Surgical Decompression of Exertional Compartment Syndrome of the Forearm in Professional Motorcycling Racers: Comparative Long-term Results of Wide-Open Versus Mini-Open Fasciotomy

Sergi Barrera-Ochoa, MD, PhD,† Sleiman Haddad, MD,* Eva Correa-Vázquez, MD,† Jordi Font Segura, MD,† Emilia Gil, MD,§ Alex Lluch, MD,*‡ Francisco Soldado, MD, PhD,¶ and Xavier Mir-Bullo, MD, PhD*†*

Objective: To compare the long-term results of 2 surgical techniques for forearm chronic exertional compartment syndrome (CECS) in professional motorcycling racers and to study a new diagnostic variable for CECS, T_{Rest}.

Design: Retrospective case series. Level of evidence: 4.

Setting: University Hospital.

Participants: Thirty-four patients identified from a surgical database who had been operated on for upper-limb CECS.

Interventions: The purpose of the study was to report and compare the long-term results of 2 surgical techniques using fasciotomies [wide-open fasciotomy (WOF) versus mini-open fasciotomy (MOF)] for forearm CECS in professional motorcycling racers.

Main Outcome Measures: Patient characteristics: Pain [visual analog scale (100-point scale)] and functional scores (Quick-DASH) at 3 months after surgery and at regular intervals during clinical visits. Surgical complications: Level of satisfaction with the outcome. Time to return to full activity after surgery.

Results: Thirty-four racers, 22 with bilateral involvement (n = 56), were diagnosed with CECS and were treated either with WOF (n = 24) or MOF (n = 32) depending on the surgeon's indication. Mini-open fasciotomy was usually selected in cases who need a faster recovery because of competition schedule. Visual analog scale and Quick-DASH improved 63 and 73 points, respectively ($P < 0.001$) with no significant difference between both surgical methods ($P = 0.512$). Both WOF and MOF were equally effective. Ninety-four percent of the patients were satisfied after 45.35 ± 12 months of follow-up, with no significant difference between surgical groups ($P = 0.642$). The time to return to full activity was 2.7 ± 1 week, also with no significant difference ($P = 0.544$). The time between when the stress testing was halted for pain and the return to baseline pressure (T_{Rest}) was superior to 15 minutes (defined as the mean minus 2 SDs) in 100% patients.

Conclusions: Surgical open or mini-invasive fasciotomy is equally successful in motorcycling racers with forearm CECS. Although the sensitivity of T_{Rest} is quite high in our series, further studies are still needed to validate its diagnostic value.

Clinical Relevance: Surgical open or mini-invasive fasciotomy is equally successful in motorcycling racers with forearm CECS.

Key Words: chronic exertional compartment syndrome, fasciotomy, open fasciotomy, mini-invasive fasciotomy, forearm, motorcycling

(*Clin J Sport Med* 2015;0:1–7)

INTRODUCTION

Chronic exertional compartment syndrome (CECS) is a well-known entity in sports medicine. Chronic exertional compartment syndrome is a reversible form of abnormally increased intramuscular pressure, which occurs during exertion.

Clinically, CECS represents a specific entity with progressive pain during exercise, which often slowly worsens over a period of months. Intracompartmental hydrostatic pressure testing before and after exercise, as recorded by dynamic pressure measurements, is considered the gold standard for confirmation of CECS.[1] Nowadays, a consensus exists around the diagnostic variables defined by Pedowitz, which are resting pressure >15 mm Hg and/or 30 mm Hg at 1 minute after exercise and/or 20 mm Hg 5 minutes after exercise. Some authors however defend the existence of a borderline subgroup of patients, with suggestive clinical features for CECS, who do not meet any of the Pedowitz diagnostic criteria and who benefit from surgical decompression. These can be classified as false negatives based on the Pedowitz criteria. In this subgroup, these authors have proposed to extend the measurement time above 5 minutes.[2–5]

Chronic exertional compartment syndrome of the forearm has been identified in specific athletic population,

Submitted for publication August 18, 2013; accepted November 9, 2014.

