate clinical translation and hence patients' benefits.

Contributors: EP, AB, and AHM conceived and designed the study. EP and AB conducted the focus groups and analysed and interpreted the data. AHM provided guidance on the study design and analysis. EP drafted the manuscript. All authors read, edited, and approved the final version of the manuscript. All authors had full access to all of the data in the study and can take responsibility for the integrity of the data and the accuracy of the data analysis.

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Competing interests: The authors declare that there are no conflicts of interest. All authors have completed the ICMJE uniform disclosure form at www.icmje.org/coi_disclosure.pdf (available on request from the corresponding author) and declare: no support from any organisation for the submitted work other than those detailed above; no financial relationships with any organisations that might have an interest in the submitted work in the previous three years; no other relationships or activities that could appear to have influenced the submitted work.

Ethical approval: The study was reviewed and approved by Imperial College London Ethics Research Committee. All participants gave written informed consent.

Declaration of transparency: AHM (study guarantor), on behalf of all the authors, affirms that this manuscript is an honest, accurate, and transparent account of the study being reported; that no important aspects of the study have been omitted; and that any discrepancies from the study as planned (and, if relevant, registered) have been explained.

Data sharing: No additional data available.

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Figure legends

Figure 1. Patients' views on Practical Issues.

Figure 2 Patients' views on Utility/Functionality.

Table

Table 1. Focus group discussion semi-structured topic guide

I. *Introduction*

- Moderators and participants introduce themselves
- Clarification on the format of the focus group and aim
- Assurance of confidentiality

II. *Wearable technology*

- Definition of wearable technology and demonstration of prototype developed
- Ask if they know of any wearable devices
- Ask if they like this kind of technology and if so why:
  Would you use it?
  How often will you be willing to wear it? Daily?
- Ask what they don't like about this kind of technology and if so why:
  What would put you off in using such technologies?

III. *Feelings about wearable medical technology*

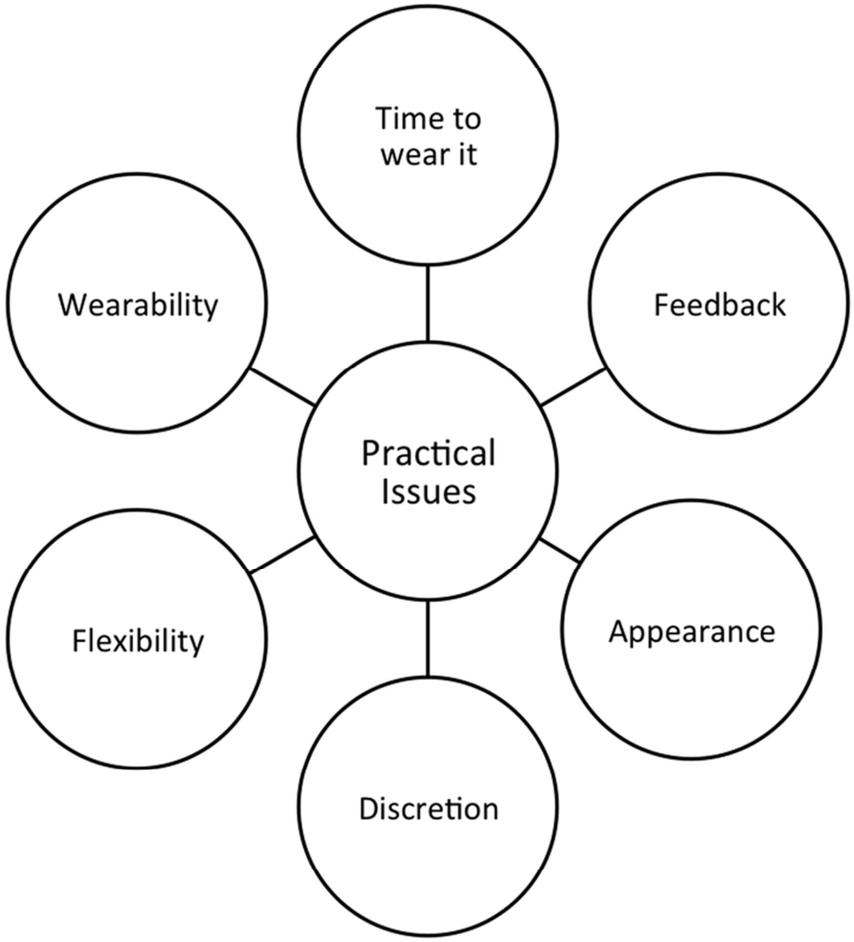
- How are you doing in general in dealing with your disease?
- Do you think wearable technology would help your current situation? If so, how?
- How do you view this technology in comparison to conventional forms of treatment? And why?
- Do you see yourself using this kind of technology? If so, how?
- Would you use this technology to monitor your rehabilitation practice in your home rather than going to a clinical practice to attend rehabilitation classes?

