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Rehabilitation after Anterior Cruciate Ligament Reconstruction: Dry Land *vs* Aquatic Rehabilitation

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SUMMARY

Purpose. Anterior cruciate ligament (ACL) rupture is a common injury in athletes and active patients. Aquatic therapy seems to be effective for the rehabilitation after ACL reconstruction, good outcomes and shorter rehabilitation time have been reported compared to dry land rehabilitation. The purpose of this study is to compare the results of dry land and aquatic rehabilitation. The hypothesis is that aquatic rehabilitation is effective and could reduce the rehabilitation time after ACL reconstruction.
Methods. After ACL reconstruction, 24 patients were randomly divided into 2 groups, group A who received standard dry land physiotherapy, and group B who received an aquatic rehabilitation protocol. Both groups received 12 rehabilitation sessions. The outcomes of the two groups have been evaluated according to the improvement of their knee ROM, the International Knee Documentation Kommittee (IKDC), the Lysholm scales, and the Visual Analogue Scale (VAS) score. We designed a prospective randomized controlled trial (RCT).
Results. The knee flexion improved in both groups during the rehabilitation period. The functional scores, according to IKDC and Lysholm scale, improved in both groups at the final follow up.
The mean score significantly improved at all time point, respectively 17.9 at T0, 33.2 at T1 and 40 at T2 (S.D. 2.07) for group A, and 20.5 at T0, 36 at T1, 41.8 at T2 (S.D. 2.06) for group B. The mean VAS score improved from 6.6 at T0 to 3.9 at final follow-up in group A, and form 5,9 at T0, to 3 at T2. When comparing the results of the two groups, no statistically significant differences have been reported.
Conclusions. Both dry land and aquatic therapy are effective for the rehabilitation of patients after ACL reconstruction, but there is not one therapy superior to the other.

KEY WORDS

Anterior cruciate injury; ACL reconstruction; aquatic rehabilitation; pool therapy; return to play.

INTRODUCTION

Anterior cruciate ligament (ACL) injury is a common injury in patients who practice sports. The incidence appears to be greatest in athletes between 15 and 40 years old which participate in pivoting sports like soccer, rugby, handball, volleyball and alpine skiing (1-3). As the rate of ACL rupture is higher in female than male population, anatomical differences as greater knee valgus, greater tibial external rotation during functional activity and laxity, and the influence of sexual hormones and menstrual cycle have been also proposed as potential pathogenetic factors (4).

The ACL does not heal spontaneously due to its poor vascularity. It provides 85% of the stability avoiding anterior-posterior translation of the tibia relative to the femur and acts as a

secondary restraint to tibial rotation and varus/valgus rotation. In addition to its mechanical function in maintaining knee stability, the ACL also contains mechanoreceptors that directly influence the neuro-muscular control of the knee (5, 6). As the ACL contributes to both the sagittal and the rotational stability of the knee, ACL deficiency may cause instability in pivoting, jumping, and landing activities, leading to meniscal and cartilage injuries, and early osteoarthritis at long term follow-up (7, 8). However, the natural history of the ACL-deficient knee as compared with the surgically reconstructed knee is not well understood (9, 10). Furthermore, there remains controversy as to the appropriate patient selection criteria for nonoperative management, as has been reported that one third of patients recover well and return to pre-injury activity level with conservative management (11, 12).
The gold standard treatment for young and active patients is ACL reconstruction (13). It can restore joint stability with low surgical risk. Some studies also demonstrated the restoration of postural stability, which can be explained by regeneration of sensory neurons after ACL reconstruction (14, 15). Over the years, numerous rehabilitation techniques and protocols have been proposed, but a rehabilitation protocol well accepted is still under investigation. Some authors hypothesized that early rehabilitation in water can improve recovery times. In literature some authors compared the effects of rehabilitation in water with more traditional dry land rehabilitation, but there is no agreement amongst authors if water rehabilitation may be superior. Peultier-Celli *et al*. compared 67 patients divided in two groups, one treated with an aquatic rehabilitation protocol *versus* a conventional rehabilitation group. The aquatic group showed faster recovery (16). Tovin *et al*. showed that pool exercises may not be as effective as dry land therapy for regaining maximum muscle strength, while aquatic rehabilitation can reduce joint effusion, edema and pain (17).
The aim of this study is to compare the outcomes of dry land and aquatic rehabilitation for patients who underwent ACL reconstruction. The hypothesis is that aquatic rehabilitation is effective and could reduce the rehabilitation time compared to dry land exercises.