From the *Orthopaedic and Trauma Department, Hospital Universitari Vall d'Hebron, Barcelona, Spain; †Hand and Upper Extremity Unit, ICATME—Hospital Universitari Quirónn Dexeus, Barcelona, Spain; ‡Hand and Upper Extremity Unit, Institut Kaplan, Barcelona, Spain; §ICATME—Institut Català de Traumatologia i Medicina de l'Esport, Institut Universitari Dexeus, Barcelona, Spain; and ¶Orthopedic Surgery Department, Pediatric Upper Extremity Surgery and Microsurgery, Hospital Sant Joan De Deu, Barcelona, Spain.

The authors report no conflicts of interest.

Corresponding Author: Sergi Barrera-Ochoa, MD, Hospital Universitari Vall d'Hebron, Passeig Vall d'Hebron 119-129, 08035 Barcelona, Spain (Dr.Barreraochoa@gmail.com).

namely, the motorcycling racers.[5–11] If nonoperative treatment fails, open or mini-invasive fasciotomy or partial fasciectomy may prove successful.[5,12–15] Nowadays, the choice of performing an open fasciectomy versus mini-invasive fasciectomy remains controversial. The advantage of open fasciotomy is the full visualization of the compartment, which allows full extirpation of fascia to decrease scarring and reoccurrence, leading to outstanding success rates, nearing 100%.[5,16] Wide-open fasciotomy (WOF) is the gold standard in treating CECS. However, as this disorder affects a highly competitive professional athlete subgroup such as motorcycling racers, some authors defend lesser invasive techniques that would offer the added advantage of reducing the time off the racing tracks, without compromising the already excellent results. Nevertheless, mini-open fasciotomy (MOF), necessitating only 2 small incisions, has fomented the concerns about an increased complication rate and symptom recurrence in some series.[12,14] Incomplete fascial release or extirpation has traditionally been incriminated in failed cases. Also, some series reported nerve injury and muscle herniation associated with the mini-invasive technique.[17] To date, the only comparative study for forearm CECS contrasts MOF to fasciectomy surgery.[12]

Objective

We aimed to analyze and compare both complications and long-term results of motorcycling racers with CECS undergoing MOF versus WOF.

Finally, we also introduced and studied a new diagnostic variable for CECS, T_{Rest}, calculated as the time between peak exertional intracompartmental pressure (P_{Max}) and return to baseline/resting pressure (P_{Rest}).

Hypothesis

It was hypothesized that MOF would be comparable to WOF in regard to successful surgical outcomes and associated complication occurrences for the treatment of CECS of the forearm in motorcycling racers.

MATERIALS AND METHODS

Patients

Local ethics committee approval was obtained. No external funding was received for this study. Patients with CECS were identified using the surgical database of a single hand surgeon with more than 20 years of experience in professional motorcycling racing pathological conditions. We could identify 96 patients operated for upper-limb CECS. Preoperative and postoperative details were obtained retrospectively from case notes.

Only patients meeting all of the following inclusion criteria were retained:

1. Professional or high-intensity motorcycling and motocross racers (>10 hours per week of training).
2. Clinical symptoms compatible of CECS for at least 6 months (pain, a feeling of tightness, hardness, or a "pumped up" sensation in the forearm, cramping, swelling, paresthesiae of the fingers, weakness, and a feeling of loss of control of the hand).
3. Documented positive compartment hydrostatic pressure measurement using the using the diagnosis criteria[5,11,18,19]: a rest pressure of more than 15 mm Hg and/or 30 mm Hg at 1 minute after exercise and/or 20 mm Hg 5 minutes after exercise.
4. Surgery involving fasciotomy of all forearm compartments.
5. Minimum follow-up of 3 years.

We excluded patients with nonprimary etiologies that might cause CECS such as fractures, burns, or previous surgical interventions in the affected upper extremity. Patients with missing data were not included.

Intracompartmental Pressure Measuring

The diagnosis of compartment syndrome of the forearm muscles was confirmed by the measurement of the deep forearm flexor compartmental dynamic pressure by 1 experienced orthopedic surgeon in all cases, minimizing the interobserver bias. Under local anesthetic, a slit catheter needle (indwelling slit catheter set; Stryker Instruments, Kalamazoo, Michigan) was introduced into the superficial and deep compartments,[20] and connected to a pressure transducer. The compartmental pressure values were registered using a pressure monitor device (pressure monitor device 783547; Hewlett-Packard, Palo Alto, California). Stress testing was done using a finger flexion–extension exercise tool bilaterally until exhaustion or impeding pain (Handgrip; IronMind, Ann Arbor, Michigan).

