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ARTHROSCOPY AND SPORTS MEDICINE

Rehabilitation before regenerative cartilage knee surgery: a new prehabilitation guideline based on the best available evidence

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Abstract

Introduction Focal cartilage defects are an increasingly relevant clinical problem especially in athletes. Cartilage regenerative surgery (CRS) including microfracture and autologous chondrocyte implantation (ACI) to treat such isolated cartilage defects in the knee joint has been well established in the last two decades. In contradiction to high-level evidence concerning the surgical technique, cell-related issues, and clinical results, the knowledge about the optimal rehabilitation process is still sparse although the importance of optimizing the rehabilitation process has recently led to new research focus in this field. The preoperative time frame may be used to start rehabilitation which may fasten the postoperative recovery and optimize clinical outcome ("Prehabilitation"—PREHAB). The aim of this article, therefore, was to review the available literature on prehabilitation concepts and to present a prehabilitation guideline for CRS patients based on the best evidence available.

Methods A systemic literature research was conducted on rehabilitation for cartilage regenerative surgery as well as prehabilitation in knee joint procedures. From the available literature a prehabilitation concept was generated and tested in 10 ACI patients.

Results As the literature search found no studies addressing prehabilitation in CRS patients, an evidence-based PREHAB program has been compiled based on the available evidence from (a) studies addressing postoperative rehabilitation in CRS patients and (b) PREHAB studies on other knee procedures including TKA. This presented prehabilitation guideline has been tested in > 50 CRS patients and was found to be feasible as all of the patients showed a good compliance and were able to perform the protocol as suggested.

Conclusion The presented PREHAB regimen may serve clinicians as a guideline for early rehabilitation of their CRS patients. Obviously, further research is mandatory to quantify its clinical effect and to demonstrate its cost-effectiveness and benefits in surgically treated patients.

Keywords Knee injuries · Knee osteoarthritis · Articular cartilage · Rehabilitation · Resistance training

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Introduction

Focal cartilage defects (FCD) are a relevant clinical problem not only in athletes but also in the general population with an increasing incidence [1, 2]. Cartilage regenerative surgery (CRS) including microfracture and autologous chondrocyte implantation (ACI) to treat isolated cartilage defects in the knee joint has been well established for the last two decades. Numerous studies have proven the safety and the clinical effectiveness of such procedures [3–7]. Very good long-term outcomes have been reported, especially in young, physically active patients treated early after the onset of symptoms [7–9]. In addition to vivid research interest addressing various modifications of surgical technique, cell-related issues, and clinical results, the knowledge about the importance of optimizing the rehabilitation process has recently led to new research focus in this field [1, 10–13]. Nevertheless, the scientific evidence on the different rehabilitation measures as well as optimal training protocols is still sparse.

In the available literature, quadriceps strength was first considered to be the key issue. Several authors reported persistent strength deficits of the knee extensors even years after cartilage regeneration surgery. Moreover, a close correlation between quadriceps muscle strength and clinical outcome has been reported. This might be of major interest, as regaining muscle performance seems to be closely associated with better clinical outcomes [14–17]. Kreuz et al. have also emphasized the relationship between continuous sports participation years after CRS and clinical long-term outcome [9, 10, 18].

The importance of quadriceps muscle strength is further underlined by the fact that muscle weakness seems to be a major risk factor in the development and progression of osteoarthritis (OA) [19–22]. Although the aetiology of focal cartilage defects (FCD) and OA cannot be generally compared, this aspect seems to be important as untreated FCD have a high risk to lead to OA. As early as 1997, Slemenda et al. showed that quadriceps muscle weakness is associated with radiological signs of osteoarthritis, independent of osteoarthritis symptoms. Further, it was stated that quadriceps muscle weakness correlated with knee pain and functional disability [19, 23]. Jackson et al. described dynamic knee instability accompanied by a significantly increased knee-joint load as a consequence of muscle weakness [22]. Recently, Wondrasch et al. demonstrated that optimizing quadriceps muscle strength in patients with FCD in the knee leads to reduced symptoms and improved functional performance [13]. Benell et al. revealed a significant pain reduction as well as better physical function in patients with medial knee OA after performing quadriceps strength training or neuromuscular training whereas no changes in the knee adduction moment (a key predictor of structural disease progression) was detected [24].

