CASE REPORT

Using Mobile Tracking Technology to Visualize the Trajectory of Recovery After Hip Arthroscopy: a Case Report

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Introduction

Femoroacetabular impingement (FAI) is a common disorder in which anatomic abnormalities of the proximal femur and/or acetabulum result in repetitive bony collision during dynamic hip motion, leading to labral tears and chondral injury [4]. Over the last decade, evidence has mounted for a prominent etiologic role of FAI in the development of hip pain and early osteoarthritis in the non-dysplastic hip [4, 12, 25]. Hip arthroscopy can effectively repair the labral tears caused by FAI and correct certain underlying bony abnormalities, but recovery from the procedure has not been described in detail.

Patient-reported outcome measures (PROMs) are the currently accepted standard to track patient progress following elective orthopedic surgery. The hip disability and osteoarthritis outcome score (HOOS) [21] and a 5-question physical function short form, the HOOS-PS [9], are commonly used for hip arthroscopy. Others include the Modified Harris Hip Score (MHHS), an overall measure of hip

condition [5, 22], the Hip Outcome Score (HOS), which measures quality of life and levels of sports and recreation in younger active patients [19], and the International Hip Outcome Tool (iHOT33), which aggregates sub-scores relating to physical and social functioning with hip-specific problems [20].

Because PROMs are typically administered at fixed post-operative time points often months apart, they may miss important information about patient recovery. A new, more continuous method of data collection could yield a more complete and accurate picture of recovery. This goal is attainable by tracking daily activities and personal metrics using smartphones or wearable devices and incorporating these metrics into patient care—an idea which is rapidly gaining traction in the medical community [2, 23, 24].

Studies have demonstrated the benefits of continuous measurement of patient data, specifically mobility [1, 16]. Cook et al. used an off-the-shelf wearable wireless accelerometer to demonstrate a correlation between number of steps taken by hospitalized elderly patients shortly after cardiac surgery, length of stay, and dismissal disposition [8]. Appelboom et al. used a wearable device to wirelessly transmit mobility data in post-operative neurosurgical patients [3]. Wearable body sensors have been used to track mobility in people with stroke and traumatic brain injury [11], in real-time feedback in computer-assisted rehabilitation [14], and in seizure detection [17].

In this investigation, we conducted a single-subject ($n=1$) study to demonstrate the use of smartphone-based mobile tracking technology during recovery from hip arthroscopy to correct FAI. We aimed to attain a more detailed picture of a patient's return to function using a smartphone application to capture hip function, weekly pain level, and daily step-count and compare this information to established PROMs administered at traditional timeframes.

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Case Report

The patient was a 22-year-old male former intercollegiate water polo player with no previous surgical history who experienced left hip pain beginning 19 months prior to surgery. He was diagnosed with an anterior labral tear in his left hip 17 months prior to surgery and returned 4 months prior to surgery with moderate non-radiating, dull/pinching pain in the groin area aggravated by deep flexion and internal rotation. The patient was unable to exercise or play water polo. Physical examination revealed limited internal rotation of the hip and pain with flexion, adduction, and internal rotation. A left hip MRI confirmed the labral tear. X-ray and CT scan showed mixed cam and pincer FAI morphology with no signs of osteoarthritis or joint space narrowing (Tonnis Grade 0, α -angle = 68° , femoral version = 12°). When non-operative management failed, the patient elected to undergo left hip arthroscopy.

The procedure was performed under combined spinal-epidural anesthesia with traction applied to the affected leg for 35 min (procedure time = 70 min). The joint was accessed under fluoroscopic guidance through a standard anterolateral portal. Two working portals were used: a modified anterior and a distal anterior lateral accessory portal. A rim impingement lesion was observed between 1 o'clock and 2 o'clock and a labral tear was identified in an arc spanning from 12 to 4 o'clock. The cartilage was otherwise normal. A T-capsulotomy was performed to fully visualize the anterior head-neck junction. A cam lesion was present in the anterior, anterolateral, inferior, superior, and superolateral portions of the femoral head. Decompression of the cam and pincer lesions was performed, as well as a synovectomy and labral tear re-fixation using four suture anchors. The capsulotomy was closed using five sutures. There were no intraoperative complications.

