A Multifactorial, Criteria-based Progressive Algorithm for Hamstring Injury Treatment

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ABSTRACT

MENDIGUCHIA, J., E. MARTINEZ-RUIZ, P. EDOUARD, J.-B. MORIN, F. MARTINEZ-MARTINEZ, F. IDOATE, and A. MENDEZVILLANUEVA. A Multifactorial, Criteria-based Progressive Algorithm for Hamstring Injury Treatment. *Med. Sci. Sports Exerc.*, Vol. 49, No. 7, pp. 1482–1492, 2017. **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 reinjury risk and optimize player performance and availability. **Purpose**: This study aimed to assess the concurrent effectiveness of administering an individualized and multifactorial criteria-based algorithm (rehabilitation algorithm [RA]) on hamstring injury rehabilitation in comparison with using a general rehabilitation protocol (RP). **Methods**: Implementing a double-blind randomized controlled trial approach, two equal groups of 24 football players (48 total) completed either an RA group or a validated RP group 5 d after an acute hamstring injury. **Results**: Within 6 months after return to sport, six hamstring reinjuries occurred in RP versus one injury 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 (effect size = 0.34 ± 0.42) in RP (23.2 ± 11.7 d) compared with RA (25.5 ± 7.8 d) (−13.8%, 90% confidence interval = −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, and 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 reinjury compared with a general protocol where long-length strength training exercises were prioritized. **Key Words:** HAMSTRING INJURY, MULTIFACTORIAL HAMSTRING REHABILITATION, INDIVIDUALIZED TREATMENT, HAMSTRING ALGORITHM

Hamstring strain injuries are the most prevalent diagnosis in football (12). Unfortunately, hamstring injury rates in football have remained unchanged, or have increased (12), during the last 30 yr. 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 one out of three hamstring injuries will recur, mostly within the first weeks of the athlete's return to sport (RTS) (27). With previous injury comprising one of the most reported nonmodifiable 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 reinjury 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 (RP) for

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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 and 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 reinjury 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 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 (23,24,39), it could conceivably provide flexible programming accounting for the specific weaknesses of each player. This design process is not possible in a preestablished, one-size-fits-all general protocol (3,38). In summary, the algorithm constitutes a theoretically objective and individualized multifactorial approach to hamstring injury rehabilitation to build a solid framework. Such a framework would allow us to obtain (i) future feedback necessary to understand how to achieve, include, or remove the different marked quantitative criteria and (ii) 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 with using a general RP in male football players. The comparison will focus on three main outcomes that directly affect daily clinical practice of any football club: number of reinjuries, 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 used in the design of this study. Semiprofessional male football players with acute hamstring strain injury (grade I tear) were randomly allocated to a rehabilitation algorithm (RA) group or an 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 (No. CE_1013; UCAM, Murcia, Spain), 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 contacting the study coordinator (E.M.R.). After 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 contraindications to the study protocol). As medical data were to be collected before final inclusion, all patients (or their parents/guardians if they were younger than 18 yr) were informed of the study nature before providing their written informed consent to participate.

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 yr of age; (ii) available to follow a rehabilitation program; (iii) currently playing on a semiprofessional/professional football team; and (iv) suspected of possessing a hamstring strain injury (of noncontact etiology), which occurred during a training or match (played within the previous 4 d) and subsequently forced the player to cease activity.

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

Diagnostic Confirmation

Potential patients then participated in a clinical and ultrasound examination within 4 d 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 two or more of the following findings, with respect to the noninjured thigh, the hamstring strain injury was confirmed: (i) localized pain on palpation of the hamstring muscles, (ii) posterior thigh

