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ABSTRACT

Introduction: Given the prevalence of hamstring injuries in football, a rehabilitation program that effectively promotes muscle tissue repair and functional recovery is paramount to minimize re-injury risk and optimize player performance and availability. **Purpose:** To assess the concurrent effectiveness of administering an individualized and multifactorial criteria-based algorithm (RA) on hamstring injury rehabilitation in comparison to employing a general rehabilitation protocol (RP). **Methods:** Implementing a double-blind randomised controlled trial approach, two equal groups of 24 football players (48 total) completed either an RA group or a validated RP group five days following an acute hamstring injury. **Results:** Within 6 months after return to sport, 6 hamstring re-injuries occurred in RP versus 1 in RA [relative risk = 6 (90% confidence interval: 1-35); clinical inference: very likely beneficial effect]. The average duration of return to sport was possibly quicker (ES=0.34±0.42) in RP (23.2±11.7 days) than in RA (25.5±7.8 days) (-13.8%, 90%CI: -34.0 to 3.4%; clinical inference: possibly small effect). At the time to return to sport, RA players showed substantially better 10-m time, maximal sprinting speed as well as greater mechanical variables related to speed (i.e., maximum theoretical speed and maximal horizontal power) than the RP. **Conclusions:** Although return to sport was slower, male football players who underwent an individualized, multifactorial, criteria-based algorithm with a performance- and primary risk factor-oriented training program from the early stages of the process markedly decreased the risk of re-injury compared to a general protocol where long length strength training exercises were prioritized.

Key words

Hamstring injury; multifactorial hamstring rehabilitation; individualized treatment; hamstring algorithm

INTRODUCTION

Hamstring strain injuries are the most prevalent diagnosis in football (12). Unfortunately, hamstring injury rates in football have remained unchanged, or have increased (12), over the last 30 years. Hamstring injuries account for one of the main causes of lost playing time and result in significant performance and financial loss to teams as a result of player unavailability (11). The available literature indicates that nearly 1 out of 3 hamstring injuries will recur, mostly within the first weeks of the athlete's return to sport (27). With previous injury comprising one of the most reported non-modifiable risk factor for hamstring injuries in football players (39), this high rate of recurrence (9, 27) fuels the debate on whether the causes of injury are intrinsically derived from the initial injury (i.e. incomplete healing process) or the result of suboptimal rehabilitation. Therefore, determining the type of rehabilitation program that most effectively promotes muscle tissue repair and functional recovery is paramount in minimizing the risk of re-injury and thus to increase player availability and consequently performance.

The structure and content of current hamstring injury rehabilitation processes are based on principles established in the mid-20th century (14). These principles are presented in the form of general protocols where one or two risk factors (3, 28, 38) are contemplated and progressed through a rehabilitation program according to the biology of muscle injury and repair. Presently, rehabilitation protocols for football players (3, 38) do not appear to place a substantial emphasis on the programming and sequencing of training loads or on the performance-related factors (e.g. ankle stiffness, horizontal forces) that might be necessary to prepare the player for unique sporting demands. For example, the well known "leg bridge" exercise (38) is not associated with the type of resistance and overall workload that the players' muscle-tendinous system will be exposed to after they return to play.

The nature underlying hamstring injuries is accepted as multifactorial and complex (1, 23). It has been suggested (24) that a systematic rehabilitation process (i.e. algorithm) consisting of an ordered sequence of steps (criteria-phases) could aid in the complicated clinical decision-making procedure of a successful return to play and subsequently decrease re-injury rates. With this algorithm approach, each phase of hamstring strain recovery depends on the outcome of the previous step and is based on an individualized response in order to progress in difficulty. Furthermore, if the algorithm is able to objectively structure the content and criteria to be met according to (i) biological tissue repair principles (20), (ii) main injury mechanism (i.e., sprinting mechanics (4, 26) and (iii) multiple risk factors associated with hamstring strain (39, 23, 24), it could conceivably provide flexible programming accounting for the specific weaknesses of each player. This design process is not possible in a pre-established, one-size-fits-all, general protocol (3, 38). In summary, the algorithm constitutes a theoretically objective and individualized multifactorial approach to hamstring injury rehabilitation in order to build a solid framework. Such a framework would allow: (i) future feedback necessary to understand how to achieve, include or remove the different marked quantitative criteria and, (ii) obtain high-quality data to avoid misleading decisions and challenge dogma that underpins 'usual care' to subject all elements of our management strategies to scientific scrutiny as previously suggested. (14).

Therefore, the aim of this study was to assess the concurrent effectiveness of implementing a multifactorial, individualized, criteria-based algorithm approach on hamstring injury rehabilitation compared to employing a general rehabilitation protocol in male football players. The comparison will focus on three main outcomes that directly impact daily clinical practice of any football club: number of re-injuries, time to return to play and sprint performance and associated mechanical outputs.

METHODS

Study design

An equally-randomized, double-blind, parallel-group and controlled trial approach was utilised in the design of this study. Semi-professional male football players with acute hamstring strain injury (grade I tear) were randomly allocated to a rehabilitation algorithm (RA) group or a rehabilitation protocol (RP) group. The study was designed and conducted by Zentrum Sport and Chair of Sports Traumatology of Catholic University of San Antonio. All procedures of this study were approved by the Ethics Committee of Catholic University of San Antonio (UCAM, Murcia, Spain; #CE_1013), followed the ethical guidelines of the Declaration of Helsinki and conformed to the recommendations of the Consolidated Standards of Reporting Trials (CONSORT) statement of 2010 (35).

Patient recruitment

In the course of two consecutive years (March 2014 to February 2016), potential patients from football teams within the southeast region of Spain were attracted and recruited to partake in this study via online advertisements, mass e-mails and personal contacts with physicians, coaches and physical therapists. As a result, 70 football players (Figure 1) showed interest in participating by contacted the study coordinator (E.M.R.). Following initial contact, potential patients engaged in a telephone and face-to-face survey to register age, availability and eligibility/ineligibility criteria (suspected hamstring strain and contra-indications to the study protocol). As medical data were to be collected prior to final inclusion, all patients (or their parents/guardians if they were under-18) were informed of the study nature before providing their written informed consent to participate.

INSERT FIGURE 1 HERE

Eligibility and ineligibility criteria

A second investigator (J.M.) determined the eligibility and ineligibility of all contacted football players from the information recorded during the surveys.

To be eligible, patients were required to be: (i) male, older than 16 years of age; (ii) available to follow a rehabilitation program; (iii) currently playing on a semi-professional/professional football team; and (iv) suspected of possessing a hamstring strain injury (of non-contact etiology) which occurred during a training or match (played within the previous 4 days) and subsequently forced the player to cease activity.