Weak hip muscles seemed to be another factor influencing knee loading patterns. In a systematic review, Cashman assessed the effect of weak hip abductors on knee valgus kinematics in healthy subjects and found a small amount of evidence that there is an increased knee valgus in healthy people with weak hip abductors [25]. Kean highlights that hip abductor strength is a significant predictor of knee adduction moment impulse [26, 27]. Cronin et al. investigated the influence of explosive hip abductor and hip extensor strength on frontal plane hip and knee kinematics during a single-leg jump-cut task [28]. Their primary finding was that females with greater hip extension strength exhibited lesser hip adduction and knee valgus motion when performing a single-leg jump-cut. Furthermore, a correlation between knee pain, knee function and hip muscle strength has been reported, so exercise for strengthening the hip muscles should be included in the rehabilitation program for patients with knee OA [29].

As the postoperative rehabilitation process following cartilage regeneration surgery is generally long and demanding, preparing patients to the postoperative procedure—prior to surgery—could be beneficial. It is generally accepted that a proper preoperative instruction and education reduce the risk of undesired events during the early rehabilitation phase, lead to better understanding of the different physiotherapy measures, facilitate correct and effective exercising, and enhance compliance [30–32]. Additionally, proper preoperative muscle function may be associated with a better clinical outcome and earlier completion of the rehabilitation process [33–35]. Nevertheless, this has never been scientifically proven in cartilage defect patients (CDP) although the concept of "prehabilitation" would appear additionally attractive to ACI patients profiting from the cell cultivation time.

The aim of this article is, therefore, to review and to present the available literature on prehabilitation concepts. We further want to describe a prehabilitation regimen for CRS patients based on the best evidence available. This prehabilitation regimen was recently worked out in our department and we have found it to be feasible in over 50 CRS patients as all of the patients showed good compliance and were able to perform the protocol as suggested. None of the patients had to interrupt prehabilitation due to increased pain or swelling. Obviously, further research is mandatory to quantify its clinical effect and to demonstrate its cost-effectiveness and benefits in surgically treated patients.

Scientific evidence

Effect of prehabilitation prior to knee arthroplasty

The concept of prehabilitation has been induced in patients awaiting various surgical procedures, including those with osteoarthritis (OA). Factors that prehabilitation programs may positively influence include muscle strength, pain, aerobic capacity, general health, patients' satisfaction, perioperative complications, duration of hospital stay, as well as the outcome of surgery including the survival of patients and implants. An actual systematic review including a meta-analysis on the effect of total-body prehabilitation on postoperative outcomes provides early evidence that prehabilitation can reduce the length of stay and may yield postoperative physical benefits [36]. The authors thereby emphasize the importance of whole body training including aerobic and strengthening exercises as well as core stability training, rather than merely focusing on improving local muscle strength.

The importance of total-body prehabilitation is supported by other studies declining positive effects of a pure strength training in knee OA patients regarding postoperative outcomes [37, 38]. In their systematic review, Ackerman and Bennell concluded that preoperative physiotherapy programs are ineffective in improving outcome after total knee replacement [37]. In another recent review, Gill showed that exercise-based interventions can reduce pain and improve physical function in people awaiting hip replacement surgery, but not knee replacement surgery [38]. Conversely, the latest Cochrane Review concluded that strength training can lead to a short-term improvement in muscle strength and functional capacities when done during times of low pain levels, the effect size being comparable to the effect of non-steroidal anti-inflammatory drugs [39]. Furthermore, McKay et al. examined the effect of a 6-week prehabilitation program on preoperative quadriceps strength in 22 patients undergoing total knee arthroplasty (TKA) [40]. The participants were randomized to either a lower body strength training program or a nonspecific upper body strength training program. Immediately before surgery, the intervention group exhibited clinically more substantial increases in quadriceps strength, walking speed, and mental health than the control group, although no significant treatment effects were apparent 12 weeks after surgery [40].