The protocol used to obtain compartmental dynamic pressure measurements (before and during the stress testing) was P_{Rest} (resting baseline mean pressure values before exercise), P_{pain} (the peak pressure at which the exercise was halted for pain), P_{1min} (pressure recorded at 1 minute of stopping the exercise), P_{5min} (pressure recorded at 5 minutes of stopping the exercise), and T_{Rest} (time between the end point pressure measurement and the return to baseline pressure).

Surgery

If signs and symptoms were suggestive for the presence of CECS, patients were informed on therapeutic options including nonoperative measures and surgical treatment. They all consented orally and in writing to a surgical procedure. The same surgeon performed all interventions. All patients had fasciotomy of all forearm compartments (superficial and deep volar forearm compartment and dorsal forearm compartment). Depending on the surgeon's indication, our attending surgeon performed either a WOF or an MOF. The surgical procedure type was selected based on the recovery time. Mini-open fasciotomy was usually selected in cases who need a faster recovery because of competition schedule. No randomization has been done as this study was a retrospective analysis. He used the technique described by Henry and cited by Allen and Barnes for open volar forearm fasciotomy[7] (Figure 1). The extensor compartment is decompressed by a longitudinal incision along the extensor aspect of the forearm, starting approximately 7 cm distal to the lateral epicondyle. We did not excise any part of fascia in neither surgical act. Mini-open fasciotomy procedure

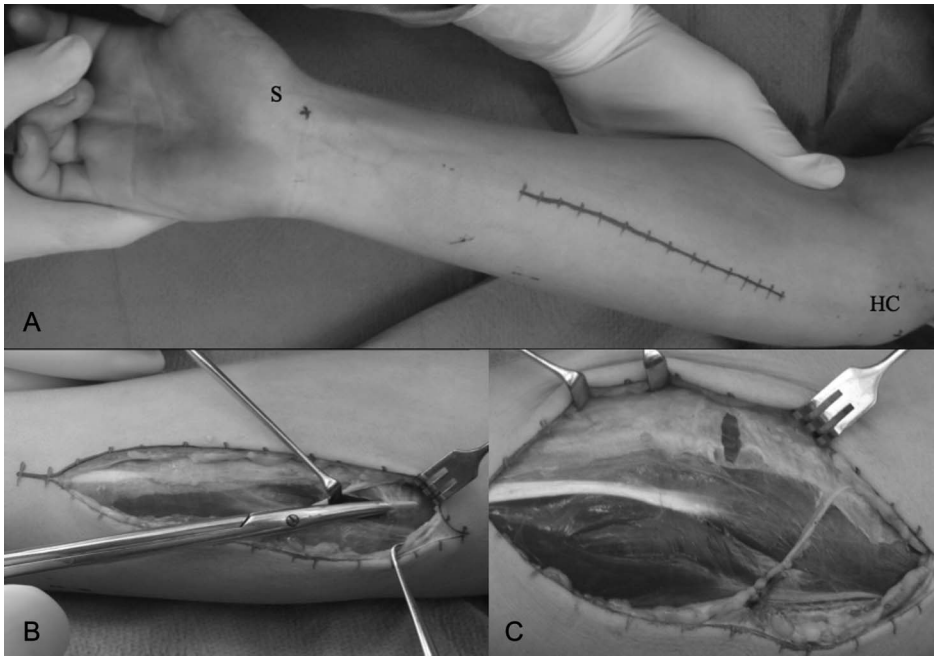

FIGURE 1. A, Anterior approach between the scaphoid and the medial humeral condyle. B, Fasciotomy of the superficial volar compartment. C, The unloading transverse fasciotomy lines.

consisted of an MOF with 2 approaches: volar for the superficial and deep compartments and dorsal for the dorsal and lateral compartments.[14,20,21] The surface landmark for the volar approach was the line between the medial epicondyle and the intersection of the palmaris longus with the proximal flexion crease of the wrist.[12] Two skin incisions, 3 cm each, were performed along this line, one 7 cm distal to the epicondyle and the other 7 cm distal to the first incision. An incision was made in the fascia and blunt dissection was conducted above and below this line, as described by Due and Nordstrand.[22] Then, to release the deep volar compartment, the dissection through these 2 skin incisions went deeper between the flexor carpi ulnaris and the flexor digitorum superficialis, aiming for the deep volar fascia overlying the flexor digitorum profundus. The deep volar fascia was incised with a regular knife in its full length. The surface landmark of the dorsal approach was the line between the lateral epicondyle and Lister's tuberosity. Two skin incisions, 3 cm each, were performed along this line, one 7 cm distal to the epicondyle and the other 7 cm distal to the first incision (Figure 2). We could easily identify the fascia between the dorsal and the lateral compartments, and they were released sequentially with the same technique as the volar approach.