Patients were termed ineligible who: (i) were suspected or verified with previous hamstring strain injuries in the same leg in the last 6 months (34); (ii) suffered an extrinsic trauma to the posterior thigh, a grade II-III tear or an avulsion (36); (iii) presented ongoing or chronic hip, knee, leg, ankle, foot or lumbopelvic injuries that required intervention by a health professional; and (iv) suffered a neurological, cardiorespiratory or systemic disorder.

Diagnostic confirmation

Potential patients then participated in a clinical and ultrasound examination within 4 days of the injury to confirm or deny the suspected hamstring strain injury. Confirmation of the injury was based on clinical examination and/or ultrasonography. If the clinical examination revealed 2 or more of the following findings, with respect to the non-injured thigh, the hamstring strain injury was confirmed: (i) localized pain on palpation of the hamstring muscles, (ii) posterior thigh pain without radicular symptoms and/or diminished flexibility during a passive straight leg raise and (iii) pain and/or weakness with resisted knee flexion at 15° measured with a handheld dynamometer (minimum difference of 20% between legs). Additionally, the verification of all hamstring strain injuries was required by ultrasonography with the determination of the grade of severity. Only grade I (structural muscle injury) hamstring strain injuries were included in the study (29). Grade I hamstring strain injuries have shown to be more frequent and prone to re-injury (9). Conversely, those football players with less than two clinical findings and/or a negative, a grade II-III or an avulsion ultrasound finding were excluded from the study (see Figure 1). Clinical examination and ultrasonography procedures were performed by the same sport medicine physician (F.M.M.) with >6 years experience as head physician of a professional football team and >15 years experience as a physician in high-performance sport in Spain. Additionally, a seasoned radiologist (F.I.) with >20 years experience in elite sport analyzed all ultrasound images. Any diagnostic discrepancy between physicians was discussed to reach a consensus.

Randomization and blinding

Eligible patients were then randomized into one of the two groups: RA group or RP group. Randomization was performed in nine blocks of 6 participants. To maintain balance among the number of subjects in each group, each block consisted of 6 labels (folded papers) prepared by an independent investigator and normally distributed as 3 RA group and 3 RP group. This randomization process, to which the physical therapist (E.M.R.) stayed unblinded in order to provide the assigned rehabilitation program, allowed us to stratify subjects according to six main parameters: playing position (i.e. goalkeeper, defender, midfield and forward), playing status (i.e. starting or substitute), age (i.e. young [≤24 years] or old [≥25 years]), mechanism of injury (i.e. high-speed running or stretching), primary injured muscle (biceps femoris, semitendinosus and semimembranosus) and history of previous hamstring strain injury. These parameters have previously been shown to affect return to sport and re-injury rates in football players (1, 23, 24, 39).

Interventions

Following the randomization process, 54 football players began one of the above-mentioned rehabilitation programs (RA or RP). Six players in total (three from each group) were removed from the study shortly after commencement due to changing football clubs (3), a traffic accident (1) and coach's decision (2). Accordingly, 48 football players constituted the RA and RP groups (Table 1).

Preceding the rehabilitation program, all subjects were requested to avoid the use of drugs and to apply the rest, ice, compression, and elevation (RICE) protocol every 2 hours. All subjects began rehabilitation on the fifth day post-injury. Both rehabilitation programs (RA or RP) were performed and controlled by the same physical therapist (E.M.R.) who was not involved in the inclusion/exclusion process nor any subsequent evaluation of the patient (i.e. clinical examination, ultrasonography, monitoring and return-to-sport assessments). In this context, each patient received a unique research number that, along with the identifying code, was stored in a secure location for the duration of the study. This research number ensured the concealment of group allocation to the remaining researchers (J.M., F.M.M., F.I., 2 external independent researchers and A.M.V.). Similarly, no patient was informed of the characteristics comprising the two rehabilitation programs (RA or RP).

Rehabilitation protocol

The RP group completed a recently described protocol which emphases loading the hamstrings during lengthening actions and is accompanied by a general rehabilitation and progressive running program (for more information about the RP, please see Askling et al. (3)). Football players assigned to RP worked on their program on a daily basis. The above-mentioned physical therapist (E.M.R.) supervised at least 4 rehabilitation sessions per week (3 sessions of general rehabilitation or progressive running program and 1 session of protocol emphasizing lengthening exercises) where players were closely monitored to follow the available instructions and guidelines provided by Askling et al. (3). When the clinical examination showed no signs of remaining injury, as indicated by Askling et al. (3), an independent researcher performed the Askling H-test; consisting of performing a straight leg raise as fast as possible to the highest point (three trials per leg, uninjured leg tested first; no warm-up). If the player experienced any discomfort during this voluntary straight leg raising, they were not allowed to return to full training extending the rehabilitation period until the H-test was repeated (interval of 3–5 days) and insecurity was eliminated. Subsequently, a sprint running test (detailed below) was performed within one month after the Askling H-test to permit the player back to the game.

Rehabilitation algorithm

The RA group performed a modified version of a previously proposed algorithm presented by Mendiguchia and Brughelli (24). Unlike the original algorithm (i.e. acute, regeneration and functional phases), the modified version removes the acute phase since the players began the rehabilitation program at 5 days post-injury (Figure 2). Reliable, subjective and objective quantifiable criteria (clinical and functional) were systematically assessed at the beginning and end of each week, by an independent researcher to determine how and when to progress a patient through each phase of the RA program and to minimise performance bias (28). When one or more of the criteria established for each phase was not achieved, the player remained in the same phase and continued with their individualized training/treatment, adding an additional afternoon session (same content) to eventually fulfill the required criteria. The program's criteria and content were selected and timed according to current knowledge on the biology of muscle injury and repair (20), the different risk factors associated with the hamstring injury (i.e. poor flexibility, diminished strength, altered lumbo-pelvic control, fatigue, etc. (39, 23, 24)) and the main mechanisms causing the injury (sprinting or stretching) (1, 40).

During the Regeneration Phase of the RA, football players daily worked both legs with a single session integrating exercises (see Video, Supplemental Digital Content 1, http://links.lww.com/MSS/A882, which demonstrates the exercises performed during the Regeneration Phase) directed at correcting the different risk factors and mechanisms related to hamstring injuries. During the Functional Phase, a three-day block training periodization (see Video, Supplemental Digital Content 2, http://links.lww.com/MSS/A883, which illustrates the exercises corresponding at each different day of the Functional Phase) was implemented to optimize training adaptations and minimize potential negative training interferences. For example, Day 1: sprint training, Day 2: strength training and Day 3: manual therapy, mobility and lumbo-pelvic control. A minimum of 3 sessions of the three-day block training was required to allow the player to return to sport. Program and activities performed during the Regeneration and Functional Phases are displayed in Table 2.

