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## Original Article

## Timing of postoperative weightbearing in the treatment of traumatic chondral injuries of the knee in athletes - A systematic review of current concepts in clinical practice

Sarah Rolf<sup>a,\*</sup>, Cheuk-Kin Kwan<sup>b</sup>, Martin Stoddart<sup>c</sup>, Yan Li<sup>a</sup>, Sai-Chuen Fu<sup>b</sup><sup>a</sup> The Division of Orthopedics and Biotechnology, CLINTEC, Karolinska Institutet, Sweden<sup>b</sup> Department of Orthopedics and Traumatology, Prince of Wales Hospital, CUHK, Hong Kong<sup>c</sup> AO Foundation, Davos, Switzerland

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## ABSTRACT

**Background:** Surgery aims to stimulate healing and enable a safe return to sport in athletes with symptomatic cartilage lesions of the knee. Timing of postoperative weightbearing is crucial, balancing a stimulation of the healing and avoiding reinjury.

To explore current concepts of timing to partial and full weightbearing and rate of return to sport in athletes after articular cartilage surgery of the knee.

Systematic Review of studies with level of evidence I-III

**Methods:** Four databases (Pubmed, Web of Science, Scopus and Embase) were searched using a pre-determined keyword strategy. Two independent reviewers screened results according to inclusion and exclusion criteria. Modified Coleman Methodology Score (mCMS) was used for the quality assessment.

**Results:** 5294 records were found. Data from ten studies was extracted after duplicate removal, title and abstract screening and full-text evaluation. Eight of the ten studies included a detailed rehabilitation protocol, including 336 out of a total athletic population of 401. 62% began partial weightbearing (PWB) 1–2 weeks postoperatively, while 38% began within 3–4 weeks. The studies that had a later PWB all returned to full weightbearing (FWB) within 6–8 weeks. One study with early PWB returned to early FWB, while the other two returned 10–12 weeks postoperatively. “Return to Sport” (RTS) was the most common reported outcome measure, with most studies reporting RTS at 80% or higher.

**Conclusion:** There is no clear evidence that the timing of weightbearing (WB) affects the outcome and return to sport in athletes after surgery for focal full-thickness cartilage lesions of the knee. On the other hand, there seems to be no adverse effects in adopting an early WB strategy, currently defined differently by different authors. Further studies directly comparing the timing of WB for specific surgical procedures in athletes and with relevant control groups is recommended. There is a need for a consensus in regard to more exactly defining “early” vs “late” weightbearing in relation to a universal and precisely defined state of healing.

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## 1. Introduction

Full-thickness chondral defects due to traumatic injuries in the knee are more common among athletes than the general

population, with an overall prevalence of 36%–63%.<sup>1,2</sup> Due to the limited regeneration potential of the articular cartilage, chondral defects that are left untreated heal poorly and can progress to osteoarthritis.<sup>3</sup> For athletes, traumatic chondral injuries can be debilitating and often require surgical interventions. These surgical procedures can either be aimed at *repairing* the cartilage tissue through microfracture (MF), subchondral drilling and abrasion arthroplasty or at *restoring* it through matrix-induced autologous/autologous chondrocyte implantation (MACI/ACI), osteochondral autograft transplantation/mosaicplasty (OAT) or osteochondral

\* Corresponding author. The Division of Orthopedics and Biotechnology, CLINTEC, Karolinska Institutet, Karolinska Universitetssjukhuset, Huddinge, K54, Stockholm, 141 86, Sweden.

E-mail addresses: [sarah.rolf@stud.ki.se](mailto:sarah.rolf@stud.ki.se) (S. Rolf), [kwanck-eric@hotmail.com](mailto:kwanck-eric@hotmail.com) (C.-K. Kwan), [martin.stoddart@aofoundation.org](mailto:martin.stoddart@aofoundation.org) (M. Stoddart), [yan.li@ki.se](mailto:yan.li@ki.se) (Y. Li), [Bruma@cuhk.edu.hk](mailto:Bruma@cuhk.edu.hk) (S.-C. Fu).

allograft procedures (OCA).<sup>3–5</sup> Clinical, radiological and histological aspects, such as magnetic resonance imaging (MRI) and arthroscopy, are used to assess the success of the chosen procedure along with a variety of functional knee scores.<sup>3</sup> However, as highlighted by Riyami and Rolf,<sup>6</sup> MRI findings correlated well with the functional knee score in professional athletes, but none of these methods were reliable in confirming hard surface healing at the defect site as defined by arthroscopic probing.<sup>6</sup>