The operating surgeon initiated a self-developed physical therapy protocol that is prescribed to all patients with labral fixation with or without FAI repair, modified as needed by the physical therapist according to the patient's progress [15]. Weeks 0–6 focused on restoring range of motion with introduction of strengthening of hip flexors. Weeks 6 and beyond focused on progressive hip and core strengthening with the goal of progressing to running and sports-specific exercises by week 16. The patient completed 3 h of continuous passive motion and 4 h of ice per day for 3 weeks, beginning the day after surgery. The patient underwent physical therapy twice weekly for 10 weeks, then once weekly for 5 weeks before transitioning to a home-exercise program. The patient was 20% weight-bearing for 10 days, progressed to weight-bearing as tolerated at 3 weeks, and weaned off crutches (2 → 1 → 0) after 4 weeks. Treadmill running program was incorporated at week 22.

The patient was followed starting 4 months pre-operatively when he was enrolled in the HSS Hip Preservation Registry, which includes MHHS, HOS, and iHOT33. These PROMs were collected based on a standard protocol at 3, 6, 9, and 12 months after surgery. This patient

completed the Registry PROMs 125 days pre-operatively, and at 92, 232, 301, and 374 days post-operatively. Of note, the patient changed cities at 125 days post-operatively.

Mobility, pain, and hip function were chosen as tracking parameters because impairments in these domains are common reasons patients elect to undergo FAI surgery [7]. After IRB approval and informed consent, Moves™ (ProtoGeo Oy; Helsinki, Finland), an accelerometer and GPS-based smartphone application that automatically and passively captures a user's step count, and Ohmage MWF (CornellTech, New York, NY), an open source smartphone application that supports survey capture, were downloaded to the patient's personal smartphone, an Apple iPhone 5 (Apple; Cupertino, CA, USA). Moves™, which is equivalent or superior in accuracy to ten other commonly used smartphone applications and wearable devices [6], tracked the patient's step count continuously from 9 days pre-operatively to 365 days post-operatively, yielding 374 data points, each representing the patient's daily step total. Hip pain was captured using a one-question ten-point numeric rating scale (NRS) for "current hip pain" and hip function was assessed using HOOS-PS. These were administered weekly via Ohmage from 2 weeks pre-operatively to 52 weeks post-operatively. The patient took the surveys twice in weeks 3 and 4, resulting in 56 total measurements. Data was downloaded remotely by investigators, who were able to view daily step count, distance traveled, and time away from home, but not the patient's GPS location.

A semi-structured interview seeking qualitative feedback on usability, accuracy, and satisfaction with the data collection instruments during the rehabilitation process was administered by investigator CS 13 weeks post-operatively. The patient was also later interviewed about the 13 week to 1 year post-operative period.

Step data were analyzed as both raw counts and 7-day moving averages to minimize the influence of outliers and for ease of visual interpretation. The 7-day moving average step count was calculated for each day as the average number of steps taken during the current day and the previous 6 days. Spearman correlation coefficients were used to assess the strength of association of 7-day moving average step count with weekly pain levels and weekly HOOS-PS scores at selected time intervals defined by recovery milestones. Correlation coefficients are reported with 95% confidence intervals. All analyses were performed using SAS 9.3 (SAS Institute, Cary, NC, USA).

The patient's daily step count was plotted in its raw form and a 7-day moving average was overlaid for clarity (Fig. 1). There was a clear upward trend in steps post-operatively that tapered off between 3 and 5 months, and the patient first exceeded his pre-operative baseline (mean number of steps taken during the pre-operative data collection period) 26 days post-surgery.

Steps (weekly moving average) and HOOS-PS scores rose in parallel between 0 and 85 days (3 months) post-operatively (Fig. 2). Whereas step count plateaued thereafter, HOOS-PS scores continued to rise between 85 days (3 months) and clearance for running (161 days: 5.5 months) with maximum scores reached by 200 days (6.7 months)

Fig. 1. Raw Moves™ output showing step totals for each day the patient was tracked (9 days pre-operatively to 365 days post-operatively). *Dark line* is seven-day moving average.