Additionally, basic aerobic conditioning commenced when the player was able to perform at least 3 sessions of running technique without any discomfort or pain in the Regeneration Phase. One running session was performed every 3 days and included 4 sets of 5 minutes at a low to moderate intensity (player rated). Later, in the Functional Phase, the running session consisted of 2 sets of 10 minutes performed at moderate to high intensity (player rated). Suspension of running sessions was permitted in the event of discomfort or pain.

Outcomes

Primary outcome measures

One of the primary outcomes of this study was re-injury occurrence registered during a 6-month period following the athlete's return to sport. If during this time a possible re-injury did occur, the physician, coach, physical therapist and/or football player had to immediately contact and inform the study coordinator (E.M.R.). The sport medicine physician (F.M.M.) would then perform a new clinical examination and ultrasonography, carried out between 2 to 5 days post-injury, the results of which were subsequently verified by the radiologist (F.I.). The additional primary outcome of this study was the summation of time to return to sport (days), consisting of the time needed from the initial occurrence of the injury to full participation in football team training and availability for match selection.

Secondary outcome measures

Secondary outcomes of this study were the effects of RA and RP on sprinting performance and horizontal mechanical properties (stronger determinant of field acceleration) at the time of returning to sport following hamstring strain injury. Since hip extensors and knee flexors play important roles in producing forward oriented ground reaction forces (26), we hypothesized that horizontal mechanical properties would permit an indirect evaluation of hamstring muscle function during high speed running actions. This evaluation would constitute a key parameter in football performance and injury perspectives (main injury mechanism).

In conjunction with this purpose, a sprint running test was performed when player felt "secure" and pain free in the Askling H-test for RP group and when all criteria to return to sport (RTS) were achieved for the RA group. The sprint running test, which was performed within a maximum of 2 weeks after returning to sport, was carried out on a different day from the Askling H-test or any other test performed during the Functional Phase.

Players were required to have not engaged in vigorous exercise within the previous 2 days prior to the sprint running test. A standardized warm-up, consisting of 5 min of low-pace (~10 km/h) running, 3 min of lower limb muscle stretching, 5 min of sprint-specific drills and three progressive 6-s sprints separated by 2 min of passive rest, was performed before the test. Subjects were then allowed 5 min of free cool-down before performing two 50-m maximal sprints, from a standing start, performed on a natural grass field. These sprints were separated by 6 min of passive rest and supervised by 2 independent researchers. Players wore their usual football shoes and ran during similar times (i.e., same hour), environmental conditions of temperature (22.5 ± 5.2°C for RA group *vs.* 20.9 ± 4.8°C for RP group), humidity (30.4 ± 15.7% for RA group *vs.* 30.4 ± 19.1% for RP group) and wind (8.6 ± 7.8 km/h for RA group *vs.* 6.5 ± 7.4 km/h for RP group) according to anemometer PCE-AM 82 (PCE Ibérica, Tobarra, Albacete, Spain).

Running speed was measured during each of the two sprints by means of a Radar Stalker ATS System (33 Hz, Radar Sales, Minneapolis, Minnesota, USA), placed on a tripod 10-m behind the subjects at a height of 1-m approximating height of subjects' center-of-mass. The resultant data were subsequently analysed using the simple field method validated by Samozino et al. (33). Briefly, this computation method is based on a macroscopic inverse dynamics analysis of the center-of-mass motion. Velocity-time data are fitted by an exponential function, after which instantaneous velocity is derived to compute the net horizontal antero-posterior ground reaction force (F), and the power output in the horizontal direction (P). Individual linear force-velocity relationships were then extrapolated to calculate theoretical maximal force (F0) and velocity (V0) capabilities, and underlying maximum horizontal external power output (Pmax).

Sixteen players from the RA group (21.7 ± 3.7 y; 73.0 ± 8.4 kg; 1.75 ± 0.07 m) and 15 from the RP group (22.1 ± 5.0 y; 73.1 ± 11.0 kg; 1.76 ± 0.10 m) performed the sprint running test. The remaining players did not undergo testing due to moving to another club or player/coach's personal decisions.

Statistical methods

Number of re-injuries is presented as counts and proportions. The differences in the number of re-injuries in football players allocated to the RA or RP groups are presented as a relative risk (RR), with the risk for the RP group divided by the risk for the RA. The uncertainty in the effectiveness of the two rehabilitation programs on re-injury risk was calculated using the percent chance or likelihood that the true value of the effect was substantial (greater than the smallest clinical importance effect). To determine the magnitude of the smallest clinical important difference or effect in terms of re-injury risk for the current study, we used the methods previously outlined by Hopkins WG et al. (18, 19). In brief, for every 10 re-injured players in one of the rehabilitation programs there are 9 injured players in the other program. That is, one in 10 injury is due to choosing a different rehabilitation program. If there are N players in RP and N players in RA, risk ratio = (10/N)/(9/N) = 10/9 (that is, 1.11). We therefore assigned this value (i.e. 1.11) as the smallest clinical important effect (18, 19). Probabilities of benefit and harm were used to make a qualitative probabilistic clinical inference about the effect in preference to a statistical inference based in a null hypothesis test (19). Briefly, the effect was deemed unclear when the chance of benefit was sufficiently high to warrant use of the treatment, but the risk of harm was unacceptable. Such unclear effects were identified as those with an odds ratio of benefit to harm of <66, a ratio that corresponds to an effect that is borderline possibly beneficial (25% chance of benefit) and borderline most unlikely harmful (0.5% risk of harm). All other effects were deemed clinically clear and expressed as the chance of the true effect being trivial, beneficial, or harmful with the following scale: 25%–75%, possibly; 75%–95%, likely; 95%–99.5%, very likely; >99.5%, most likely.

Continuous variables are presented as means ± SD unless otherwise stated. Data were first log-transformed to reduce bias arising from non-uniformity error. The standardized difference or effect size (ES, 90% confidence limit [90%CL]) in the selected variables was calculated using the pooled baseline SD. Threshold values for Cohen ES statistics were >0.2 (small), >0.6 (moderate), and >1.2 (large) (19). Uncertainly in the estimated of effects on days to return to sport and sprinting performance and associated mechanical outputs was expressed as 90% confidence limits and as probabilities that the true value of the effect was beneficial, trivial, or harmful in relation to threshold values for benefit and harm. For those measurements, a threshold was 0.20 of the between-players SD in the baseline assessment (19). Quantitative chances of beneficial/better or detrimental/poorer effect were assessed qualitatively as indicated above.