Postoperatively, a compressive dressing was applied for 2-3 days. Patients were encouraged to do range-of-motion and weight-bearing exercises immediately thereafter to prevent adhesions and scaring. Both groups (WOF and MOF) received the same postoperative care.

Variables

The following patients' characteristics were noted: age, sex, height, weight, body mass index, dominant hand, and profession. Visual analog scale (VAS) (100-point scale) and functional scores (Quick-DASH) were recorded before surgery, at 3 months after surgery, and at regular intervals during clinical visits. The VAS levels were categorized as severe (>70 points), moderate (31-70 points), mild (10-30), and no pain (<10 points). Surgical complications were classified as major (neurovascular or symptom recurrence) or minor complications (such as hematoma, skin problems, superficial infection, or muscle herniation). The level of satisfaction with

FIGURE 2. A, Intraoperative image of a fasciotomy through a minimally sized incision. B, Dorsal approach of MOF.

the outcome was evaluated through a 5-point scale. The time to return to full activity after surgery was also recorded.

Statistical Analysis

Statistical analysis was performed using SPSS Statistics, Windows version 17.0.1 (SPSS Inc, Chicago, Illinois). The VAS and Quick-DASH scores were analyzed for skewness and kurtosis, and a Wilcoxon signed-rank test was used to compare the median preoperative and postoperative scores. A Mann–Whitney *U* test was used to compare VAS and Quick-DASH reductions in both surgical procedures. Correlations between variables were contrasted using the Pearson coefficient. Data were expressed as mean ± SD if normally distributed or as median and range. For all tests, $P < 0.05$ was considered significant.

RESULTS

According to the mentioned inclusion criteria, we finally selected 34 racers with CECS operated between 1 January, 2000, and 31 December, 2009. Two patients with missing data were not included. Between 2000 and 2009, 16 cases (47%) were treated by WOF and 18 cases (53%) were treated by MOF. Demographic and clinical data of these 34 are listed in Table. Patients were all men participating in motocross/speed competitions of various levels. A total of 25 patients were right handed, 7 were left handed, and 2 were ambidextrous.

Twenty-two patients had bilateral arm involvement and 12 did not, accounting for a total of 56 surgically intervened CECS. Patients suffering from bilateral CECS had the same type of surgery performed bilaterally during the same surgical act. We had 24 cases of WOF (16 patients in total of which 9 had bilateral involvement). The remaining 32 cases were treated with MOF (18 patients of which 13 had bilateral involvement).

The history of patients was characterized by pain as the principal presenting symptom. The symptoms lasted for a mean of 10.3 ± 4.4 months (6-24 months). Pain began after a mean of 6.8 ± 3.1 minutes (range, 2-13 minutes) of motorcycle training or competition time.

TABLE. Characteristics of Patients Operated for Forearm CECS

	Total	WOF Group	MOF Group
Sex, male/female, n	34/0	16/0	18/0
Follow-up, mean ± SD, mo	45 ± 8	46 ± 8	43 ± 5
Age, mean ± SD, yrs	24 ± 6	24 ± 6	23 ± 6
Height, mean ± SD, cm	168 ± 9	170 ± 9	167 ± 9
Weight, mean ± SD, kg	55 ± 8	56 ± 7	55 ± 8
Body mass index, mean ± SD	20 ± 2	20 ± 2	20 ± 2
Level of motocross, n	34	16	18
Speed Racer Int	11	3	6
Speed Racer Nat	15	6	7
Motocross Int	8	3	4
Motocross Nat	12	4	1
Compartment affected, n	56	24	32
Volar	18	6	12
Dorsal	0	0	0
Volar + dorsal	38	18	20

Compartmental Pressures

Intracompartmental pressure measurements were performed in all 34 patients (Figure 3).

