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Prosthetists' perceptions of information obtained from a lower limb prosthesis monitoring system: a pilot study

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Abstract

Introduction—Prosthetists have limited knowledge of their patients' use of a prosthesis outside of the clinical environment. Prosthesis-mounted monitors can be used to directly measure patients' prosthesis use and activity. Prosthetists' opinions regarding potential clinical applications for sensor-based information may inform further development of this technology. A pilot study was conducted to assess prosthetists' perceptions of prosthesis use and activity information obtained by a monitoring system.

Materials and methods—Three local prosthetists were recruited to participate in the study. One patient with transtibial amputation from each prosthetist volunteered to wear limb presence and activity monitors for two weeks. Collected data were used to determine prosthesis use and activity. Each prosthetist completed a survey, examined clinical reports of their patient's prosthesis use and activity, and participated in a semi-structured interview. Survey results and interview transcripts were analyzed to identify and compare prosthetists' perceptions.

Results—Prosthesis use and activity varied among patients. Prosthetists over- and under-estimated patient activity, relative to measurements recorded by the monitors. All three prosthetists selected multiple clinical applications for the prosthesis use and activity information in the survey, and several additional applications were suggested during the interviews. When presented with multiple report formats, prosthetists found features of each to be clinically useful.

Conclusions—Prosthesis-mounted monitors may provide prosthetists with a better understanding of their patients' prosthesis use and activity. Information provided by the monitoring system may inform clinical decisions and promote evidence-based practices.

Keywords

artificial limb; ambulatory monitoring; amputation; sensor; instrument; accelerometry; walking

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Introduction

Prosthetists are trained to provide comprehensive care to people with lower limb amputation. Prosthetic care includes patient assessment, formulation of a treatment plan, fitting of an appropriate prosthesis, and follow-up support.¹ Determination of appropriate prosthetic interventions for individuals with lower limb amputation can be challenging due to variability in patients and the variety of components available to address patients' needs. Prosthetists and other health care providers generally base treatment decisions on patient observations and information reported by each individual. However, recent emphasis on evidence-based practices has encouraged use of standardized instruments to assess outcomes, track progress, and communicate with interdisciplinary team members.² Performance-based outcome measures, for example, can assess patients' functional abilities. Similarly, patient-reported outcome measures can solicit valuable information about prosthesis users' perceptions of their health. While performance-based and self-report measures may inform prosthetists about patients' health, they may not well characterize patients' use of a prosthesis at home or in the community.³

Prosthesis-mounted monitors have the potential to compliment standardized outcome measures by providing clinicians with additional insight about their patients' behaviors and experiences outside of the clinic.³ Accelerometers, for example, can be used to assess activity over extended periods.^{4,5} Data from accelerometers can also be used to characterize specific types of activity.^{6,7} More recently, accelerometers have been combined with a limb presence monitor to measure both prosthesis use (i.e., when a user dons or doffs the prosthesis) and activity (i.e., when a user is standing, sitting, or walking).⁷ In theory, the combined information could be used to select prosthetic componentry, educate patients about healthy or adverse behaviors, diagnose prosthetic fit issues, communicate outcomes to other allied health professionals, and justify treatment decisions. However, how prosthetists view information obtained from prosthesis-mounted monitors or the extent to which they find this information useful is unknown.

The goals of this study were to assess prosthetists' perceptions of information obtained by a prosthesis monitoring system and determine the clinical value derived from such information. Prosthetists' estimates of patients' prosthesis use and activity were obtained via survey and compared with measurements recorded by the system. Technical quality of two clinical reports was evaluated to determine the optimal format for presenting prosthesis use and activity data. Clinical value of the information was explored to identify possible applications for prosthesis-mounted monitors. The authors proposed expected results based on their clinical and scientific experience. It was anticipated that prosthetists' estimates of prosthesis use and activity would be relatively accurate, but that prosthetists' would be uncertain in their estimates. Additionally, it was expected that prosthetists would unanimously identify patient documentation, componentry selection, and reimbursement justification as potential applications for prosthesis use and activity information. Lastly, it was expected that prosthetists would identify useful features in each clinical report.

