

The hamstrings are more impacted than the quadriceps after severe ankle sprain

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Abstract

Ankle sprains (AS) are common in the military population, with a prevalence 5 to 8 times higher than that for civilians. The aim of this study was to evaluate in patients with severe AS the impact of disuse on thigh muscle induced by unloading and immobilization due to care. This study focused on muscle trophicity and dynamometric strength. In this observational prospective study, assessments were repeated at 3 visits: close to injury, 15 and 30 days following the sprain. The injured limb was compared to the contralateral limb. A dynamometer assessment was used to monitor changes in strength and fatigue of the thigh muscles of both limbs. Isometric and isokinetic concentric evaluation of peak torque (PT_{iso} and PT_{dyn}), total work (Wt), and peak torque time integral (IPT) of thigh muscles. Full follow-up was obtained in 30 subjects. The injured limbs showed significant deficits in the mean (SD). The quadriceps PT_{iso} and IPT deficits were $-12.6\% \pm 1.9\%$ ($P < .0001$) and $-13.27\% \pm 1.8\%$ ($P < .0001$), respectively. The quadriceps PT_{dyn} showed a significant deficit since V2 ($-12.25\% \pm 2.0$). The quadriceps Wt presented a significant deficit of $-4.2\% \pm 2.4$ ($P < .0007$) at 1 month. The hamstring PT_{dyn} deficit presented a mean loss of $-16.5\% \pm 2.4\%$ ($P < .0001$). The hamstring Wt deficit was $-13.7\% \pm 2.3\%$ ($P < .001$). The analysis of variance showed that the grade of the sprain had a significant effect on the quadriceps PTq deficit ($P < .016$) but not the type of discharge. Our study showed that disuse leads to a significant deficit in the strength of knee muscles within 1 month. It is noteworthy that the hamstrings are more affected than the quadriceps. The rehabilitation protocol to prevent the risk of iterative ankle injuries and secondary knee injuries should incorporate early training of both quadriceps and hamstrings.

Abbreviations: AS = ankle sprain, CMA = military medical center, IKDC = international knee documentation committee, IPT = integral peak torque time, MRI = magnetic resonance imaging, PT dyn = isokinetic peak torque, PT iso = isometric peak torque, Wt = total work.

Keywords: ankle sprain, disuse, isokinetic, peak torque, rehabilitation, unloading

1. Introduction

Ankle injuries are a major factor in the amount of time lost to active military duties. In addition, a history of injury within the previous 2 years increased the risk of iterative injuries from 93% to 160%.^[1] Ankle sprain (AS) is the most common musculoskeletal injury in the physically active population (up to 50% of sports injuries) and is common in the general population, with approximately one AS per 10,000 person-days worldwide.^[2] It is even more common in the military population, with a prevalence 5 to 8 times higher than that for the civilian population. In the general population, 20 to 74% of sprains are complicated by chronic ankle instability. Unfitness for the military population is <1 month; and appropriate management generally allows good recovery with a return to activities.

However, the risk of recurrent injury is higher when recovery is early.^[2,3]

The most common complication of an AS is a reinjury of the AS on the ipsilateral or contralateral limb in the adult working population.^[4] Finally, it appears that an AS also has consequences on the biomechanics of the knee and can lead to impairment of this joint.^[5,6] The impact on the leg muscles could not be assessed because of the healing time, but the thigh muscles could be assessed. The level of muscle atrophy and loss of strength is naturally focused on the leg muscles. Patients with chronic ankle instability exhibited large deficits in total extrinsic muscle volume and demonstrated significantly smaller soleus muscle volume.^[7] However, what are the other muscles in the injured lower limb? This pathology is a relevant subject of study because of its frequency, economic impact, and assessment of

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thigh muscle function is interesting since the entire lower limb is impacted. Loss of strength and muscle atrophy have consequences on the speed and quality of recovery. Therefore, it is essential to evaluate it for a better understanding.

In the management of patients for orthopedic surgery follow-up care, we are challenged with a transient loss of function associated with amyotrophy and loss of strength of the muscles of the above and underlying joints in the operated area.^[8-10] The term “simple atrophy” is used to differentiate this situation from those in which neuromuscular pathologies are the origin of muscle weakness. Simple atrophy follows medium to severe AS, especially in the sural triceps. Disuse may correspond to a decrease or cessation of muscle activity secondary to unloading of the lower limbs.^[11] Disuse occurs in several clinical situations. Numerous studies have demonstrated that muscular atrophy is a complex phenomenon. In addition to the decrease in the cross-sectional diameter of muscle fibers and the consequent loss of strength, deeper transformations may occur, such as changes in the heavy chains of myosin or the type of muscle fiber.^[12,13] This should add additional difficulties to rehabilitation. If atrophy is well-documented in the leg muscles following a severe AS, what about the thigh muscles? To evaluate these phenomena, it is necessary to set up a means of measuring trophicity, strength, and fatigue. More, the assessments made on the knee after an ankle sprain, which is not done in common practice, creates an original model of disuse.