RESULTS

Re-injury

The occurrence of re-injury within 6 months is displayed in Table 3. There were substantial differences in the rate of re-injury at 6 months between groups (Table 3).

Time to RTS

The average duration of RTS was possibly quicker (ES = 0.34 ± 0.42) in the RP group (23.2 ± 11.7 days) compared to the RA group (25.5 ± 7.8 days) (-13.8%, 90%CI: -34.0 to 3.4; 70/28/2%, possibly small effect).

Sprint test

The RA group presented substantially improved 10-m, Top Speed, V0 and Pmax performance measures compared to the RP group (Table 4). Trivial and unclear changes were observed 5-m and FH0 (Table 4).

DISCUSSION

The purpose of this study was to examine the effectiveness (re-injuries, time to return to sport and sprint performance) of an individualized and multifactorial criteria-based algorithm on hamstring injury rehabilitation compared to a general rehabilitation protocol (which aims at loading the hamstrings during lengthening actions as an optimal treatment after acute hamstring injury) in football players. The main findings of the study were that players allocated to the RA group experienced (i) substantially less re-injuries, specifically in the early recurrences period, (ii) substantially more time in returning to sport following the injury, and (iii) substantially greater performance (i.e. 10-m, top speed) and mechanical variables related to speed factors (V0 and Pmax) compared to the RP group.

Our results show that the RA, integrating the temporal sequencing of the different and multiple risk factors related to hamstring injury with a performance oriented training program from the early stages of the process, markedly decreased re-injury risk compared to the RP where long length strength training exercises are prioritized. In this way at return to sport, the player who followed the RA presented a lower risk (4%) compared to a typical footballer with no history of previous injury (12-16%) (40).

The fact that the RP group, focusing on lengthening exercises, suffered 6 re-injuries after the athlete returned to play (25%) contrasts the absence of those (0%) found in a recent study with elite male and female football players (3). This may be partly explained by the different standard of players (professionals *vs.* semi-professionals in the present study) and the shorter average time to return to football practice reported in the current study (23 *vs.* 28 days in the former), impairing the maturation healing process and consequently exposing players to a higher risk of recurrence. Albeit speculative, the number of relapses recorded during the first four weeks post RTS in the RP lengthening-based group (data not presented) might confirm the above hypothesis. However, substantially longer RTS time (i.e. 51 days), after what was defined as a "protocol of conventional exercises" resulted in only 1 re-injury (3%) (3), casts doubts on the direct cause-effect relationship between earlier RTS and the increased risk of re-injuries. In this regard, the fact that in the present study's players in the RA group did not show the same trend of re-injuries as the RP group suggests that the modification of predisposing factors and/or the higher volume and intensity of the rehabilitation treatment program (see discussion below) may be more important than time to RTS *per se*.

The percentage of re-injury in previous rehabilitation studies, mostly involving football players, varies between 0-30% (3, 15, 31, 38) and is greater for grade 1 injuries (29), which constituted 100% of the injuries in the present study. The therapeutic approach shared by those studies was characterised by restoring muscle function of the localized injured area (i.e. knee flexors strength and/or flexibility) and paying little attention to other, more remote zones believed to play an important role on hamstring muscle function (e.g. contralateral hip flexors and lumbo-pelvic control). To the authors' knowledge, there is only one study available in male football players that have undertaken a criteria-based rehabilitation programme, reporting a 12% re-injury rate within 2 months of clinical discharge (38). Our most likely explanation of why the RA of the present study induced lower re-injury rates (4% within 6 months of clinical discharge) is based in the intervention's design (programming/progression) and content (multifactorial and performance-oriented) (Table 2). The selection of content (see Video, Supplemental Digital Content 1 and 2, http://links.lww.com/MSS/A882 and http://links.lww.com/MSS/A883, which illustrates the exercises corresponding at each phase) in the RA are based on a detailed and functional analysis of the different risk factors potentially associated with the hamstring injury and in the main mechanism causing the injury (sprinting or lengthening actions). Subsequently, the contents were sequenced in order to progress in a step by step basis according to their difficulty/intensity (e.g. weights, opposing forces, muscle length). The contents also take into account the current knowledge on the biology of muscle injury and repair and verify the procedure by means of objective criteria referring to the localized injured area and external factors that can influence it. For example, the choice of hamstring and gluteal strength training exercises, important from injury and performance perspective, were classified as hip or knee dominant (in the case of the hamstring) to stimulate the different muscle bellies (25). Similarly, gluteal workouts were selected based on the length–tension profile of each exercise and interaction with the contralateral leg to cover its different roles during sprint (7). In regard to intensity issues, hamstring training advanced according to progressive tension and functional aspects associated with action mode (isometric to eccentric to plyometric) and muscle length while the gluteus workout progressed on load intensity (weight percentage).

Another main advantage and innovative feature of the proposed approach (beyond its individualized and multifactorial nature), compared to previous rehabilitation studies involving football players, is that the RA program includes adjustments of both intensity and volume of the programs (3, 15, 31, 38). Although any comparison to previous studies is difficult as a result of a lack of detailed description of actual volume and intensity of the intervention undertaken, the large differences in the main outcome (re-injury rate) in favour of the RA proposed in this study can be related with the higher training load accomplished (see Table 2). In this regard, the importance of the training load carried out during the recovery process has recently been highlighted (5). Thus, a program design involving higher volume and intensity periodization, as found in the present study, might result in a more appropriate stimulus to confer enough protection during the athlete's return to sport and consequently reduce the risk of re-injury. On the basis of our results, further studies should verify whether the RA program presented here could, at least in part, be considered as an efficient training stimulus for secondary prevention, once the players have returned to practice, and even as primary prevention as physical conditioning.

Another relevant aspect inherent to any rehabilitation process refers to the injury time and consequently the availability and performance (sport-economic) side of player-club binomial. Despite starting on day 5 following injury, the return to sport duration achieved in this study in both treatment formats is comparable (21 to 51 days) to that seen in previous studies involving mainly football players (3, 15, 31, 38). However the RP, emphasising lengthening exercises, resulted in a possibly quicker (small effect) return to sport compared to the RA, emphasising an individualized and multifactorial intervention. The need to achieve each of the quantitative criteria in each of the phases and the 3 day block training periodization (sprint, strength, manual therapy/mobility/lumbo-pelvic control) followed in the Functional Phase of the RA (minimum 3 blocks) may be one of the explanations for this difference between the two treatments (Figure 2).