Methods

Overview

A pilot study was conducted to assess prosthetists' perceptions of information obtained from limb presence and activity monitors. Prosthesis use (i.e., wear time, donning, and doffing) and activity (i.e., sitting, standing, and walking) data were collected and presented to prosthetists in clinical reports. Data measured from the prosthesis monitoring system were compared to prosthetists' use and activity estimates. Surveys and semi-structured interviews were used to evaluate the technical quality of the clinical reports and to explore potential applications for prosthesis use and activity information.

Instrumentation

A minimally-intrusive, lightweight monitoring system was used to measure patients' prosthesis use and activity. The system included a novel limb presence monitor and two activity monitors. The limb presence monitor was developed previously for the purpose of identifying when a user's prosthesis was donned or doffed.⁸ The limb presence monitor consisted of an inductance-based proximity sensor, termed the WAFER, a magnetic target, and an electronics enclosure (Figure 1).

The WAFER included a 30.5 mm diameter inductive antenna, a 470 pF capacitor, and a 10k thermistor contained within a 1.3 mm thick polymer shell. It was adhered inside the prosthetic socket and used to detect proximity of a coated sheath worn over the residual limb. The WAFER sensor contoured to the socket wall and minimally affected local socket shape. The magnetic target consisted of a sheath (2H-PSWR-MD, Knit-Rite, Kansas City, KS), coated with a thin layer of iron-seeded polymer in the posterior distal region,⁸ that was worn over the elastomeric liner. The electronics enclosure contained an inductive sensing chip (LDC1614, Texas Instruments, Dallas, TX) and other components described in detail elsewhere.⁸ The enclosure was mounted to the outer surface of the prosthetic socket and connected to the WAFER with thin electrical wires.

The WAFER generated a local inductive field when powered by components in the electronics enclosure. The inductive sensing chip measured changes in oscillation frequency that occurred when the magnetic target came into close proximity with the WAFER. Limb presence data were sampled at 10 Hz. The socket was considered donned when the magnetic target was adjacent to the WAFER and doffed when the target was distant to the sensor. Collectively, donning and doffing were categorized as "prosthesis use."

Two triaxial accelerometers (GT3X+, ActiGraph, Pensacola, FL) were used to measure patients' postures and activities. One accelerometer was encased in a semi-flexible gel to conform to the limb and attached to an elastomeric liner on the thigh, proximal to the patella. The second accelerometer was affixed to the ankle area of the prosthesis using a hook and loop fastener. As in prior studies, accelerometers were configured to sample at 40 Hz in order to differentiate activities and postures.^{6,7} Signal magnitude and inclination measurements were used to determine when the individual was sitting, standing, or walking; ⁷ these were termed "activity."

Accuracy of the monitoring system components has been established in prior investigations.^{7–9} An early version of the monitoring system, which used a power-inefficient infrared limb presence sensor, was compared to visual observations of participants with transtibial amputation as they performed a 30-minute scripted out-of-laboratory protocol.⁷ Mean absolute differences in times spent sitting, standing, and walking were 2.7%, 5.7% and 1.7%, respectively. The energy-efficient, inductive limb presence sensor was compared to the infrared sensor in a follow-up study.⁹ The inductive sensor showed clear signal changes when prosthesis users changed socks, demonstrating the WAFER sensor could effectively detect when users doffed their prosthesis. In field testing with two transtibial prosthesis users, the inductive sensor showed less than 3% signal loss over 2–4 weeks.⁸ Collectively, these results indicate that the monitoring system is capable of accurately measuring prosthesis use and activity over extended periods in the field.

Participants

Prosthetist participants were recruited through emails sent to local clinicians. Selection criteria included active certification through the American Board for Certification in Orthotics and Prosthetics, active licensure through the Washington State Department of Health, and three years or more of experience treating patients with lower limb amputation. Prosthetists were asked to distribute flyers to patients eligible and willing to wear the monitoring system for two weeks. Patient selection criteria included 18 years of age or older, unilateral transtibial amputation, and greater than 6 hours of self-reported daily use of a definitive prosthesis with an elastomeric liner. Individuals who had participated in prior laboratory studies were excluded to avoid behavioral changes due to familiarity with prosthesis-mounted monitors. Patients with residual limb wounds were excluded. All procedures were reviewed and approved by the University of Washington Human Subjects Division.