MATERIALS AND METHODS

Twenty-eight consecutive patients affected by ACL injury were enrolled at a single institution. All patients were informed about the experimental study and declared that they understood the purpose of the study, signing an informed consent.

Ethics

All procedures were in accordance with the 1964 Helsinki declaration and its later amendments. The study protocol was approved by the Local Committee for Medical and Health Research Ethics, Villa Erbosa Hospital, Gruppo San Donato, Bologna, Italy (number of protocol 223/2020 – Date of approval: May 20, 2020). All patients gave informed consent prior to being included into the study. All methods were carried out in accordance with relevant guidelines and regulations.

Inclusion and exclusion criteria

Twenty-eight consecutive patients affected by ACL injury were enrolled at a single institution. Patients were eligible for enrollment according to the following inclusion criteria: body mass index (BMI) ≤ 30 kg/m^2, candidates for an arthroscopic procedure based on a previous magnetic resonance imaging (MRI) positive for isolated ACL injury, age of the patients at the time of surgery between 18 and 40 years, positive pivot-shift and Lachman pre-operative tests.
The exclusion criteria were associated injuries such as meniscal tears, posterior cruciate or collateral ligaments injury, cartilage defects. Patients with a varus or valgus malalignment greater than 5°, previous intra-articular fractures or joint infections, cardiac and/or respiratory comorbidities were not included. Patients who were not able to follow the post postoperative instructions and rehabilitation were excluded from the study.

Patient assessment

A detailed physical examination was conducted in all patients, who were examined by fully trained orthopedic surgeons with a special interest in knee surgery. All patients underwent standard weight-bearing anterior-posterior (AP) and lateral plain radiographs of the knee, and an MRI was indicated to confirm the ACL rupture and exclude associated injuries.
The rehabilitation protocol consisted in 12 sessions, three sessions a week over four weeks, and all patients have been examined after the first rehabilitation session (T0), after the 6th session (T1), and at the end of the treatment (T2-12th session). The range of motion (ROM) was recorded at each control. The progress of physiotherapy was evaluated through the International Knee Documentation Committee (IKDC) and Lysholm scale, which assess the presence of symptoms, the degree of sporting activity and the functionality of the joint itself (18, 19). The Visual Analogue Scale (VAS) score was also recorded at each time point. Safety was assessed by recording all adverse events during treatment.

Surgery and rehabilitation protocol

All surgeries were performed by the senior surgeon (GP). Hamstring autograft have been used to reconstruct the injured ALC. Gracilis and semitendinosus tendons, once removed, were folded in half to obtain a new ligament with four strands. All patients received intravenous controlled

analgesia for 12 h, and they were discharged the day after surgery. Standard thromboembolic prophylaxis with low molecular weight heparin (LMWE) for 30 days.
All patients underwent rehabilitation at the same physiotherapy facility, equipped with a therapeutic pool and gym. All the patients began passive mobilization of the operated knee with kinetec from the first day after surgery. After 2 weeks, after the complete closure of surgical wounds, they were randomly divided into two groups, the control group (A) that followed the standard dry land treatment protocol, and the experimental group (B) that followed an aquatic treatment protocol. Both groups received 3 sessions of therapy a week. Patients who belonged to group B received one session a week on dry land, and 2 sessions in swimming pool under the direct supervision of an expert and trained physiotherapist. During the treatment, the number of repetitions and intensity of the exercises have been improved according to the clinical condition of the patient (**table I**).

Statistical analysis

The average and standard deviation values were calculated and subsequently compared with each other. To verify the

Table I. Rehabilitation protocols of control **(A)** and experimental **(B)** group.