Finally, in addition to returning the player to sport as safe and fast as possible, all rehabilitation processes should strive to do so in the best possible conditions with respect to performance. As sprint acceleration is a key component of performance in football and constitutes the primary hamstring injury mechanism (1, 40), it was given emphasis within the design of the algorithm rehabilitation programme (Table 2). As such, early engagement in sprinting speed factors (e.g. running technique, specific strength) which progressed into actual sprinting (both acceleration and peak speed) resulted in a significant volume (a minimum of ≈ 1000-m per player) of speed training performed before clinical discharge. Earlier hamstring rehabilitation studies systematically programming and periodizing sprint training loads in football players are lacking

(3, 38). Nevertheless, the present findings support the pertinence of such an approach as sprint performance (i.e. 10-m and 20-m) and associated speed-related mechanical (i.e. V0 and Pmax) variables were greater in the RA group compared to the RP group (Table 4). However, despite the two groups being matched by age, playing position, status, mechanism of injury and primary injured muscle, we cannot exclude that sprinting speed and mechanical performance differences were present before the injury occurred. Another possibility, albeit speculative, could be that the observed differences in speed-related mechanical variables might be related with other factors. Specifically, the apprehension of pain (32) for the injured player to produce high power outputs during a relatively unpracticed movement (i.e. long sprints) throughout the rehabilitation period could have played a role in the reduced ability to attain high speeds in the RP group. Future experimental work should be conducted to evaluate the actual effectiveness of rehabilitation programmes on game-related physical performance variables (e.g. sprinting speed).

This study has some limitations, including a small sample size, which is a characteristic of other studies in this area (2, 34). Furthermore, our study population was limited to semi-professional male football players. Thus, our findings might not necessarily apply to female football players, to other sports or to higher-level football players. Additionally, only grade 1 injuries were investigated in the present study. While this type of injury is the most common, and cause the majority of days absent, further studies are needed to determine whether the findings of the present study apply to higher degree hamstring injuries. Finally, with 6 events in one group and 1 in the other, the relative risk of the current study should be interpreted with caution. Thus, future studies including more events should confirm the effectiveness of the proposed hamstring rehabilitation process.

CONCLUSIONS

In summary, male football players who underwent an individualized, multifactorial, criteria-based algorithm, which integrated the temporal sequencing of the different and multiple risk factors potentially related to hamstring injury with a performance- and primary risk factor-oriented training program from the early stages of the process markedly decreased the risk of re-injury, improved sprint performance and mechanical properties but resulted in a possibly slower (small effect) return to sport compared to a general protocol where long length strength training exercises were prioritized.

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CONFLICT OF INTEREST

The authors report no conflict of interest. There was no internal or external funding in support of this project. The results of the present study do not constitute endorsement by the American College of Sports Medicine and are presented clearly, honestly, and without fabrication, falsification, or inappropriate data manipulation.

REFERENCES

1. Arnason A, Sigurdsson SB, Gudmundsson A, Holme I, Engebretsen L, Bahr R. Risk factors for injuries in football. *Am J Sports Med.* 2004;32(1 Suppl):5S-16S.

2. Askling CM, Tengvar M, Tarassova O, Thorstensson A. Acute hamstring injuries in Swedish elite sprinters and jumpers: a prospective randomised controlled clinical trial comparing two rehabilitation protocols. *Br J Sports Med.* 2014;48(7):532-9.

3. Askling CM, Tengvar M, Thorstensson A. Acute hamstring injuries in Swedish elite football: a prospective randomised controlled clinical trial comparing two rehabilitation protocols. *Br J Sports Med.* 2013;47(15):953-9.

4. Bezodis IN, Kerwin DG, Salo AI. Lower-limb mechanics during the support phase of maximum-velocity sprint running. *Med Sci Sports Exerc.* 2008;40(4):707-15.

5. Blanch P, Gabbett TJ. Has the athlete trained enough to return to play safely? The acute:chronic workload ratio permits clinicians to quantify a player's risk of subsequent injury. *Br J Sports Med.* 2016;50(8):471-5.

6. Butler D. *Mobilization of the nervous system*. Melbourne: Churchill Livingstone; 1991. 139 p.

7. Contreras BM, Cronin JB, Schoenfeld BJ, Nates RJ, Sonmez GT. Are all hip extension exercises created equal? *Strength Cond J.* 2013;35(2):17-22.

8. Croisier JL, Ganteaume S, Binet J, Genty M, Ferret JM. Strength imbalances and prevention of hamstring injury in professional soccer players: a prospective study. *Am J Sports Med.* 2008;36(8):1469-75.

9. de Visser HM, Reijman M, Heijboer MP, Bos PK. Risk factors of recurrent hamstring injuries: a systematic review. *Br J Sports Med.* 2012;46(2):124-30.

10. De Vos RJ, Reurink G, Goudswaard GJ, Moen MH, Weir A, Tol JL. Clinical findings just after return to play predict hamstring re-injury, but baseline MRI findings do not. *Br J Sports Med.* 2014;48(18):1377-84.

11. Ekstrand J. Keeping your top players on the pitch: the key to football medicine at a professional level. *Br J Sports Med.* 2013;47(12):723-4.

12. Ekstrand J, Waldén M, Hägglund M. Hamstring injuries have increased by 4% annually in men's professional football, since 2001: a 13-year longitudinal analysis of the UEFA Elite Club injury study. *Br J Sports Med.* 2016;50(12):731-7.

13. Freckleton G, Cook J, Pizzari T. The predictive validity of a single leg bridge test for hamstring injuries in Australian Rules Football Players. *Br J Sports Med.* 2014;48(8):713-7.

14. Hamilton B. Hamstring muscle strain injuries: what can we learn from history? *Br J Sports Med.* 2012;46(13):900-3.

15. Hamilton B, Tol JL, Almusa E, et al. Platelet-rich plasma does not enhance return to play in hamstring injuries: a randomised controlled trial. *Br J Sports Med.* 2015;49(14):943-50.

16. Hamilton RT, Shultz SJ, Schmitz RJ, Perrin DH. Triple-hop distance as a valid predictor of lower limb strength and power. *J Athl Train.* 2008;43(2):144-51.

17. Harvey D. Assessment of the flexibility of elite athletes using the modified Thomas test. *Br J Sports Med.* 1998;32(1):68-70.

18. Hopkins WG, Batterham AM. Error Rates, Decisive Outcomes and Publication Bias with Several Inferential Methods. Sports Med 2016;46:1563-73.

