Assessing the Functionality and Comfort of Chest Heart Rate Monitor Use During Acute Orthopedic Trauma Surgery

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Abstract

Objective: This equipment test sought to investigate whether wireless chest heart rate (HR) monitors function properly and are comfortable when worn under surgical apparel and lead.

Methods: Three participants donned chest heart rate monitors, surgical scrubs, and surgical lead aprons in a simulated operating room. For approximately 40 minutes, they conducted a series of movements that mimics those used during acute trauma surgeries while heart rate metrics (including heart rate variability) data was collected and comfort was evaluated.

Results: All chest HR monitors stayed in position and did not produce discomfort in any participants. Additionally, despite their location under surgical lead, the HR monitors successfully transmitted data to the collection hub 98.92% of the time.

Conclusions: Chest-worn HR monitors function properly and in this instance are comfortable to wear in the tested operating room, encouraging their use by trauma surgeons to further test these devices and study their physiologic response to different operations.

1. Introduction

Technological advancements have led to an explosion of devices that continuously record health data and have become ubiquitous in many areas of life. Initially popular among athletes who used the data to understand how their bodies were responding to their training and recovering between workouts, biometric monitoring is beginning to attract the attention of healthcare workers who are looking to improve their health and performance (Daanen et al., 2012). Surgeons have many parallels with athletes—such as the need to perform under high-pressure situations and quickly recovery between cases—making them an ideal starting point for investigating how biometric monitoring could be effectively adopted in a healthcare setting (Cocks et al., 2014).

Heart rate is one of the oldest and most widely used health metrics (Achten & Jeukendrup, 2003). Continuous heart rate monitoring provides valuable insights into an individual's fitness level, effort (internal workload), calorie expenditure, and more (Jensen et al., 2013; VandeBunte et al., 2022). Historically heart rate was primarily reported as the average number of heart beats per minute. More recent advancements in hardware have allowed for accurate and reliable measurement of heart rate variability (HRV) (Quintana et al., 2012). HRV refers to the variation in the time interval between consecutive heartbeats, measured in milliseconds (ms), and serves as a non-invasive measure of autonomic nervous system (ANS) activity, reflecting the heart's adaptability to various physiological and external stimuli (Kim et al., 2018). Typically, a low resting HRV suggests an activation of the sympathetic (fight or flight) branch of the ANS, suggesting reduced ability of the body to cope with internal or external stimuli and stressors. On the other hand, higher HRV during acute psychological stress is associated with better performance (Thomas & Viljoen, 2019). Research has shown that higher HRV is linked to greater prefrontal cortex activation, improved cognitive performance, enhanced working memory, and extended sustained attention (Hilgarter et al., 2021; Jiménez Morgan & Molina Mora, 2017). Furthermore, HRV has been shown to change rapidly, declining over the course of minutes or hours depending on the extent of the physiologic load (Corrigan et al., 2023).

Heart rate monitors have more recently been integrated into watches and worn on the wrist via photoplethysmography (PPG), but this location poses a significant challenge for surgeons who wish to measure their physiological load during operations because anything worn below the elbow violates sterility protocols (Bali, 2021). Additionally, wrist worn heart rate monitors have significantly reduced accuracy, especially for HRV, when measured against gold standard ECGs (Merrigan et al., 2022). Bicep worn heart rate monitors would solve the sterility problem, but they have similar accuracy issues as the wrist worn devices since they both utilize photoplethysmography which cannot measure HRV during movement. As a result, chest worn heart rate electrocardiogram (ECG) monitors have the potential

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to provide highly accurate HR and HRV readings without contaminating the sterile field, enabling surgeons to monitor their physiologic strain during operations. Understanding the cardiovascular strain that surgeons experience while operating could reveal opportunities to tailor interventions that augment their performance during and recovery between operations. This could have downstream effects including reduced surgeon burn out and improved patient outcomes.

While chest worn heart rate monitors offer valuable data, their integration into the operating room (OR) faces a few potential challenges. First, surgeons wear multiple layers of clothing, including hospital scrubs, lead aprons, and sterile gowns, so the physical ergonomics and comfort of wearing a chest strap heart rate monitor must be considered. Since healthcare professionals already face significant physical demands in the OR, adding a device under their protective clothing could potentially exacerbate these stresses and impair their performance. Additionally, orthopedic acute trauma surgery is very physically demanding often causing surgeons to sweat profusely during operations. Therefore, the ability for a chest strap to comfortably stay in position while wet and during dynamic full body activity must also be assessed. Finally, HRV is a much more data and computationally intensive metric than standard heart rate, necessitating that data continuously be transmitted from the chest strap to an external collection and storage device. It is unknown whether lead aprons will disrupt the wireless connection between the chest strap and the data storage device.