IV. *Impact on relationships*

- If you did decide to use this technology how do you think it would impact on your daily interactions with others?
- Do you think it would change how you interact with medical professionals?
- Do you think it would affect your home life/working environment (if applicable)?
- What are your views on data privacy?

V. *Closing*

- Is there anything else you would like to say about what we have discussed?
- Thank everyone for their time and useful participation



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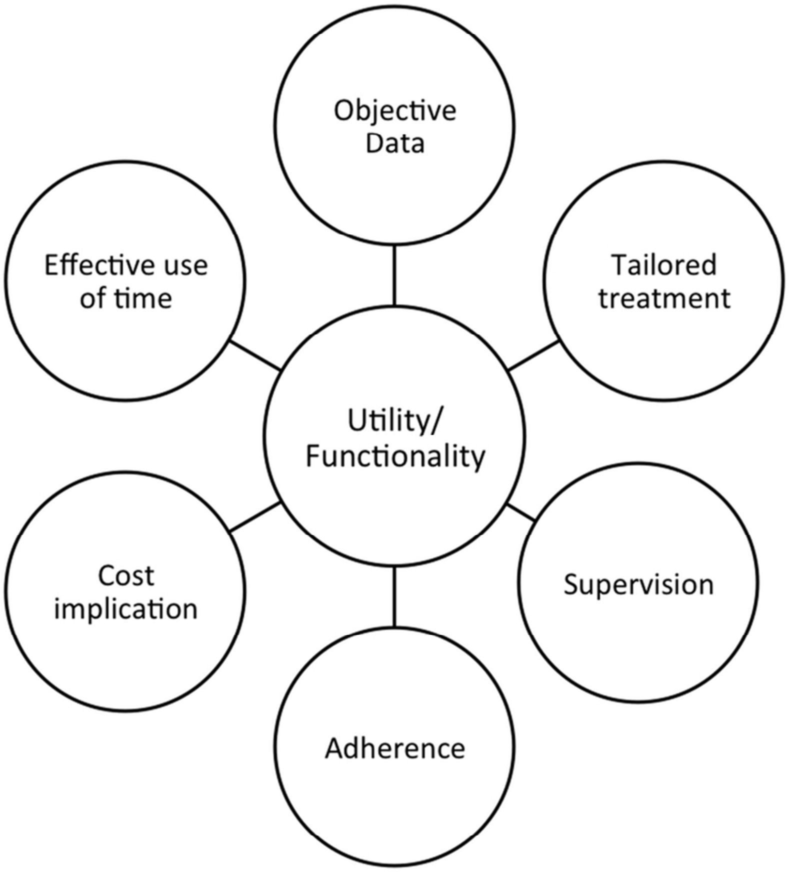

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A Knee Monitoring Device and the Preferences of Patients Living with Osteoarthritis: A qualitative study

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A Knee Monitoring Device and the Preferences of Patients Living with Osteoarthritis: A qualitative study

Enrica Papi, Athina Belsi, Alison H. McGregor

Department of Surgery and Cancer, Imperial College London, Charing Cross Hospital, W6 8RF, London, UK Enrica Papi research associate Department of Surgery and Cancer, Imperial College London, St Mary's Campus, W2 1BL London, UK Athina Belsi senior teaching fellow Department of Surgery and Cancer, Imperial College London, Charing Cross Hospital, W6 8RF, London, UK Alison H. McGregor professor

Correspondence to: Enrica Papi e.papi@imperial.ac.uk, +44(0)20 3313 8833

Abstract

Objectives: To identify osteoarthritis patients' perspective, in particular design requirements and mode of use, of wearable technology to support the rehabilitation pathway. This study is part of a user-centred design approach adopted to develop a rehabilitation tool for osteoarthritis patients.

Design: Qualitative study using a focus group approach; data management via a thematic analysis of patients' responses.

Participants: Twenty-one osteoarthritis patients (Age range: 45-65 years old) participated in one of four focus groups. Recruitment continued until data saturation.

Setting: The study was conducted in a University setting.

Results: Main determinants of user acceptance of a wearable technology were appearance and comfort during use. Patients were supportive of the use of wearable technologies during rehabilitation and could recognise their benefit as monitors for their progress, incentives to adhere to exercise, and tools for more informed interaction with clinicians.

Conclusions: This paper should encourage adoption and development of wearable technology to support rehabilitation of osteoarthritis patients. It is pivotal that technological development takes into account patients' views in that it should be small, light, discrete, not "appear medical" or challenge the identity of the user. Derived data should be available to both patients and clinicians. Furthermore, wearable technologies should be developed to operate in two modes: for exercise guidance and assessment only and for unobtrusive everyday monitoring. The

information obtained from this study should guide the design of new technologies and support their use in clinical practice.

Strengths and limitations of this study

- Focus groups permitted us to have an in-depth insight into patients' views on the use of wearable technology.
- Osteoarthritis patients from diverse socioeconomically background participated in the study.
- Participants were not able to test the technology.
- This paper presents patients' views of wearable technology which to date have largely been ignored in technology development which accounts for the low uptake of these technologies.