Specific rehabilitation protocols detail the steps needed to provide the best mechanical environment in the joint for the cartilage tissue to heal and the patient to return to their previous activity level.<sup>5</sup> These can vary depending on a variety of factors such as the patient's physical activity level prior to surgery, other predisposing factors such as age, comorbidities and employment, and of course the surgical method chosen.<sup>5,7–11</sup> Yet, compared with the extensive investigations in regard to the surgical interventions, scientific evidence on the postoperative rehabilitation is limited. One systematic review that examined the rehabilitation protocols after MACI procedures in the knee found that 13/22 papers lacked or insufficiently reported postoperative rehabilitation protocols.<sup>12</sup> Postoperative rehabilitation is, however, of paramount importance for healing surgically treated traumatic chondral lesions. An improper accelerated weightbearing can lead to excessive stress on the surgical site, leading to inflammation, pain, and graft failure, while a delay in movement and weightbearing often leads to joint stiffness, muscle weakness and a delay in healing.<sup>7–10</sup> A systematic review found that patients can have gait deviations, muscle strength and functional deficits five to seven years after an ACI or microfracture operation.<sup>4</sup>

Time to partial and full weightbearing (PWB and FWB) as well as the return to sport rate are important landmarks in the postoperative rehabilitation of cartilage injuries. The type of force exerted on the knee is also important to consider during rehabilitation, such as compression, traction and pivoting forces as well as the timing and duration of the impact. On the one hand, it is vital not to overload the repair site too early after the surgical procedure to avoid graft failure, but on the other, it is also important that the site is activated during rehabilitation to encourage healing and restoration to normal structure and function.<sup>5,7–10,13</sup> It is currently recommended for patients to have a limited postoperative weightbearing of between four to twelve weeks, but an earlier time to weightbearing (WB) could have the potential to allow the patient to return to sport earlier.<sup>5,8,9</sup> Since all patients are unique and the variabilities can differ widely, it can be difficult to conduct a valid clinical study that looks at all these factors.<sup>5,7,10</sup> This systematic review examines the available literature regarding the time to partial and full weightbearing as well as the rate of return to sport for athletic patients that undergo articular cartilage surgery of the knee.

## 2. Aim

A systematic review was executed to explore postoperative timing to partial and full weightbearing and return to sport rate in athletes after articular cartilage surgery of the knee.

## 3. Methods

### 3.1. Search strategies

Four databases (Pubmed, Web of Science, Embase and Scopus) were systematically searched in September 2020 by two independent reviewers using a predetermined keyword strategy (See Appendix 1). The results of these searches were merged into Endnote, where the duplicates were removed. The remaining

records were screened by title and then by abstract independently by both reviewers in accordance to the predetermined inclusion/exclusion criteria. The reference lists of relevant systematic reviews and meta-analyses found in this search were also evaluated for records that matched the inclusion/exclusion criteria but had not been found in the database search. See the attached Preferred Reporting Items for Systematic Reviews and Meta-Analyses (PRISMA) statement (Fig. 1) for further details.

### 3.2. Inclusion and exclusion criteria

The inclusion criteria were research articles written in English that focused on human focal traumatic chondral lesions of the knee in athletes. Papers that focused on chondral lesions with knee comorbidities, such as ACL ruptures or meniscal tears, were animal or in-vitro studies or were abstracts, book chapters and reviews were excluded. To maintain a level of evidence of III for this systematic review, all records with a level of evidence of IV or below were excluded.

### 3.3. Data extraction and methodological quality

The data extraction table included information of the study characteristics such as the level of evidence and sample size. Demographic data of the athletic cohort such as age, sex, sport type and level were included. Surgical data such as lesion location and severity, type of surgery and follow-up time, as well as the rehabilitation protocol including time to partial and full weightbearing and outcome measures were extracted. Due to the heterogeneity of the outcome measures in the studies, the data from three of the most commonly used outcome measures were extracted: the International Knee Documentation Committee Score (IKDC), the rate and time to Return to Sport (RTS) and Previous Activity Level (PAL). The data extraction was conducted separately by the two independent reviewers, and then compared for differences. Any differences were settled via mutual agreement by all authors. Due to the heterogeneity of the data, meta-analysis of the data was not possible.