Topp et al. examined the effect of a preoperative exercise intervention on knee pain, functional ability and quadriceps strength among patients with knee osteoarthritis before and after TKA surgery [35]. Patients in the exercise intervention group improved their performance in three out of four functional tasks and had significantly better results in pain scales and quadriceps strength. The control group's performance improved in two of the four functional tasks: their pain decreased, their nonsurgical leg strength increased, and they exhibited greater leg strength asymmetry [35].

Effect of prehabilitation before other surgical knee interventions

Apart from the wide range of studies on ACL injured patients, there are only few reports on prehabilitation measures in surgical procedures of the knee. There is one study by Kean et al. investigating the effects of a 12-week preoperative high-intensity resistance training program for patients undergoing high tibial osteotomy [41]. The patients in the preoperative training group scored significantly higher in the KOOS subscales "sport", "recreation" and "activities of daily living" 6 months after surgery [41].

Nevertheless, the evidence from randomized controlled trials is still very limited. Most of the studies included either small numbers of patients or relatively short follow-up periods (median 3 months). Additionally, most of the studies do not provide an adequate description of the components of the prehabilitation program, the amount of loading, the frequency of the training sessions and the duration of the prehabilitation phase as well as patients' compliance. Where stated, the loads needed to induce central and peripheral adaptations improving muscle strength and neuromuscular control are not reached. Furthermore, the definitions of "prehabilitation" as well as the outcome measures are heterogeneous across studies. In summary, the evidence on prehabilitation prior to TKA and other knee surgeries is still inconclusive. Resistance training of the quadriceps and whole body training involving aerobic and strengthening exercises seem important to achieve positive effects.

Proposed prehabilitation protocol

Development of the program

Before developing an effective prehabilitation program, functional deficits associated with the disease of interest need to be evaluated and analysed. The main complaints of patients with focal cartilage lesions in the knee are linked to the main symptoms of these patients including unspecific knee pain and/or recurrent joint effusion [10, 42]. The latter is especially likely to cause range of motion (ROM) deficits and altered neuromuscular control [43]. Furthermore, patients with focal, full-thickness cartilage lesions have presented significant strength deficits in the quadriceps [13, 44]. Hence, the prehabilitation program should address the issues of "improving neuromuscular control", "improving muscular strength", "improving general fitness", "reducing joint effusion" and "respecting each patient's pain level".

General aspects

As mentioned before, preoperative quadriceps strength, neuromuscular control, and general fitness are considered the most important factors in the postoperative functional ability of patients with focal cartilage defects in the knee [26]. To increase muscular strength, strength training novices are required to participate in at least two, ideally three training sessions per week (ACSM guidelines) [41]. In trained intermediates or athletic populations, the number of training units should be raised to four to six per week. The minimum total time to achieve strength gain is 4–6 weeks, which induces an increase in maximum contractile muscle force mainly due to neuronal adaptations [45]. Structural changes in the muscle architecture including muscle fibre hypertrophy can be expected after 3 months [46].

In a classical approach, a single training unit should include free-weight lifting and machine exercises done in one to three sets per exercise (2–3 min rest between sets) at 60–70% of the individual one-repetition-maximum (1

RM) in untrained subjects, whereas loading at 70–100% of 1 RM is advisable for those in advanced training condition [47]. Concentric, eccentric, and isometric muscle exercises should be combined to address all muscle contraction modes. Multiple-joint exercises should be preferred because of their functional relevance in activities of daily life [47]. Newer models prefer a mix of intensities within the training units [48, 49].