19. Hopkins WG, Marshall SW, Batterham AM, Hanin J. Progressive statistics for studies in sports medicine and exercise science. *Med Sci Sports Exerc.* 2009;41(1):3-13.

20. Järvinen TA, Järvinen M, Kalimo H. Regeneration of injured skeletal muscle after the injury. *Muscles Ligaments Tendons J.* 2014;3(4):337-45.

21. Kelln BM, McKeon PO, Gontkof LM, Hertel J. Hand-held dynamometry: reliability of lower extremity muscle testing in healthy, physically active, young adults. *J Sport Rehabil.* 2008;17(2):160-70.

22. Liebenson C, Karpowicz AM, Brown SH, Howarth SJ, McGill SM. The active straight leg raise test and lumbar spine stability. *PM R.* 2009;1(6):530-5.

23. Mendiguchia J, Alentorn-Geli E, Brughelli M. Hamstring strain injuries: are we heading in the right direction? *Br J Sports Med.* 2012;46(2):81-5.

24. Mendiguchia J, Brughelli M. A return-to-sport algorithm for acute hamstring injuries. *Phys Ther Sport.* 2011;12(1):2-14.

25. Mendiguchia J, Garrues MA, Cronin JB, et al. Nonuniform changes in MRI measurements of the thigh muscles after two hamstring strengthening exercises. *J Strength Cond Res.* 2013;27(3):574-81.

26. Morin JB, Gimenez P, Edouard P, et al. Sprint Acceleration Mechanics: The Major Role of Hamstrings in Horizontal Force Production. *Front Physiol.* 2015;6:404.

27. Orchard J, Best TM. The management of muscle strain injuries: an early return versus the risk of recurrence. *Clin J Sport Med.* 2002;12(1):3-5.

28. Pas HI, Reurink G, Tol JL, Weir A, Winters M, Moen MH. Efficacy of rehabilitation (lengthening) exercises, platelet-rich plasma injections, and other conservative interventions in acute hamstring injuries: an updated systematic review and meta-analysis. *Br J Sports Med.* 2015;49(18):1197-205.

29. Peetrons P. Ultrasound of muscles. *Eur Radiol.* 2002;12(1):35-43.

30. Reurink G, Almusa E, Goudswaard GJ, et al. No association between fibrosis on magnetic resonance imaging at return to play and hamstring reinjury risk. *Am J Sports Med.* 2015;43(5):1228-34.

31. Reurink G, Goudswaard GJ, Oomen HG, et al. Reliability of the active and passive knee extension test in acute hamstring injuries. *Am J Sports Med.* 2013;41(8):1757-61.

32. Robinson ME, Dannecker EA. Critical issues in the use of muscle testing for the determination of sincerity of effort. *Clin J Pain*. 2004;20(6):392-98.

33. Samozino P, Rabita G, Dorel S, et al. A simple method for measuring power, force, velocity properties, and mechanical effectiveness in sprint running. *Scand J Med Sci Sports.* 2016;26(6):648-58.

34. Sanfilippo JL, Silder A, Sherry MA, Tuite MJ, Heiderscheit BC. Hamstring strength and morphology progression after return to sport from injury. *Med Sci Sports Exerc.* 2013;45(3):448-54.

35. Schulz KF, Altman DG, Moher D. CONSORT 2010 statement: updated guidelines for reporting parallel group randomised trials. *J Pharmacol Pharmacother.* 2010;1(12):100-7.

36. Silder A, Thelen DG, Heiderscheit BC. Effects of prior hamstring strain injury on strength, flexibility, and running mechanics. *Clin Biomech (Bristol, Avon).* 2010;25(7):681-6.

37. Thorborg K, Roos EM, Bartels EM, Petersen J, Hölmich P. Validity, reliability and responsiveness of patient-reported outcome questionnaires when assessing hip and groin disability: a systematic review. *Br J Sports Med.* 2010;44(16):1186-96.

38. Tol JL, Hamilton B, Eirale C, Muxart P, Jacobsen P, Whiteley R. At return to play following hamstring injury the majority of professional football players have residual isokinetic deficits. *Br J Sports Med.* 2014;48(18):1364-9.

39. van Beijsterveldt AM, van de Port IG, Vereijken AJ, Backx FJ. Risk factors for hamstring injuries in male football players: a systematic review of prospective studies. *Scand J Med Sci Sports.* 2013;23(3):253-62.

40. Woods C, Hawkins RD, Maltby S, Hulse M, Thomas A, Hodson A. The Football Association Medical Research Programme: an audit of injuries in professional football—analysis of hamstring injuries. *Br J Sports Med.* 2004;38(1):36-41.

FIGURE LEGENDS

Figure 1. Flow diagram outlining enrollment and testing procedures.

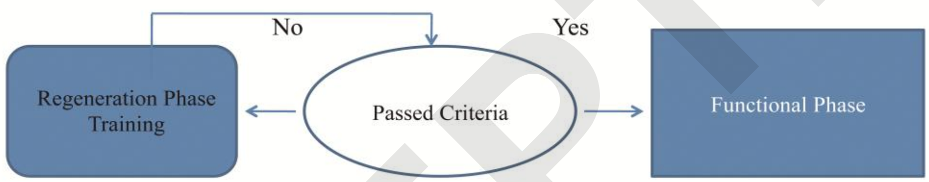
Figure 2. Criteria used to progress a football player through each phase of rehabilitation algorithm.2a. Regeneration phase criteria. 2b. Functional phase criteria.

Figure 1

a

Regeneration Phase

Variable	Test	Criteria for Progression
Pain after injury	Prone with knee flexed to 15° (10)	No pain
Isolated strength at long muscle lengths	Prone with knee flexed to 15° (21)	< 10% asymmetry
Neural deficiencies	Slump test (6)	No pain
Hamstring flexibility	Active knee extension (AKE) test (31)	< 10% asymmetry
Hip flexor flexibility	Modified Thomas test (MTT) (17)	+5 symmetry below horizontal



b

Functional Phase

Variable	Test	Criteria for Progression
Pain	Palpation (10)	No pain
Peak torque (H/H) and conventional ratio (H/Q)	Isokinetic knee flexion/extension at $60°·s^{-1}$ (8)	< 10% H/H and H/Q > 0.45 (Biodex) or > 0.47 (Cybex)
Hip extension strength	Prone hip extension (37)	< 10% asymmetry between legs
Distance	Triple hop test (16)	< 10% asymmetry between legs
Endurance (Repetition number)	Single leg bridge test (13)	> 25 and < 10% asymmetry between legs
Torsion capabilities	ASLR test (22)	No compensations
Insecurity and Pain	Askling H-test (2, 3)	No pain and insecurity