AS were classified into 3 grades: mild, moderate, severe^[14] (I, II or III, see Materials and methods).

Diagnosis of injuries to the anterior talofibular ligament, which is almost always injured in AS, requires imaging to ascertain the degree of severity of the injury. This is especially true for discriminating between grades II and III.^[15,16] Ultrasound is a noninvasive tool for the validation and accuracy of clinical diagnosis. However, it is operator dependent and is most useful when performed by an experienced senior physician.^[17-19] Treatment of AS grade I does not require immobilization or unloading. In contrast, grade II and III AS require partial or total unloading during the first month of treatment. Ninety percent of these injuries involve the lateral tibiotarsal ligament. Immobilization of the tibio-tarsal joint was relatively long (between 3 and 6 weeks, depending on the grade). Unloading of the injured limb, total, or partial, by crutching leads to disuse.

Clinical follow-up requires quantitative and qualitative assessment of muscle capacity. From a quantitative point of view, the loss of strength is usually evaluated at an early stage using analytical grids of the “testing” type or functional grids. However, these evaluations remained partially subjective.^[20,21]

The occurrence of AS cannot be anticipated. This makes it impossible to establish an objective measure of the strength of the subjects before injury. It is important to ensure that there are no prior deficits in either the ankle or the knee muscles. This could be the case in patients with a history of trauma to these joints with or without surgical treatment. If so, it would introduce a major bias in the assessment of strength. The use of questionnaires, such as the Lysholm form, can ensure that the patient has recovered their physical abilities by asking about their pretrauma status. A poor score on the lower limb with a history of trauma is a good criterion for exclusion. Conversely, good recovery and, therefore, equivalent scores for the 2 limbs is not a criterion for exclusion.

The evaluation of amyotrophy is often objectified by measuring the circumference of the limb segment without any possible differentiation between agonists and antagonists in the same segment. In addition, this assessment often focuses on the ankle. If the muscles of the tibiotarsal joint are evaluated, this is not necessarily the case for those of the knee. It is essential to analyze the impact of disuse on the knee flexors and extensors. This will allow appropriate rehabilitation for

each patient to reduce the recovery time and the risk of iterative injury.^[5] Through this prospective study, we sought to evaluate the impact of disuse on thigh muscles suffering from an acute AS requiring immobilization and unloading. With the ankle joint immobilized, we examined the quadriceps and hamstrings on both sides. Isometric and isokinetic forces and the volume of each muscle compartment were measured. Recruitment targets a military population with severe ASs requiring immobilization by an inflatable splint and crutch release.

2. Materials and methods

2.1. Participants

All patients enrolled in this study came from the Brest Defense Force Base, which has approximately 25,000 members. Physical and sports activities are integral to the training and leisure activities of this population. Injuries may occur during these activities. The injured patients are taken care of by the Army Medical Center (CMA)* during military harbor and/or Health military teaching hospital Clermont-Tonnerre emergencies. All the patients were admitted to the trauma emergency department.

The inclusion criteria targeted subjects who were as follows: military, athletic, active, between 18 and 45 years of age, and grade II or III sprain. This classification^[14] is built as follows:

- Grade I corresponds to a ligament strain. Clinical signs are usually moderate. The anterior talofibular bundle is most frequently affected and in 65% of cases in isolation. The patient can walk with full weight-bearing. It never progresses to instability.
- Grade II corresponds to a partial tear of the ligament that may involve one or more bundles. The edema and ecchymosis are localized and moderate. The patient can walk. However, the patient must use crutches and is unable to support himself. Secondary instability is rare but can be found.
- Grade III corresponds to a complete tear of one or more bundles of the lateral ligament. There is always significant diffuse edema and ecchymosis. The pain is intense and diffuse over the lateral malleolus. It is strictly impossible to bear weight. The severity of the sprain is related to the extent of the lateral ligament rupture. The first bundle injured is always the anterior talofibular. If the injury continues, it then reaches the calcaneofibular bundle and then the posterior talofibular. All 3 fascicles may be completely ruptured. Secondary instability is possible.

The grade of the sprain was confirmed by ultrasound at the Military Hospital Military Unit. Only 1 experienced operator selected eligible patients for the study to limit the interoperator impact.^[16,17] Inclusion was achieved within 3 days of sprain occurrence.

The criteria for noninclusion were phlebitis, pregnancy known to the patient, chronic ankle instability, traumatic aftermath of the ankle, surgical aftermath of one of the knees (an operated knee with total functional recovery before the sprain is not excluded (cf. Lysholm score), and traumatic aftermath of the knee (idem). We used the Lysholm knee scoring scale (see Supplemental 1, Supplemental Digital Content, <http://links.lww.com/MD/H102>) to detect any pre-existing pathology that could influence athletic performance. The level of physical activity was stratified into 4 levels using International Knee Documentation Committee (IKDC 2000, subjective knee evaluation form) level activity questions,^[22] which is a gold standard for clinical knee evaluation.