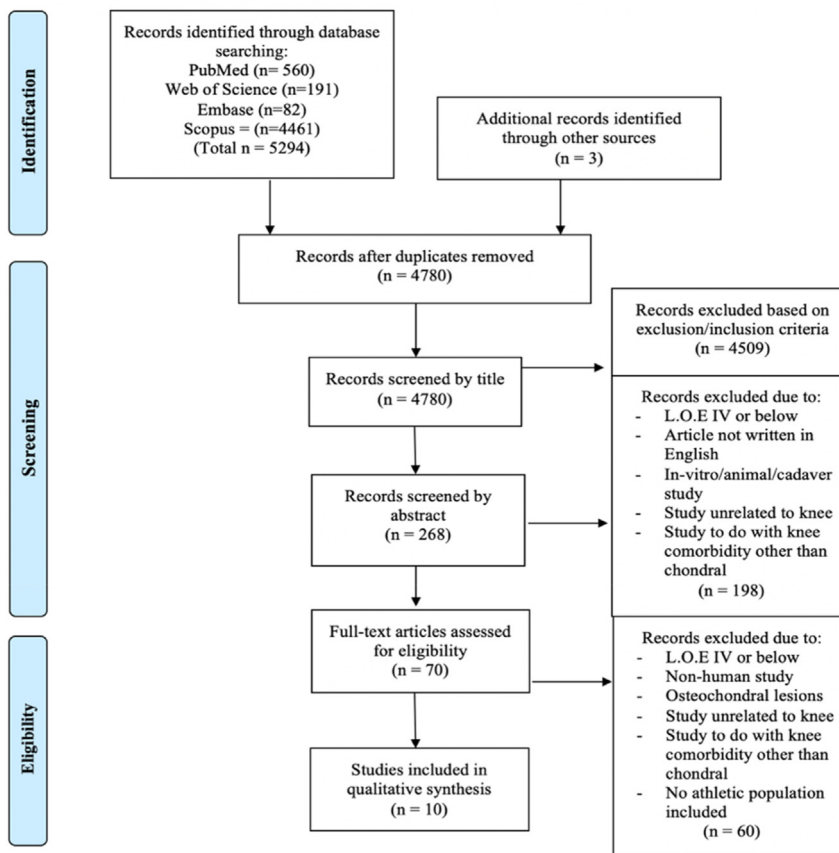
The Modified Coleman Methodology Score (mCMS) as adapted by Ramponi et al.<sup>14</sup> and used by Steinwachs et al.<sup>15</sup> was used for the quality assessment of the included studies and conducted by both reviewers independently, compared for differences and finalized after mutual agreement. Using a set list of criteria specified by mCMS, a score of 0–100 was assigned to each result, divided into scores of excellent (85–100), good (70–84), fair (55–69) and poor (<55).

## 4. Results

The search of the four chosen databases yielded a total of 5294 records using the keyword strategy (see Appendix 1). 4777 records remained after duplicate removal. After screening the records by title and abstract, 70 full-text articles were assessed for eligibility. A total of 10 articles were eligible for final analysis after meeting the inclusion criteria and level of evidence requirements. Three of the final records were not found in the keyword search of the databases but were added after reviewing the reference lists of other systematic reviews and meta-analyses within the same field.<sup>16–18</sup> (See Fig. 1).

### 4.1. Study characteristics

Three level I studies<sup>19–21</sup> were from the same research group, two randomized controlled trials of the same patient cohort and a ten-year follow-up of that cohort, and were therefore grouped



**Fig. 1. PRISMA Flow Diagram.** Shows the results of the database search and subsequent inclusion/exclusion of results. L.O.E: Level of Evidence.

together. The entire population cohort totaled 616, with 401 athletes included. The athletes were either competitive (within different sports) or recreational. Only three of the studies were done on a defined, homogenous sporting group, namely basketball in Harris et al.<sup>22</sup> and Namdari et al.<sup>18</sup> and soccer in Kon et al.<sup>23</sup> All the other cohorts included a mixture of different sports. The mean age of the athletic populations was 28.3 years with a standard deviation of  $\pm 4.8$ .<sup>16–25</sup> Four of the ten studies did not include a female population,<sup>16,18,22,23</sup> while 34–39% of the cohorts in the remaining studies were female.<sup>17,19–21,24,25</sup> (Table 1).

#### 4.2. Treatment

Half of the studies performed either ACI surgery or one of the later generations of ACI on their patient cohorts,<sup>16,17,23–25</sup> the other half used either MF or Osteochondral Autograft Transfer System (OATS).<sup>18–22</sup> All but two of the studies<sup>18,22</sup> specified a grade III or IV chondral lesion according to the International Cartilage Repair Society (ICRS), located on the femoral condyle, trochlea or patella. As seen in Table 1, there was a large variation in the chosen outcome measures between the different studies.

#### 4.3. Rehabilitation protocol

Table 2 shows that eight out of the ten studies, 336 out of the 401 athletes, presented a detailed rehabilitation protocol that specified both the time to partial weightbearing (PWB) and full weightbearing (FWB).<sup>16,17,19–21,23–25</sup> All studies used a pre-determined protocol, that is to say, no study aimed to compare the

potentially varying outcomes of using an early return to weight-bearing compared to that of a later return.

62% of the athlete population began PWB within 1–2 weeks postoperatively, while 38% began within 3–4 weeks. Della Villa et al.<sup>16</sup> and Ebert et al.<sup>24</sup> included further detail of the early weightbearing process; both studies gradually increased the weight used in the specified weightbearing exercises on a weekly basis, see Table 2 for more detail. All of the studies used Continuous Passive Motion, CPM, within 48hrs of the operation apart from the Gudas et al. studies that did not use CPM at all.<sup>19–21</sup>

Fig. 2 clearly demonstrates the lack of direct correlation between an earlier time to PWB and an earlier return to FWB. Of the three studies that had a time to PWB within 1–2 weeks, two of them had, in fact, the longest return to FWB; Ebert et al.<sup>24</sup> with 10 weeks and Kreuz et al.<sup>17</sup> with 12 weeks. Niethammer et al.<sup>25</sup> was the only study with both an early time to PWB and early return to FWB. The studies that had a later time to PWB,<sup>16,19–21,23</sup> all returned to FWB within 6–8 weeks.

