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Clinical Viewpoint

The Evolution of Rehabilitation and Return to Sport Following Cartilage Surgery

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Rehabilitation after knee cartilage repair or restoration can be a challenging and nuanced process. Historically, conservative rehabilitation protocols have been characterized by limited weightbearing and restricted range of motion (ROM) were created to primarily protect the repaired cartilage but did little for progression into higher level activity. Recent literature has supported accelerated protocols in a variety of cartilage procedures ranging from osteochondral allograft (OCA) Osteochondral autograft surgery (OATS) to matrix-based scaffolding procedures such as Matrix Induced Chondrocyte Implantation (MACI) or Denovo procedures. Advances in technology such as blood flow restriction (BFR) and testing equipment with progressive rehabilitation from the acute phase through the return to sport continuum have made it possible to return to a higher level of activity and performance than first thought of for these procedures. This clinical viewpoint discusses the evolution of knee cartilage rehabilitation characterized by early but progressive weightbearing and early ROM while maintaining early homeostasis in the knee, and then its progression to return to sport and performance in the higher-level athlete.

Level of evidence

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No matter the location of the country, or the specialty of the clinic, the ever-looming diagnosis of knee osteoarthritis cannot help to rear its ugly head. These ailments start as a minor cartilage delamination but can evolve into a bone on bone arthritis which at times can tri-compartmentalize and lead to knee replacement at some time in the patient's lifespan. In the past 2-3 decades we have not only seen an aging overall social population, but also degenerative cartilage injuries that have developed via sports injuries and more vigorous exercise programs. With this, the incidence of cartilage injuries has increased tremendously and now in the younger population has necessitated advanced rehabilitation protocols and testing to return a person to their optimal level of sport. One of the first osteoarticular transplants was described as being done as early as 1925,[1] and one of the first osteochondral allografts was performed in the early 70's. Since then, surgical techniques, the use of biologics and the evolution of rehabilitation as a whole has contributed to the growth and success of this surgery. The evolution of rehab after cartilage surgery is multifaceted because surgery has evolved from mainly microfracture surgeries to now advanced osteochondral auto/allografts, and Autologous Chondrocyte Implantation (ACI) surgeries. The nuances of rehabilitation in this field can be very descriptive and extensive, but this viewpoint will discuss the evolution of rehabilitation and how changes have helped the success of this surgery and patient population, specifically range of motion changes, weight bearing progression, usage of bracing, blood flow restriction training, and advanced return to sport testing.

RANGE OF MOTION

In the context of an osteochondral allograft or autograft, traditionally range of motion has not been particularly restricted in this patient population. Some restrictions in the

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first 2 weeks post operatively were utilized at the onset of cartilage surgery, and some surgeons seem to follow similar restrictions today. The premise of motion restriction has changed throughout the decades though. At first it may have been believed that forced passive range of motion would hinder overall healing of a fragile donor graft, but as surgical technique and rehabilitation has evolved the restrictions are mostly in place as to not aggressively push flexion in the knee and cause more effusion in an already compromised knee complex. After 2 weeks most guidelines will permit ROM as tolerated, with an effort to achieve > 120 degrees of flexion by 6 weeks post-op. A difference would only be seen in a ACI or Matrix-Induced Autologous Chondrocyte Implantation (MACI) procedure in which the consensus is to start at 45 deg flexion and increase 15 degrees each week, achieving 90 degrees by week 4. After that period, progressing ROM as tolerated with the goal of reaching full motion by weeks 7 to 9.

The usage of a continuous passive motion (CPM) machine, in today's rehab setting has varied usage. In the past it was thought that this was the best way for the newly introduced cartilage graft to gain nutrition since weight bearing was limited. As time evolved, we have seen that this joint nutrition is better achieved through gradual weight bearing, which will be discussed later. Some surgical protocols still involve the use of CPM for the first 6 weeks,[2] but in this authors opinion with proper guided physical therapy in this first 6 weeks motion can easily be maintained and progressed with edema control, gentle progressive PROM and stretching, and when achievable, stationary bike to help promote motion.

WEIGHTBEARING PROGRESSION

The evolution of weight bearing with cartilage procedures has changed most markedly over the last three decades. In the procedure's infancy, patients were mainly non-weight bearing for several reasons, primarily fearing damage to the new fragile graft despite the lesion's location. As time has evolved, weightbearing progressions have trended towards more permissive progression but can be highly individualized by a number of factors including lesion location, size, surgical procedure, graft type and surgeon preference. We have seen those lesions along the patella (since it is not a weight bearing surface), can have immediate partial weight bearing and become weight bearing as tolerated in as little as 2 weeks. Some procedures such as an ACI or MACI procedure still follow a graded weight bearing progression for tibial femoral grafts to aid with integration and maturation of the implanted cartilage, as the newly implanted membrane incorporates into the knee. For example, a MACI procedure to the weightbearing surface of the lateral femoral condyle may initially start with toe-touch weightbearing (TTWB) (for approximately 2 weeks) and gradually progress to weightbearing as tolerated (WBAT) by 6 weeks post-operatively. However, for osteochondral allografts and autografts limited weight bearing in the initial stages has been challenged. As the understanding of the biology and biomechanics of cartilage have advanced, so have the notions that non-weightbearing in the initial stages help overall graft healing. As mentioned before the usage of the CPM machine was used so that nutrients of the synovial fluid would be expressed into the newly placed cartilage and promote healing. Now we see that weight bearing promotes the nutrients from the synovial fluid into the cartilage matrix, stimulating an anabolic chondrocyte response.[3-6]