The study population was recruited between September 2011 and February 2013 among military personal who came from the French Navy. We included 34 patients.

2.2. Study design

This study was a prospective cohort study in which the subject was his own control. The healthy lower limb of each subject served as the control for the injured limb. The injured ankle was immobilized using a removable boot. The total rehabilitation management duration was 8 weeks (± 2 weeks). All parameters of the study were evaluated at baseline (first visit V1 = D0-4) and at visits V2 (D15 ± 2), and V3 (D30 ± 2).

2.3. Intervention program

2.3.1. Chronology of observations and unloading. Measurements were performed in 3 stages. Visit 1 (V1, inclusion visit) took place within 0–3 days of the initial trauma. This delay was necessary to allow for the screening of admissible patients for the study, outside working hours, or on weekends. It also allowed for a reasonable period of reflection for the patients to provide their consent. Patients were subsequently assessed for 15 days (V2) and 1 month (V3) after initial trauma (Supplemental 2, Supplemental Digital Content, <http://links.lww.com/MD/H103>). The timeline of unloading according to the grade of the AS is reported in (Supplemental 3, Supplemental Digital Content, <http://links.lww.com/MD/H104>). For grade II, the treatment consisted of total unloading for 7 days followed by 2 weeks of partial unloading. For grade III, partial unloading was set to 3 weeks and partial loading to 1 week.

The management protocol was standardized for grade II and III sprains. Unloading was 4 weeks with removable immobilization boot + crutch + support stockings on the injured limb + protocol of classical physiotherapy care during this period without work in charge.

Immobilization varied from 3 to 6 weeks, depending on severity. Full loading was performed between 3 weeks (grade II) and 7 weeks (grade III). The crutches allowed full or partial loading (Supplemental 3, Supplemental Digital Content, <http://links.lww.com/MD/H104>). Partial loading of the injured limb was taught to the patient (10–20% of the body weight depending on the pain). All measurements were performed during the unloading period.^[23,24]

2.4. Outcome measures

The principal investigator (RG) carries out the measurements for all the patients.

2.5. Clinical assessment of the knee

This assessment was performed to ensure that there were no contraindications to the isokinetic knee assessment. The examiner checks for knee trauma associated with AS and the absence of contraindications to the isokinetic knee test.^[23–26]

Thigh perimeter measurements were taken 5, 10, and 20 cm above the patella.

2.6. Pain intensity

Pain was systematically assessed using the visual analog scale (VAS). The VAS was systematically used throughout the tests and during the entire follow-up. VAS scores ranged from 0 to 10 in accordance with the HIA pain monitoring protocol. For each therapeutic action, the patient’s condition before and after the action was recorded using the VAS.^[25,26]

2.7. Knee muscle strength

Isometric and isokinetic measurements of dynamic knee extension and flexion were performed using a Con-Trex MJ (CMV AG, Dübendorf, Switzerland). Reliable isokinetic data and isometric measurements of muscle strength and fatigue under dynamic conditions using the Con-Trex MJ machine have been demonstrated.^[27–31]

The isokinetic assessment was performed identically at V1 (day 1 up to day 4), V2 (day 15), and V3 (day 30). The installation on a Con-Trex machine was standardized: chair with an 85° backrest, shoulders, and pelvis strapped with belts, arms crossed over the torso, tested thigh strapped to the seat, tested leg strapped to the counter support at a height sufficient to leave the ankle brace in place, and at the same level for measurements