post-operatively. Both steps and HOOS-PS scores plateaued after clearance for running; however, HOOS-PS scores fluctuated, sometimes dropping below the maximum score, suggesting that full hip health had not yet been achieved. Accordingly, steps (7-day moving average) and HOOS-PS scores exhibited a very strong positive correlation in the first 85 days (3 months) post-operatively, and a strong positive correlation from the day of surgery to the beginning of the running program (Table 1). All other recovery intervals demonstrated very weak correlations between steps and pain (Table 1). Pain spiked with surgery but declined quickly, plateauing until 85 days (3 months) before tapering to 0 (Fig. 2). Steps and pain exhibited weak or very weak correlations at all measured recovery intervals (Table 1). A strong, negative correlation was observed between the weekly HOOS-PS and pain scores over the entire study period (r_s [95% CI] -0.79 [$-0.87, -0.67$]) and from the day of surgery to clearance for running (0.71 [$-0.86, -0.45$]) (Fig. 3). The correlation was moderate between clearance for running and 1 year post-operatively (-0.58 [$-0.78, -0.28$]). There were dynamic fluctuations in recovery captured by the weekly HOOS-PS survey (Fig. 3). HOOS-PS scores decreased substantially after surgery and increased to the point when the patient was weaned off crutches, but plateaued thereafter until 85 days (3 months) post-operatively. Scores improved steadily after the 85-day (3 months) timepoint and the highest score possible was achieved soon after the patient was cleared for running. The fluctuations in recovery captured by weekly HOOS-PS scores were not captured by the conventional PROMs (mHHS, iHOT-33, HOS) due to their infrequent administration (Fig. 3).

The patient described himself as a frequent phone user. Moves™ and Ohmage were the first health-tracking apps he had used. The patient noted that the technology did not impede his recovery. He found the interfaces easy to

navigate. The HOOS-PS and pain NRS took less than 1 min to fill out per week. He interacted with Moves™ multiple times daily and Ohmage once a week. The patient reported at his 13-week interview that having a daily activity log allowed him to set concrete goals and record milestones including walking as far or long as prior to surgery, and returning to work, running, or sports. Using this activity history, he could compare his pre- and post-operative activity daily, and felt proud when he achieved personal goals and was encouraged to meet new ones. Achieving milestones increased his confidence in his abilities and reduced the feeling of disability and limitation. Furthermore, viewing previous days' data allowed the patient to become more aware of his progress, eliminating the errors and inconsistencies of relying on memory to assess the progression of recovery. Upon interview about the 13 week to 1 year post-operative period, the patient reported that the application had more utility during the initial versus later phases of recovery given that it did not track sports activities.

The patient indicated that filling out the weekly HOOS-PS and pain surveys helped him reflect on his weekly progress, including the limitations and improvements of his hip function. Along with the mobility data, this self-evaluation helped him feel that he was improving in specific and diverse ways, i.e., those activities assessed in the HOOS-PS.

Finally, the patient reported concerns that the HOOS-PS question regarding running difficulty was not applicable until 22 weeks post-operatively, when he was cleared to begin running.

Discussion

Continuous patient tracking using smartphone-based applications was used successfully to visualize recovery after FAI

Fig. 2. Relationship between hip function, pain, and mobility: weekly HOOS-PS scores plotted alongside weekly pain score and 7-day moving average of step count.

surgery in one patient. Steps and HOOS-PS scores exhibited a strong positive correlation in the first 85 days (3 months) post-operatively, demarcating a period of major post-operative recovery. Steps and pain exhibited weak correlations at all intervals. Weekly HOOS-PS scores showed dynamic changes while traditional PROMs scores were collected less frequently and showed more static trends. The patient reported a seamless integration of the technology into his daily life, and he indicated that he felt it helped him take an active role in his recovery, providing psychological benefit in perception of recovery.

As anticipated, continuous monitoring revealed details about the time course of surgical recovery that are not usually considered in current research studies. HOOS-PS scores returned to pre-operative levels after 161 days (5.5 months) with maximum scores reached by 200 days (6.7 months), suggesting that a major component of hip functionality is recovered within this 85–180 day (3–6 months) time period. The HOOS-PS scores and daily step count showed dynamic fluctuations corresponding to the patient's disability and recovery events such as ambulation without crutches, returning to work, and returning to running. This close mirror of recovery was missed by the

traditional PROMs, which were administered only twice during the period of greatest change, and continued to be administered at the same intervals after most of the recovery was complete.

Our finding that only one PROM (HOS Sport Score) showed meaningful change between 3 and 6 months when weekly HOOS-PS scores showed clear progression suggests that the conventional instruments may not be adequately sensitive, even if administered at appropriate time points. Learning how closely this patient's time course of recovery reflects the norm in a larger cohort will have important ramifications for improving accuracy in future studies of the treatment of FAI.