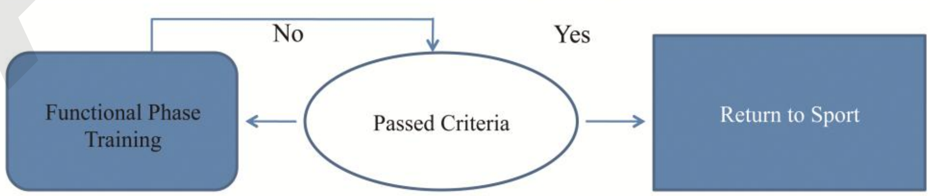


Figure 1

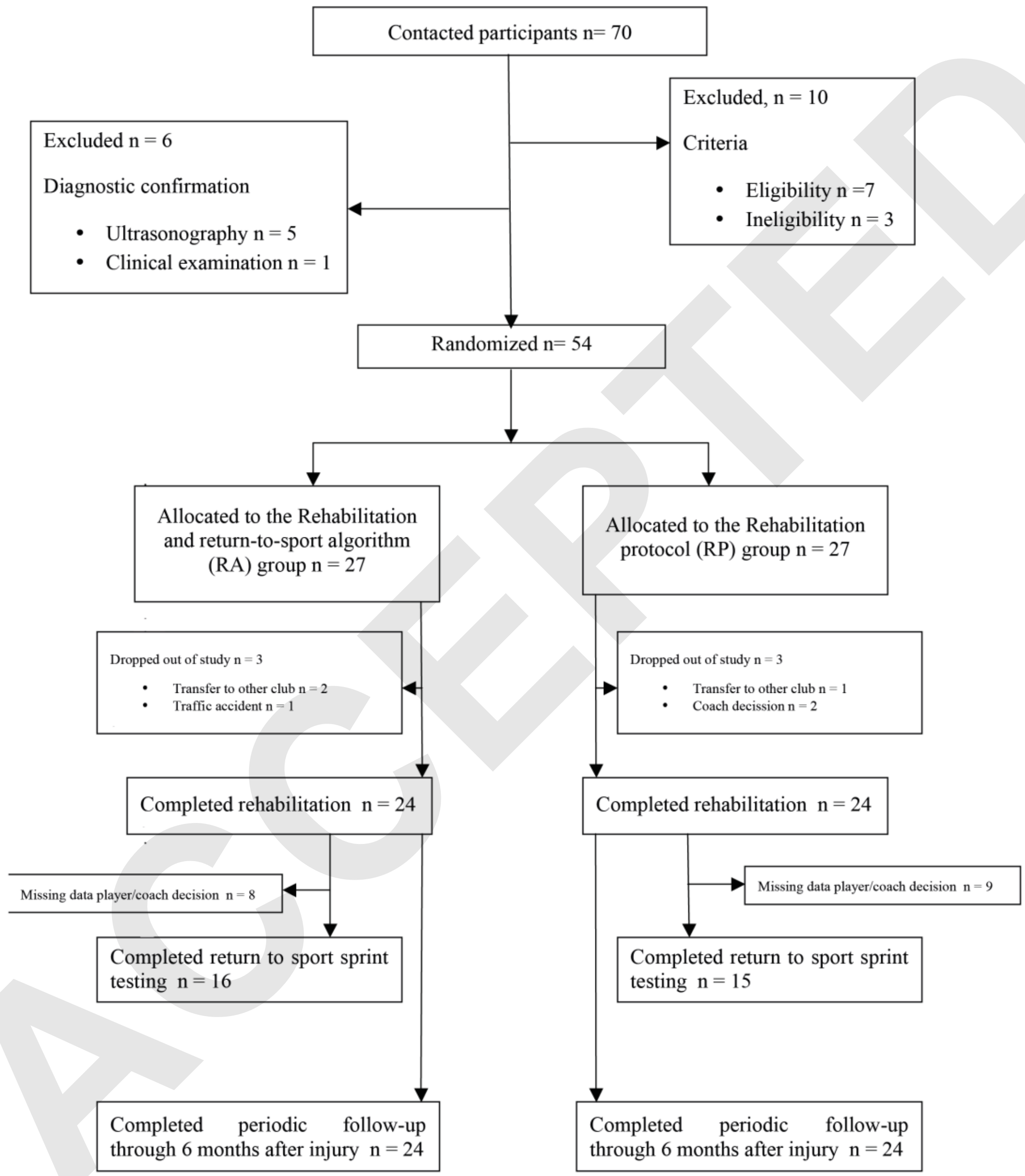

Contacted participants n= 70
Excluded n = 6
Diagnostic confirmation
Ultrasonography n = 5
Clinical examination n = 1
Excluded, n = 10
Criteria
Eligibility n =7
Ineligibility n = 3
Randomized n= 54
Allocated to the Rehabilitation and return-to-sport algorithm (RA) group n = 27
Allocated to the Rehabilitation protocol (RP) group n = 27
Dropped out of study n = 3
Transfer to other club n = 2
Traffic accident n = 1
Dropped out of study n = 3
Transfer to other club n = 1
Coach decission n = 2
Completed rehabilitation n = 24
Completed rehabilitation n = 24
Missing data player/coach decision n = 8
Missing data player/coach decision n = 9
Completed return to sport sprint testing n = 16
Completed return to sport sprint testing n = 15
Completed periodic follow-up through 6 months after injury n = 24
Completed periodic follow-up through 6 months after injury n = 24

Table 1. Baseline characteristics of patients.

	Rehabilitation Protocol (n = 24)	Rehabilitation Algorithm (n = 24)
Age (years)	22.9 ± 6.0	24.0 ± 4.4
Body mass (kg)	72.7 ± 13.1	74.1 ± 8.3
Height (m)	1.77 ± 0.09	1.76 ± 0.07
Playing Position		
Defender	9 (38)	8 (33)
Midfielder	4 (17)	4 (17)
Attacker	9 (38)	12 (50)
Goalkeeper	2 (8)	0 (0)
Playing Status		
Starting	22 (92)	20 (83)
Non-starting	2 (8)	4 (17)
Injury Type		
Sprinting	13 (54)	13 (54)
Stretching	8 (33)	6 (25)
Other	3 (13)	2 (8)
Unknown	0 (0)	3 (13)
Previous hamstring injuries	6 (25)	5 (21)

Data are either shown as mean ± standard deviation (SD) for continuous variables or frequency and valid column percentage (%) for categorical variables.

Table 2. Rehabilitation and return-to-sport algorithm programme for hamstring injury.