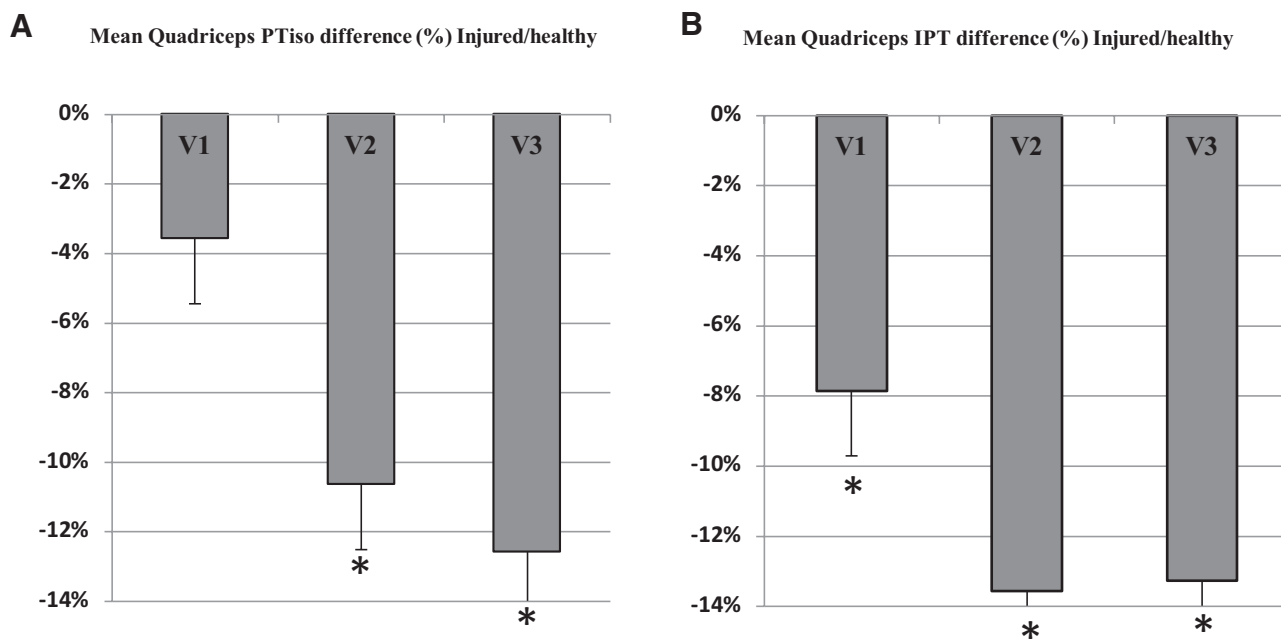


Figure 1. A, Change in the quadriceps mean PTiso deficit between HL and IL over 1 month. B, Change in the quadriceps mean IPT deficit between HL and IL over 1 month: a significant deficit is found at all visits. Data are expressed as mean \pm SE (* shows a significant difference between IL and HL). HL = healthy limb, IL = injured limb, IPT = integral peak torque/time.

on the healthy side (Supplemental 4, Supplemental Digital Content, <http://links.lww.com/MD/H105>).

The contralateral limb was left free of motion. The installation markings were standardized using the Con-trex system interface and stored in the Human Kinetics 1.7.5-build002 software database. This allowed us to replicate the patient setup for each assessment session (V1, V2, and V3). The amplitude was adjusted with a reference zero obtained from the horizontal plane, determined by the machine for each limb tested and at each visit. The extension stop corresponded to the maximum voluntary active cold extension ($-16.5^\circ \pm 4.7^\circ$). The flexion stop was arbitrarily set at 105.5° of flexion (correction made by Con-Trex of 6.5° bringing the effective stop to 98.8°). These settings allowed a working range of $80^\circ \pm 4.4^\circ$. This provided a sufficient amplitude for the analysis of the isokinetic data. These values were stored automatically by the software and used identically for all patient evaluations. Therefore, the flexion-extension movement was constant for each visit, allowing comparison of the isokinetic work measurements (Wt).

Warm-up was standardized according to the service protocol, with 10 minutes on an ergo cycle at 60–70 rpm at a power equivalent to the subject's weight (1 W/kg). The injured ankle was held in a rigid splint at 90° of ankle flexion using a Co-Plus band. This rigid splint is a standard lift that is usually used to compensate for foot lift deficits in hemiplegia rehabilitation. This allowed the subject to cycle without straining the ankles. In addition, during the assessment, the ankle remained protected from unwanted movements.

Gravity correction was performed for each limb tested and measurement. This option was particularly interesting because, during the initial assessment, the injured ankle was held in an ankle splint. Therefore, the splint weight was not included in the results.

2.8. Measurements

Each subject was asked to perform 2 tasks on the dynamometer in the following order: isometric quadriceps contractions and isokinetic concentric flexion/extension of the knee at $180^\circ/s$. Each patient performed 3 isometric contractions of 6 s at a fixed angle (80° of flexion), with 30 s rest between. A concentric isokinetic test of 25 repetitions was performed after a learning trial of 3 repetitions. Verbal encouragement of the subjects was systematic and standardized. Each task was followed by 1 minute of rest.^[28,32,33] The noninjured limb was assessed for the first time, and the injured limb was assessed for the second time.

The isometric parameters recorded were the maximal peak torque of the quadriceps (PTiso, Nm) and the PTiso/time integral over 6 s of the quadriceps (IPT, Nm·s). The best values obtained in the 3 tests were selected.

The isokinetic parameters recorded were the concentric peak torque of the quadriceps and hamstrings over 25 repetitions (PTdyn, N.m) and the total dynamic concentric work of the quadriceps and hamstrings over 25 repetitions (Wt, J). All parameters were recorded for both limbs in each patient.

2.9. Statistical analyses

To work out the sample size, we calculated the sample size for 2 means (paired/cross-over)-hypothesis testing, with a standard deviation of difference measured at 14.5%, an effect size of 10% as in literature, significant level 0.05, power level 0.8, and a drop out of 35%. The drop-out level was chosen because of the distance of patients' homes from the examination center, which can lead to patient no-shows. The sample size calculated was 17 and the corrected one was 27. To use parametric tests in case of a non-normal distribution, we planned to go up to a height of 30. There were 4 patient no-shows, so the inclusions were conducted up to 34.