At the initial visit, researchers confirmed patients met eligibility criteria and obtained informed consent. Each patient was interviewed to collect demographic (e.g., age and sex), medical (e.g., level and etiology of amputation), and prosthesis-related information (e.g., estimated daily prosthesis use) while the monitors were attached to the prosthesis. The patient was then instructed to go about his or her normal daily routine and keep the monitors attached to the prosthesis at all times. Patients were contacted by investigators at least three times (i.e., one day after leaving the laboratory, one week after leaving the laboratory, and 1–2 days before returning to the laboratory) to verify fit of the monitoring system and remind users to recharge the system nightly. After two weeks, the patient returned to the laboratory and the instruments were removed. Two weeks has been recommended as the minimum period for prosthesis monitoring in order to measure the diversity of activities in which individuals typically engage.⁴

Data Processing

Limb presence data were divided into 24-hour periods, excluding partial days when the patient visited the laboratory. A custom MATLAB script (Mathworks, Natick, MA) was used to graph limb presence data. Changes in proximity of the magnetic target to the WAFER sensor were used to identify prosthesis use as ‘donned’ or ‘doffed’, as described

previously.⁸ Activity data from the accelerometers were analyzed using a custom MATLAB algorithm and procedures described elsewhere.^{6,7} Briefly, a decision tree classified activity during donned periods as ‘sitting,’ ‘standing,’ or ‘walking.’

Clinical reports were created to present each patient’s prosthesis use and activity information to their prosthetist. As visualization of data affects how (and how quickly) health information may be interpreted,¹⁰ two versions of the report were created to assess different ways the data could be displayed. One version presented limb presence and activity data in an integrated report (Figure 2, Supplement 1). A second version displayed components of the data in a partitioned report (Figure 3, Supplement 1).

Survey and Interview

An ad hoc survey was designed to gather prosthetists’ personal information (i.e., demographic and professional experience), duration of relationship with the patient, estimates of the patient’s prosthesis use and activity, and opinions about the clinical value of the monitoring system data. Estimates of prosthesis use were quantified as number of doffs and overall duration of use (i.e. hours from first don to last doff of the day). Estimates of activity were quantified as the hours each patient spent sitting, standing, and walking with the prosthesis. The survey also required the prosthetist to associate each estimate with a degree of confidence, by asking “How confident are you in the accuracy of your estimate?” Confidence was rated using a five-point ordinal scale and qualitative descriptors (i.e., “not at all,” “a little bit,” “somewhat,” “quite a bit,” or “very much”) used in other standardized surveys.¹¹ The survey also included a list of possible clinical applications for which the information could be used. The list was developed through consultation with experienced clinicians (i.e., prosthetists and physical therapists).

A standardized interview guide was developed to facilitate semi-structured interviews with prosthetist participants. The guide included questions related to specific topics of interest (e.g., additional clinical applications for the prosthesis use and activity information, technical quality of the clinical reports). These guiding questions served as a general outline for the interview; however, elaboration and additional discussion of each topic was permissible and expected. For example, technical quality was assessed with questions that inquired as to how clearly the clinical report information was presented. Subsequent discussion included challenges with integrating monitoring information into electronic health record systems. This method of qualitative interviewing is consistent with approaches described in the literature.¹²

The survey and interview guide were pilot tested using expert assessment and field testing techniques.¹³ Several clinical experts (e.g., prosthetists, physical therapists, rehabilitation psychologists) were asked to review the survey and interview guide, and comment on their clarity and content. Lastly, a prosthetist, not included in the present study, was presented data from one patient, surveyed, and interviewed. The interview transcript was reviewed by the researchers and used to enhance the interview methodology. Guiding questions were modified for clarity, and verbal probing techniques were revised to reduce bias.

Data Analysis

Quantitative analyses were used to compare prosthesis use and activity estimates to measured values, and to identify which outcomes (i.e., time of prosthesis use; time sitting, standing, walking, or doffed, or number of doffs) were over- or under-estimated. Prosthetists' confidence in their estimates was characterized by examining frequency of response options selected. Clinical applications from those presented in the survey were tabulated. Interview transcripts were reviewed, and other applications and treatment points identified. Comments related to clinical value of the prosthesis use and activity information, and technical quality of the clinical reports were outlined in a qualitative summary.

Results

Participants

Ten prosthetists from four clinics responded to the recruitment request and were eligible to participate in the study. Five of these prosthetists' patients contacted investigators to express interest in the study. One patient was excluded due to participation in prior laboratory studies. Another was excluded because he was not using an elastomer liner. The remaining three candidates and their prosthetists were enrolled in the study (Tables 1 and 2). All patients were successfully fit with the prosthesis-mounted monitors and completed the monitoring protocol.