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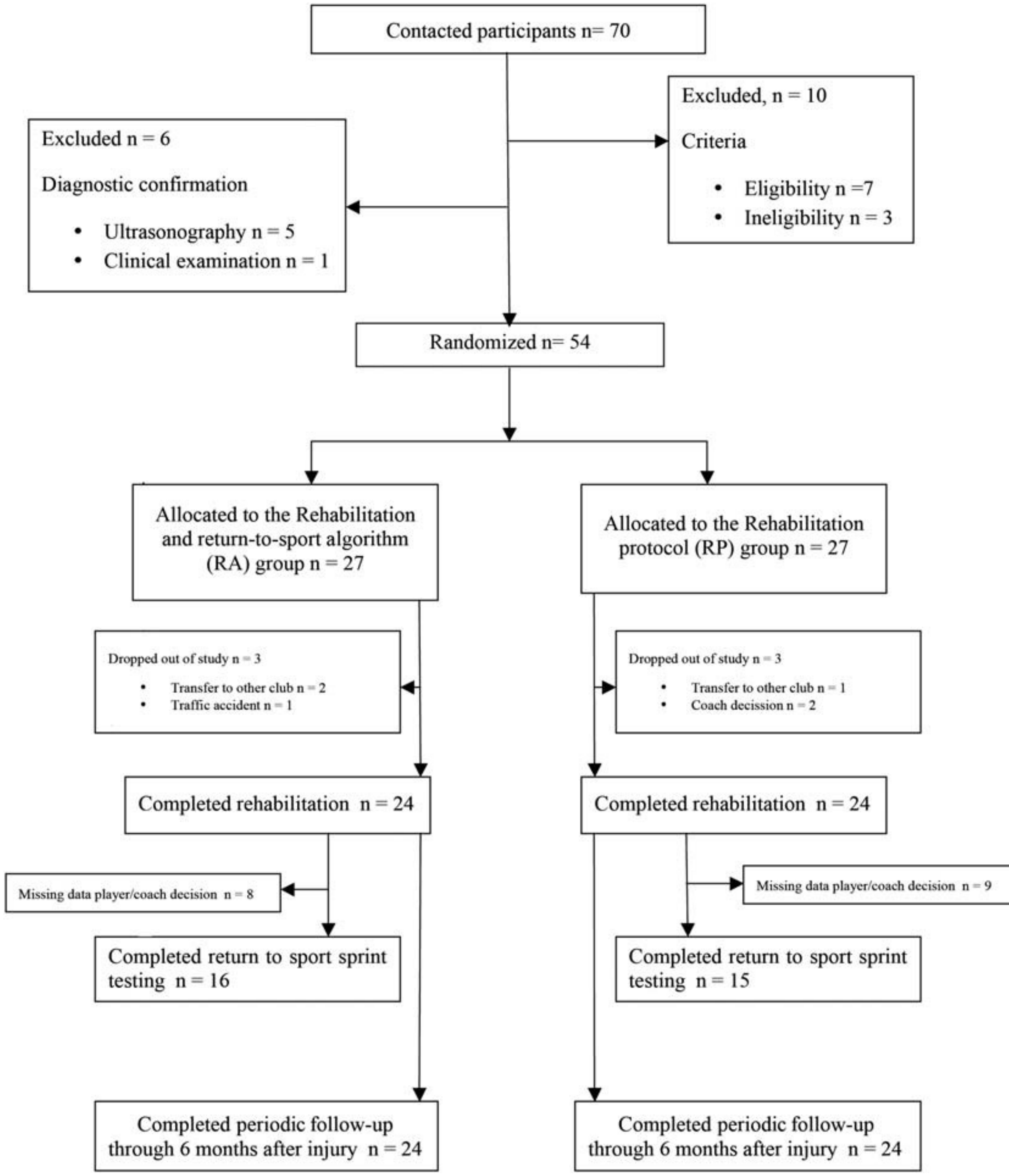


FIGURE 1—Flow diagram outlining enrollment and testing procedures.

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). In addition, 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 reinjury (9). Conversely, those football players with less than two clinical findings and/or a negative, a grade II–grade 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 yr experience as head physician of a professional football team and >15 yr experience as a physician in high-performance sport in Spain. In addition, a seasoned radiologist (F.I.) with >20 yr 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 six participants. To maintain balance among the number of subjects in each group, each block consisted of six labels (folded papers) prepared by an independent investigator and normally distributed as three

RA group and three RP group. This randomization process, to which the physical therapist (E.M.R.) stayed unblinded 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 yr] or old [≥25 yr]), 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 RTS and reinjury rates in football players (1,23,24,39).

Interventions

After the randomization process, 54 football players began one of the previously 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), 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 protocol every 2 h. All subjects began rehabilitation on the fifth day postinjury. 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 or any subsequent evaluation of the patient (i.e., clinical examination, ultrasonography, monitoring, and RTS 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., two external independent researchers, and A.M.V.). Similarly, no patient was informed of the characteristics comprising the two rehabilitation programs (RA or RP).

TABLE 1. Baseline characteristics of patients.

	RP (n = 24)	RA (n = 24)
Age (yr)	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)
Nonstarting	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 ± SD for continuous variables or frequency and valid column percentage (%) for categorical variables.

RP. The RP group completed a recently described protocol that 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 previously mentioned physical therapist (E.M.R.) supervised at least four rehabilitation sessions per week (three sessions of general rehabilitation or progressive running program and one 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 d), and insecurity was eliminated. Subsequently, a sprint running test (detailed in the next section) was performed within 2 wk after the Askling *H*-test to permit the player back to the game.