Normality assumptions were evaluated using the Shapiro-Wilk test. All results followed a normal distribution for the target variables (PTiso, IPT, PTdyn, and Wt). Repeated-measures analysis of variance was used. When ANOVA was significant, paired measures t-tests were used as post hoc tests to compare injured and healthy limbs on variables of interest. Statistical significance was set at $P < .05$ were considered statistically significant. Statistical analyses were performed using XLSTAT Basic + software (version 2020.3.3.0).

2.10. Ethics and Dissemination

Our study was a noninterventional study. The local ethics committee accepted this study on February 8, 2011, under the number 815 HIACT/BLRH/SAG. All participants signed a consent form prior to the experiments.

3. Results

3.1. Study attrition

Over the inclusion period, 2149 ankle injuries were recorded in the emergency department; 623 were grade II or III (29%), and 1526 were grade I (71%). Among patients presenting to the HIA-CT emergency department, the reasons for noninclusion were civilian status (see inclusion criteria: military staff) or refusal to participate in the study. Injured service members typically continue their convalescence at home, which may leave them far away from the HIA. Their distance from the medical center did not allow for follow-up in the study.

We included 34 patients, 4 of whom left the study prematurely (impossibility of performing all planned visits) (Supplemental 5, Supplemental Digital Content, <http://links.lww.com/MD/H106>).

3.2. Population

The study population was recruited between September 2011 and February 2013 from among military personnel who came from the French Navy. We included in the study. A total of 30 patients completed the follow-up period. They were young subjects (28.7/–6.7 years), and a majority of them were men (94.1% male, 5.9% female).

The average Lysholm score was 99.7 (SD = 1.4) for both lower limbs. This allowed us to assume that there was no pretraumatic deficit in either the ankles or knees. The mean age allowed us to assume that our sample included young adults. Based on the mean BMI, it is reasonable to assume that our subjects were not overweight. To summarize, we deal with a sample of a youth and sporty population. In terms of athletic level, only the 3 highest levels are represented out of the 5.^[34,35] Participant characteristics, according to their sporting levels, are summarized in (see Supplemental 6, Supplemental Digital Content, <http://links.lww.com/MD/H107>). For the type of sports practiced, 4 classes were selected: contact pivot sports, pivot sports, jumping sports, and line sports. Their distribution was 32.3%, 11.8%, 2.9%, and 52.9%, respectively. The latter represents the majority (running, cycling, etc.), as it includes the standard physical activities featured in military physical training.

3.2.1. Pain intensity. The visual analog scale (VAS) was routinely used and is a valid and reliable measure for chronic pain. Also, Gallagher et al showed that a difference of 13 mm/100 on a VAS represents, on average, the minimum change in acute pain that is clinically significant, which allowed for detecting a change in pain level.^[25,36] Before each test, ankle and/or knee pain was systematically searched using a VAS scale, and none was found in the patients included. No ankle or knee pain occurred during the evaluation regardless of the patient being tested.

Table 1
Participants' characteristics according to sportive level (N= 34).

Time base-line	V1 = first visit following sprain (D0-3)			Visit 2 (D15)			Visit 3 (D30)		
	Mean variation injured leg—healthy leg (%)	SE	P	Mean variation injured leg—healthy leg (%)	SE	P	Mean variation injured leg—healthy leg (%)	SE	P
Q PTiso	-3.53	1.87	.04	-10.64	2.36	.0001	-12.58	1.91	.0001
Q IPT	-7.86	2.37	.0001	-13.56	4.51	.001	-13.27	1.87	.0001
Q PT dyn	-1.40	2.49	.155	-10.20	2.27	.0001	-9.46	1.83	.0001
Q Wt	1.72	2.79	.50	-4.14	2.57	.05	-4.16	2.41	.044
H PT dyn	-13.86	2.56	.0001	-18.37	2.71	.0001	-16.55	2.44	.0001
H Wt	-15.12	2.02	.0001	-14.02	2.74	.0001	-13.74	2.27	.001

Dynamometer's values of interest: mean deficit of IL compared to HL, expressed in rates (%) for quadriceps (Q) and hamstrings (H). Data are expressed as mean ± SE. The 3 measurement times are described in days: D0 on the day of the sprain or within 3 days depending on the actual date of medical consultation; Day 15 and Day 30 have been done plus or minus 2 days to be performed on a working day. Significant p's are in bold.
 HL = healthy limb, IL = injured limb.

3.2.2. Ethics and dissemination. The mean difference in circumference between the 2 thighs was <1 cm, regardless of the height of measurement. Similarly, no significant differences were observed during the observation period.

3.3. Quadriceps and hamstrings muscle strength

3.3.1. Isometric comparison of the injured limb to the healthy limb. For PTiso, the differences between the healthy and injured quadriceps were significant at the last 2 visits (V1, P = .04; V2, P < .0001; V3, P < .0001). The average deficit at 1 month of unloading was 12.6% ± 1.9% (Fig. 1A). The results are summarized in Table 1.