Prosthesis Use and Activity

Patients' prosthesis use and activity varied. Average daily prosthesis use, as measured by the monitoring system, was 7.4 (PT1), 17.5 (PT2), and 18.2 (PT3) hours. Average time spent sitting, standing, and walking while using the prosthesis were 1.5, 3.7, and 1.7 hours (PT1); 10.9, 2.3, and 0.9 hours (PT2); and 11.0, 5.4, and 0.6 hours (PT3). On average, patients doffed their prosthesis 0.8 (PT1), 3.2 (PT2), and 1.7 (PT3) times per day.

Both prosthetists' and patients' estimates differed from prosthesis use and activity measured by the monitoring system. On average, patients' estimates of daily prosthesis use differed by 5.8 hours from that measured by limb presence monitors. Prosthetists' estimates differed by an average of 9.3 hours (Figure 4).

One prosthetist (PR1) overestimated his patient's daily prosthesis use by 6.7 hours, while the others (PR2, PR3) underestimated their patients' use by 10.0 and 11.7 hours, respectively. Prosthetists' estimates of patients' sitting, standing, and walking were above and below the values recorded by the monitoring system (Table 3). Notably, standing was the only activity that was consistently under-estimated. No activity was consistently over-estimated.

Prosthetists were only moderately confident in their prosthesis use and activity estimates. Prosthetists most often indicated they were "somewhat" confident (9 of 15 estimates). Less frequently, they noted they were "a little bit" (2 of 15 estimates) or "quite a bit" (4 of 15 estimates) confident. None of the prosthetist participants indicated they were "not at all" or "very much" confident. Prosthetists were generally least confident (i.e., "somewhat" or less)

in times spent standing or walking. They were most confident (i.e., “somewhat” or better) in daily use, times spent sitting, and number of doffs.

Generally, higher confidence was not associated with increased estimate accuracy. Across prosthetists, prosthesis use was least accurately estimated (average absolute difference = 9.3 hours), but estimated with fairly high confidence (i.e., “somewhat” or “quite a bit”). Conversely, walking was most accurately estimated (average absolute difference = 1.8 hours), but estimated with relatively low confidence (“a little bit” or “somewhat”).

Clinical Applications

Prosthetists selected between six and eight of the eight clinical applications for prosthesis use and activity information listed in the survey (Table 4). Additional applications discussed in the interviews included establishing population-specific reference values for prosthesis use and activity, assisting with K-level determination, setting prosthetic rehabilitation goals, verifying home and community activity, troubleshooting prosthetic fit issues, and identifying physical or mental health issues.

Prosthetists also discussed points within or periods during the prosthetic intervention process when information obtained from prosthesis-mounted monitors may have clinical value. All three prosthetists noted that monitoring information may be useful between preparatory and definitive prosthesis fitting. Two prosthetists (PR1, PR2) suggested that data from prosthesis-mounted monitors could be used for periodic follow-ups. The other prosthetist (PR3) instead thought the data would be better used immediately before and after a prosthetic adjustment or componentry change.

Prosthetists also suggested the monitoring system could be used with upper limb (PR1, PR2, PR3), transfemoral (PR1, PR3), and partial foot (PR3) prosthetic patients. Further, prosthetists noted that lower limb (PR1, PR3), upper limb (PR1, PR3), and spinal (PR1) orthotic patients may be candidates for a monitoring system like the one studied.

Technical Quality

Prosthetists’ opinions differed regarding the effectiveness of information presented within the clinical reports. One prosthetist preferred the integrated report (PR3), one preferred the partitioned report (PR2), and another suggested that both versions effectively communicated prosthesis use and activity information (PR3). Preferred features of the integrated report included the convenience of a shorter document (PR1) and the comprehensive data included in the chronological daily timelines (PR3). However, one prosthetist noted that it was difficult to quickly absorb all information included in the integrated report (PR2). Preferred features of the partitioned report included the weekly and period (i.e., two-week) data summaries (PR1) and easily-interpretable pie charts (PR2). One prosthetist perceived redundancy in the partitioned report and felt that information could be presented more succinctly (PR1).