That said, there is still a lack of consensus on the optimal post-operative weight bearing regimen after an allograft or autograft surgery. Kane et. al in 2017 in a retrospective study described the trends present in weight bearing post-surgery, and most surgeons were still demonstrating restrictive initial weight bearing but progressing to full weight bearing by 6 weeks post op.[3] Recent studies have also shown that a surgeon's experience in the procedure may influence their permissiveness in post operative guidelines, which includes weight bearing progression.[4] With all of this in mind cautious progression with weight bearing should be utilized throughout the rehab process in order to decrease rates of recurrent pain and/or joint effusion. Being too aggressive has be shown to overtax the healing cartilage and result in proteoglycan loss and a deterioration of mechanical properties. It is imperative that the rehab professional not only follow the surgical guidelines but can understand and recognize the signs of overload that can lead to increased inflammation and delayed overall healing.

BRACING AFTER SURGERY

The age-old question of to brace or not to brace after surgery will continue to be asked throughout generations of rehabilitation. The construct, extent of surgery, and limited knowledge of cartilage healing made the notion of bracing after surgery a non-negotiable factor as to not damage an implanted graft early on. Limiting overall motion by the patient was one of the safeguards used to ensure that the newly implanted cartilage would heal. As time has gone on there are two things that have happened. First, we see that implanted cartilage grafts are much heartier and heal better than first thought. There is a robust mechanical fixation of the graft during surgery, leading to a stable construct after an initial period of bracing to avoid excessive shearing forces and graft damage.[7] Bordes et al., showed in an analysis of 969 patients post ACL reconstruction there was no difference in the frequency or severity of complications between three groups with different bracing protocols including a rigid-knee brace, hinged knee brace, and no brace at all. Furthermore, the group with no brace had lower rates of early post-operative stiffness. After this initial period, brace discharge is allowed if the patient demonstrates adequate quadricep control.[8] It has been our experience that prolonged brace usage leads to more quadriceps inhibiition, in the early stages of rehabilitation. It should be noted that discharge from bracing should be a collaboration between the surgical and rehabilitation team so as to make sure that both parties are satisfied with overall protection and quadriceps activation respectively. A mainstay of cartilage rehab is to engage the quadricep musculature in order to support the healing knee complex. Chronic degen-

eration of the knee joint can lead to a progressive strength loss in patients secondary to pain and the inability to gain strength due to it. Excessive bracing can lead to a quad avoidance gait pattern and in turn weakness in the complex. Ligamentous laxity in this patient population is not the problem, so once proper quad activation is obtained a cessation of brace usage is necessary to progress strength in the quadriceps musculature and avoid further disuse. In this author's experience for most patients, this is seen as about 2-3 weeks after surgery.[9] Again, it is the job of the rehab professional to use a criteria-based progression (minimal effusion, full knee extension, quadriceps control) to make a decision, and not base the decision merely on time.

BLOOD FLOW RESTRICTION TRAINING

As mentioned before chronic knee pain and degenerative cartilage can inhibit a person from fully participating in strength training secondary to pain with higher intensity strength training. This effect flows over into post-surgical rehabilitation, because although the cause of the pain and dysfunction (the inherent cartilage lesion) is corrected, the patient still has limited overall weight bearing in the initial phases, joint effusion, and still the inability to push higher loads. The adjunct of blood flow restriction (BFR) in this population has shown tremendous effects by improving overall quadricep atrophy and strength utilizing low external loads, 20-30% of 1 rep max.[10,11] Research in this patient population is not heavily documented, but it is well documented in patients with osteoarthritis, patellofemoral pain and inpatient military personnel.[12-16] The usage of BFR in the ACL population has also been better researched and used to date, with evidence indicating the ability to improve overall quadriceps activation and strength along with decreasing joint effusion and pain.[17] The overall effect of exercise in populations with musculoskeletal conditions in general, especially knee conditions, can be attenuated in the presence of pain[18] due to a detrimental effect on motor control and muscle function[19] and can lead to compensations and modified movement patterns. The implementation of BFR in this population can help decrease overall joint inflammation, modulate overall pain, and help with muscle hypertrophy in a joint with limited loading capacity. As the rehabilitation process progresses BFR can continue to be used so as to not overload the joint with progressive training but by continuing to make strength gains. Implementing this technology not only at the beginning, but throughout the rehab process will help progress the strength of the quadriceps and help the patient progressively load the knee joint. Proper load of the joint throughout the rehab process will prevent overloading during the performance stage and prevent joint effusion and pain in the late phases of rehabilitation and return to sport.