Currently, PROMs are typically administered at 3, 6, 9, and 12 months after hip arthroscopy. However, if full recovery were found to occur in most patients by 200 days (6.7 months), measuring PROMs at 180 days (6 months) should be reconsidered as it would likely underestimate the number of patients in whom the surgery was "successful." Whether another measurement at 270 days (9 months) would include most patients who will eventually reach full recovery could only be known by repeating the current study in a larger cohort. On the other hand, our patient's HOOS-PS

Table 1 Spearman correlation coefficients across different post-operative time intervals

Time period	Weekly moving average steps vs. HOOS-PS	Weekly moving average steps vs. pain
0 days postop to cleared for running	0.68 (0.39, 0.84)	−0.39 (−0.68, −0.01)
Cleared for running to 365 days (12 months) postop	0.10 (−0.27, 0.44)	−0.05 (−0.40, 0.32)
85 days (3 months) postop to cleared for running	−0.09 (−0.71, 0.61)	0.09 (−0.61, 0.71)
0 to 85 days (3 months) postop	0.88 (0.69, 0.96)	−0.33 (−0.70, 0.18)
0 to 365 days (12 months) postop	0.09 (−0.18, 0.35)	−0.11 (−0.36, 0.16)

Fig. 3. Comparison between traditional PROMs as administered by the hospital Registry, and weekly HOOS-PS and pain scores administered via the patient's smartphone.

scores continued to show small fluctuations through the first year.

The weakening of the correlations between HOOS-PS scores and mobility and pain over time indicates that our mobile tracking tool may be most relevant before patients return to normal mobility and higher-level activities. As a patient's activities may include other activities beyond walking after achieving normal ambulatory mobility, step count becomes more prone to variation, making it a less accurate and meaningful measure of mobility. For example, the patient's step count declined to below pre-operative levels after he changed cities (around 120 days [4 months] post-operatively), which reflected a more sedentary daily routine rather than a reduction in hip function. Similarly, HOOS-PS does not measure higher-level activities in athletes and more active patients. It quickly plateaued once our patient reached running progression. However, in less active patients, HOOS-PS may accurately measure recovery at all timepoints. Nevertheless, restricting the use of this tool to initial stages of recovery can optimally indicate whether the patient is progressing properly toward normal function.

The finding that steps correlated only weakly with pain was surprising, given that, as expected, hip function as measured by HOOS-PS correlated strongly with pain before the patient was cleared for running. One reason for the weak correlation between steps and pain may be the requirement for weight-bearing precautions after surgery, resulting in low step counts despite adequate post-operative pain control. Our findings may also suggest that hip pain affects the activities queried in HOOS-PS (descending stairs, getting in/out of bath/shower, sitting, running, twisting/pivoting on loaded leg) more than walking, which requires little flexion or rotation of the hip joint. Post-operative pain should be

well controlled with medication, and a decrease in, if not alleviation of pain would be expected once the immediate post-operative period has passed. Indeed, pain scores for our patient were low, even immediately after surgery.

Continuous mobility and functional data like those collected here can also inform rehabilitation protocols for individual patients. There is a lack of high-quality evidence supporting any specific rehabilitation protocol after hip arthroscopy [13]. Current guidelines define four phases of rehabilitation after FAI surgery: Immediate post-operative rehabilitation (0–4 weeks), sub-acute rehabilitation (4–8 weeks), return to recreational activities (8–12 weeks), and return to sports and higher-level function (12–16 weeks) [10, 18, 26]. Use of the mobile tracking data may help the physical therapist tailor the protocol for each patient, moving him or her through the appropriate phase not simply based on predetermined time points, but based on the patient's actual mobility and a weekly assessment of hip function.

Quantifying progress daily can also help patients take a more active role in their recovery, setting goals for each stage. Our patient reported feeling encouraged and motivated by seeing his step totals increase daily, consistent with other published reports of the positive reinforcement of setting and meeting personal recovery goals [27].

Our findings support the potential and benefits of continuous patient monitoring demonstrated in the literature, specifically the ease of data collection. Rigorous testing of whether mobile tracking technology can improve patient recovery after orthopedic and other procedures is a promising area for future study. Specifically, we believe that free smartphone applications such as Moves™ have the highest potential to affect the way data is collected in orthopedic surgery patients. Given the

prevalence of smartphones in today's society and the large socioeconomic range of patients undergoing orthopedic surgery, such applications are significantly more accessible than wireless wearable devices such as those used in other studies [8]. Since Moves™ has been shown to be equivalent in accuracy to many wearable devices, these benefits will not be at the expense of data quality.