Sensorimotor and strength training

Sensorimotor training has been shown to enhance the rate of force development [50–52]. Adding sensorimotor training in strength training thus multiplies the effects of strengthening exercises, establishes the basis of postural stability and neuromuscular joint control, and encourages effective and energy-efficient kinesics' behaviour [51–53]. It is of particular interest in cartilage defect patients (CDP) because much less weight has to be put on the joint itself to attain a strengthening effect.

Resistance training in CDP should contain training elements addressing central adaptation processes as well as peripheral stimuli [13, 54]. Additionally, the ideal training program should include open kinetic chain exercises (OKC) and closed kinetic chain exercises (CKC) to stimulate hamstrings and quadriceps muscles and enhance intermuscular coordination. As the highest tibiofemoral compression forces have been measured in submaximal flexion in CKC exercises compared to submaximal extension in OKC exercises, those positions should be avoided in patients with tibiofemoral defects. Patellofemoral compression is maximized in full flexion in CKC and in mean extension in OKC [55]. As CKC exercises (e.g., squatting exercises) produce twice as much hamstring activity as OKC exercises (e.g., leg curl or leg press), quadriceps activation is greatest in submaximal flexion in CKC and submaximal extension in OKC. Andersen et al. observed the highest muscle activation of both quadriceps and hamstrings using leg curl exercises followed by leg press and squat [56]. It is important to consider that their subjects were beginners, whereas Escamilla's group measured trained weight lifters performing perfect squats [55]. This highlights the importance of the ideal execution of exercises, leading to the optimal utilization of muscle fibres [57]. In their review paper, Escamilla et al. describe the shear and compression forces in the knee joint as a function of joint angle in dynamic squatting. The deeper the flexion, the higher the patellofemoral and tibiofemoral shear and compression forces are. Squats are, therefore, recommended in a ROM of 0° to 50° knee flexion. Conversely, in healthy individuals deep squats are promoted to maximize muscle activation [55].

The proposed program

Warm-up

Aerobic exercise at 55–70% of the individual maximum heart rate over 20 min is proposed combining general warm-up with aerobic exercise. According to ACSM guidelines, cardiorespiratory fitness routines should be done three to five times per week with cyclic movements involving the big muscle groups (walking, running, cycling, cross-country skiing and aqua fitness) at 55–90% of the patient's maximum heart rate [58].

Sensorimotor exercises

As sensorimotor training (SMT) is mentally and physically highly demanding, SMT training was always conducted first. The exercises we chose include benches, side benches, squats, vertical jumps, single-leg toe touches and lateral jumps. The demands were successively increased adding wobbling boards or Airex® pads as well as jumps and lunges according to the subject's training progress.

The bench static Goal: Strengthen the core muscles to ensure body's stability in movements.

Starting position: lying on your stomach, supporting yourself on your forearms and feet.

During exercise: lift your upper body, pelvis and legs up until your body is in a straight line from head to foot. Your elbows are directly under your shoulders. Pull in your stomach and gluteal muscles. Hold this position for 20–30 s. Return to starting position, take a break of about 20 s and repeat the exercise.

Repetitions: two sets, 20–30 s each.

Progression after six training sessions to

The bench alternate legs Starting position: like bench static.

During exercise: lift your upper body, pelvis and legs up until your body is in a straight line from head to foot. Your elbows are directly under your shoulders. Pull in your stomach and gluteal muscles. Lift each leg in turn for 20–30 s. Return to starting position, take a break of about 20 s and repeat the exercise.

Repetitions: two sets, 20–30 s each.

Caution! Do not sway or arch your back. Do not raise your buttocks.

Sideways bench static Goal: To strengthen the lateral core muscles to ensure the body's stability in movements.

Starting position: lying on your side with the knee of your lowermost leg bent to 90° and supporting yourself on your forearm and lowermost leg.

During exercise: lift your pelvis and uppermost leg until they form a straight line with your shoulder and hold this position for 20–30 s. Your supporting arm's elbow is directly under your shoulder. Return to the starting position, take a break of about 20 s and repeat the exercise on the other side.