Group A	Group A
3rd postoperative week	
Static bicycle	Water temperature 32 °C
Lymphatic drainage	Warm-up in water
Passive mobilization of the knee by a physiotherapist	Active mobilization of the hip and knee
Isometric strengthening exercises of the quadriceps muscle	Walking
Stretching exercises	Muscle strengthening exercises
	Swim
4th postoperative week	
Static bicycle	Warm-up in water
Closed chain exercises	Active mobilization of the hip and knee
Quadriceps and hamstrings strengthening exercise	Walking
	Muscle strengthening exercises
	Swim
5th postoperative week	
Static bicycle	Warm-up in water
Quadriceps, hamstrings and adductor muscle strengthening exercises	Active mobilization of the hip and knee
Monopodalic exercises	Walking on tiptoe and heel
Core stability exercises	Muscle strengthening exercises adding a 2 kg weight
	Proprioception
	Swim
6th postoperative week	
Static bicycle	Warm-up in water
Muscle strengthening exercises	Active mobilization of the hip and knee
Monopodalic exercises	Walking on tiptoe and heel
Core stability exercises	Muscle strengthening exercises adding a 2 kg weight
Proprioception	Proprioception
	Swim

The treatment protocols of group A and B are shown in this table. The intensity and number of repetitions of exercises proposed to experimental patients' group increased according to their clinical conditions and responsiveness to the physiotherapy.

effectiveness of the present study, the Student's statistical t-test was used, by means of which it was possible to compare the two groups A and B and evaluate the differences in the starting and ending treatment values within the same group. The purpose of this test is to verify if the average value of a data distribution deviates significantly from the reference value P. The P-value was set at a value equal to 0.05 which is equivalent to 95% of the actual significance of the test.

RESULTS

Four subjects were excluded from the study, two for each group. One changed rehabilitation protocol before the end of the study and was lost at follow-up, and 3 subjects were excluded because associated injuries were detected during surgery. Twenty-four patients met the inclusion criteria, 12 for group (13 males, 11 females; mean age 28 for group A, 26.3 for group B; range 19-35). No statistically significant differences were observed for variables such as age, sex, height, weight, BMI.

The knee flexion improved in both groups during the rehabilitation period, and a statistically significant improvement have been reported at the T1 and T2 compared to the baseline (**table II**). The mean knee flexion of group B was slightly better compared to control (**figure 1**), without any statistically significant difference (p = 0.74). All patients achieved full knee extension.

The mean IKDC score significantly improved at all time point for both groups, respectively 17.9 at T0, 33.2 at T1 and 40 at T2 (S.D. 2.07) for group A, and 20.5 at T0, 36 at T1, 41.8 at T2 (S.D. 2.06) (**table III**), but there was not a statistically significant difference between groups (p = 0.24). In particular, the IKDC score was slightly better for patients who received the hydrokinetic therapy in water (**figure 2**), but not significant.

Table II. Mean ROM and standard deviation of group A and B.

	Flexion (°)			Odds		
			Group A			
	T0	T1	T2	Δ T1-T0	Δ T2-T1	Δ T2-T0
Knee flexion	83.8	101.8	118.7	18	16.9	34.9
SD	3.5633	4.7065	3.5194	3.2193	4.2525	4.3580
P-value				0.0	0.0	0.0
			Group B			
	T0	T1	T2	Δ T1-T0	Δ T2-T1	Δ T2-T0
Knee flexion	84.9	101.7	120.5	16.8	18.7	35.5
SD	3.7285	3.5961	4.7958	3.8337	4.9749	5.5507
P-value				0.0	0.0	0.0

This tables shows the mean and standard deviation regarding the knee flexion of group A and B in the three-time point. Subsequently, the differences (D), means and standard deviations of the times T0-T1, T1-T2, T0-T2 have been calculated for each group.

Table III. Mean IKDC scale and SD.

	IKDC			Odds		
			Group A			
	T0	T1	T2	Δ T1-T0	Δ T2-T1	Δ T2-T0
Mean ICDK	17.9	33.2	40	15.6	6.7	22.4
SD	2.2712	2.6568	2.0776	1.7824	1.9195	2.4680
P-value				0.0	0.0	0.0
			Group B			
	T0	T1	T2	Δ T1-T0	Δ T2-T1	Δ T2-T0
Mean ICDK	20.5	36	41.8	15.4	5.8	21.2
SD	2.4391	4.4493	2.0664	2.3812	1.8656	2.2832
P-value				0.0	0.0	0.0

A significant improvement of the IKDC scale during the rehabilitation have been shown in both groups. A slightly higher improvement of scores have been reported in group B, but not statistically significant.