	REGENERATION PHASE	FUNCTIONAL PHASE
Manual Therapy	Manual therapy: - Plantar fascia, gastrocnemius and hamstring (avoiding injury site) massage - Lumbar Z-joint mobilization - Sliding Neural Mobilization (3 x 12 reps) NMES	Manual therapy: - Plantar fascia, gastrocnemius and hamstring (injury site included) massage - Lumbar Z-joint mobilization **1, 2, 3**
Flexibility	Psoas static flexibility with pelvic retroversion (4 x 15 sec) Quadriceps dynamic mobility (2 x 8 reps) Hamstring dynamic mobility with fitball (2 x 8 reps) Hamstring dynamic mobility supine (2 patterns) (2 x 8 reps)	Hamstring dynamic mobility + contralateral psoas flexibility (2 x 5 reps) Hamstring wall flexibility (Push/Pull) (3 x 3 reps) **2, 3**
Gluteus	**Gluteus Maximus** (Choose an option daily as pain tolerated): **Option A** Prone hip extension (2 x 10 reps x 3 sec) Single leg bridge + contralateral kick (as tolerated) (2 x 5 reps x 3 sec) Double leg bridge (50% BW; 3 x 6 reps x 3 sec) **Option B** Hip thrust (40% BW; 3 x 6 reps x 3 sec) Single leg bridge + contralateral kick (as tolerated) (10% BW; 2 x 4 reps x 3 sec) Single leg hip thrust + contralateral kick (as tolerated) (3 x 6 reps x 3 sec) **Gluteus Medius:** Clamshell with band (3 x 6 reps x 3 sec) Side lying hip abduction with band (3 x 6 reps x 3 sec)	**Gluteus Maximus** (Choose an option): **Option A** **2** Single leg hip thrust (10% BW; 3 x 4 reps x 3 sec) Double leg hip thrust (60% BW; 3 x 8 reps x 3 sec) Walking sled push (75% BW; 15 m x 2 reps) **Option B** Single-leg foot and shoulder elevated hip thrust + contralateral kick (2 x 4 reps x 3 sec) Single leg back extension + perturbations (2 x 4 reps) Swing leg hip extension + contralateral hip flexion (2 x 3 changes) **Gluteus Medius:** Side step running with band (5 m x 5 go and back) Monster running with band (5 m x 5 go and back)
Hamstring strength	Prone isometrics (mid and long length) (2 x 5 reps x 5 sec) Standing long length isometrics (2 x 5 reps x 5 sec) Supine isometrics (tolerated degrees) (2 x 5 reps x 3 sec) Submaximal eccentric manual resistance in prone (intensity as tolerated) (2 x 8 reps)	(4 Hamstring strength exercises per session selecting 2 hip dominant and 2 knee dominant) **HIP dominant** **2** Double leg deadlift with 4 kg medicine Ball (2 x 8 reps) Lunge (15% BW; 2 x 6 reps) Single leg deadlift with 15kg + step up (2 x 6 reps)

		KNEE dominant Double leg slide curl (2 x 6 reps) Nordic hamstring (2 x 4 reps) Sprinter eccentric leg curl (2 x 6 reps)	
Plyometrics		Double leg hurdle hop with trunk flexion (2 x 4 reps) Double broad jump with 5 kg (2 x 4 reps) 2 consecutive explosive scissor jumps (3 times) Single leg horizontal jump (2 x 3 reps)	**2**
Ankle stabilizers	Double leg hamstring / gastrocnemius disassociation drill (3 x 6 reps) Single leg hamstring / gastrocnemius disassociation drill (2 x 6 reps) Step bounding side to side (25% BW; 2 x 10 reps)	Ankle drill 1 (20% BW; 10 m x 4 reps) Ankle drill 2 (20% BW; 10 m x 4 reps)	**2**
Lumbopelvic control	Side bridge feet in bench + perturbation (2 x 5 reps x 5 sec) Birdog (2 x 5 reps x 5 sec) Long lever posterior pelvic plank (2 x 4 reps x 5 sec) Leg scissors arms on the floor (2 x 5 reps x 5 sec)	Stir de pot with fitball (3 x 2 reps) Leg Scissors arms on the chest (2 x 5 reps x 5 sec) Single-leg stand rotating reaches 4 kg (2 x 6 reps) TRX helicopter (2 x 4 reps) Sprinter push/pull with pulleys (2 x 6 reps)	**2. 3**
Running technique	**Frontal plane** running drills Low- to moderate-intensity sidestepping (10 m x 5 reps) Low- to moderate-intensity grapevine stepping (10 m x 5 reps) Low- to moderate-intensity steps forward and backward over a tape line while moving sideways (10 m x 5 reps) **Sagittal plane** running drills (vertical emphasized execution specially first days or painful subjects) - 8 running exercise drills (statics in place dynamics over 8m) Running 5 m + 5 m deceleration (4 reps) Running 10 m + 5 m deceleration (3 reps) Running 15 m + 5 m deceleration (2 reps)	**Warm Up:** Hamstring Ballistic stretching (2 x 6 reps) Static "B" drill with resisted band (2 x 5 reps) Hurdle drills (1 set walking lower intensity, 1 set bounding higher intensity) Hurdle drill 1 (2 reps) Hurdle drill 2 (2 reps) Hurdle drill 3 (2 reps) Hurdle drill 4 (2 reps) Military march (15 m x 2 reps) Lunge + deadlift (4 reps for each leg) Lunge + "B" drill (4 reps for each leg) From Skipping to running (20 m x 4 reps) Sprint bounding (15 m x 3 reps) Running with hurdle jumps (15 m x 1 rep) Sprinting 5 m (3 reps), 10 m (3 reps), 15 m (4 reps), 20 m (3 reps), 30 m (2 reps) and 40 m (1 rep) (15 sec of rest per each 1 sec sprinting) Sled push resisted accelerations (30% BW) 5 m (3 reps) and 10 m (2 reps)	**1**

* Mild discomfort allowed during exercises execution

Reps, repetitions; m, meter; sec, seconds; BW, body weight; NMES, Neuromuscular electrical stimulation.

1 = Contents corresponding to the training day 1; 2 = Contents corresponding to the training day 2; 3 = Contents corresponding to the training day 3. Minimum of 3 blocks 1-2-3 in the Functional phase before return-to-sport.

Supplemental Digital Content

- Supplemental Digital Content 1. Video which demonstrates the exercises performed during the regeneration phase of rehabilitation algorithm. Avi

- Supplemental Digital content 2. Video which illustrates the exercises corresponding at each different day of the functional phase. Avi