1. P_{Rest} (resting baseline mean pressure values before exercise) were 7.10 ± 3.98 mm Hg (range, 1-14 mm Hg). None of the 34 riders fit the Pedowitz diagnostic criteria of resting pressure (resting pressure of more than 15 mm Hg) (sensitivity of 0%).
2. P_{pain} (peak pressure during the exercise test provocation). The exercise provocation resulted in a more than 4-fold rise in the baseline pressure, up to 32.35 ± 3.79 mm Hg (range, 25-41 mm Hg). All patients demonstrated this increase.
3. P_{1min} (pressure recorded at 1 minute of stopping the exercise) declined to 27.15 ± 3.25 mm Hg (range, 22-33 mm Hg). Only 2 patients met the Pedowitz criteria of "30 mm Hg at 1 minute after exercise" (sensitivity of 5.9%).
4. P_{5min} (pressure recorded at 5 minutes of stopping the exercise). At the 5-minute time interval, the pressures declined to 21.35 ± 3.58 mm Hg (range, 18-24 mm Hg). Thirty-three patients met the Pedowitz criteria of "20 mm Hg at 5 minutes after exercise" (sensitivity of 97%).
5. T_{Rest} (time between the end point pressure measurement and the return to baseline pressure) was 19.77 ± 3.06 minutes (range, 16-26 minutes).

Functional Results After Surgery

The average time to return full riding capacities was 2.7 ± 1 week (range, 0-4 weeks): WOF 2.7 ± 0.86 (range, 0-4 weeks) versus MOF 2.8 ± 0.80 (range, 1-4 weeks) (Figure 4). No significant difference was found between MOF and WOF in this respect ($P = 0.544$).

Pain scores are reported in Figure 4. Overall, mean VAS scores decreased from 79 (range, 45-100) to 16 (range, 3-40) ($P < 0.001$). In the WOF group, mean scores improved from 78 (range, 50-100) to 15 (range, 3-35) ($P = 0.001$) and in

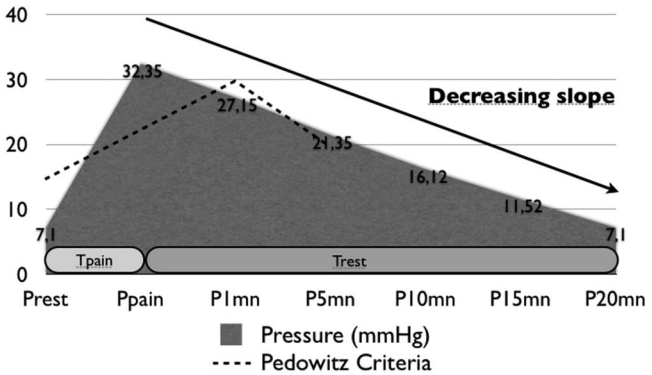

FIGURE 3. Intracompartmental pressure measure means of patients operated for forearm chronic exertional compartment syndrome.

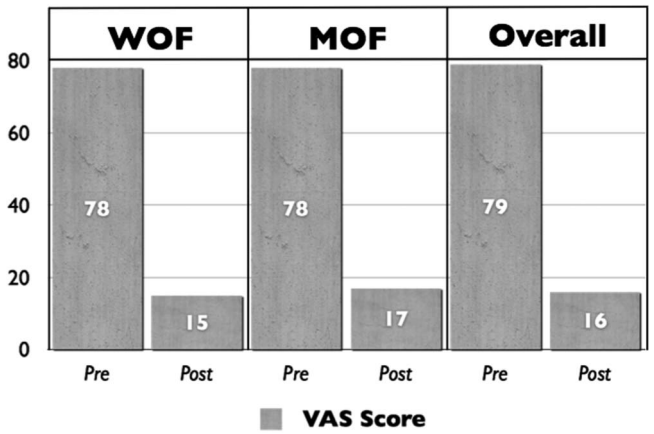

FIGURE 4. VAS score before and after surgery (WOF, MOF, and overall).

the MOF group from 78 (range, 45-97) to 17 (range, 5-40) (n = 18; $P = 0.028$).

Overall mean Quick-DASH scores decreased from 85 (range, 70-100) to 12 (range, 0-25) ($P < 0.001$) (Figure 5). In the WOF group, mean scores improved from 84 (range, 71-100) to 15 (range, 0-25) ($P = 0.001$) and in the MOF group from 86 (range, 69-100) to 12 (range, 0-20) (n = 18; $P = 0.001$).