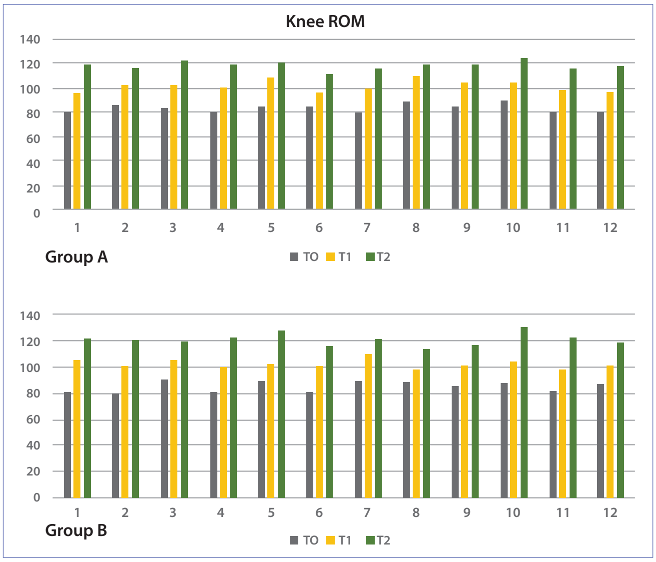

Figure 1. Knee ROM of group A and B.

For both groups, the graph shows the improvement in knee flexion of all patients at the end of treatment in both groups, but no statistically significant differences have been detected between intervention and control group.

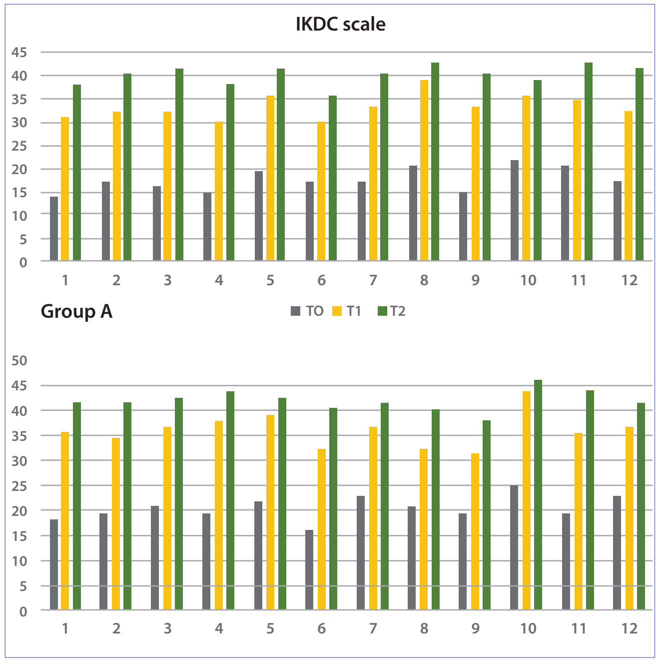

Figure 2. ICDK scale.

The ICDK scale showed better scores in group B than group A at all time points, but the difference is not statistically significant.

The Lysholm scale also improved during the rehabilitation in both groups. At T0 the mean Lysholm scale of group A and B was respectively 20.5 (SD 5.7912) and 22.5 (SD 6.12), and at the end of the treatment protocol it improved to 50.1 (SD 5.42) and 52 (SD 5.32) (**table IV**). When comparing intervention and control group, the results were better for patients of group B (**figure 3**), but not statistically significant ($p = 0.95$).
The VAS score showed an improvement during the rehabilitation period in both groups (**table V**). The median preoperatory VAS score improved from 6.6 at T0 to 3.9 at T2 in group A. The mean VAS score in group B was 5.9 at T0, 4.3 at T1 and 3 at T2. The improvement was statistically significant in both groups, but when comparing, no significant differences have been found ($p = 0.71$).
No adverse events have been recorded during the treatment period in both groups.