Repetitions: two sets 20–30 s each side.

Progression after six training sessions to

Sideways bench raise and lower hip Starting position: lying on your side with both legs straight and supporting yourself on your forearm.

During exercise: raise your pelvis and legs until your body forms a straight line from the uppermost shoulder to the uppermost foot. Now lower your hips to the ground and raise them back up again. Repeat for 20–30 s. Your supporting arm's elbow is directly under your shoulder. Change sides and repeat.

Repetitions: two sets 20–30 s each side.

Caution! Do not tilt your shoulders or pelvis forward or backward.

Single-leg toe touch Goal: To strengthen and stabilize the thigh and hip muscles.

Starting position: standing on one leg with a gentle bend in your knee. Your other leg is bent at 90° flexion in the knee and hip.

During exercise: bend forward and try to touch your toes on the standing leg with the contralateral hand. Pull your body back up to a standing position and repeat this for 15–20 s. Change sides and repeat.

Repetitions: two sets, 15–20 s each side.

Progression after six training sessions to

Single-leg toe touch adding an Airex® pad Do the exercise as before, but put an Airex® pad under the foot of your standing leg.

Caution! Do not let your knees buckle inwards.

Squats with toe raise Goal: To strengthen the hamstrings and calf muscles and improving movement control.

Starting position: stand with your feet apart at hip-width and put your hands on your hips.

During exercise: slowly bend your hips, knees, and ankles until your knees are flexed to 90° while leaning your upper body forward and keeping your back straight.

Then straighten your upper body, hips, and knees. When your knees are completely straight, stand on your toes and then slowly lower yourself down again, before straightening up more quickly. Repeat this for 20–30 s. Take a 20-s break and repeat.

Repetitions: two sets, 20–30 s.

Caution! Do not let your knees buckle inwards. When leaning your upper body forward, keep your back straight.

Progression after six training sessions to

Lunges Starting position: stand with both feet hip-width apart on the floor, with your hands on your hips.

During exercise: lunge forward slowly. As you lunge, bend your hips and knees slowly until your leading knee is flexed to 90°. The bent knee should not extend beyond the toes. Keep your upper body straight and your pelvis horizontal. Repeat this lunge for 15–20 s. Change sides and repeat.

Repetitions: two sets, 15–20 s.

Caution! Do not let your leading knee buckle inwards. Do not bend your upper body forward.

Vertical jumps.

Goal: Improving jumping power and movement control.

Starting position: stand with your feet hip-width apart with your hands on your hips.

During exercise: slowly bend at your hips, knees, and ankles until your knees are flexed to 90°. Lean your upper body forwards, keeping your back straight. Maintain this position for 1 s, then jump as high as you can. While you jump, straighten your whole body. Land softly on the balls of your feet with slight bend at hips and knees. Repeat these jumps for 20–30 s. Take a break of 30 s.

Repetitions: two sets, 20–30 s.

Caution! Do not let your knees buckle inwards. Do not land with extended knees.

Progression after six training sessions to

Side-to-side bounds Starting position: standing on one foot in half squat position, facing 90° from your direction of travel.

During exercise: allow your lead leg to do a countermovement inward as you shift your weight to the outside leg. Jump as quickly and energetically as possible. Land softly on the ball of your feet with slight bend at hip and knee. Lean your upper body forward, keeping your back straight throughout the exercise. Repeat the exercise for 20–30 s, then take a 30-s break.

Repetitions: two sets, 20–30 s.

Caution! Do not let your knee buckle inwards. Keep your upper stable and facing forward.

Strength training

Muscular strength is a key component that should be trained two to three times per week including exercises on leg press, leg curl, the nordic hamstring exercise and hip muscle exercise with pulley resistance [41]. After six training sessions the 1 RM should be verified again to determine load progression.

One-leg leg press (45° position) Goal: To strengthen the leg and hip muscles, especially m. quadriceps femoris and m. gluteus maximus.