Neither patient in the WOF group suffered major complications. One patient in the MOF had a recurrence of his symptoms. Four patients (25%) in the WOF group presented minor complications (2 hematoma, 1 cutaneous problem, 1 superficial infection, and 0 muscle herniation). Seven patients (38.9%) in the MOF group presented minor complications (4 hematoma, 1 skin problem, 2 superficial infections, and 0 muscle herniation).

There was no significant difference between MOF and WOF in terms of time to return to full riding capacities ($P = 0.54$), preoperative VAS and Quick-DASH ($P = 0.83$ and 0.91), postoperative VAS and Quick-DASH ($P = 0.10$ and 0.67), reduction in VAS and Quick-DASH ($P = 0.94$ and 0.83), and clinical minor or major complications ($P = 0.66$ and 0.10).

Ninety-four percent (32/34) of the patients were very satisfied with the outcome with both techniques, whereas 2 were fairly satisfied (MOF, n = 1; WOF, n = 1) after the 3-year follow-up. One rider did not benefit from surgery (MOF) with symptoms recurring 2 months after surgery. He was successfully treated with WOF and was not included in the WOF group.

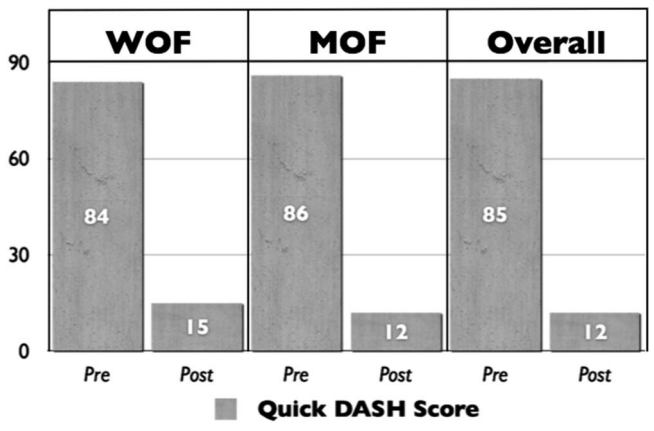

FIGURE 5. Quick-DASH score before and after surgery (WOF, MOF, and overall).

DISCUSSION

Different surgical techniques have been devised to treat CECS. The current gold standard according to experts' opinion and small series is WOF, with success rate neighboring 100% and a very low index of complications.[5,12–15] Some authors have associated facial extirpation to the open fasciotomy technique as to decrease recurrence rates and scare formation.[23,24] This could be boosting the real results of WOF and could give an edge to this technique when compared with the MOF where fasciectomy is very much limited by the small surgical field. Direct comparison between fasciectomy procedures and WOF is poorly justified. The choice of performing an additional partial fasciectomy as a first-line procedure also remains controversial.[25] Although a pilot study suggests that this technique may be effective,[23] not a single study has comprehensively evaluated the effectiveness of this technique or compared its success in different forearm compartments. Other authors, such as Winkes et al,[5] indicate that partial fasciectomy and pure fasciotomy are both equally successful on the long term. Overall, ten studies (with 60 patients overall) reported results in the motorcycling/motocross racers population.[5,7–12,14,16,26] Forty-one of these patients were treated using MOF[5,12,14] with a mean success rate of 83% and 12 with WOF with a success rate of 95%. However, some of the MOF patients had additional fasciectomies to the standard MOF, as per the surgeon's preference.[11] This would make any direct comparison between MOF and WOF difficult, as the added fasciectomy can be enhancing WOF results. Therefore, comparable and reproducible results between both techniques could not be found.

To our knowledge, this study is the largest cohort of patients with forearm CECS secondary to motorcycling/motocross riding. Also, it is the sole series comparing 2 pure fasciotomy techniques. Our results indicate that WOF or MOF of the forearm flexor compartment is equally successful for the treatment of forearm CECS in motorcycling racers, although MOF had a higher rate of minor complications, with no statistical significance whatsoever. Our results were comparable to those previously reported and that without the added fasciectomy. Attending to these results, we can affirm that there is no need to perform any fasciectomy. Furthermore, in our series, none of the operated patients suffered from muscle herniation, a typical complication often associated with fasciectomies. This would render our comparison between MOF and WOF even more reproducible and valid, confirming usefulness of the mini-invasive procedure.[5] From 2000 to 2009, the cases who need a faster recovery because of competition schedule were treated by MOF.