In this equipment test, we use a simulated OR experience to evaluate the feasibility of 1) wearing a chest heart rate monitor in the OR and 2) transmitting live HR and HRV data collection while wearing surgical lead and sterile gown. Our hypothesis is that it is comfortable and feasible to wear chest heart rate monitors in the OR without interfering with the surgeon's movements or the collection of HR and HRV data.

Methods

This equipment testing feasibility study, involved three healthcare workers, two female and one male. These individuals were age 25 to 42 years old and represented a variety of physical fitness levels. The test was conducted in a surgical simulation center at the hospital where the test took place. The space included almost everything that what would be found in a functional operating room, enabling test conditions to closely mirror those of an actual operating environment.

At the start of the testing, each participant was equipped with a Polar chest strap along with a Polar Team Pro transmitter puck (Polar USA). This chest-worn heart rate strap was selected due to its ability to accurately record and transmit HR and HRV measurements in active individuals when compared to a gold standard ECG(Quintana et al., 2012). The approximately one inch wide strap wraps around the torso and is held in place via friction with the help of a rubberized texture on the underside of the strap (**Figure 1**). In order to ensure accurate reading, the strap must be in direct contact with the participant's skin—except in extreme cases, chest hair does not impact accuracy. Each participant was then outfitted with standard surgical scrubs and a surgical lead apron to replicate the attire typically worn during surgery (**Figure 2**). Data was transmitted in real-time from the Polar Team Pro transmitter pucks to an iPad system over Bluetooth, allowing for immediate collection and monitoring of the participants' heart rates. ECG signals were measured at 1000Hz and HR and HRV reported every second (HR) and every beat in ms (HRV).

The equipment test period lasted for 40 minutes. During this time, participants conducted a series of physical movements designed to elevate their heart rate, increase their core temperature, and induce perspiration. These activities included fast walking, squats, lunges, and jumping jacks. The intention was to simulate the physical exertion and subsequent perspiration levels that would be comparable to those experienced in an operating room. Once the initial exercise sequence was completed and the participants were suitably perspiring, they conducted motions mimicking those experienced in an orthopedic trauma operating room. These motions included repetitive unilateral and bilateral overhead arm swings, unilateral and bilateral cross body arm swings, stationary traction pulls, and stationary pushing. To evaluate the comfortability of the heart rate monitor, participants were asked before, during, and after the test period how the strap felt, whether it impeded any of their movements, and if the strap stayed in place.

Upon conclusion of the data collection period, heart rate and heart rate variability data were exported from the Polar Team Pro system and analyzed using Kubios software to determine minimum, maximum, and average heart rate and RMSSD heart rate variability over the test period. RMSSD (Root Mean Square of Successive Differences) is the square root of the mean of the squares of differences between adjacent normal-to-normal intervals (NN) intervals(Shaffer & Ginsberg, 2017). It reflects the beat-to-beat variance in heart rate and is often used to estimate the vagally mediated changes reflected in HRV.

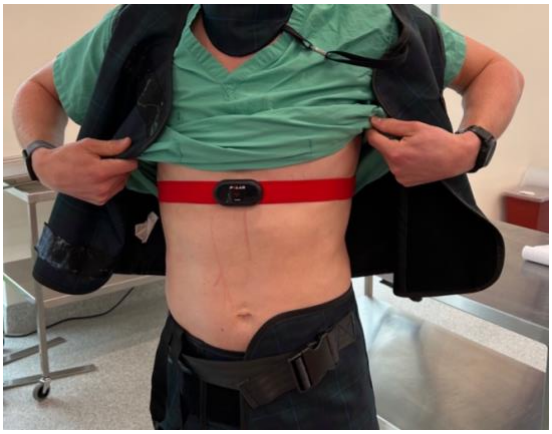

Figure 1: Study participant wearing a Polar Team Pro strap and transmitter. The black centerpiece is known as a "puck" which processes, stores, and transmits all the data.

Figure 2: Study participants outfitted in surgical scrubs and lead aprons in the simulated operating room where the study took place. Polar Team system can be seen on the right side of the operating table.

Results

The results of this equipment test demonstrate the feasibility of wearing a chest heart rate monitor without producing discomfort in participants nor impeding a series of dynamic movements that are often undertaken during surgical procedures. Furthermore, the results show that HR and HRV data may effectively be collected and transmitted even when a heart rate monitor is worn under a surgical lead apron and other apparel.