#### 4.4. Return to sport/previous activity level

RTS rate, and to a certain extent, return to PAL rate, were the most common outcome measures used in all the studies. As seen in Table 3 and Fig. 3, nine out of the ten studies reported RTS, while PAL was reported in three. Gudas et al.<sup>19</sup> and Kon et al.<sup>23</sup> have two cohort groups each depending on the treatment choice and have reported this data separately, this is specified in Fig. 3 with the treatment choice next to the author's name. For the Gudas studies, the data from the 2012 study was used, as the data here was divided

**Table 1**  
Study characteristics and demographic data.

Authors	L.O.E.	Sample size	Athletes	Mean Age (SD)	Sport/Level Participated	Surgery	Postop. follow-up	Outcome Measures
Della Villa et al. <sup>16</sup> 2010	III	65	31	23.5 (5.7)	Competitive athletes	ACI	1y, 2y & 5y	Clinical assessment, IKDC, EQ-VAS, Tegner Score, The cartilage standard evaluation form/knee
Ebert et al. <sup>24</sup> 2019	III	97	97	36.8 (11.3)	Recreational athletes, level not defined	MACI	1y, 2y & 5y	KOOS, Satisfaction Questionnaire, Isokinetic Knee Strength evaluation
Gudas et al. <sup>19–21</sup> 2005, 2006 & 2012	I	57	57	24.6 (6.54), OAT 24.3 (6.8), MF 27.7 (4.73)	Competitive athletes, n = 23 Recreational athletes, n = 34	OAT or MF	6, 12, 24 & 36 mo	Clinical assessment, MRI, Modified HSS, ICRS
Harris et al. <sup>22</sup> 2013	III	82	41	27.7 (4.73)	Competitive athletes, basketball	MF	Up to 5y	RTS rate and performance
Kon et al. <sup>23</sup> 2011	II	41	41	26.5 (4.5), MF 23.7 (5.7), ACI 34.97 (8.07)	Competitive athletes, soccer	ACI, 2nd gen or MF	2y & 7.5y	IKDC, ICRS, Tegner Score, EQ-VAS and recovery time
Kreuz et al. <sup>17</sup> 2007	II	118	69	28.6	Competitive & recreational athletes	ACI	6, 18 & 36 mo	MRI, ICRS and Cincinnati Score, questionnaire
Namdari et al. <sup>18</sup> 2009	III	72	24	32.1	Competitive athletes, basketball	MF	N/A	RTS rate and performance
Niethammer et al. <sup>25</sup> 2020	III	84	41	32.1	Recreational athletes	MACI	1y, 2y, annually & up to mean 8y	Tegner Score, UCLA Activity Scale, IKDC subjective, VAS on movement, Lysholm Score

ACI: Autologous Chondrocyte Implantation, EQ-VAS: EuroQol Visual Analogue Scale, HSS: Hospital for Special Surgery Knee Score, ICRS: International Cartilage Repair Society Knee Score, IKDC: The International Knee Documentation Committee Score, KOOS: Knee Injury and Osteoarthritis Outcome Score, L.O.E: Level of Evidence, MACI: Matrix-Induced Autologous Chondrocyte Implantation, MF: Microfracture, MRI: Magnetic Resonance Imaging, OAT: Osteochondral Autograft Transfer System, RTS: Return to Sport, SD: Standard Deviation, UCLA: University of California and Los Angeles.

**Table 2**  
Rehabilitation protocols.

Authors & surgical procedures	Rehab prot.	Time to partial weightbearing (weeks from surgery)	Time to full weight-bearing (weeks from surgery)	Return to Sport (RTS)
Della Villa et al. <sup>16</sup> 2010. ACI	Yes	CPM 6–8hr/day from day 2. PW: 3–4 weeks Water running: Week 3 10–20% to Week 8 50% of bodyweight Gym exercises: Week 3 20% to Week 7–8 100% of bodyweight	7–8 weeks	41 weeks
Ebert et al. <sup>24</sup> 2019. MACI	Yes	CPM within 12–24hrs after surgery. PW: 1–2 weeks, <20% of bodyweight 3–4 weeks 30–40% 6–7 weeks 60–80%	10–12 weeks	52 weeks
Gudas et al. <sup>19–21</sup> 2005, 2006 & 2012. OAT or MF	Yes	No CPM PW: 4 weeks, 20 kg weightbearing	8 weeks	17–26 weeks
Harris et al. <sup>22</sup> 2013. MF	No	N/A	N/A	N/A
Kon et al. <sup>23</sup> 2011. ACI, 2nd gen or MF	Yes	CPM or self-assisted mobilization after Day 2. PW: 4 weeks	6–8 weeks	Individual clinical evaluation
Kreuz et al. <sup>17</sup> 2007. ACI	Yes	CPM 12hr after surgery, 6–8hr/day Crutch-assisted touchdown weightbearing for 6 weeks	12 weeks	Individual clinical evaluation. 4 months for no-contact/low-impact sport, 12–24 months full-contact sports
Namdari et al. <sup>18</sup> 2009. MF	No	N/A	N/A	N/A
Niethammer et al. <sup>25</sup> 2020. MACI	Yes	CPM after 24hrs bedrest. Femoral defects, partial load of 20 kg recommended for 6 weeks. Flexion limited for patellar defects, increased gradually over 6 weeks	6 weeks	Not defined

