Recovery of Effusion in Patients Following Anterior Cruciate Ligament (ACL) Reconstruction Surgery and Associations with Knee-related Outcomes: A Systematic Review

Introduction

The anterior cruciate ligament (ACL) is the most commonly injured ligament in the knee with more than 200,000 ACL tears occurring each year in the United States alone.[1,2] While some patients opt for non-surgical rehabilitation, up to 90% of patients in the United States elect to undergo arthroscopic ACL reconstruction (ACLR) using an autograft or allograft.[3,4]

Modern post-operative ACLR rehabilitation protocols typically consist of phases with specific criteria to be met before advancing to the next phase. This allows the patient to progress as quickly and safely as possible.[5,6] Resolution of knee joint effusion is one of the primary goals in the early phase of rehabilitation. Knee joint effusion is an accumulation of intracapsular fluid within the knee joint and is considered to be an indirect marker of inflammation that may contribute to quadriceps inhibition, decreased knee range of motion, difficulty with weight-bearing, altered joint kinematics, diminished proprioception, and suboptimal healing of the ligament-bone interface.[6–12] Some degree of knee joint effusion is expected post-operatively due to the inflammatory reaction induced by the surgical procedure.[7] However, the presence of persistent effusion during rehabilitation indicates a prolonged inflammatory response in the knee joint, which may reflect an inability to meet the functional demands placed on the knee. Persistent effusion may delay recovery and is considered to be a poor outcome.[7] While knee joint effusion assessment is considered routine practice for patients post-ACLR, there is no clear standard by which to measure effusion in clinical practice, which limits the ability to understand normal recovery.

We do not currently have a reference for the normal recovery of knee joint effusion in the first year after ACLR. Additionally, there are no known studies that seek to analyze existing associations between post-ACLR effusion recovery within one-year and knee-related outcomes such as the International Knee Documentation Committee Subjective Knee Form (IKDC), the Knee Injury and Osteoarthritis Outcome Score, and the Lysholm Knee Scoring Scale within two years post ACLR.[13]

Therefore, the purpose of this systematic review was to fill gaps in the literature by answering the following clinically relevant questions:

Question 1: What measurements are used to evaluate knee effusion post-ACLR in the clinic and clinical research?

Question 2: For patients up to one-year post-ACLR, what is the normal recovery timeline regarding knee effusion?

Question 3: For patients up to one-year post-ACLR, is knee effusion within the first year related to outcomes within 2 years after knee surgery?

Methods

Search Strategy

Pub Med, Sport Discus, Web of Science, Scopus, PEDro, Embase, and CINAHL were searched for articles published between January 1980 and January 2020. The 1980 time period was chosen due to the use of the arthroscope for ACLR beginning in the 1980s.[14] The umbrella search terms, equivalent terms, and MeSH terms used in the search can be seen in Appendix 1, Table 1. Although the definition of effusion best fits the review questions, “swelling” and “edema” were used as equivalents due to their occasional synonymous use in the literature with effusion.[15,16] The Pub Med search strategy is shown below.

Pub Med Search strategy (Appendix I, Table 1):

((((((((“ACL”) OR “anterior cruciate ligament”) OR “anterior cruciate ligament[MeSH Terms]”) OR “anterior ligament reconstruction[MeSH Terms]”) OR “Bone-Patellar Tendon-Bone Grafts[MeSH Terms]”) OR “Bone-Patellar Tendon-Bone Grafting[MeSH Terms]”))) AND ((((((“swelling”) OR “edema”) OR “effusion”) OR “edema[MeSH Terms]”)))

Selection Criteria

Inclusion criteria for the articles selected were: (1) human patients who underwent ACLR with an arthroscopic procedure, (2) subjective or objective effusion measurement within one-year post-ACLR with the method of measurement indicated, (3) full-text publication, (4) RCT, cohort study, case-control study, cross-sectional study, laboratory study, or case series. Exclusion criteria were: (1) animal subjects, (2) no ACLR, (3) ACL repair only, (4) no report of knee joint effusion within 1-year post-ACLR, and (5) concurrent multi-ligament injury, meniscal repair, or other concurrent injury thought to be likely to skew the data collected. Studies including patients who underwent meniscectomy concurrently with ACLR were permitted. Studies that only measured effusion via biomarkers for inflammation were not included. Studies were also excluded if the timing of the measurements was not stated. Studies using a GORE-TEX prosthetic ligament were excluded due to their high complication rate and lack of relevance to current practice.[17,18] Similarly, studies were excluded if an arthroscopic surgical procedure was not utilized as non-arthroscopic procedures are not commonly used.[4] Case reports, systematic reviews, and meta-analyses were excluded. For all articles that were not published in English, an English translation was requested. If no English translation was available, the article was excluded.