Table IV. Lysholm scale

	Lysholm			Odds		
			Group A			
	T0	T1	T2	Δ T1-T0	Δ T2-T1	Δ T2-T0
Mean score	20.5	40.2	50.1	19.6	9.9	29.5
SD	5.7912	4.6147	5.4244	2.6013	5.5179	7.3294
P-value				0.0	0.0	0.0
			Group B			
	T0	T1	T2	Δ T1-T0	Δ T2-T1	Δ T2-T0
Mean score	22.5	39.6	52	17	12.3	29.4
SD	6.1268	4.8866	5.3258	3.7040	4.2711	7.1282
P-value				0.0	0.0	0.0

The mean value and standard deviation of the Lysholm scale of A and B are shown in this table. The Student's test showed a significant improvement of the Lysholm scale during the rehabilitation in both groups. The patients of Group B showed a little higher improvement from T1 to T2, compared to group A, but not statistically significant.

Table V. VAS score.

	VAS score			Odds		
	Group A					
	T0	T1	T2	Δ T1-T0	Δ T2-T1	Δ T2-T0
Mean VAS	6.6	5	3.9	1.7	1	2.7
SD	1.2309	1.1645	0.9962	0.7538	0.7930	1.1382
P-value				0.01	0.12	0.0
	Group B					
Mean VAS	5.9	4.3	3	1.5	1.3	2.9
SD	1.0836	1.1547	0.8528	0.7930	0.8876	1.0836
P-value				0.002	0.004	0.0

This table shows the mean and standard deviation of VAS scale in group A and B in the three time points.

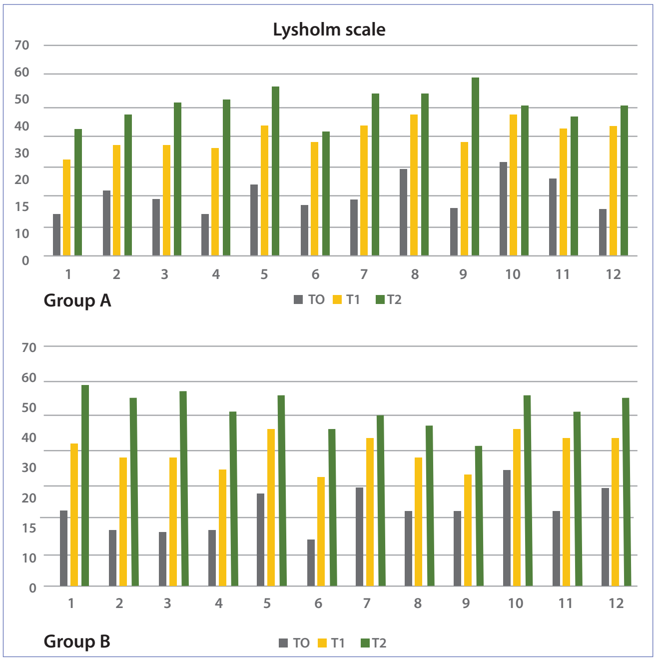

Figure 3. Lysholm scale.

The Lysholm scale showed better scores in group B than group A at all time points, but not significant.

DISCUSSION

The aim of this study was to compare the results of two different rehabilitation protocols for patients who underwent ACL reconstruction, dry land and aquatic therapy.

The aquatic environment has broad rehabilitative potential, extending from the treatment and rehabilitation of acute injuries to chronic diseases, in particular for patients affected by musculoskeletal problems. The effects of aquatic therapies have been studied since they were described for the first time by Charles L. Lowman in 1911 (20), who was the first to introduce therapeutic tubs to treat patients with cerebral palsy and spasticity. Aquatic immersion has many biological effects, extending across all homeostatic systems. The blood flow is increased during therapeutic exercise in water compared to dry land, determining a greater oxygen availability to muscles and catabolites drainage (21). Aquatic environment showed many beneficial effects on pain perception. Skin sensory nerve endings are stimulated, and different studies suggest that sensory overflow may act as pain modulator, increasing the pain threshold, improving pain and function (22). The hydrostatic effects of immersion significantly reduce soft tissue edema (23). The human body immersed in water to a depth of 120 cm is subjected to a hydrostatic pressure which is slightly greater than normal diastolic blood pressure. This hydrostatic pressure is effective to reduce the edema. Weight bearing can be easily controlled by water immersion. A person immersed to the symphysis pubis has effectively offloaded 40% of the body weight, approximately 50% when further immersed to the umbilicus, while xiphoid immersion offloads 60%-75% of body weight (24)

Gravitational forces can be controlled so that only muscle torque forces act on the injured site, allowing active assisted range-of-motion activities, and strength exercises (25). Another important propriety of water is viscosity, which is the resistance of a fluid to movement of neighboring portions relative to one another, and indicates the opposition to flow. A limb moving into the water is subjected to the resistive effects of the fluid. Viscous resistance increases as more force is exerted against it, and as the velocity of the movement increases, but that resistance drops immediately on cessation of force. Thus, viscosity is useful to control the strength apply to the injured limb, while when the patient feels pain and stops movement, the force drops precipitously as water viscosity stop the movement. This allows enhanced control of strengthening activities within the pain threshold.