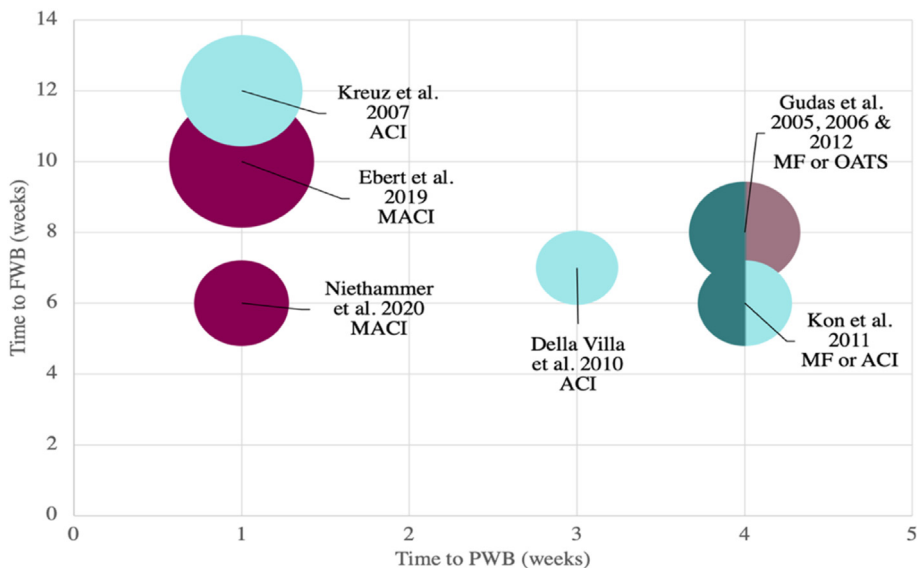
CPM = Continuous Passive Motion, OAT: Osteochondral Autograft Transfer System, MF: Microfracture, ACI: Autologous Chondrocyte Implantation, MACI: Matrix-Induced Autologous Chondrocyte Implantation.

into a further subgroup based on diagnosis (ACD).<sup>19</sup> There are therefore nine patient cohorts with RTS rate shown in Fig. 3.

In seven of the nine patient cohorts, RTS was 80% or over<sup>16,19,22–25</sup> (see Table 3 and Fig. 3). The highest percentage of RTS was 96.4% in the Niethammer et al. study for recreational athletes. Interestingly, in this cohort only 59.4% returned to PAL.<sup>25</sup> The lowest RTS rate (56%) was reported in the MF-ACD subgroup in the

Gudas et al., 2012 study.<sup>19</sup> Kreuz et al. was the one study that only reported return to PAL, not RTS, with 94% for a combined group of competitive and recreational athletes.<sup>17</sup>

Two studies with competitive athletes included data for the IKDC score. Della Villa et al. who reported an RTS of 80.6%, also recorded a doubling of the IKDC score after ACI from a mean pre-operative value of 44.4 to the one-year follow-up, 84.7.<sup>16</sup> The



**Fig. 2. Postoperative Weightbearing Versus Surgical Method.**

This figure shows the time to partial weightbearing (PWB) when plotted against full weightbearing (FWB) the surgical methods where this data was available (336/401 athletes). Each circle represents one patient cohort, the size of the circle corresponds with the size of the cohort and the colours are specific to the surgical procedure used, e.g. purple for MACI. The earliest time to PWB resp. FWB was used. For example, if the timeframe for PWB was 1–2 weeks in the protocol, 1 week was used as the time to PWB. ACI = Autologous Chondrocyte Implantation, MACI = Matrix-Induced Autologous Chondrocyte Implantation, MF = Microfracture, OATS = Osteochondral Autograft Transfer System. (For interpretation of the references to colour in this figure legend, the reader is referred to the Web version of this article.)