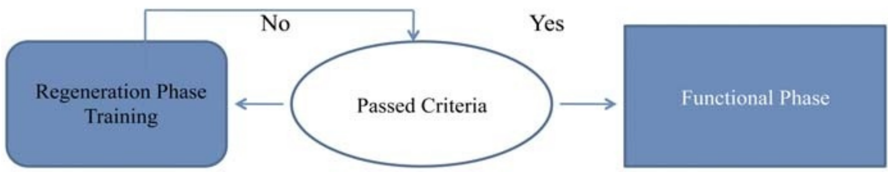
RA. The RA group performed a modified version of a previously proposed algorithm presented by Mendiguchia and Brughelli (24). Unlike the original algorithm (i.e., acute, regeneration, and functional phases), the modified version removes the acute phase because the players began the rehabilitation program at 5 d postinjury (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 minimize 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 lumbopelvic control, fatigue, etc. [23,24,39]), 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 3-d 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

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 $60° \cdot s^{-1}$ (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

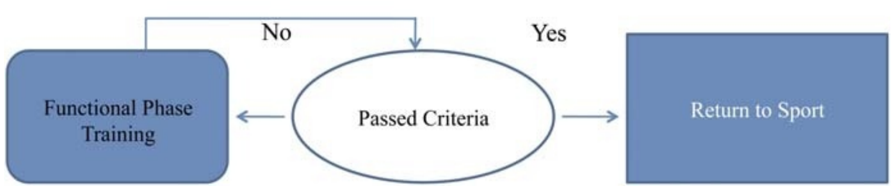


FIGURE 2—Criteria used to progress a football player through each phase of RA. A, Regeneration phase criteria. B, functional phase criteria.

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 lumbopelvic control. A minimum of three sessions of the 3-d block training was required to allow the player to RTS. Program and activities performed during the regeneration and functional phases are displayed in Table 2.

In addition, basic aerobic conditioning commenced when the player was able to perform at least three sessions of running technique without any discomfort or pain in the regeneration phase. One running session was performed every 3 d and included four sets of 5 min at a low to moderate intensity (player rated). Later, in the functional phase, the running session consisted of two sets of 10 min performed at moderate to high intensity (player rated). Suspension of running sessions was permitted in the event of moderate discomfort or pain.

Outcomes

Primary outcome measures. One of the primary outcomes of this study was reinjury occurrence registered during a 6-month period after the athlete's RTS. If during this time a possible reinjury did occur, the physician, coach,

TABLE 2. Rehabilitation and RTS algorithm program 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** 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) **2**
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** 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) **2**
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 the 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**

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 three blocks 1-2-3 in the functional phase before RTS.
Reps, repetitions; BW, body weight; NMES, neuromuscular electrical stimulation.
[a]Mild discomfort allowed during exercises execution.

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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, conducted between 2 and 5 d postinjury, 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 RTS (d), 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 after hamstring strain injury. Because 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 RTS were achieved for the RA group. The sprint running test, which was performed within a maximum of 2 wk after returning to sport, was conducted 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 d before the sprint running test. A standardized warm-up, consisting of 5 min of low-pace (~10 $km \cdot h^{-1}$) 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 cooldown 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 two independent researchers. Players wore their usual football shoes and ran during similar times (i.e., same hour), environmental conditions of temperature (22.5°C ± 5.2°C for RA group vs 20.9°C ± 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 $km \cdot h^{-1}$ for RA group vs 6.5 ± 7.4 $km \cdot h^{-1}$ 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, MN), 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 analyzed 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 anteroposterior 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 (F_0) and velocity (V_0) capabilities and underlying maximum horizontal external power output (P_{max}).

Sixteen players from the RA group (21.7 ± 3.7 yr, 73.0 ± 8.4 kg, 1.75 ± 0.07 m) and 15 from the RP group (22.1 ± 5.0 yr, 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

The number of reinjuries is presented as counts and proportions. The differences in the number of reinjuries 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 reinjury 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 reinjury risk for the current study, we used the methods previously outlined by Hopkins et al. (18,19). In brief, for every 10 reinjured players in one of the rehabilitation programs, there are nine injured players in the other program. That is, 1 in 10 injuries is due to choosing a different rehabilitation program. If there are N players in RP and N players in RA, risk ratio = $(10 / N) / (9 / N) = 10 / 9$ (i.e., 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; and >99.5%, most likely.

Continuous variables are presented as means ± SD unless otherwise stated. Data were first log-transformed to reduce bias arising from nonuniformity error. The standardized difference or effect size (ES, 90% confidence interval [CI]) 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 RTS and sprinting performance and associated mechanical outputs was expressed

TABLE 3. Reinjury number and relative risk at 6 months after RTS by allocated group.

	Protocol	Algorithm	Protocol vs Algorithm		
			Relative Risk (90% CI)	Chances for Beneficial/Trivial/Harmful	Clinical Inference
Reinjury number (%)	6 (25%)	1 (4%)	6 (1; 35)	95/2/3	Very likely beneficial

as 90% CI 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-player SD in the baseline assessment (19). Quantitative chances of beneficial/better or detrimental/poorer effect were assessed qualitatively as indicated previously.