Introduction

Wearable technologies, defined as portable devices that can be embedded in the user's outfit as part of the clothing or an accessory, enables data gathering, mostly related to health and fitness, over extended periods of time unobtrusively.[1,2] Recent advancements in miniaturised electronics in parallel with the growing number of technologically adept, amongst our population, have fostered an increased interest in wearable technology and their use for clinical purposes. This is further supported by the recognised benefits derived from long-term monitoring of patients in real life environments, and the predicted reduction in healthcare costs following adoption of such technologies.[1,2]

Rehabilitation based on exercise therapy is recommended for people living with osteoarthritis (OA).[3] Exercising conveys benefits for patients including reduced pain, enhanced joint function and quality of life.[4] OA patients however are reluctant to adhere to prescribed rehabilitation program over long time periods, compromising and limiting the benefits of this intervention.[5] Adherence increases during supervised exercise sessions but delivery of these is economically resourceful.[6] Among the reasons leading to poor adherence, the majority are related to organisational issues such as time and locations concerns and conflicts with everyday commitments.[6] Psychosocial issues, poor motivation and lack of understanding of the rehabilitation content and perceived benefits further affect adherence.[6,7]

Wearable technology gathering information relating to patients' function could potentially be used to provide feedback on accomplished goals in rehabilitation and inform treatment to maximise the benefit of care to each individual's specific need. Moreover being portable they will allow patient monitoring and guidance during exercise in their chosen environment overcoming organisational barriers to adherence. Despite the numerous wearable systems introduced in research scenarios, clinical adoption remains poor.[8] Most of the studies conducted to date have focused on the validation and use of wearable technology in the laboratory environment.[8,9,10] Moreover, the systems were confined to analysis and comparison of movement patterns between healthy and pathological populations with only few using the acquired data for feedback to patients and application in clinical practice.[8] When wearable technology was used to measure complex descriptors of human movement, such as joint kinematics variables, usually acquired with laboratory based equipment,[11,12,13] the systems used were cumbersome and difficult to operate by non-experts. Researchers have focused mainly on the engineering aspects of the technology with users' preferences receiving little attention.[14] This in part explains the mismatch between the number of available technologies and their clinical adoption. Questions like: Are the measures collected and analysed within research practice beyond their mathematical correctness of easy interpretation for clinical use?; How can they be employed by patients or clinicians in the management of disabilities?; How can additional information change patients' attitude towards rehabilitation regimes?; How would they like the extra information being utilised?; Which form of feedback is preferred? How long would patients wear a device?; And What should it look like?; remain answered. The few studies that have explored patients requirements have identified that patients want systems to be small, with minimal interference with their everyday tasks, and be easy to use.[14,15,16] Few if any of the technologies developed to date reflect these requirements. Patients' and health professionals' preferences should be an integral part in the design process of the technology for it to progress into clinical practice and ultimately lead to patient benefit. The questions reported above should be rigorously explored at an early stage of the design process.

We therefore have adopted a user-centred approach while developing a wearable technology to monitor knee functional status in patients affected by OA. The technology, in its prototype form,[17] is characterised by a small flexible polymeric conductive strip embedded into a pair of leggings. Small wearable electronics are connected with the flexible sensor to allow wireless data acquisition. To foresee clinical translation of our technology and finalise its design, we discussed with patients their views, preferences and expected use of the technology. This paper articulates the requirements for the design process. Although, this paper focuses on a particular technology, our custom built wearable system, it also allows generalisation of the findings to be applied to the design of wearable technology for rehabilitation purposes, in particular in relation to patients' intended use.

Methods

This was a qualitative study using focus groups to investigate patients' perspectives of wearable technology. The study protocol was approved by Imperial College Ethics Research Committee (Ref: ICREC_13_2_6), and all participants provided written informed consent prior to taking part in the study. Patients were recruited from the Imperial College NHS Trust physiotherapy departments and local communities via poster advertisement. Twenty-one adults (19 females, 2 males, age range: 45-65 years old) suffering from OA volunteered to take part in this study. Participants were sampled based on being diagnosed with OA through clinical assessment or imaging, undergoing rehabilitation and having a good understanding of written and spoken English. They were excluded from the study if they presented with neurological conditions that may have influenced their cognitive function.

Each patient participated in one of four focus groups, which took place in a quiet room of the Imperial College Charing Cross Campus. The duration of each focus group was between 45 and 60 minutes. Two moderators (AB, EP) facilitated the discussion following a semi-structured topic guide. Table 1 shows the discussion flow stream with some associated questions. Each focus group begun with an introduction clarifying the format of the discussion and assuring the confidentiality of the information exchanged. The aims of the study were thoroughly described and an explanation of what wearable technology is and of the prototype developed was provided. The prototype of the flexible sensor unit and electronics components were shown to the group. The debate could then be articulated following topics in Table 1. Each focus group was audio-recorded and verbatim transcribed to allow subsequent analysis.