Starting position: assume a stable sitting position on the leg press machine with your hands on the handles to fix your position. Put your right foot in a 1 o' clock position, or your left foot in 11 o'clock position. Start to press with 90° bent knee and hip.

During exercise: press the platform up with one leg to nearly full knee extension. Hold this contracted position for a second, then slowly return to the 90° knee bent position. Take a 2-min break. Repeat the exercise 8–12 times.

Repetitions: four sets, 8–12 repetitions with 70–80% of 1 RM, alternatively mix the intensities within the week [59].

Caution! Do not let the knee buckle inwards.

One-leg leg curl: leg extension Goal: To strengthen the m. quadriceps.

Starting position: assume a stable sitting position with your legs under the pad, foot pointed forward and hands holding the side bars. You need to adjust the pad so that it falls just above your ankle. Also make sure that your leg forms a 90° knee angle.

During exercise: press your lower leg against the foot-pad and extend your leg to the maximum as you exhale. Make sure that the rest of your body remains stationary on the seat. Pause for a second in the contracted position. Slowly lower your weight back to the original position as you inhale. Take a 2-min break. Repeat the exercise 8–12 times. If performing the exercise in full ROM is painful, ROM may be adapted to patient's complaints and the site of the cartilage defect.

Repetitions: two sets 8–12 repetitions with 70–80% of 1 RM.

One-leg leg curl: leg flexion Goal: To strengthen the hamstrings.

Starting position: take a stable sitting position. Place the back of lower leg on top of the padded lever just between the ankle and the calf. Secure the lap pad against your thigh, just above the knee. Then grasp the side handles on the machine and ensure that your leg is completely straight right in front of you.

During exercise: as you exhale, pull the machine lever as far as possible to the back of your thigh by flexing the knee. Ensure that the rest of your body remains stationary on the seat. Maintain this contracted position for a second. Slowly return to the starting position as you inhale. Take a 2-min break. Repeat the exercise 8–12 times.

Repetitions: two sets 8–12 repetitions with 70–80% of 1 RM.

Nordic hamstrings Goal: To strengthen the rear thigh muscles.

Starting position: kneeling on a soft surface with knees hip-width apart and crossing your arms across your chest. Your partner kneels behind you and with both hands grips your legs just above the ankles while pushing them with his body weight to the ground.

During exercise: your body should be completely straight from your head to your knees. Slowly lean forward, trying to keep that position with your hamstrings. When you can no longer maintain that position, gently put your weight on your hands, falling into a press-up position. Take a 30-s break. Repeat this exercise five times.

Repetitions: five times for as long as possible.

Caution! Do not bend at your hips.

Comment: this is a demanding exercise that should only be induced when the knee joint is no longer irritated.

Hip muscle exercise with pulley resistance Goal: To strengthen the hip abductor muscles.

Starting position: stand tall with one shoulder next to the cable machine and your legs shoulder-width apart. An ankle attachment should be placed around the ankle far from the cable machine. Place your hands on your hips.

During exercise: raise the weighted leg out laterally as high as possible. Pause and then reverse the motion back to starting position. Repeat the exercise 8–12 times.

Repetitions: two sets 8–12 repetitions with 70–80% of 1 RM.

Caution! Avoid leaning from one side to the other during the movement. Keep your upper body centred the entire time.

All exercises are displayed in Figs. 1, 2, 3, 4, 5, 6, 7, 8, 9, 10, 11, 12, 13, 14, 15 and 16 in "Appendix".

Discussion

The aim of our research was to develop and propose a standardized prehabilitation regimen based on the best available evidence for patients with full thickness cartilage defects of the knee joint awaiting cartilage regenerative surgery. We, therefore, searched the available literature systematically and derived the training program described above. The selection of the exercises was made to address all relevant aspects for focal cartilage defect patients, suggested in the literature. As a matter of cause, they are not unalterable and may be modified by similar or additional exercises. Avoidance of subjective pain levels exciding 3/10 on a visual analogue scale should always be respected.