Discussion

Prosthetists' perceptions of information obtained by a prosthesis monitoring system suggested broad clinical applicability. Knowledge of patients' prosthesis use and activity is presently limited due to the way in which such information is traditionally obtained.¹⁴ Substantial differences between prosthetists' estimates and data measured by prosthesis-mounted monitors in this study allude to well-established challenges in obtaining accurate information related to patient activity.¹⁵ Objective information derived from prosthesis-mounted monitors can address recognized limitations to self-report methods (e.g., perception, social desirability, and recall)^{16,17} and provide prosthetists with accurate details about patients' experiences outside of the clinic. A prosthesis monitoring system like that studied here therefore conveys novel information, and compliments knowledge obtained from performance-based and self-report outcome measures.

Prosthesis Use and Activity

Consistent with previous research that examined agreement between self-reported and measured activity,¹⁸ two of the three patients in the present study did not accurately estimate their daily prosthesis use. In the prior study, participants with lower limb amputation logged their daily activity in a diary while wearing a step activity monitor (StepWatch3, Modus Health, Edmonds, WA).¹⁸ Investigators found that participants with transtibial amputation reported their activity with only 57% accuracy, when compared to monitor measurements. Further, participants showed no bias towards over- or under-reporting their activity. Patients in the present study also did not consistently over- or under-report their prosthesis use (Figure 4).

Similar to patients in the present study, prosthetists did not accurately estimate prosthesis use. Results showed prosthetists' estimates both exceeded (PR1) and fell short (PR2, PR3) of measured prosthesis use. Thus, even scaling a patient's reported use (i.e., applying a proportional correction) is unlikely to accurately estimate their true use of the device. Prince *et al.* drew a similar conclusion in a review of directly-measured and self-report physical activity in adults.¹⁹ Further, estimate inaccuracies cannot be attributed to specific activities (i.e., sitting, standing, or walking) as no single activity consistently contributed to prosthetists' over- and under-estimates of daily prosthesis use. The relative uncertainty with which prosthetists in this study made their estimates also suggests that prosthesis-mounted monitors could increase both practitioners' knowledge of and confidence in their patients' use of a prosthesis outside the clinic.

Clinical applications

All three prosthetists in this study conveyed a positive attitude towards prosthesis-mounted monitors and indicated several applications where information derived from a monitoring system may provide clinical value (Table 4). Applications clustered around two central concepts – evidence-based decision making and justification.

Recent studies to develop or evaluate prosthesis-mounted monitors (e.g., pedometers,²⁰ step monitors,^{5,18,20–22} or load cells²³) for people with lower limb amputation have often been

motivated by the need for objective information to guide clinical decisions. A key advantage to the monitoring system used in the present study over other technologies is the capability to measure donning and doffing, as well as time spent performing different activities (e.g., sitting, standing, and walking) with the prosthesis. Access to outcomes beyond step activity may have intrigued prosthetists in this study because such information provides clinicians with greater knowledge of their patients' prosthesis-related behaviors. Prosthetists indicated this knowledge may inform changes to the prosthesis or aid in the selection of new prosthetic components. They also noted that prosthesis use and activity information may allow physical therapists to set, monitor, and revise patient goals. Traditionally, the process of goal-setting, much like prosthetic prescription, relies on patients' self-report of activities performed at home and in the community.²⁴ Objective information provided by prosthesis-mounted monitors can therefore inform both evidence-based component selection and goal-setting.

Justification was also a common application selected by all three prosthetists. A desire for objective data to support clinical decisions is unsurprising, given third-party payers' increasing demands for evidence to support provision of prosthetic devices.²¹ Selection of components is linked to Medicare Functional Classification Level (i.e., K-level);²⁵ a relatively coarse assessment of patients' potential use of a prosthesis. Monitoring technologies allow for a more granular view of patients' prosthesis use and activity, and may better substantiate the need for specific components. Advocates of similar monitoring technologies have also suggested that knowledge of patients' function outside the clinic can support K-level determination.^{21,22}

In addition to broad applications, clinicians identified periods within the episode of care where sensor-based information would be useful. All three prosthetists suggested that monitor data would be useful when patients are wearing a preparatory prosthesis. Prosthesis use and activity information during this period may be particularly useful, as rapid volume fluctuation and changes in patients' mobility often occur.²⁶ Prosthetists suggested that using monitors during this period may help to determine when the patient is ready to advance to the definitive prosthesis. They also indicated that prosthesis use and activity information could be used for periodic follow-up assessments. Prosthetists suggested that frequent donning and doffing may indicate a poor fitting prosthesis. Socket fit has been identified as the single-most important issue related to prosthesis use.²⁷ Periodic patient assessments long after they receive the definitive prosthesis may also allow prosthetists to identify potential problems.