However, our results show that WOF or MOF have the same average time to return full riding capacities. Nowadays, the optimal surgical procedure for forearm CECS is still under debate. As both groups reported similar success rates, with a low index of complications, one may lean to perform the least invasive technique. Still, the results of our study should be confirmed through a prospective study design.

Chronic exertional compartment syndrome is a challenging entity to objectively prove and should be included in the differential diagnosis of any athlete patient presenting forearm pain. During our revision, we found 16 excluded patients (22 cases) presenting symptoms compatible with CECS and that would have been missed if strictly following the Pedowitz diagnostic criteria. They can be classified as false negatives based on the Pedowitz criteria. They were proposed surgery based on the clinical findings and were largely benefited from the decompression. Based on the findings of our patients' population (56 cases were true positives and 22 cases were false negatives), we could say that the diagnostic variables proposed by Pedowitz have low sensitivity in confirming CECS in the forearm [sensitivity of the P_{Bl} = 0% (0/78), sensitivity of P_{1min} = 1.3% (1/78), sensitivity of P_{5min} = 56.4% (44/78)]. This led us to join other authors in questioning the Pedowitz criteria's sensitivity, especially that these were highly variable as seen in our population. In false-negative subgroup, some authors have proposed to extend the measurement time above 5 minutes.[2–5] Our observations, along with other reports, stress the need to find a new and more sensitive single variable to diagnose CECS. Instead, clinical history and examination are paramount in the diagnosis of CECS with the highest sensitivity, and it is the best predictor for successful surgical outcome.[11,18]

Our proposed T_{Rest} eliminates the interpersonal variability in baseline pressure (the least reliable diagnostic variable), using the person's own baseline pressure as his own reference line. Also, and as seen, the longer the time interval after ceasing the activity, the more reliable the pressure reading is at diagnosing CECS (P_{5min} is more sensitive than P_{1min}). This has pushed some authors[5,9,19,27] to consider that the most important criterion for diagnostic forearm CECS may be the slope of decreasing pressures over time. This slope however might prove challenging to calculate. We consider that the dynamic and continuous pressure measurement during and after the stress test provided us with a potentially more reliable and more readily available variable: Time between end point pressure and return to baseline pressure (T_{Rest}). We could as such measure the slope of decreasing pressures over time. Mean values of this variable in this study population were 19.77 $\pm$ 3.06 minutes (range, 15-26 minutes). If we consider the lower cutoff limit of T_{Rest} being 2 SDs below the mean value, the sensitivity of $T_{Rest} > 15$ minutes is 95%. Although the procedure to obtain the variable T_{Rest} increased the time using a slit catheter, we did not have any complications such as hematoma and infection. Nevertheless, should be noted as limitations to recommend the use of the T_{Rest} variable that nowadays the highest diagnostic sensitivity in determining a successful surgical outcome is still a well-defined clinical presentation.

This article being a retrospective analysis of a surgical database suffers from inherent limitations, the most important of which is that no randomization has been done between the 2 surgical populations. Also, the choice of type of surgery to be performed depended on the surgeon's preference after consulting with the patient; therefore, this is a limitation in making procedure efficacy comparison. Nevertheless, both MOF and WOF groups were comparable in terms of patients' characteristics.