The differences between the IPTiso of healthy and injured quadriceps were significant at 3 visits: at V1, the average deficit on the injured side was -7.98% ± 1.9 (P < .0001); at V2, the deficit was -10.66% ± 2.7 (P < .001), and at V3, the deficit was 12.88% ± 1.6 (P < .0001) (Fig. 1B).

3.3.2. Isokinetic comparison of the IL to the HL The quadriceps differences between the PTdyn of the healthy and injured limbs were significant at the last 2 visits (V1, P = .155; V2, P < .0001; V3, P < .0001). The average deficit at 1 month of unloading was 9.5% ± 2.

For Wt, the difference was significant at the last 2 visits (V1, P = .5; V2, P < .05; V3, P < .044). The average Wt deficit at 1 month of unloading was 4.2% ± 2.4%. We note that there was no significant difference over time for the Wt of the quadriceps on the healthy side, and a significant difference for the injured side (P > .0007) over the 3 visits (Fig. 2A,B).

The hamstring differences between the PTdyn of the healthy and injured hamstrings were significant at all 3 visits (V1, P < .0001; V2, P < .0001; V3, P < .0001). The average deficit at 1 month of unloading was 16.5% ± 0.2%.

For the hamstring Wt, the difference was significant at all 3 visits (V1, P < .0001; V2, P < .0001; V3, P < .001). The average Wt deficit at 1 month of unloading was 13.7% ± 2.3%. Repeated measures ANOVA showed a significant intersubject

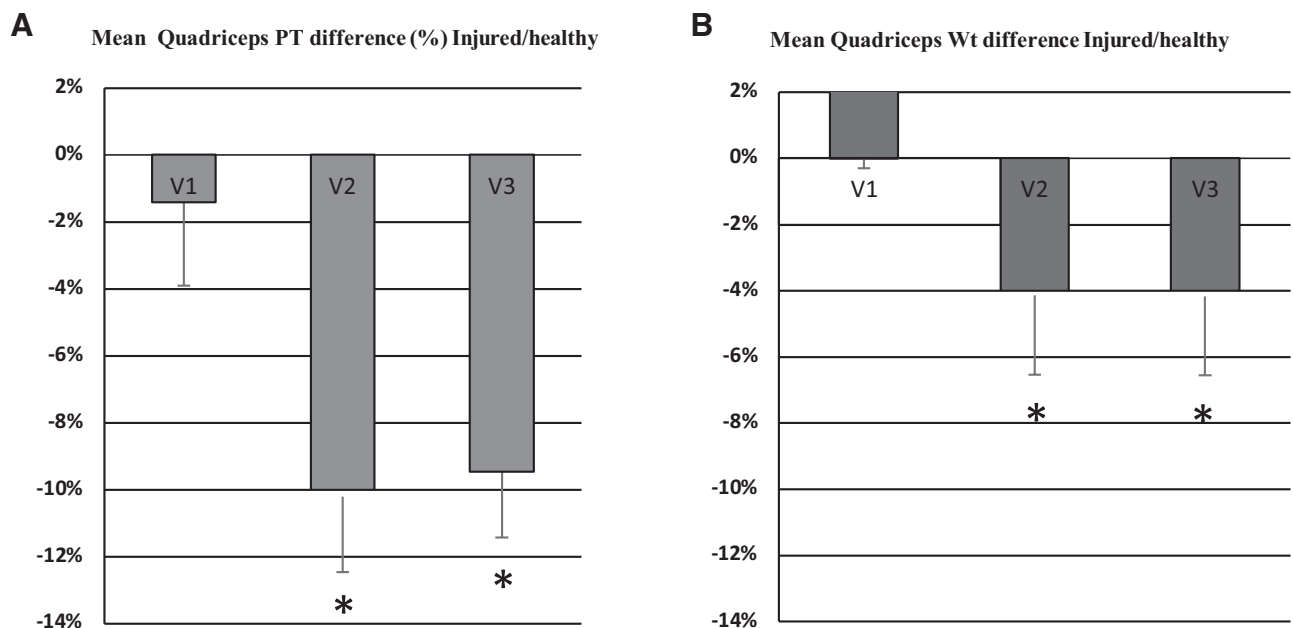


Figure 2. A. Mean deviation of the concentric peak torque at 180°/s of the IL quadriceps compare to HL (%). B. Mean deviation of the Wtq at 180°/s of the injured limb hamstrings compare to healthy (%), on 1 month. Data are expressed as mean ± SE (* shows a significant difference between Injured and Healthy limb). HL = healthy limb, IL = injured limb, Wtq = quadriceps total work.

effect ($P < .0004$) for the comparison between healthy and injured limbs. As for the intrasubject effect, only the repetition effect was significant ($P < .01$), showing variation over time (Fig. 3A,B).

The ANOVA with repeated measures showed that the grade of the sprain had a significant effect on the PTq deficit (greater deficit with greater grade) ($P < .016$), but not the type of unloading, partial or total.