A thematic analysis was conducted on each focus group at respondent level using Framework Methodology[18]. Data analysis was conducted separately by the two moderators for cross-validation of the outputs from each focus group before grouping the results. Key themes were identified from which concepts could be developed. These were used for comparison among focus groups and for data mapping and interpretation. Data saturation was reached during analysing the fourth focus group hence recruitment was ceased. Classification of patients' responses in the different themes and concepts identified was done in Microsoft Excel spreadsheets.

Results

Only a few patients (9/21) were aware of what wearable technology was and could provide valid examples of such systems. Providing a comprehensive explanation of what wearable technology is and by showing them the prototype we developed, allowed us to proceed in the discussion on their views and preferences.

The focus groups revealed recurrent concepts as these were expressed in the participants' views. The findings suggested five overarching themes patients associated with wearable technology, which are linked and intertwined: *practical issues, utility/functionality, patient-doctor communication, social impact and empowerment*. For the aim of this paper, which looks into design requirements for our wearable system, only the first two themes will be discussed in detail. *Practical issues* and *utility/functionality,* along with their associated concepts are presented in Figures 1 and 2.

Where quotes are reported the acronym FG followed by number 1 to 4 is used to indicate the focus groups, and F or M indicate gender, female or male respectively, of the participants at the focus group they attended.

Practical Issues

Patients associated wearable technology with practical issues and the impact of these on their life. The views expressed covered areas around sensor wearability, appearance, when to- and how long for- to wear the device, comfort and design, but also discreetness and privacy.

All patients expressed a positive attitude towards wearing our wearable technology, although different views emerged on how long they would be willing to wear it. For instance, some participants were willing to wear it only for few hours per day, particularly when exercising:

'*I could envisage wearing it for a few hours a day, like when I was specifically doing exercises or something that was giving a lot of feedback either to me or to the clinician, but I'm not sure that I would be happy wearing it all day everyday*' (FG2, F1),

but some would also wear it over prolonged periods, as they acknowledged the advantage of a real situation monitoring:

'*It would be good information for the clinical team to get that [data collection], even when we're just walking down the street or whatever* ' (FG3, M1),

'*It's when you're actually out, trying to get on the bus or trying to get off the bus, that you really find that your weakest bits are going and so that would be able to identify some of those. So yes indeed, I would, is the answer to that*' (FG3, F1).

While wearing preferences during the day varied, all patients agreed that they would not wear the device at night and when relaxing.

Patients also discussed their preferences in the way wearable technology could be embedded in clothing. An issue patients noted with the current prototype was related to the integration of the sensor onto a pair of leggings and the unlikelihood of wearing leggings throughout a day. Rather, they stated the preference of having the sensor integrated into a band to be positioned around the knee:

'*I would prefer a band, something that's simple, just put it on quickly, take it off quickly, and get on with it*'. (FG4, M1).

Different design options which would accommodate and fit better with their lifestyle were also discussed*:*

'Do you think a distinction should be made between something you wear for exercise as opposed to something you'd wear all day because you're going on a walk? I guess people would be willing to put certain things on as part of exercising as opposed to day to day, all day' (FG1, F4).

Other patient preferences however had to do with skin colour and having the option for wearable technology to match it, so that it would be less visible and more discreet:

'*Personally I don't see it as a feature so I would want mine to be a nude colour. I'm not wearing it because I want it to be seen. I'm wearing it because I want to know how my knee's doing*' (FG4, F2).

The older participants were not concerned on the appearance of the technology, a finding which suggests that age played a role in their views:

'*I don't think in our ages orange fluorescent or spotted or striped will make a difference we don't need a fashion item'* (FG1, F4).

When discussing day-by-day use of the technology among the factors that would discourage patients to wear it would be if the system is '*uncomfortable*', '*itchy*', 'hot' and if it '*buckles up'*, '*bulges out'* and '*moves around'*, suggesting that a small size and weight would also facilitate acceptance:

'I think weight would be a major factor as to whether, how long you could cope with it' (FG2, F3);

'*If it's something small you're much more likely to wear it all day'* (FG4, F2).

Flexibility in the choice of clothing was another important issue highlighted in patients' views, as they would prefer to have a choice in what they wear, rather than having to put on a specific clothing item just because the sensor would be attached to it. For this reason, having the sensor embedded in leggings was disliked.

'*I wouldn't want it in a pair of leggings because I wouldn't want you determining what I wore. I would want it as a band and then I'd wear what I want. It gives you flexibility as to what you wear it'* (FG4, F2).

It was raised that specific clothing could be identified as 'patient clothing', thus bringing in concerns of being 'labelled as patients'. Identity intrusion seemed to be an important demotivator:

'*I think if it's in a pair of leggings automatically you have become a patient. Do you know what I mean? You've become medicalised, whereas if you're just wearing a band then you're you with a band. It's a different thing and you keep your identity with the band*' (FG4, F3).