All participants found the strap to be comfortable throughout the test period regardless of sex and agreed that wearing the device would not distract them from effectively conducting a surgical operation. Interestingly, participants remarked that the lead apron improved the comfortability of the strap, causing the sensation of the strap to "vanish" once they put the lead apron on. This is most likely due to the fact that the lead apron covers a larger body surface area and more tightly hugs the body than the heart rate strap. Furthermore, the lead apron is heavy and stiff, generating greater pressure on the body than the lightweight and flexible heart rate monitor. As a result, any difficulties with movement were attributed to the lead apron rather than the heart rate monitor. Not only was the strap deemed to be comfortable, but no participants reported comfort issues related to the heart rate puck either. This piece of plastic is inflexible, much thicker than the strap, and sits right on top of the participants sternum, leading it to stick out about ½ inch from the participants chest (**Figure 1**). Despite the puck's relative thickness compared to the rest of the strap, the lead apron did put pressure on the puck leading to discomfort.

The strap successfully stayed in place despite the perspiration and movement. Throughout the test, no participants reported noticeable strap movement leading to discomfort or a change in strap position. This held true even after heavy perspiration and vigorous movement. The steadfastedness of the strap was further supported by the high quality of the heart rate data collected. In order to accurately measure HRV, the heart rate monitor electrodes must maintain constant contact with the skin and remain in position close to the heart. Furthermore, strap movement against the skin is known to cause noise in the data, reducing measurement accuracy. Despite these challenging criteria, HRV and HR data was collected nearly continuously for all participants. As seen in **Table 1**, Participant 1 had an average HR of 107 beats per minute (bpm) and HRV of 11.0 milliseconds (ms). Participant 1's minimum HR was 82 bpm and maximum was 151 bpm. Participant 2 had an average HR of 92 bpm and HRV of 14.2 milliseconds ms. Participant 2's minimum HR was 67 bpm and maximum was 116 bpm. Participant 3 had a much lower HR and higher HRV reading, which is not surprising given their status as an elite endurance athlete. Participant 3 had an average HR of 53 bpm and an HRV of 77.6 ms. Their minimum heart rate was 40 bpm and his maximum HR was 103 bpm.

Importantly, very little data loss was noted. Participant 1's heart rate monitor only lost 1.15% of its data over 41:22 minutes of collection time. Participant 2's heart rate monitor only lost 0.52% of its data over 42:06 minutes of collection time. Participant 3's heart rate monitor only lost 1.52% of its data over 47:32 minutes of collection time. When taken across all three participants, only 1.08% of

expected data was lost during collection and transmission, despite needing to pass through (or around) a layer of surgical lead.

Participant	Average Heart Rate Variability (ms)	Average Heart Rate (beats per minute)	Max Heart Rate (beats per minute)	Minimum Heart Rate (beats per minute)
1	11.0	107	151	82
2	14.2	92	116	67
3	77.6	53	103	40

Table 1: Summary of Heart Rate and Heart Rate Variability data for each participant

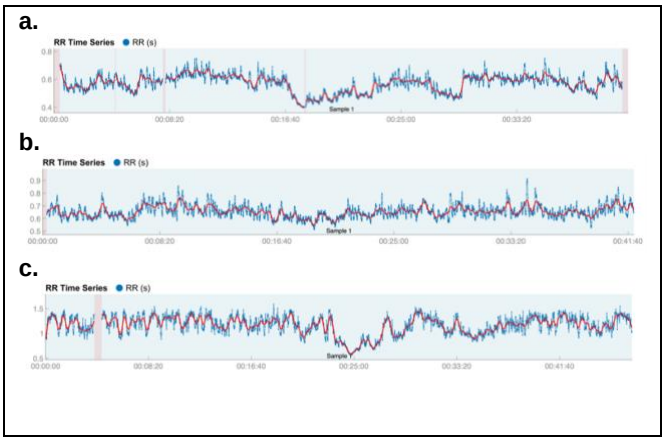

Figure 3: HRV data for each participant

Discussion

The potential of continuous biometric monitoring devices to improve health and wellbeing in a variety of settings has seen a significant focus in recent years, primarily driven by advancements in wearable technology. Now, technology that used to be the size of a desktop computer can fit on an individual's wrist. In healthcare, there is great enthusiasm to figure out how to use these devices and their vast array of data to optimize the performance of healthcare professionals (Lu et al., 2020). In this equipment test, we sought to explore the feasibility of using heart rate monitors in the operating room to collect HR and HRV data. This environment presents unique challenges as surgeons are required to wear full sterile gear along with heavy and bulky surgical lead aprons. In the test setting, our results suggest that chest heart rate monitors may be worn during operations without impairing surgeon movements or causing discomfort all while collecting and transmitting data seamlessly despite the barriers created by surgical apparel. While a simple design, this equipment test has important implications for the implementation of personal health monitoring and digital health solutions in the operating room and for performance monitoring in future research studies.