4. Discussion

The main findings are that AS leads to significant alterations in thigh muscle function, and unexpectedly, the hamstrings are more impacted than the quadriceps. Also, we observed no trophicity variation in 1 month, but strength significant loss. More, using isokinetic dynamometer, we observed that IPT and Wt should be used to counterbalance PTiso and PT dyn to state the real degree of muscle variation in strength.

Considering the trophicity evaluated using perimetry, our results did not show any significant variation. We could have expected trophicity variation due to the disuse condition.^[8,9] However, in this study, the knee was not directly affected by initial trauma. Moreover, there was no pain before and after the dynamometric tests and the systematic evaluation of pain at both the ankle and knee levels during the measurements did not show any. The absence of amyotrophy may be explained by the relatively short duration of unloading and free movement of the knee, which remains a minimum active (i.e., activity to maintain balance when crutching). In other conditions, when the knee is immobilized, muscle wasting is observed within the first 2 weeks.^[10,37,38]

Considering the isometric evaluation, the PT iso-and IPT showed a significant and similar deficit (~12%) of quadriceps strength on the injured side in V2 and V3. In V1, only the IPT showed a significant difference between the 2 lower limbs. The deficit on the injured side in the IPT was significant, which was twice the value of the PTiso deficit. It seems that IPT allows for earlier detection of the deficit than PTiso to detect a loss of strength. This can be explained by the fact that IPT reflects

the muscle activity over the entire duration of the contraction, whereas PTiso only reflects the maximum reached over the same duration. Therefore, it would be interesting to link these 2 parameters to detect a loss of strength that might not be revealed with a single PTiso measurement.

The results of PTdyn and Wt were similar considering the concentric isokinetic activity of the quadriceps. Indeed, the variation observed in the total work in V2 and V3 (versus the healthy side) was half that of the peak torque variation. Over 25 repetitions, the total work considered the entire mechanical response of the muscle, while the torque peak was set to the best value. We could expect to see a Wt variation in the same proportions as PTdyn, since the first one is calculated from the instantaneous values of the second. However, while this is the case for some subjects, the mean difference observed is lower for Wt than for PTdyn. Here, it appears that Wt minimizes the deficit on the injured side. Regarding the results for the hamstrings, the differences observed between HL and IL in PTdyn and Wt were similar. A comparison of the 2 variables supports the result given by PTdyn. Therefore, it seems interesting to link these 2 parameters to confirm or moderate the result given by PTdyn. One hypothesis to explain this difference between the isometric and dynamic evaluations is that the isometric measurement reflects the maximum force related to the loading activity, while the dynamic measurement reflects the force related to the movement. If the knee joint can move freely but is subjected to unloading, the isometric force will be the most impacted. Considering the concentric isokinetic activity of the hamstrings, the deficits of the injured side compared to the healthy side were similar at the 3 visits for Pth and Wth. Surprisingly, the deficits observed on the injured side were greater in the hamstrings than in the quadriceps. Indeed, since the quadriceps is the main muscle involved in standing and walking, one might expect the opposite result.

Therefore, another reason must be explored to explain the loss of strength. Nerve impulses play a major role in the mechanical responses of the neuromuscular complex. In our study, the early onset of strength deficit, apart from any affection of the knee joint and its muscles, suggests the role of neurological control.^[39]