Likewise discreteness and maintaining one's privacy were therefore a major concern in the decision to wear a technology or not:

'*If you have something that draws everybody's attention to it you're going to be questioned about it and, to be honest with you, I don't really want to go through my medical history with the world*' (FG4, F1),

and particularly the appearance could bias their appreciation of the system '*if it looked too medical I would be less happy wearing it*'(FG2,F1).

Patients, hence, suggested paying attention on to the design to avoid the stereotype of a medical item but without looking '*too out of the ordinary*', '*If it looked quite nice, it is a piece of clothing, I'd be much happier wearing it than if it looked like a kind of medical thing* '(FG2, F1).

There were also suggestions that the sensor should provide haptic feedback in the form of vibration or little impulse '*as a little reminder to telling you you're not walking in the correct way, come on, get it right, you'll find it easier in the long run'* (FG2, F3). However in doing so it should remain '*silent*' to not '*draw attention to yourself in anyway*' and hence be discreet.

Utility/Functionality

The majority of participants recognised the benefits of being monitored to obtain objective data on their joint functional status and it was acknowledged that this would be useful for themselves as well as for their clinicians. Their responses connected the use of wearable technology with issues such as the advantages of constant and objective monitoring, the impact that using this data would have on adherence and compliance, as well as managing their condition and reducing the relevant costs. These issues are developed below.

In terms of using themselves the data gathered with the use of wearable technology, patients were positively keen in obtaining more information on their condition so that they could observe their progress, monitor their status and guide their actions:

'*It would be very nice to have something which could actually inform you as to what you might be doing, how you might be moving incorrectly and how to correct that problem to really stop it before it becomes an issue*' (FG4, F3).

Interestingly, it was perceived that having clearer information about their health would motivate them to comply in a consistent way to treatment and improve their condition:

'*The thing is if we know we're doing something right, we're going to progress so much better, aren't we?*' (FG2, F3).

The participants also talked about adherence, as there were some who more directly saw the device as a way to adhere more with exercise regimes, once supervised sessions ceased, also facilitated by the ability to perform exercise at home:

'*I do them [the exercise], only because over the years I have now learnt that if I don't it gets very much worse. If I'd had something like that to prompt me ten years ago when I didn't do my exercises, I probably would have done them more and it would have been better. I may not have, but I have now become quite diligent, so that's OK, but I think it might have helped to have had something like that when I was less diligent*' (FG2, F1);

'*So we can do it at home. We can do it by ourselves really*' (FG3, F2).

The technology was seen as an alternative way to provide supervision when away from a clinical setting to '*reinforce what you learn and helping you to remember how to do it'* and hence maintain achieved benefits without *slip back into bad habits* ':

'The physio tells me that I'm walking too much on one side or the other side of my foot, and I do that, but I'm simply myself not aware of it, so if there was something that was just reminding me, that would be brilliant' (FG2, F1).

Patients also discussed the advantages of having an ongoing data gathering of their function, especially when they would be away from their clinicians, and how this could prove beneficial in their subsequent visits in terms of management and planning ahead:

'*I mean it's like having a physiotherapist by your side so when you do go and see her, him or her, they've got all this, they've been there with you and so they can say, well, this is what you were doing, I was there. Not really, but sort of, because of the machine.*' (FG3, F1).

In relation to how participants perceived the usefulness of objective data in the treatment decision-making process, it was felt that objective information would help them during the consultation by providing a clear explanation of their current status beyond their subjective description:

'*So having something which can be more precise rather than you trying to explain is I think a very attractive step forward really because it gives proper data rather than your understanding of what it is you're doing*' (FG4, F3),

and would also provide clinicians with extra information to tailor treatment to each patient:

'*Help the physio to give you the best exercises which are geared just for your needs*' (FG1, F1).

On a more personal level, there were also thoughts that the use of the technology could help patients to make a more effective use of their time during the rehabilitation process:

'*I think it could also save the need to attend a hospital, doctor or physio appointment, if the data could be transmitted using the internet, downloaded and transmitted that way, because I know they do it for, particularly in remote communities. They do ECGs and all that remotely. The data could be sent to your healthcare professional, and they could say, yeah, that's fine, we don't need to see you or I think perhaps we'd better have a, you'd better come and see us*' (FG2, F3).

Analogously the accessibility of objective information on function could speed up the assessment process:

'*A quicker, less pain, hopefully, at the end you will have more information, your problem will be sorted out quicker, whereas if you're going the traditional route you're talking about months sometimes*.'(FG4, F3).