Prosthetists in this study noted other areas of practice where sensor-based information may be beneficial. For example, prosthetists noted that prosthesis-mounted monitors could be used with upper limb patients. In theory, an upper limb monitoring system could identify prosthetic fit issues prior to abandonment. Given the high incidence of rejection in upper limb prosthetics,²⁸ information regarding use and activities could help diagnose problems, identify solutions, and inform prescription practices. Research to investigate monitoring in other areas of prosthetics or orthotics may be warranted.

Technical Quality

Each of the prosthetists expressed preferences about how monitor information was presented in clinical reports. They found features in both the integrated and partitioned reports useful. A similar result was reported in a study by Allwood *et al.*, where clinicians were presented with health outcomes data, displayed in multiple formats (e.g., tables, bar charts, and icons). Participants found advantages and disadvantages to each, and generally preferred to have data in more than one form.²⁹ Le *et al.* conducted a study where ten physicians were asked to quickly make clinical decisions based on information presented in three different formats (i.e., bar charts, polygon charts, and donut display). Results suggested that the display type influenced decisions made, and similar to this pilot study, preferences varied between participants.¹⁰ The method by which health information is displayed also varies between patients and clinicians.³⁰ Customizable reports may allow clinicians or patients to self-select a format that most effectively communicates prosthesis use and activity information. Development of customizable displays may therefore be an important consideration as prosthesis-mounted monitors are translated to clinical practice.

Limitations and Future Directions

One limitation of this study is the small sample size. However, knowledge gained may inform development of a larger study. For example, clinical applications identified by prosthetists may inform development of a survey to evaluate other clinicians' opinions of prosthesis monitoring technologies. The small sample in this study also precluded conducting a formal qualitative assessment. Interviews with additional prosthetists would allow researchers to identify codes and themes,¹² and investigate ideas (e.g., effects of prosthesis use and activity information on patient-prosthetist communication, goal-setting, and clinical decision-making) that surfaced in this pilot study.

Another limitation of this study is that prosthetist participants were less experienced (7.3 years, on average) and younger (34.3 years, on average) than most prosthetists in the US.³¹ Estimates and confidence measured in this study may differ from those of prosthetists with more clinical experience. Additionally, all three prosthetists in this study had worked with their patients for less than a year. Future studies may wish to include patients with short and long-term clinical relationships in order to determine whether length of relationship is associated with greater estimate accuracy. This study also paired each prosthetist with only one patient. Future studies may include multiple patients for each prosthetist to determine whether estimate accuracy varies, and identify which factors (e.g., cognitive ability and communication style) are associated with less accurate estimates (and thus indicate which patients may be candidates for monitoring).

It is also possible that the accuracy of prosthetists' estimates were affected by changes in patient behaviors due to presence of the monitoring system. A two-week monitoring period and removal of testing days from each data set were used to mitigate behavioral changes. Further, patients were instructed to wear their prosthesis normally. Researchers verified that normal activity was maintained at the final visit. Thus, prosthetists' estimates were likely unaffected by atypical patient behaviors. However, to address concerns associated with changes in patient behaviors, future studies could monitor participants for longer periods. An

extended monitoring period may allow researchers to identify behaviors associated with monitoring (i.e., presence of a Hawthorne effect) that occur initially but dissipate over time. Future studies could also include development of a more discreet monitoring system. A system that is smaller, integrates directly into a prosthetic socket, and requires less frequent charging may better encourage users to maintain their normal behavioral patterns.

Lastly, only two clinical report formats were included in this study. Given that prosthetists preferred features from both reports, researchers may wish to evaluate additional display formats^{10,32,33} or develop a report that can be configured^{29,33} by the prosthetist in future studies.

Conclusions

Survey results and qualitative interviews revealed that prosthetists find information obtained from a prosthesis monitoring system valuable. When displayed effectively, information provided by prosthesis-mounted monitors can inform clinical decisions and improve treatment for prosthesis users. A better understanding of patients' true prosthesis use and activity can facilitate an evidence-based approach to clinical practice and mitigate prosthetists' reliance on patient-reported history. Ultimately, knowledge gained from prosthesis-mounted monitors can help prosthetists' provide quality prosthetic care and achieve optimal patient outcomes.