RESULTS

Reinjury

The occurrence of reinjury within 6 months is displayed in Table 3. There were substantial differences in the rate of reinjury 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 d) compared with the RA group (25.5 ± 7.8 d) (−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, V_0, and P_{max} performance measures compared with 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 (reinjuries, time to RTS, and sprint performance) of an individualized and multifactorial criteria-based algorithm on hamstring injury rehabilitation compared with a general RP (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 reinjuries, specifically in the early recurrences period; (ii) substantially more time in returning to sport after injury; and (iii) substantially greater performance (i.e., 10 m and top speed) and mechanical variables related to speed factors (V_0 and P_{max}) compared with 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 reinjury risk compared with the RP where long-length strength training exercises are prioritized. In this way at RTS, the player who followed the RA presented a lower risk (4%) compared with a typical footballer with no history of previous injury (12%–16%) (40).

The fact that the RP group, focusing on lengthening exercises, suffered six reinjuries 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 semiprofessionals in the present study) and the shorter average time to return to football practice reported in the current study (23 vs 28 d 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 4 wk post-RTS in the RP lengthening-based group (data not presented) might confirm the previously mentioned hypothesis. However, substantially longer RTS time (i.e., 51 d), after what was defined as a "protocol of conventional exercises," resulted in only one reinjury (3%) (3), casts doubts on the direct cause–effect relationship between the earlier RTS and the increased risk of reinjuries. In this regard, the fact that the present study's players in the RA group did not show the same trend of reinjuries 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 in the next paragraph) may be more important than time to RTS *per se*.

The percentage of reinjury in previous rehabilitation studies, mostly involving football players, varies between 0%

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TABLE 4. Sprinting performance and mechanical variables (mean ± SD) for RA and protocol groups and the standardized differences (with 90% confident limits) and probabilistic inferences about the true standardized magnitude in the means between groups.

	RP (*n* = 15)	RA (*n* = 16)	Differences Observed between RP vs RA		
			Standardized Differences (90% CI)	MBI	Qualitative Assessment
5 m (s)	1.38 ± 0.10	1.35 ± 0.08	−0.27 (−0.80 to 0.26)	(19/0/81)	Unclear
10 m (s)	2.15 ± 0.15	2.08 ± 0.10	−0.46 (−0.96 to 0.05)	(7/0/93)	Likely
Top speed ($m \cdot s^{-1}$)	7.7 ± 0.7	8.4 ± 0.4	0.75 (0.29 to 1.22)	(99/0/1)	Very likely
V_0 ($m \cdot s^{-1}$)	8.2 ± 0.9	8.9 ± 0.5	0.71 (0.24 to 1.18)	(99/0/1)	Very likely
FH0 ($N \cdot kg^{-1}$)	7.9 ± 1.3	7.9 ± 1.1	0.06 (−0.47 to 0.59)	(58/0/42)	Unclear
P_{max} ($W \cdot kg^{-1}$)	16.0 ± 2.9	17.5 ± 2.5	0.47 (−0.04 to 0.98)	(94/0/6)	Likely

MBI, magnitude-based inferences.

and 30% (3,15,30,31,38) 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 characterized 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 lumbopelvic control). To the authors' knowledge, there is only one study available in male football players that have undertaken a criteria-based rehabilitation program, reporting a 12% reinjury rate within 2 months of clinical discharge (38). Our most likely explanation of why the RA of the present study induced lower reinjury 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 Contents 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 is 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 to progress in a step-by-step basis according to their difficulty/intensity (e.g., weights, opposing forces, and 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, was 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, whereas 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 with 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 with 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 (reinjury rate) in favor 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 conducted 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 RTS and, consequently, reduce the risk of reinjury. 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 after injury, the RTS duration achieved in this study in both treatment formats is comparable with that seen in previous studies involving mainly football players (21 to 51 d) (3,15,31,38). However, the RP, emphasizing lengthening exercises, resulted in a possibly quicker (small effect) RTS compared with the RA, emphasizing an individualized and multifactorial intervention. The need to achieve each of the quantitative criteria in each of the phases and the 3-d block training periodization (sprint, strength, manual therapy/mobility/lumbopelvic control) followed in the functional phase of the RA (minimum three 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 program (Table 2). As such, early engagement in sprinting speed factors (e.g., running technique and 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 and 20 m), and associated speed-related mechanical (i.e., V_0 and P_{max}) variables were greater in the RA group compared with 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 programs 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 semiprofessional male football players. Thus, our findings might not necessarily apply to female football players, to other sports, or to higher-level football players. In addition, only grade 1 injuries were investigated in the present study. Although 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 six events in one group and one event 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 reinjury, improved sprint performance and mechanical properties, but resulted in a possibly slower (small effect) RTS compared with a general protocol where long-length strength training exercises were prioritized.

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