REFERENCES

1. van den Brand JG, Nelson T, Verleisdonk EJ, et al. The diagnostic value of intracompartmental pressure measurement, magnetic resonance imaging, and near-infrared spectroscopy in chronic exertional compartment syndrome: a prospective study in 50 patients. *Am J Sports Med.* 2005;33:699–704.
2. Wasilewski SA, Asdourian PL. Bilateral chronic exertional compartment syndromes of forearm in an adolescent athlete. Case report and review of literature. *Am J Sports Med.* 1991;19:665–667.
3. Mannarino F, Sexson S. The significance of intracompartmental pressures in the diagnosis of chronic exertional compartment syndrome. *Orthopedics*. 1989;12:1415–1418.
4. Styf J, Forssblad P, Lundborg G. Chronic compartment syndrome in the first dorsal interosseous muscle. *J Hand Surg Am.* 1987;12:757–762.
5. Winkes MB, Luiten EJ, van Zoest WJ, et al. Long-term results of surgical decompression of chronic exertional compartment syndrome of the forearm in motocross racers. *Am J Sports Med.* 2012;40:452–458.
6. Detmer DE, Sharpe K, Sufit RL, et al. Chronic compartment syndrome: diagnosis, management, and outcomes. *Am J Sports Med.* 1985;13:162–170.
7. Allen MJ, Barnes MR. Chronic compartment syndrome of the flexor muscles in the forearm: a case report. *J Hand Surg Br.* 1989;14:47–48.
8. Garcia Mata S, Hidalgo Ovejero A, Martinez Grande M. Bilateral, chronic exertional compartment syndrome of the forearm in two brothers. *Clin J Sport Med.* 1999;9:91–99.
9. Goubier JN, Saillant G. Chronic compartment syndrome of the forearm in competitive motor cyclists: a report of two cases. *Br J Sports Med.* 2003;37:452–453.
10. Jeschke J, Baur EM, Piza-Katzer H. Chronic compartment syndrome of the flexor muscles in the forearm due to motocross. *Handchir Mikrochir Plast Chir.* 2006;38:122–125.
11. Zandi H, Bell S. Results of compartment decompression in chronic forearm compartment syndrome: six case presentations. *Br J Sports Med.* 2005;39:35.
12. Fontes D, Clement R, Roure P. Endoscopic aponeurotomy for chronic exertional compartmental syndrome of the forearm: report of 41 cases. *Chir main.* 2003;22:186–196.
13. Rorabeck CH, Fowler PJ, Nott L. The results of fasciotomy in the management of chronic exertional compartment syndrome. *Am J Sports Med.* 1988;16:224–227.
14. Croutzet P, Chassat R, Masmejean EH. Mini-invasive surgery for chronic exertional compartment syndrome of the forearm: a new technique. *Tech Hand Up Extrem Surg.* 2009;13:137–140.
15. de Fijter WM, Scheltinga MR, Luiting MG. Minimally invasive fasciotomy in chronic exertional compartment syndrome and fascial hernias of the anterior lower leg: short- and long-term results. *Mil Med.* 2006;171:399–403.
16. Brown JS, Wheeler PC, Boyd KT, et al. Chronic exertional compartment syndrome of the forearm: a case series of 12 patients treated with fasciotomy. *J Hand Surg Eur Vol.* 2011;36:413–419.
17. Leversedge FJ, Casey PJ, Seiler JG III, et al. Endoscopically assisted fasciotomy: description of technique and in vitro assessment of lower-leg compartment decompression. *Am J Sports Med.* 2002;30:272–278.
18. Pedowitz RA, Hargens AR, Mubarak SJ, et al. Modified criteria for the objective diagnosis of chronic compartment syndrome of the leg. *Am J Sports Med.* 1990;18:35–40.
19. Schoeffl V, Klee S, Strecker W. Evaluation of physiological standard pressures of the forearm flexor muscles during sport specific ergometry in sport climbers. *Br J Sports Med.* 2004;38:422–425.

20. Gelberman RH, Garfin SR, Hergenroeder PT, et al. Compartment syndromes of the forearm: diagnosis and treatment. *Clin Orthop Relat Res.* 1981;161:252–261.
21. Rowland S. Fasciotomy, treatment of compartment syndrome. In: Green DP, ed. *Operative Hand Surgery*. 3rd sub ed. New York, NY: Churchill Livingstone; 1993:661–694.
22. Due J Jr, Nordstrand K. A simple technique for subcutaneous fasciotomy. *Acta Chir Scand.* 1987;153:521–522.
23. Slimmon D, Bennell K, Brukner P, et al. Long-term outcome of fasciotomy with partial fasciectomy for chronic exertional compartment syndrome of the lower leg. *Am J Sports Med.* 2002;30:581–588.
24. Bell S. Repeat compartment decompression with partial fasciectomy. *J Bone Joint Surg Br.* 1986;68:815–817.
25. Tzortziou V, Maffulli N, Padhiar N. Diagnosis and management of chronic exertional compartment syndrome (CECS) in the United Kingdom. *Clin J Sport Med.* 2006;16:209–213.
26. Kouvalchouk JF, Watin Augouard L, Dufour O, et al. Chronic stress-related compartment syndrome of the forearm [in French]. *Rev Chir Orthop Reparatrice Appar Mot.* 1993;79:351–356.
27. Rydholm U, Werner CO, Ohlin P. Intracompartmental forearm pressure during rest and exercise. *Clin Orthop Relat Res.* 1983; 175:213–215.