RETURN TO SPORT AND TESTING

As the 21st century has evolved so has the active population in the world. In decades past it was seen that an aging population decreased their overall exercise regimen and became more sedentary or participated in exercise programs that were easier and less taxing for the most part. In today's world it is not uncommon to see the aging population still participating in higher level activities. Cartilage surgery in its early stages was a "salvage" surgery, that was meant to decrease a patient's pain so that normal functional activities could be performed. Fast forward to 2023, and we see that due to the heartiness of the implants and constructs it is possible to progress to high level activities. Balasz et al demonstrated that in a cohort of high-level basketball players, 80 percent returned to their previous level of competition.[20] In a systematic review of return to sport after surgical management of cartilage lesions in the knee, Krych et al., demonstrated cartilage restoration surgery had a 76 % return to sport at mid-term follow-up. Of the surgical techniques included, osteochondral autograft transplantation (OAT) offered the fastest time to return to sport time (mean = 5.2 ± 1.8 months) with the highest rates of return to sport (93%). Osteochondral allograft transplantation and ACI took longer to return to sport (9.6 ± 3.0 months for OCA and 11.8 ± 3.8 months for ACI) but also resulted in high RTS rates (88% and 82%, respectively.). Microfracture took a longer time to return to sport (9 mos on average), but also yielded the lowest overall return to sport rate (58%).[21] This may be a factor of why the choice of microfracture for the higher level athletes and activity has evolved into using a more viable and durable osteochondral autograft. This along with the fact that the fibrocartilage clot formed after a microfracture surgery has a limited overall shelf life and viability for higher level loads and athletic activity causing a higher failure rate in this population.[22-26] If this patient population is going to return to high level sport and performance it is necessary to make sure that qualitative along with quantitative measures are reached to make sure that they not only return safely but at a high level if needed.[27] Serial strength testing throughout the rehabilitation process using handheld or fixed dynamometers or isokinetic testing is needed to make sure that optimal quadricep and lower extremity strength is attained so that the joint is not overloaded. Isometric strength assessments with force plates and fixed dynamometers can allow the clinician to look beyond peak force and look at force/time derivatives such as rate of force development (RFD) over various time epochs ($RFD_{100,}$ $RFD_{150,}$ etc.) Deficits in RFD have been shown to persist past the resolution of peak isometric strength. In a cohort of 45 male professional soccer players deficits in RFD remained 6 months post ACLR despite full recovery of maximum voluntary isometric contraction (MVIC) on an isometric leg press test.[28] Historically, hop testing has been used as a measure of lower extremity power in RTS testing after knee injuries. Recent work by Kotsifaki et al., demonstrated that looking at the propulsive phase of hop testing does a poor job of evaluating knee and quadriceps function.[29,30] This is problematic as hop distance is reported as the primary measure for LE power in several studies.[31] Performance metrics such as jump height in a single leg vertical jump can be used to better assess vertical lower extremity power output and overall knee function.[30,32,33] Reactive strength ability during drop

vertical jump tests (DVJ) and single leg drop vertical jump tests (SL DVJ) can be assessed with force plates, contact mats, and cell phone applications.[29-37] Technological advancements such as dual force plate technologies can permit even more in-depth analysis of phase specific asymmetries that is beyond the scope of this commentary.[38,39] Finally looking at movement characteristics is important in this patient population since faulty movement patterns have been engrained in this population to compensate for pain that was present. Individuals will often use a hip/trunk strategy with functional movement patterns to avoid large knee extension moments and mask residual strength and power deficits.[40-42] Movement screening can be implemented in any clinic situation because it can be as easy as using a simple video capture to a more complex motion capture system. The main point is that if patients can now return to higher-level activity and sport, it is not just the surgeon's responsibility to make sure that a technically sound surgery is performed and that biological healing as taken place, but the rehab professional's job to test in a quantitative and qualitative aspect to make sure they are ready to reach such high level demands.

SUMMARY

The evolution of cartilage surgery has made great strides in the past 3 decades with surgical advances that have made it possible to return to an elevated level of activity and sport. Cartilage implants have proved to be sturdier and have shown much more durability than when they were first introduced. However, although documented here, rehabilitation guidelines seem to have evolved a bit slower than the actual surgery. With the aging population becoming more active it is essential that we continue to progress with rehabilitation guidelines in a safe manner, but also keeping in mind that protocols should also be adjusted as techniques have become more refined and implants becoming more robust. With many surgeons there is still a fear factor in trying to progress weight bearing a bit faster or not prescribing a CPM machine after surgery. This may be because they all may not fully trust in the rehabilitation professional in progressing patients properly, and hence still the rigid protocols in place. Progression of weight bearing and ROM, along with inclusion of advanced strengthening techniques can help evolve rehab even further than where it is presently. In the authors opinion the realm or cartilage rehabilitation continues to be an evolving artform which should continue to be advanced in the coming years. Surgical research continues to evolve with cartilage, but further research in the rehabilitation and return to performance realm must be initiated by the rehabilitation community to further progress protocols and rehab for the higher-level population which will be getting these procedures in the future.

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