**Table 3**  
**Return to Sport (RTS), Return to Previous Activity Level (PAL) and IKDC score.**

Authors & surgical procedures	Sport/Level Participated	Return to Sport, RTS/Return to Previous Activity Level, PAL (%)	Average Time to Return to Sport (RTS)/ Previous Activity Level, PAL (SD)	IKDC (SD) (The International Knee Documentation Committee Score)
Della Villa et al. <sup>16</sup> 2010. ACI	Competitive athletes	80.6% <b>RTS</b>	RTS: 12.4 (1.6) months, Athlete	44.4 (2.9) <b>ACI, Preop</b> 84.7 (11.7) <b>ACI, 1y</b>
Ebert et al. <sup>24</sup> 2019. MACI	Recreational athletes	82.4% 1y <b>RTS</b> 85.9% 5y <b>RTS</b>	Not defined	N/A
Gudas et al. <sup>19–21</sup> 2005, 2006 & 2012. OAT or MF	Competitive athletes, n = 23 Recreational athletes, n = 34	<b>MF-ACD RTS</b> 56% (1y) 70% (3y) 50% (10y) <b>OAT-ACD RTS</b> 93% (1y) 100% (3y) 43% (10y)	RTS: 6.5 months, <b>MF</b> RTS: 6.5 months, <b>OAT</b>	N/A
Harris et al. <sup>22</sup> 2013. MF	Competitive athletes, basketball	83% <b>RTS</b> (71% RTS following season)	RTS: 9.20 (4.88) months (to next NBA game)	N/A
Kon et al. <sup>23</sup> 2011. ACI, 2nd gen or MF	Competitive athletes, soccer	80% <b>RTS</b> , 75% <b>PAL</b> , <b>MF</b> 86% <b>RTS</b> , 67% <b>PAL</b> , <b>ACI</b>	RTS: 8 months ( <b>MF</b> , before 1st game) RTS: 12.5 months ( <b>ACI</b> , before 1st game)	47.3 (8.5) <b>MF, Preop</b> 86.8 (9.7) <b>MF, 2y</b> 43.2 (13.7) <b>ACI, Preop</b> 90.5 (12.8) <b>ACI, 2y</b>
Kreuz et al. <sup>17</sup> 2007. ACI	Competitive & recreational athletes	94% <b>PAL</b>	PAL: 18 months	N/A
Namdari et al. <sup>18</sup> 2009. MF	Competitive athletes, basketball	67% <b>RTS</b> (58% RTS for >1 full season)	RTS: 6.3 months	N/A
Niethammer et al. <sup>25</sup> 2020. MACI	Recreational athletes	96.4% <b>RTS</b> 59.4% <b>PAL</b>	Not defined	69.4 (17.4) <b>MACI, Mean 8y</b>

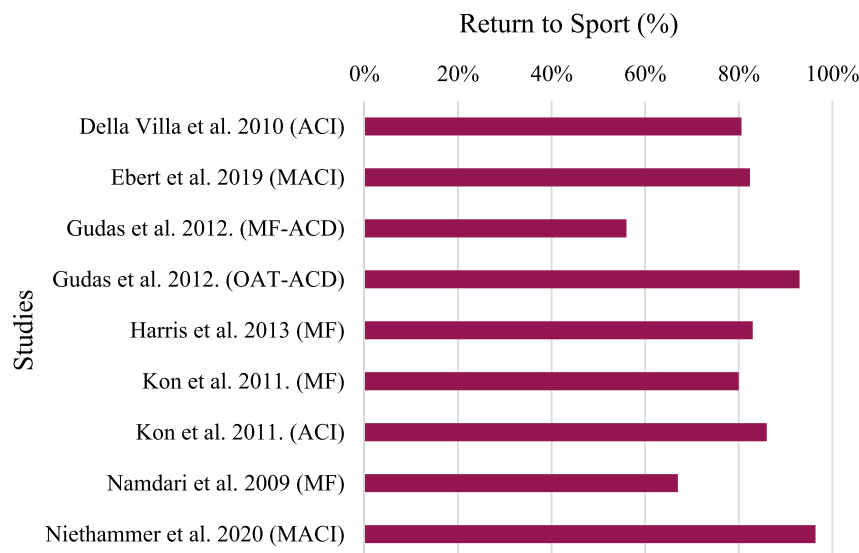
ACD = Articular Cartilage Defect, ACI = Autologous Chondrocyte Implantation, MACI = Matrix-Induced Autologous Chondrocyte Implantation, MF = Microfracture, OAT = Osteochondral Autograft Transfer System, Preop = Preoperative, SD = Standard Deviation.

corresponding figure for the ACI cohort of soccer players in the Kon et al. study (RTS 86%) was 43.2 preoperatively to 90.5 at the two-year follow-up. Kon et al. also demonstrated that the MF cohort (RTS 80%) similarly improved from 47.3 preoperatively to 86.8 at the two-year follow-up.<sup>23</sup> In regard to long-term follow-up, Niethammer et al. showed data at an average of 8 years postoperatively for recreational athletes with a mean IKDC score of 69.4.<sup>25</sup> The MRI findings at the ten-year follow-up by Gudas et al., 2012, showed that there were objective signs of osteoarthritis in 25% of their OATs cohort and 48% of their MF cohort.<sup>19</sup>

**4.5. Quality assessment**

Four out of the ten articles assessed using the mCMS scored “excellent”.<sup>17,19–21</sup> Three received a “good” score,<sup>23–25</sup> two received a score of “fair”<sup>16,22</sup> and one article received a “poor” score of 42 but was included because it studied a homogenous group of competitive basketball players and controls.<sup>18</sup> The average mCMS score ±SD was 77 ± 17.2, with the highest<sup>20</sup> score being 97 and the lowest<sup>18</sup> 42.