The important aspect of the suggested program is the fact that all components needed for perfect leg axis stabilization are addressed. As the demanding program was successfully used in several CRS patients during the cell cultivation time we consider this program feasible. We are aware of the lack of scientific evidence, making some of our suggestions contestable. The key components of the program will be discussed in detail below.

Core stability

The trunk's stability and its effect on knee stability has been the subject of numerous investigations, especially when preventive measures for athletes at an increased risk for knee injuries are involved. There is evidence that weak trunk musculature and poor core stability are predictors of injuries to the lower extremities [60–63]. We, therefore, believe that core stability exercises must be integrated in a sensorimotor or neuromuscular-oriented training program for the lower extremities.

Strengthening the hip abductors

Hip abductor weakness appears to be associated with an increased knee valgus leading to pathologic knee moments [25]. Additionally, patients with knee OA present significantly weakened hip abductors, leading to the recommendation of including hip abductor training in structured rehabilitation programs [27].

Plyometrics and dynamic stabilization

Several working groups have been investigating the quantification of the load on human cartilage via high-resolution magnetic resonance technology (MRT). In their review in 2006, Eckstein, Hudelmaier und Putz concluded that human cartilage is only mildly deformed by physical activity, and that it recovers within 90 min after the load [64]. It is the tissue's biomechanical composition that determines the degree to which cartilage is deformed. The stiffer it is, the less it can be deformed. Femoral cartilage is much stiffer than tibial cartilage, meaning that the loss of thickness is primarily restricted to the tibia's joint surface. Dynamic loads involving more extensive knee-joint movements (e.g., cycling, running up and down stairs, doing knee-bends) lead to a greater loss of volume in the knee joint than do static loads. However, the loss of thickness is greater in conjunction with static loads (eg, static squats). It is assumed that the greatest deformation is associated with reactive loads (like when jumping), but one must remember that cartilage is 80–90% fluid that has little occasion to deform during reactive loads and, therefore, probably hinders the deformation of solid cartilaginous elements.

There is to date no data on cartilage deformation in patients with focal cartilage defects but we do know that injured cartilage in general loses its rigidity. Eckstein et al. [64, 65], Myer et al. [66] and Nagano et al. [67] have demonstrated that plyometrics and balance training can lead to reduced knee valgus stress. Their study results led them to conclude that specialized training for patients with isolated cartilage damage is most suitable when the load is dynamic and involves a larger range of movement. Plyometric or reactive exercises can be incorporated requesting the duration of the load to be brief—above all to enable the fluid parts of the cartilage matrix to participate in the load. If the exact location of the cartilage damage is known, the exercises can be limited to an appropriate joint angle. Several publications also showed that the correct execution of the exercises is mandatory [68, 69]. This may be trained in preoperative setting.

Another key element of "prehabilitation" is to physically and mentally prepare the patients on the postoperative follow-up period. There is evidence that exercise programs are more likely to succeed in patients who have a positive view of the suggested program, so this program should be explained in detail and anticipated results should be defined together with the patient [31]. Greater exercise adherence is reported to be an important factor in the effectiveness of exercise programs and in better pain, physical function and self-perceived effects [30, 70, 71]. Therefore an optimal patient management is necessary to ensure effective patient education in order to maximize compliance with the rehabilitation program.

Practical applications

Many studies have shown that consistent rehabilitation programs, especially those involving cartilage regenerative interventions, play an extremely important role in the success of surgery, particularly in supporting the intervention and not undermining it. We believe that prehabilitation can contribute to reducing anxiousness about the intervention, as the patient is already familiar with and has practiced the exercises that he or she will be expected to do during rehabilitation after surgery. We could expect to observe both physiological and psychological effects from such a program. It will be the goal of subsequent investigations to quantify such effects and to observe the effects on long-term outcomes.

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Compliance with ethical standards

Conflict of interest The authors declare that they have no conflict of interest.