Supplementary Material

Refer to Web version on PubMed Central for supplementary material.

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Figure 1.

Prosthesis monitoring system components: 1. Thigh accelerometer adhered to the proximal-anterior aspect of the liner, proximal to the patient's patella. 2. Ankle accelerometer secured laterally at the ankle. 3. Magnetic target on the distal-posterior aspect of the nylon sheath, worn over the elastomeric liner. 4. Electronics enclosure secured to the outside of the socket. 5. Wires leading from the electronics enclosure to the WAFFER. 6. WAFFER secured to the distal-posterior aspect of the inside of the socket.

Figure 2.

An integrated report showed limb presence and activity data in a condensed format. The integrated report was two pages long, and showed one week of data on each page. Prosthesis use and activity data, including the time when the prosthesis was first donned; periods of sitting, standing, and walking throughout the day; periods when the prosthesis was doffed, and the time when the prosthesis was last doffed were displayed in a chronological daily timeline (A and B, left).. Relative times (i.e., percent of each prosthesis day) and absolute times (i.e., number of hours during each prosthesis day) the patient spent sitting, standing, walking, or had the prosthesis doffed were displayed graphically and numerically (A and B, right).

Figure 3.

A partitioned report presented the following isolated components of the limb presence and activity data: A. Daily prosthesis use, including the time when the prosthesis was first donned; periods when the prosthesis was doffed, and the time when the prosthesis was last doffed; no activity data were included; B. Time spent sitting, standing, and walking per day; C. Percentage of overall time spent sitting, standing, or walking; D. Weekly summary statistics, percentage of overall time spent sitting, standing, or walking (top); average time spent sitting, standing, and walking (middle), and average prosthesis use (bottom); E. Two-week period summary statistics, including percentage of overall time spent sitting, standing, or walking (top); average time spent sitting, standing, and walking (middle), and average prosthesis use (bottom).

Figure 4. Average daily prosthesis use as estimated by prosthetists, as estimated by patients, and as measured by the prosthesis monitoring system. (PT = patient)

Table 1

Prosthetist participant demographic information.

Participant	Age	Gender	Experience	At current location
PR1	37	M	6 years	5 years
PR2	30	F	6 years	1 year
PR3	36	M	10 years	7 years

Table 2

Patient (transfemoral prosthesis user) demographic information.

Participant	Age	Gender	Amputation Cause	Time since amputation	K-Level*
PT1	25	M	Traumatic	4 years	3
PT2	68	M	Dysvascular	9 months	3
PT3	59	F	Dysvascular	10 months	3

* As determined by investigators

Comparisons of prosthetists' estimates of prosthesis use and activity, and measurements obtained from the monitoring system.

Table 3

Prosthetist	Parameter	Daily use (hours)	Sit (hours)	Stand (hours)	Walk (hours)	Doffs (counts)
PR1	Estimate	14.0	6.0	2.0	6.0	5.0
	Confidence	somewhat	somewhat	somewhat	somewhat	quite a bit
	Measured	7.4	1.5	3.7	1.7	1.1
	Difference	6.7	4.5	-1.7	4.4	3.9
PR2	Estimate	8.0	6.0	1.5	2.0	4.0
	Confidence	quite a bit	somewhat	somewhat	somewhat	somewhat
	Measured	17.5	10.9	2.3	0.9	4.8
	Difference	-9.5	-4.9	-0.8	1.1	0.8
PR3	Estimate	6.5	5.0	1.0	0.5	12.0
	Confidence	somewhat	quite a bit	a little bit	a little bit	quite a bit
	Measured	18.2	11.0	5.4	0.6	1.8
	Difference	-11.7	-6.0	-4.4	-0.1	10.2

Table 4

Clinical applications for prosthesis use and activity information.

Application	PR1	PR2	PR3
Justification for reimbursement	•	•	•
Patient education		•	•
Indicator for prosthesis adjustment	•	•	•
Determination of socket type or componentry	•	•	•
Patient progress documentation	•	•	•
Office information database			•
Information to share with physical therapists	•	•	•
Information to share with referring physicians	•	•	•

PR = prosthetist