Many aquatic post-operative rehabilitative programs have been designed according to the idea that they could be more effective compared to normal dry land exercises. Peultier-Celli *et al*. (16) compared 67 patients divided in two groups, one treated with an aquatic rehabilitation protocol, *versus* a dry land rehabilitation group. The aquatic group had faster recovery according to the authors, but only 2 of the 7 parameters analyzed showed a statistically significant improvement. Zamarioli *et al.* (26) reported a faster recovery after 9 weeks in patients treated with aquatic rehabilitation after ACL reconstruction, according to pain, ROM, muscle strength, swelling, and muscle mass circumference. However, the differences were not statistically significant, in accordance with the present study. Biscarini *et al*. (27) developed a biomechanical and hydrodynamic theoretical model to calculate the knee joint load during underwater knee extension exercises. This biomechanical work highlights that aquatic exercises can theoretically be usefully and safely implemented in the rehabilitation program following ACL surgery. Exercises performed in the aquatic and dry land environment were also compared by Becker, reporting better knee function and muscle strength in patients who received pool therapy (28). Conversely when the exercise is static or involves a vertical movement, the cardiovascular and neuromuscular activity is reduced in water. This is a product of the effect of buoyancy (29). However, results are still controversial, as some authors agree that exercise in water may not be as effective as exercise on land for regaining maximum muscle strength (17). Therefore, although good outcomes have been reported after aquatic exercise for rehabilitation of patients after ACL reconstruction, therapeutic pool exercises are not included in many standard protocols and guidelines (30).

According to our study, both dry and aquatic therapy showed a significant improvement of all the parameters analyzed, as knee ROM, functional score and pain. This data supports the hypothesis that rehabilitation in water is effective for rehabilitation after ACL reconstruction. Both the ROM and the VAS score showed a slightly better improvement in patient who received aquatic rehabilitation program, but, according to many studies available in literature, the differences were not statistically significant.

Aquatic therapy after ACL reconstruction seems to be effective to improve knee function, because statistical significant improvement of functional scores have been reported evaluated according IKDC and Lysholm scale. Slightly better outcomes have been reported for patients after aquatic therapy compared to dry land after 12 sessions. This could support the assumption that rehabilitation in water can reduce the time of rehabilitation. However, successful return to sports after ACLR is influenced by multiple physical and psychological factors. Neuromuscular, balance, proprioception impairments and kinesiophobia may negatively influence perceived knee function and the pre-injury activity level (31, 32).

We are aware of the limitations of our study. The first is the small size of our cohort, 24 patients. The lack of statistical power due to the small sample size is another limitation of our study, but we do not claim which our conclusions can be extended to the general population. Furthermore, the short-term follow-up did not allow us to draw final conclusions on longer-term outcomes and differences between these two rehabilitation protocols.

CONCLUSIONS

Aquatic rehabilitation seems to be as effective as dry land therapy for rehabilitation of patients who underwent ACL reconstruction. When compared, aquatic protocol showed a slight better outcome according to pain and function after 12 sessions of rehabilitation therapy, but the difference was not statistically significant. Further studies are required to confirm these results and to identify the most appropriate rehabilitation protocol for patients who suffered an ACL injury.

FUNDINGS

None.

DATA AVAILABILITY

All the relevant outcome and results are included into the table of this manuscript. Data are also available from the corresponding author on reasonable request.

CONTRIBUTIONS

GP: surgeries. ET, DCV: patients' treatment. GP, ET, AT: patients' examination. ET, AGV, RM literature review. ET, AGV: writing – original draft. GP, DCV, RB: writing – review & editing. GP, RM, RB: supervision, writing – review & editing. All authors: final approval.

CONFLICT OF INTERESTS

The authors declare that they have no conflict of interests.

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