Participants also highlighted how the use of technology could, in addition to saving time, reduce costs for themselves:

'*I'd say cost and/or time because, time is a personal cost and you can spend hours waiting for X-rays, waiting, going to see physios, waiting, going to see your GP who spends ages for his letter before it gets to the consultant who's away for three months who when you finally, all of that is time and it's tedious and it's phone calls and it's, so I think time and cost*.' (FG4, F2);

as well as for the healthcare system:

'*If a patient, I don't know what it costs, is it £600 a visit or something? Well, that's a lot of money saved (by healthcare system) if you're just cutting out a few visits, money that could be used for everybody's benefit'* (FG2, F3).

The cost of the actual system, although with suggestions to be reasonably inexpensive, was not seen as a limitation to its adoption:

'Well if it's going to help me I don't care what it costs, to be honest. It's to my benefit. What's my health worth to me?' (FG3, M1).

Discussion

This study investigated patients' preferences in relation to wearable technology and how they envisaged its optimal design in relation to use. Overall patients showed a positive response towards the use of technology within a rehabilitation context and recognised the benefits that they could obtain from its use.

The main determinants for acceptance of a wearable system were identified in its appearance and comfort in wearing it. Design requirements were discussed in detail.

Among these, patients expressed the necessity for a wearable system to be small, stable, lightweight, and discrete to enable them to wear their usual outfit with no constraints and no identity intrusion. In this regard, integration into a pair of leggings for daily use was discouraged. As for how long to wear it, all patients agreed to not wearing the system over night and most advocated its use during exercising. However, a few patients recognised the benefits of wearing it whilst out and about. This is in line with clinicians' and researchers' beliefs of the importance of data in real life scenarios of daily activities and most of all the need of objective data over self-reported measures of function to tailor and optimise treatment provision.[1,19] How and when patients will wear the system will be key in identifying the functional variables (e.g. knee range of motion, distance, step numbers, exercise performance) that could be acquired over the defined period and the mode of feedback (e.g. real-time, progress plot) that will be useful for clinical applications, encompassing both patient and clinician use.

With regard to how to use the wearable technology participants recognised the benefits of using the device as a system for supporting themselves over their rehabilitative course. In particular, they indicated the usefulness of the system in monitoring their function, encouraging and motivating them exercising, providing virtual supervision, correcting their movement and as new means of communication with health professionals. The fact that participants perceived the use of technology as an incentive to adhere to rehabilitation regimes supports current trends of finding effective approaches to motivate patients exercising and ensure continuity of rehabilitation in the long-term to maximise its success.[20,21,22] The use of wearable technology could offer a novel way to deliver rehabilitation for OA patients at home whilst ensuring virtual supervision via aerial data sharing with clinicians. This, however, is only possible if new developed systems align with users' preferences. Patients could also envisage a more effective use of their time and money derived by the additional information available from the system. All participants agreed that the information collected would give them more control over their condition and permit their clinicians to be more informed about their problems facilitating individualised treatment planning.

Our findings suggest the need for a sensor targeted to exercise guidance and assessment solely and a sensor that could also allow, unobtrusive monitoring in everyday environments. This implies different design and technical specifications to take into account in the developmental stage along with a choice of clinical outputs. Issues of data storage, transmission, visual feedback either in real time or in the form of periodical report, accuracy and clinical utility of the outputs measured, all need to be fully addressed for the technology to prove useful and meet users' requirements. Moreover, some participants also suggested the use of haptic feedback to correct their movement; this will add another challenge to developers. Vibration motors used for gait retraining over a 6-week period have been shown to be effective in reducing knee adduction moment and pain in a small knee OA cohort with results retained at one month follow-up.[23] Therefore, there is great potential to use technology to improve outcomes in patients with OA of the knee. Such potential will increase if the findings from our study are considered in finalising the technology along with clinical trials to establish optimal OA treatment prescription, delivery and management in the long-term. The use of technology has been speculated to lead to new evolving patient-driven healthcare models where the information available will empower the patients in being more engaged on their conditions, as our participants also revealed, but this will also influence how clinicians deliver treatment and use the information collected to make new recommendations.[24]

The design requirements identified, agree with those outlined in the current literature but addressed the perceived need in the literature to explore patients' preferences in relation to wearable technology.[14] Previous studies reported on health-related information acquisition via portable devices or home sensors rather than functional monitoring,[14,25,26,27,28] considered a population other than osteoarthritis,[14,26, 28,29,30,31] identified design requirements without asking patients for their preference,[16] or used a questionnaire approach rather than an open debate. It is known that focus groups permit a deeper investigation of participants' views.[14,15] There have been brief reports on patients' experience after using a particular device but these focused more on technical aspects.[32,33] In contrast to previous studies, the cost of the system itself was not seen as a factor to limit adoption since it was perceived that the benefits outweighed the costs. [14,34] Our patients could foresee a long-term advantage in using the device as a way to employ NHS resources more effectively for '*everybody's benefit'*. Moreover, beyond the design requirements of the device, we also asked different questions from previous studies, including how patients felt about the use of a wearable system for their condition and how they would fit it in their routine and use it to their benefit. This is where commercial wearable devices fall short: they are well-designed in terms of aesthetics and usability but are mainly designed to track fitness, mostly in healthy people and sports-addicts, they lack the clinical interlink in tracking functional outcomes and lack the understanding of specific clinical population needs.[31] Whereas those devices could be used as an incentive to keep people active, patients asked for direct measures of knee function and performance rather than general activity levels or calories burned which are more commonly obtained from devices currently on the market. Moreover, when used in a randomized clinical trial, one of these market devices did not improve activity levels over a control group,[35] highlighting once more the need for effective solutions to help patients adhere to rehabilitation regimes and address users' needs in relation to technology. For the development of our technology we adopted a user-centred and holistic approach, previously recommended,[36] to enrich the technology value and meet user requirements, thus facilitating future uptake.