Being able to monitor a surgeon's HR in real time could be invaluable in helping them improve their performance and recover better between cases. Like athletes, knowing HR and HRV could help prevent surgeons from overexerting and could provide them with an objective measure of their stress. It is known that decision making and performance declines with fatigue and when under stress. Thus, HR and HRV information could be used to indicate times for breaks or targeted, short mindfulness sessions which have been shown to improve surgeon mood and performance (Cooper et al., 2022). Furthermore, an understanding of the stress that their bodies experience while working could encourage surgeons to optimize or adopt habits that enhance their overall wellbeing. While real-time surgeon HR and HRV could be a valuable tool, it must be implemented carefully to ensure privacy and to not distract from the operation at hand.

A primary concern when integrating wireless technology, such as a Bluetooth heart rate monitor, in operating rooms is signal interference. Heavy materials, such as surgical aprons, could potentially hinder the effectiveness of such devices due to signal blockage. However, our test found that the heart rate monitor's Bluetooth signal was minimally affected by the presence of lead aprons in the simulated operating room setting as evidenced by the low amount of missing data reported.

Comfort is an equally important consideration for personal health monitoring among surgeons, especially in the high-stress environments of an operating room where distractions must be minimized. The comfort of the chest-worn heart rate monitor under the x-ray lead apron was found to be not only satisfactory, but it virtually disappeared when worn with a lead apron given the much higher relative discomfort of the surgical lead, which adds to its feasibility for long-term use in similar scenarios. Comfort among both sexes was reported, which is important given the proper placement of the strap just inferior to the breasts, which was an initial concern for the female participants. Furthermore, the chest strap did not slip or move out of position despite heavy perspiration and vigorous movement by the participants. This is crucial because if a strap were to slip during a surgical operation, not only would it

distract the surgeon, but it could also potentially cause to a break in sterility protocols if the surgeon were to try to stop it from sliding down their torso, endangering the patient and slowing the operation.

This equipment testing study has certain limitations that warrant consideration. First, the small sample size limits the generalizability of our findings across the wider population of surgeons. In addition, the test duration of only 40 minutes is significantly shorter than the actual length of many surgical procedures, which can last several hours. Thus, the endurance and comfort of using the heart rate monitor over long durations remain uncertain. Furthermore, our research was conducted in a simulated operating room (OR) setting, not a real OR, which may not reflect the same environmental and psychological pressures experienced during actual surgeries. Adding to this, the test used simulated movements instead of the authentic movements a surgeon would perform during procedures. Consequently, this might impact the comfort of the strap and the efficacy of its data collection during real surgery. As a result, future studies should aim to address these limitations to validate and extend our findings.

Altogether, this test demonstrates that the chest worn heart rate monitors can be used effectively at the tested institution and encourages future research to evaluate its performance elsewhere, over extended periods of use, and during actual surgical procedures. With the rapidly evolving field of digital health solutions and an ever present interest in improving surgical outcomes, this study provides a steppingstone towards implementing personal health monitoring among surgeons and leveraging that data to improve surgeon performance.

Conclusion

In summary, our limited study demonstrates that chest-worn heart rate monitors can be used in the tested surgical environment. The monitor maintains its relative position and enables unimpeded mobility even during complex movements inherent in acute orthopedic trauma surgery. Its resistance to slipping under intense perspiration and dynamic activity underlines its suitability for real-world surgical conditions. Importantly, surgical attire, including lead aprons and scrubs, did not obstruct data transmission, confirming the ability of chest HR monitors to capture essential physiological parameters uninterrupted. This trial inspired the implementation of new, ongoing studies that utilize heart rate monitors in real world operating rooms to understand the cardiovascular strain that surgeons experience while operating and what factors impact HR and HRV changes in the operating room. Furthermore, these encouraging results endorse a wider investigation of these devices and other biometric monitoring devices in other surgical environments and whether they can potentially augment surgical performance and ultimately patient outcomes.

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