Monitoring of Muscle Oxygen Saturation Using Wearable Technology in a Healthy Population and Longitudinally in an Age-Matched Cohort of Patients Post- Anterior Cruciate Ligament Reconstruction

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INTRODUCTION:

Current clinical practice guidelines for return-to-play (RTP) following anterior cruciate ligament reconstruction (ACLR) rely on a combination of chronobiologic time, RTP functional and strength testing, and clinical judgement. Currently, there are no internal variables utilized to predict readiness for return to play. The purpose of this study is to utilize a wearable muscle oxygen sensor to collect muscle oxygen saturation (SmO_2) in healthy athletes and an age-matched cohort to provide an internal variable to track physiologic readiness for RTP.

METHODS:

Fifty healthy athletes aged 14-30 without history of lower extremity injury were enrolled to participate in a combination of aerobic, isometric, and strength testing while wearing muscle oxygen sensors. Athletes participated in a 1-hour training regimen consisting of fan-bike exercises, maximal-time isometric holds, and uni-/bilateral leg press. Muscle oxygen sensors were placed on the vastus medialis bilaterally allowing for continuous collection of muscle oxygen saturation (SmO_2). An age-matched cohort of 28 athletes who underwent ACLR were prospectively enrolled alongside the healthy cohort. For all ACLR patients, demographics, graft type, and quadriceps girth were collected at each visit. ACLR patients subsequently underwent the same testing protocol at 6-, 9-, and 12-month timepoints post-surgery. For each athlete, the time-paired difference in SmO_2 was calculated by subtracting the left leg SmO_2 % from the right leg SmO_2 %. Data analysis was completed utilizing R-statistical analysis. Analysis was limited to bilateral exercises to minimize confounding variables.

RESULTS:

A total of 50 healthy athletes, consisting of 21 males and 29 females (mean age 20.1 yo; range: 18-22 yo) and 28 athletes post-ACLR, consisting of 16 males and 12 females (mean age 16.5 yo; range: 14-21 yo), successfully enrolled and completed the research trial. 25/28 surgical athletes received a patellar tendon autograft, and three received a quadriceps autograft. Within the healthy cohort, the mean difference in SmO_2 did not statistically differ between the right and left legs (Table 1). Healthy athletes exhibited a normal variation in SmO_2 of ± 5% between their right and left legs (Figure 1). On average, surgical athletes did not see a return of normal muscle physiology by the 6- and 9-month time points but did by the 12-month time-point (Table 1, Figure 2). On an individual level, 8/28 athletes at 6-months, 10/28 athletes at 9-months, and 20/28 athletes at 12-months saw recovery of physiologic SmO_2. Based on current clinical practice guidelines, mean timeframe for RTP was 10.8 months. Individually, 0/28 at 6-months, 15/28 patients at 9-months and 26/28 patients at 12-months met clinical criteria for RTP. Among the 8/28 athletes whose SmO_2 did not return to normal, five met traditional criteria for clearance at 9-months, and three were cleared for RTP at 10.7 months, 12.8 months, and 17.8 months. Quadriceps girth changed by <1mm as a whole, no relationships between quadriceps girth and internal muscle physiology was found.

DISCUSSION AND CONCLUSION:

Based on a healthy population of athletes, SmO_2 readings should fall within ±5% of the healthy leg. Utilizing the healthy cohort as a control, surgical athletes did not see a recovery of normal muscle physiology until the 12-month timeframe in most cases. Many athletes who do meet criteria for RTP based on current clinical practice guidelines were not seen to have normal SmO_2 physiology at their time of clearance. At the same time, eight of 28 athletes were found to have normal muscle physiology at the 6-month timeframe, based on SmO_2. Incorporation of an internal measure for recovery can supplement the current guidelines which rely on external measurements and assessment.

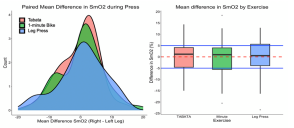

Figure 1. Distribution and box plots of healthy athletes by exercise. IQR, representing the middle 50% of healthy athletes, was ±5% for all exercises.

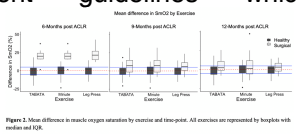

Figure 2. Mean difference in muscle oxygen saturation by exercise and time-point. All exercises are represented by boxplots with median and IQR.

Table 1. Difference in mean SmO_2 in healthy and ACLR athletes, stratified by exercise and time point. Among the healthy cohort, mean SmO_2 did not statistically differ between the right and left legs. Surgical athletes SmO_2 statistically differed between the surgical and contralateral legs at all time points based on repeated measure t-testing (all $p < 0.005$). Utilizing a cutoff of 5% difference based on the IQR of healthy athletes, surgical athletes on average saw recovery of internal physiology by 12-months.

	TABATA	1-Minute Fan Bike	Bilateral Leg Press
Healthy (Right Leg – Left Leg)	-0.3 95%CI [-.7, .1]	-0.2 95%CI [-1.6, 1.3]	-0.9 95%CI [-2.6, .8]
6mo post-op	11.9 95%CI [11.2, 12.5]	10.5 95%CI [8.5, 12.5]	11.9 95%CI [9.2, 14.7]
9mo post-op	6.55 95%CI [5.9, 7.2]	7.5 95%CI [5.5, 9.5]	3.58 95%CI [1.1, 6.1]
12mo post-op	3.4 95%CI [2.8, 4.0]	5.0 95%CI [3.1, 6.9]	6.7 95%CI [4.5, 8.9]

Table 2. Comparison of number of athletes being meeting criteria to be cleared for return to play based on current clinical practice guidelines compared to number of athletes with return of normalized muscle physiology.

	6-months	9-months	12-months
Clinical RTP	0/28	15/28	26/28
Normalized muscle physiology	8/28	10/28	20/28