Although we focused on an OA population our findings are transferable to other conditions where pain and joints movement are the focus of rehabilitation. Studies involving chronic pain have highlighted similar outcomes.[28,31] However despite the main concepts being similar, the clinical outputs may change; therefore each technology should be tailored to each clinical presentation, adhere to clinical guidelines in the assessment of patient performance and consider emotional states associated with the condition considered when defining goals.[31] For example, our device could permit monitoring of performance-based tests that are recognised by the clinical community as a measure to monitor OA patients' function. [37] Similarly these could be adjusted to other conditions.

There were no restrictions in participants' recruitment with regards to their background, financial capacity and ethnicity to provide a general view of our population. Our sample represents a typical OA group, aged 45 and over, with the majority being female.[38] However, participants were only recruited within the London area and were unable to try out the devices, which are limitations of the study.

In conclusion, this paper presents a qualitative study aimed to investigate patients' preferences of the design and usage of wearable technology. Outputs from this study should guide the design of wearable technology to maximise user acceptance. Participants were positive and supportive for the use of technology as a rehabilitation aid that should be taken into account in the clinical environment. This should encourage developer and researcher to address patients requirements to accelerate clinical translation and hence patients' benefits.

Contributors: EP, AB, and AHM conceived and designed the study. EP and AB conducted the focus groups and analysed and interpreted the data. AHM provided guidance on the study design and analysis. EP drafted the manuscript. All authors read, edited, and approved the final version of the manuscript. All authors had full access to all of the data in the study and can take responsibility for the integrity of the data and the accuracy of the data analysis.

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Competing interests: The authors declare that there are no conflicts of interest. All authors have completed the ICMJE uniform disclosure form at www.icmje.org/coi_disclosure.pdf (available on request from the corresponding author) and declare: no support from any organisation for the submitted work other than those detailed above; no financial relationships with any organisations that might have an interest in the submitted work in the previous three years; no other relationships or activities that could appear to have influenced the submitted work.

Ethical approval: The study was reviewed and approved by Imperial College London Ethics Research Committee. All participants gave written informed consent.

Declaration of transparency: AHM (study guarantor), on behalf of all the authors, affirms that this manuscript is an honest, accurate, and transparent account of the study being reported; that no important aspects of the study have been omitted; and that any discrepancies from the study as planned (and, if relevant, registered) have been explained.

Data sharing: No additional data available.

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Figure legends

Figure 1. Patients' views on Practical Issues.

Figure 2 Patients' views on Utility/Functionality.

Table

Table 1. Focus group discussion semi-structured topic guide

I. *Introduction*

- Moderators and participants introduce themselves
- Clarification on the format of the focus group and aim
- Assurance of confidentiality

II. *Wearable technology*

- Definition of wearable technology
- Ask if they know of any wearable devices and demonstration of prototype developed
- Ask if they like this kind of technology and if so why:
  - Would you use it?
  - How often will you be willing to wear it? Daily?
- Ask what they don't like about this kind of technology and if so why:
  - What would put you off in using such technologies?

III. *Feelings about wearable medical technology*

- How are you doing in general in dealing with your disease?
- Do you think wearable technology would help your current situation? If so, how?
- How do you view this technology in comparison to conventional forms of treatment? And why?
- Do you see yourself using this kind of technology? If so, how?
- Would you use this technology to monitor your rehabilitation practice in your home rather than going to a clinical practice to attend rehabilitation classes?

IV. *Impact on relationships*

- If you did decide to use this technology how do you think it would impact on your daily interactions with others?
- Do you think it would change how you interact with medical professionals?
- Do you think it would affect your home life/working environment (if applicable)?
- What are your views on data privacy?