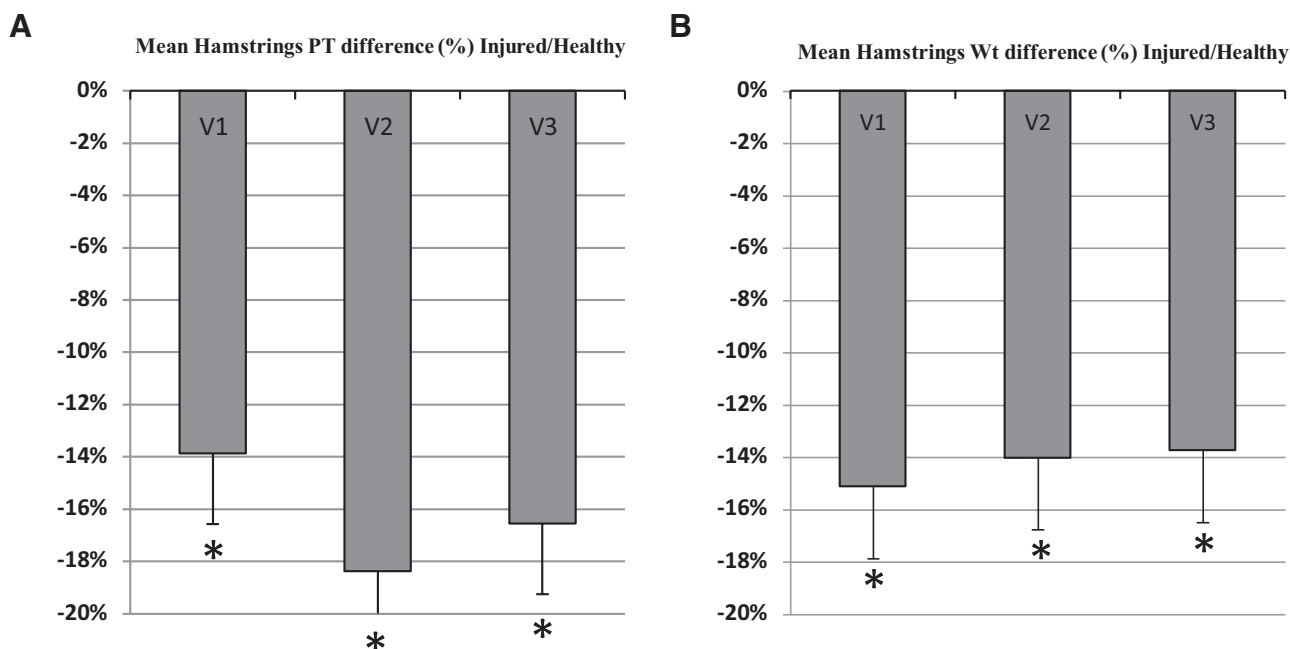


Figure 3. A. Mean deviation of the concentric peak torque at 180°/s of the IL hamstrings compare to HL (%), on 1 month. B. Mean variation of the Total Work at 180°/s of the injured limb hamstrings compared to healthy (%), on 1 month. Data are expressed as mean \pm SE (* shows a significant difference between In.

Here, too, complementary means of exploration seem necessary. Surface electromyography (SEMG) is a noninvasive and useful tool for evaluating and understanding these modifications.^[40,41]

Our results showed that the hamstrings were more affected than the quadriceps were. Therefore, it is necessary to improve the evaluation of these muscles. If the risk of iterative injuries after an AS is mainly centered on the ankle, there is an impact on knee injuries.^[42] In addition, a decrease in active knee stability contributes to chronic ankle instability.^[5,6] Therefore, it is essential to include rehabilitation of the knee musculature during post-traumatic ankle rehabilitation.

Finally, it appears that the grade of the sprain has a significant effect on the PT deficit but not the type of unloading. Partial unloading or a lack of unloading did not seem to influence the results. If we look at dynamic PT, our results show a greater decrease in the posterior compartment (hamstrings) than in the anterior compartment (quadriceps).

We acknowledge some limitations in the present study. The assessments of trophicity require the use of objective measures to differentiate between the different muscle compartments of the thigh, anterior and posterior. The use of MRI imaging could be a good method with the advantage of being noninvasive.^[43] Moreover, the rapidity of onset of the loss of strength and the absence of global atrophy of the thigh, suggests a neurological involvement. The addition of observation means such as surface electromyography would be interesting to explore the neurological component. Thus, muscles with a tonic profile evolve toward a phasic profile; loss of strength is therefore associated with greater fatigability.^[44] MRI can be used to assess changes in this order through T2 variation.^[45] Moreover, the rapidity of onset of the loss of strength and the absence of global atrophy of the thigh, suggests a neurological involvement. Combining SEMG with force measurements would complement the information provided by MRI and monitoring of changes in fatigue and recruitment (RMS and median frequency^[40,46]). However, surface electromyographic recording, in addition to force measurements, could provide indications of the central or peripheral origin of muscle weakness conditions.^[47] This could allow for a better understanding of neuromuscular adaptations in clinical settings.

5. Conclusions

The results of our study show that the effect of disuse on a healthy joint and healthy muscles (knee, quadriceps, and hamstrings) leads to a significant deficit in the strength of agonists and antagonists of this joint within 1 month. Notably, the hamstrings were more affected than the quadriceps. Moreover, the grade of the sprain seems to be correlated with the extent of the deficit, more so than with the type and length of unloading. Finally, it appears that the isometric torque peak measure should be counterbalanced by the isometric torque peak integral for the detection of early changes. Similarly, the total work counterbalanced the peak torque in the dynamic measurements. This suggests that these 2 parameters should be combined to correctly analyze the isokinetic test results.

So those findings suggest that to improve clinical daily practice, it should be pertinent to consider knee muscles in AS rehabilitation, to use unloaded activities as a countermeasure to amyotrophy on short unweight-bearing treatment (on month), and IPT and Wt need to be added in the dynamometer muscle report.

However, our study has limitations. The assessments of trophicity require the use of objective measures to differentiate between the different muscle compartments of the thigh, anterior and posterior. The use of MRI imaging could be a good method with the advantage of being noninvasive. Moreover, the rapidity of onset of the loss of strength and the absence of global atrophy of the thigh, suggests a neurological

involvement. The addition of observation means such as surface electromyography would be interesting to explore the neurological component. To prevent the risk of both iterative ankle injuries and secondary knee injuries, it is essential to incorporate routine thigh muscle strengthening (healthy and injured sides) into the rehabilitation protocol for AS. This will ensure a safe return to operational activities for the military personnel.

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