There are limitations in using this approach. Moves™ does not automatically track activities other than running or walking (such as the stationary bicycle used during the patient's rehabilitation program), or activities during which the patient did not carry his phone. Therefore, total activity was underestimated. Improvements in measuring activity types and intensity could improve future post-operative tracking. On the other hand, a Hawthorne effect may have been present in that the patient may have increased his activity by virtue of wearing the device. In this case, total activity may be overestimated and the timeline of his return may or may not be typical. However, if this Hawthorne effect persists across subjects, it may be beneficial in increasing post-operative activity.

Additionally, though the patient reported daily compliance with Moves™ during the semi-structured interview, this could not be remotely monitored so compliance with the application could not be objectively assessed. Lack of compliance with the mobile tracking application could also lead to an underestimation of mobility. The patient noticed that Moves™ failed to count the slow steps he took on crutches during the first 1–2 weeks post-operatively, underestimating the step totals for these days. Appelboom et al., wirelessly tracking post-operative neurosurgery patients using a wearable device, also reported a systematic underestimation bias in step count in more debilitated patients [3]. Quantitative studies are needed to confirm these effects in an orthopedic population using Moves™, as our results were subjective in nature. Due to the novel nature of both the method of data collection and the data itself, as well as the lack of precedent for processing such data, our representations may not be the most complete assessment of recovery. As mobile health technology becomes more pervasive, researchers will perfect the processing and representation of mobile health data, allowing larger studies to be conducted more efficiently. Finally, given the single-subject study design analyzing a young man who is comfortable with technology, our results may not be generalizable. Studies in larger cohorts of various ages and different levels of familiarity with technology are required to confirm the findings of our study.

Using smartphone-based mobile technology during recovery from hip arthroscopy to correct FAI, we found that weekly measurement of HOOS-PS and daily step monitoring captured detailed fluctuations of the patient's recovery that were more informative and provided more insight than traditional PROMs.

Compliance with Ethical Standards

Conflict of Interest Nabil Mehta, BSE; Claire Steiner, MBBS/BMedSc; Kara G. Fields, MS; and Danyal H. Nawabi, MD, FRCS have declared that they have no conflict of interest. Stephen L. Lyman,

PhD reports personal fees from Journal of Bone and Joint Surgery, grants from NIAMS and AHRQ Center for Evaluation and Research in Therapeutics, outside the work.

Human/Animal Rights: All procedures followed were in accordance with the ethical standards of the responsible committee on human experimentation (institutional and national) and with the Helsinki Declaration of 1975, as revised in 2008 (5).

Informed Consent: Informed consent was obtained from all patients for being included in the study.

Required Author Forms Disclosure forms provided by the authors are available with the online version of this article.

References

1. Appelboom G, Camacho E, Abraham ME, et al. Smart wearable body sensors for patient self-assessment and monitoring. *Archives of Public Health = Archives belges de sante publique*. 2014; 72: 28.
2. Appelboom G, LoPresti M, Reginster JY, et al. The quantified patient: a patient participatory culture. *Current Medical Research and Opinion*. 2014; 30: 2585-2587.
3. Appelboom G, Taylor BE. Mobile phone-connected wearable motion sensors to assess postoperative mobilization. 2015.
4. Beck M, Kalhor M, Leunig M, et al. Hip morphology influences the pattern of damage to the acetabular cartilage: femoroacetabular impingement as a cause of early osteoarthritis of the hip. *The Journal of Bone and Joint Surgery British Volume*. 2005; 87: 1012-1018.
5. Byrd JW, Jones KS. Prospective analysis of hip arthroscopy with 2-year follow-up. *Arthroscopy: The Journal of Arthroscopic & Related Surgery: Official Publication of the Arthroscopy Association of North America and the International Arthroscopy Association*. 2000; 16: 578-587.
6. Case MA, Burwick HA, Volpp KG, et al. Accuracy of smartphone applications and wearable devices for tracking physical activity data. *JAMA*. 2015; 313: 625-626.
7. Clohisy JC, Knaus ER, Hunt DM, et al. Clinical presentation of patients with symptomatic anterior hip impingement. *Clinical Orthopaedics and Related Research*. 2009; 467: 638-644.
8. Cook DJ, Thompson JE, Prinsen SK, et al. Functional recovery in the elderly after major surgery: assessment of mobility recovery using wireless technology. *The Annals of Thoracic Surgery*. 2013; 96: 1057-1061.
9. Davis AM, Perruccio AV, Canizares M, et al. The development of a short measure of physical function for hip OA HOOS-Physical Function Shortform (HOOS-PS): an OARS/OMERACT initiative. *Osteoarthritis and Cartilage/OARS, Osteoarthritis Research Society*. 2008; 16: 551-559.
10. Edelstein J, Ranawat A, Enseki KR, et al. Post-operative guidelines following hip arthroscopy. *Current Reviews in Musculoskeletal Medicine*. 2012; 5: 15-23.
11. Fulk GD, Combs SA, Danks KA, et al. Accuracy of 2 activity monitors in detecting steps in people with stroke and traumatic brain injury. *Physical Therapy*. 2014; 94: 222-229.
12. Ganz R, Parvizi J, Beck M, et al. Femoroacetabular impingement: a cause for osteoarthritis of the hip. *Clinical Orthopaedics and Related Research*. 2003; 412: 112-120.
13. Grzybowski JS, Malloy P, Stegemann C, et al. Rehabilitation following hip arthroscopy—a systematic review. *Frontiers in Surgery*. 2015; 2: 21.
14. Jovanov E, Milenkovic A, Otto C, et al. A wireless body area network of intelligent motion sensors for computer assisted