**Fig. 3. Proportion of Athletes Returning to Sport (RTS %).** 9/10 studies reported RTS %. Where applicable, data from different groups within studies have been included to elucidate potential differences in RTS %. ACD = Articular Cartilage Defect, ACI = Autologous Chondrocyte Implantation, MF = Microfracture, OAT = Osteochondral Autograft Transfer System.

## 5. Discussion

There is no clear evidence that the timing of WB affects the outcome and return to sport in athletes after surgery for focal full-thickness cartilage lesions of the knee. On the other hand, there seems to be no adverse effects in adopting an earlier weightbearing strategy, as defined differently by different authors. An interesting observation is the fact that only one of the three studies that had an early time to PWB also had an early return to FWB (Fig. 2).<sup>25</sup> The other two studies with early PWB, Kreuz et al.<sup>17</sup> and Ebert et al.,<sup>24</sup> had, in fact, the longest return to FWB out of all the studies.

Of the eight articles that included a detailed rehabilitation protocol, none evaluated per se whether an earlier time to PWB led to an earlier return to FWB and thereby possibly an earlier RTS in athletes. Instead, varying predetermined protocols and functional outcome scores were used to measure the success of the treatment and rehabilitation. So, despite the treatment for this type of injury being very common<sup>2</sup> and in use since the early 1990s,<sup>26,27</sup> the importance of balancing protected healing versus stimulating early weightbearing after surgery has not yet been systematically studied in athletes. It is also interesting to note that there is no correlation between the timing to weightbearing and a specific surgery type. For example, both Della Villa et al.<sup>16</sup> and Kreuz et al.<sup>17</sup> used ACI. The former allowed PWB at 3–4 weeks and FWB after 7 weeks,<sup>16</sup> while the latter allowed PWB from the first week and didn't allow FWB until 12 weeks.<sup>17</sup> The same can be said for the other surgical methods employed in the evaluated studies, despite principal differences in the surgical techniques.

A randomized controlled study by Ebert et al.<sup>28</sup> investigated the outcomes of a traditional versus accelerated postoperative rehabilitation protocol after MACI surgery in a non-athletic population. Both groups used CPM postoperatively, but the “accelerated” group progressively increased WB immediately after surgery while the “traditional group” had a 5-week period of “touch-toe” WB. FWB was allowed in the “accelerated” group after 8 weeks, while the traditional group returned to FWB at 11 weeks. After three months, the accelerated group had an improved function and reduced knee pain with no graft complications.<sup>28</sup> These results were maintained

at both two<sup>29</sup> and five<sup>30</sup> years after surgery. Kraeutler et al.<sup>31</sup> conducted a systematic review to evaluate randomized controlled trials of MACI procedures in the knee to see whether a delayed weightbearing was associated with improved outcomes. They compared patient groups that underwent a 6-, 8- or 10/11-week-long rehabilitation protocol to return to FWB and found there were no significant differences in failure rates between the groups in regard to when the patients returned to FWB.<sup>31</sup>

“Return to Sport” is a useful measure to gain an overall perspective on the proportion of athletes able to return to their sport. However, a return to sport after a “successful” operation, but at a lower activity level, may well be perceived as a failure by the athlete. The expectation of the athlete in any sport suffering this type of injury and requiring surgical treatment is to be able to return safely to a previous or higher activity level both in the short- and long-term. The short-term risk of a too early WB is reinjury and the need for further operations, while the long-term risk is a progression of the cartilage injury into osteoarthritis.<sup>7</sup>

This contradictory outcome was evident in the Niethammer et al. study from 2020, where RTS was 96.4% but return to PAL was only 59.4%. Niethammer et al. concluded that there was a shift from the high-impact sports to “less strenuous activities” post-operatively. Almost half of the recreational athletes in this cohort returned to sport but not at the same level or perhaps even the same type of sport as before their operation.<sup>25</sup> The professional athletes who per definition compete in high-impact sports do not have this option. The competitive soccer players who underwent ACI surgery in the prospective cohort study by Kon et al. had a similar outcome as that found in the Niethammer et al. study. In the Kon et al. study, 86% returned to sport but only 67% returned to their previous activity level. With a follow-up time of three-years, this outcome may be interpreted as permanent, implying that in 33.3% of the players, this injury was, in fact, career-threatening.<sup>23</sup>

Gudas et al.<sup>19–21</sup> treated both recreational and competitive athletes and had a follow-up time of 10 years. They showed that OATS had a superior RTS after one year with 93% compared to MF with 56%. At three years, OATS had a remarkable 100% RTS while MF had only 70% RTS in comparison. But by the ten-year follow-up,

only 43% of the OATs and 50% in the MF cohort participated in their previous sport. Since the average age of the athletes in this cohort was only 24, it would mean that over half of them had stopped participating in their previous sport at an average of 34 years old. That there were objective signs of osteoarthritis in 25% of the OATs cohort and a staggering 48% of the MF cohort in the 10-year follow-up<sup>19</sup> could imply that these injuries, independent of treatment, can lead to symptomatic osteoarthritis in a large proportion of these athletes in the long-term, even though the result regarding RTS can also partly be due to the natural lifespan of an athletic career.<sup>19–21</sup>