V. *Closing*

- Is there anything else you would like to say about what we have discussed?
- Thank everyone for their time and useful participation

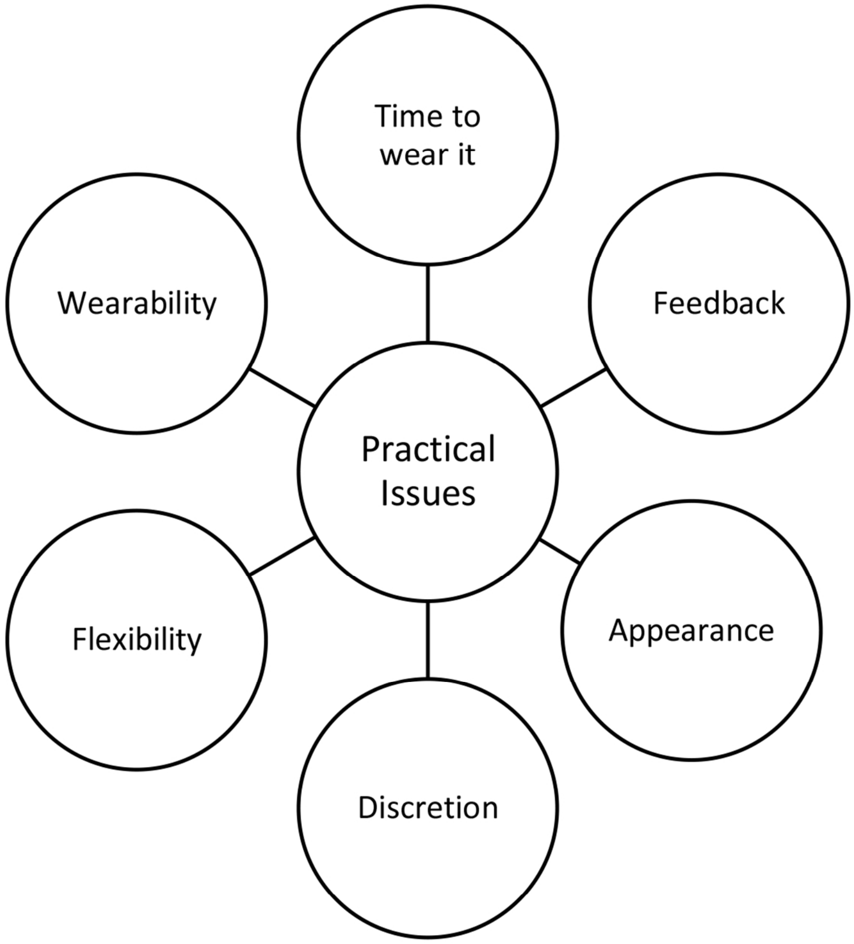

Figure 1. Patients' views on Practical Issues.
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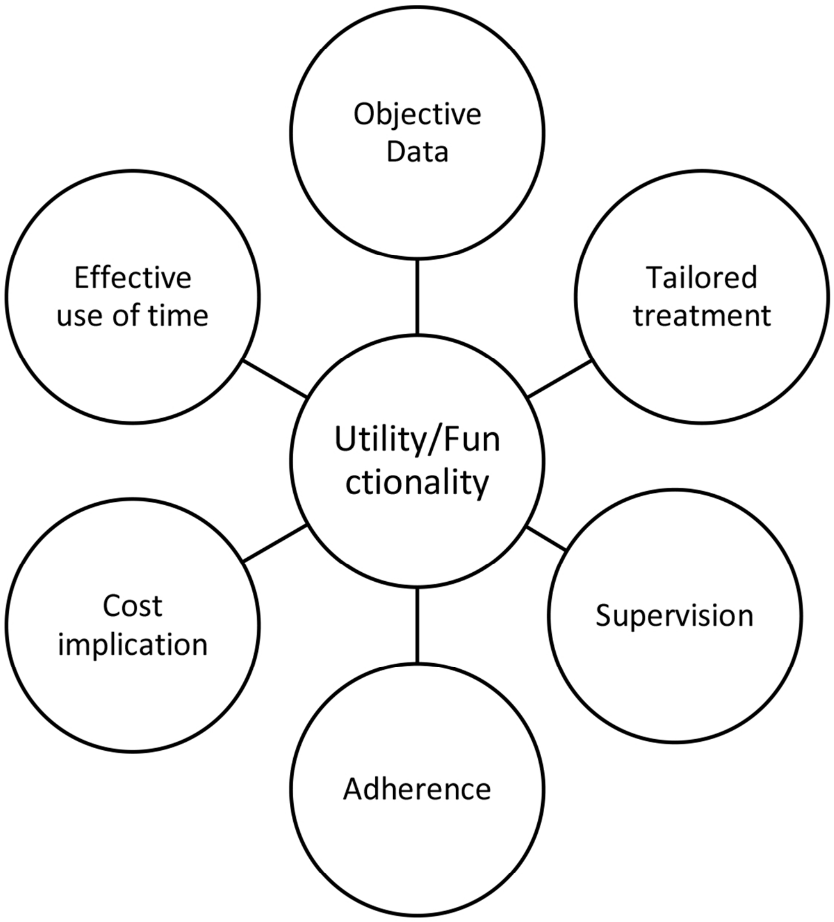

Figure 2 Patients' views on Utility/Functionality.
114x117mm (300 x 300 DPI)