- physical rehabilitation. *Journal of Neuroengineering and Rehabilitation*. 2005; 2: 6. doi:10.1186/1743-0003-2-6.
15. Kelly BT. Hip arthroscopy rehabilitation-labral refixation with or without FAI component. Accessed 23 Oct 2016.
 16. Kuehn BM. Is there an app to solve app overload? *JAMA*. 2015; 313: 1405-1407.
 17. Lockman J, Fisher RS, Olson DM. Detection of seizure-like movements using a wrist accelerometer. *Epilepsy & Behavior: E&B*. 2011; 20: 638-641.
 18. Malloy P, Malloy M, Draovitch P. Guidelines and pitfalls for the rehabilitation following hip arthroscopy. *Current Reviews in Musculoskeletal Medicine*. 2013; 6: 235-241.
 19. Martin RL, Kelly BT, Philippon MJ. Evidence of validity for the hip outcome score. *Arthroscopy: The Journal of Arthroscopic & Related Surgery: Official Publication of the Arthroscopy Association of North America and the International Arthroscopy Association*. 2006; 22: 1304-1311.
 20. Mohtadi NG, Griffin DR, Pedersen ME, et al. The Development and validation of a self-administered quality-of-life outcome measure for young, active patients with symptomatic hip disease: the International Hip Outcome Tool (iHOT-33). *Arthroscopy: The Journal of Arthroscopic & Related Surgery: Official Publication of the Arthroscopy Association of North America and the International Arthroscopy Association*. 2012;28:595–605; quiz 606–510.e591.
 21. Nilsson AK, Lohmander LS, Klassbo M, et al. Hip disability and osteoarthritis outcome score (HOOS)—validity and responsiveness in total hip replacement. *BMC Musculoskeletal Disorders*. 2003; 4: 10.
 22. Potter BK, Freedman BA, Andersen RC, et al. Correlation of Short Form-36 and disability status with outcomes of arthroscopic acetabular labral debridement. *The American Journal of Sports Medicine*. 2005; 33: 864-870.
 23. Rettner R. The quantified self: how data-obsessed trackers push toward healthier lives. 2014. <http://www.livescience.com/44618-quantified-self-culture.html> Accessed 15 Sept 2015
 24. Swan M. Emerging patient-driven health care models: an examination of health social networks, consumer personalized medicine and quantified self-tracking. *International Journal of Environmental Research and Public Health*. 2009; 6: 492-525.
 25. Tannast M, Goricki D, Beck M, et al. Hip damage occurs at the zone of femoroacetabular impingement. *Clinical Orthopaedics and Related Research*. 2008; 466: 273-280.
 26. Wahoff M, Dischiavi S, Hodge J, et al. Rehabilitation after labral repair and femoroacetabular decompression: criteria-based progression through the return to sport phase. *International Journal of Sports Physical Therapy*. 2014; 9: 813-826.
 27. Watson SM (2014) Stepping down: rethinking the fitness tracker. *The Atlantic*.