Ethical approval This article does not contain any studies with human participants or animals performed by any of the authors.

Appendix: Prehabilitation program

Warm up

See Figs. 1 and 2.

Fig. 1 Stationary bike

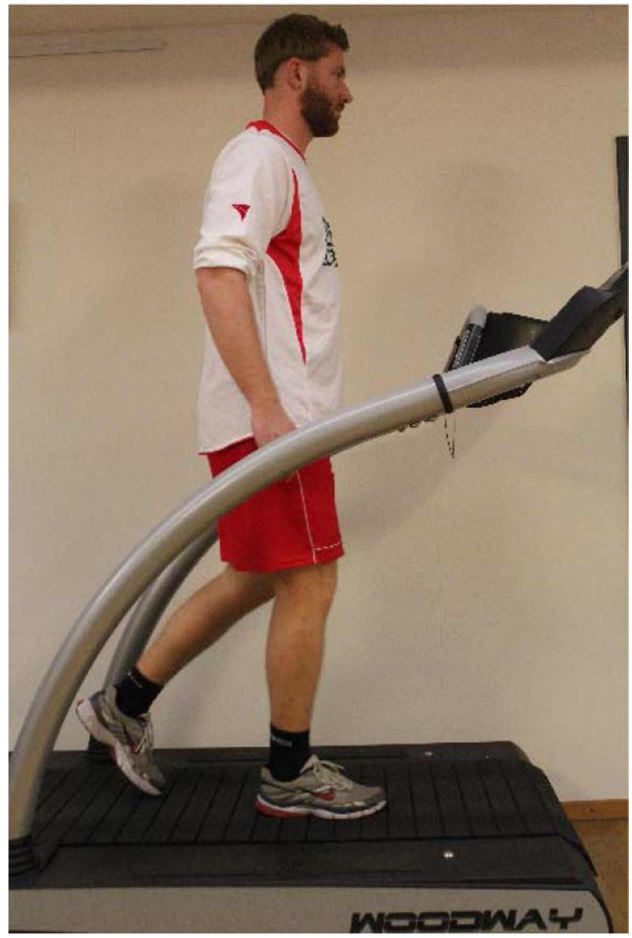

Fig. 2 Treadmill

Sensorimotor exercises

See Figs. 3, 4, 5, 6, 7, 8, 9, 10 and 11.

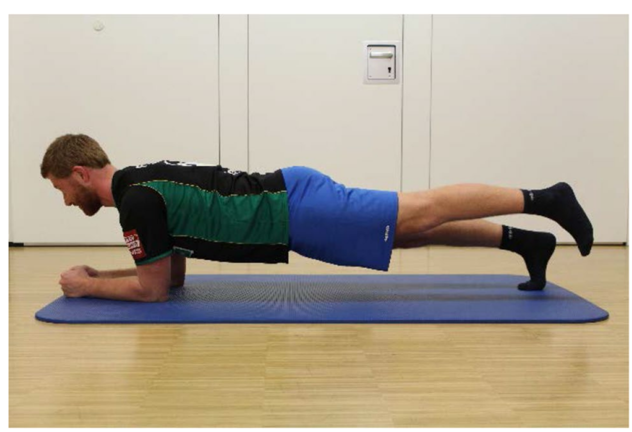

Fig. 3 Bench alternate legs

Fig. 4 Sideway bench static

Fig. 6 Single-leg toe touch adding an Airex® pad

Fig. 5 Single-leg toe touch

Fig. 7 Squats

Fig. 8 Squats with toe raise

Fig. 9 Lunges

Fig. 10 Vertical jumps

Fig. 11 Side to side-bounds

Strength training

See Figs. 12, 13, 14, 15 and 16

Fig. 12 One-leg leg press (45° position)

Fig. 13 One-leg leg curl: leg extension

Fig. 14 One-leg leg curl: leg flexion

Fig. 15 Nordic hamstrings

Fig. 16 Hip abduction with pulley resistance

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