The rehabilitation protocol was very detailed in two of the studies. Della Villa et al.<sup>16</sup> and Ebert et al.<sup>24</sup> both used CPM, which produces close-chain compression and traction forces to the knee,<sup>8</sup> early after surgery, and allowed PWB within 1–2 weeks<sup>24</sup> and 3–4 weeks<sup>16</sup> respectively. Della Villa et al. used both water running and gym exercises to control a percentual increase in load related to bodyweight during the weeks after the operation and began PWB after 3–4 weeks. Ebert et al. also used a percentual increase in load related to bodyweight to increase the WB, but began PWB already after the first week. The time to FWB also differed, with Della Villa et al. beginning to fully WB at 7–8 weeks while Ebert began at 10–12 weeks. Despite these differences, both cohorts had an RTS rate of 80.6%<sup>16</sup> and 82.4%<sup>24</sup> respectively. While the detailed protocol on WB is described, neither author has an objective assessment of rehabilitation compliance. Without this data, it is not possible to say whether the outcomes, such as RTS, are specifically due to the chosen rehabilitation protocol.

Studies that focused on any other comorbidities to do with the knee apart from focal chondral injuries were excluded as part of the inclusion and exclusion criteria. However, during the full-text assessment of the remaining articles, it became apparent that there were many studies whose focus was focal chondral injuries of the knee but had also included some patients that had a co-procedure, such as ACL reconstruction, performed at the same time as the chondral surgery. This can of course affect the final outcomes of those studies, and thereby the outcomes evaluated in this systematic review. However, the rehabilitation protocols for these patients were the same as for the rest of their cohorts.

The main reason for applying early WB to the operated knee is to avoid negative effects of immobilization and simultaneously to stimulate healing by mechanical load to the operated part of the knee. The direct mechanical load to the operated site is very difficult to establish in clinical practice. To some extent: CPM, isokinetic exercises, leg-press activities and cycling can reasonably control such mechanical load using closed and open-chain activities. Most of the specified rehabilitation described as PWB and FWB are more difficult to interpret from this perspective. The mechanical load to the operated knee is affected by a range of factors such as compliance, compensatory loading to the non-injured leg, involuntary changes to the biomechanics such as limping, use of crutches or knee orthotics. This will make a true evaluation of the mechanical load to the operated area at different timepoints very difficult.

Further high-level, prospective controlled studies focused on athletes with traumatic chondral injuries of the knee are needed. Considering the observed long-term outcomes, a study that compares operative treatment with no treatment, i.e. the natural course of the chondral injury, is of importance since no such challenge to the indication for surgery has been done. Biomechanical studies evaluating the actual forces affecting the operated knee during the different postoperative phases of WB through the use of force-plates, 3D-imaging and electromyography may also be helpful to understand more of the healing process.

Another interesting aspect that needs to be addressed in future studies is the lack of data for female athletes. Four out of the ten

studies included in this systematic review did not include a female cohort, while roughly a third of each cohort in the other studies were female. This lack of female representation is reflected and analyzed in two prospective cohort studies; Kreuz et al.<sup>32</sup> analyzed the influence of sex in regard to ACI outcomes and Frank et al.<sup>33</sup> that evaluated the outcomes after osteochondral allograft transplantation surgery. Both studies confirm that there is very little data studying this aspect. The former concluded that there was indeed a difference in both clinical and MRI outcome between the sexes after ACI surgery, while the latter found no obvious difference. Kreuz et al. concluded that more research analysing potential sex-specific correlations in regard to the defect location, clinical results, biomechanical data could even lead to the development of an individualized rehabilitation protocol adapted to suit females.<sup>32</sup>

## 6. Conclusion

There is no clear evidence that the timing of WB affects the outcome and return to sport in athletes after surgery for focal full-thickness cartilage lesions of the knee. On the other hand, there seems to be no adverse effects in adopting an early weightbearing strategy, currently defined differently by different authors. Further studies directly comparing the timing of WB for specific surgical procedures in athletes and with relevant control groups is recommended. In summary, there is no consensus on the “best practice” in this regard and there is a need for a consensus in regard to more exactly defining “early” vs “late” weightbearing in relation to a universal and precisely defined state of healing.

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## Declaration of competing interest

None.

## Appendix 1

Keyword Strategy.

**Search #1:** (“articular cartilage” OR cartilage OR chondral OR osteochondral OR defect OR lesion) AND (knee OR tibiofemoral OR patellofemoral OR patella)

**Search #2:** surgery OR microfracture OR “autologous chondrocyte implantation” OR “autologous transplantation” OR “osteochondral autograft” OR “osteochondral allograft” OR “osteochondral transplantation” OR “subchondral drilling”

**Search #3:** Athletes OR Athlete

**Search #4:** Timing OR weight-bearing OR “Weight Bearing” OR Weightbearing OR Loadbearing OR Load-Bearing OR “Load Bearing”

**Search #5:** #1 and #2 and #3 and #4

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