The lead author (G.D.) and one other author (T.H. or E.S.) independently reviewed the title and abstracts using the inclusion and exclusion criteria to identify potentially relevant articles. Full-text review for final inclusion was additionally performed by the lead author (G.D.) and one other author (T.H. or E.S.). A third author (L.T.) resolved conflicts at both stages of screening.

Data Extraction and Analysis

Once the articles that met the inclusion and exclusion criteria were selected, the lead author (G.D.) independently extracted data relevant to each research question from each article. Information extracted for descriptive analysis included the year of publication, study design, graft type, surgical approach, sample size, sex, age, anthropometrics, concurrent pathology, and time from injury to ACLR. Effusion measurement methods and values were recorded at each available time point in the first year post-ACLR. Mean and variance data for like measurement types were combined at various time intervals when the following criteria were met: the study was not a case series, ≥2 studies contributed data for a given effusion measurement during the time interval, and the data included a measure of variance. The time intervals are provided in Appendix I, tables 6 and 7. Associations reported between effusion within 1-year post-ACLR and knee-related outcomes within two years post-ACLR were recorded. Knee-related outcome data was also extracted if there were significant effusion differences found between groups within 1-year post-ACLR to allow for further identification of associations between knee joint effusion and knee-related outcomes not directly stated by the authors of each study.

Assessment for Risk of Bias

A risk of bias assessment was performed on all studies that contributed to questions 2 and 3 since risk of bias was not applicable for question 1 (Appendix I, Table 3). The Cochrane Risk

of Bias 2 (ROB-2) tool is a domain-based risk of bias assessment tool that was used to assess bias for all randomized studies included in this systematic review.[19] The domains included in this assessment tool intended to identify the risk of bias stemming from the randomization process, deviations from intended interventions, missing outcome data, measurement of the outcome, and in the selection of the reported result.[19] For non-randomized studies included in this systematic review, the risk of bias was assessed using the RoBANS tool which helped identify the risk of bias within each of six domains.[20] The domains addressed in the RoBANS tool were selection of participants, confounding variables, measurement of intervention, blinding of outcome assessment, incomplete outcome data, and selective outcome reporting.[21]

Results

The Preferred Reporting Items for Systematic reviews and Meta-Analyses (PRISMA) flow diagram of the search results is given in Figure 1 (See Appendix I).[22] After duplicates were removed, initial database searches identified 1883 potentially relevant articles with 146 selected for full-text review after the title and abstract screening. Thirty-four articles met the inclusion and exclusion criteria and were included in the final review (Appendix I, Table 2). Of 34 included studies, 17 were randomized control trials (RCTs), 2 were control trials without a stated randomization status, 3 were cohort studies, 6 were comparative or intervention studies without a control group, and 6 were case series (Appendix I, Table 2). The publication year from included articles ranged from 1993 to 2019 with half the articles published in 2010 or later (Appendix I, Table 2). All 34 studies included in the review contributed to question 1 while 4 studies contributed to question 2, and 16 studies contributed to question 3. Thirteen studies were found to have a high risk of bias while two studies had a low risk of bias (Appendix I, Table 3).

Additionally, 4 studies were found to have an unclear risk of bias due to a lack of a detailed description of methods (Appendix I, Table 2).

Across the studies included in this review, effusion data from 2474 subjects were collected. The sample sizes of the included studies ranged from 10 to 969 subjects (Appendix I, Table 2). Twenty-nine studies reported sex distribution among the participants with all studies including both male and female subjects except for Sharifzadeh et al. and Sarrafan et al.which included only male subjects (Appendix I, Table 2).[23,24] Across studies, there were 1675 (76%) male subjects and 516 (24%) females. Twenty-eight studies reported the mean age of the subjects while 2 studies reported the median age (Appendix I, Table 2). The studies that reported mean age included 2249 subjects with the mean age being 26.8 years. Twenty-nine studies reported the graft type used for ACLR with 11 using patellar tendon (PT) autograft exclusively, 11 using hamstring tendon (HT) autograft exclusively, 4 using PT or HT autografts, 1 using PT or quadriceps tendon (QT) autografts, 1 using a PT autograft or allograft, and 1 study using a PT Autograft, HT Autograft, Anterior Tibialis Allograft, Tibialis Posterior Allograft, or Achilles Tendon Allograft (Appendix I, Table 2). Five studies reported mean BMI data for study participants while one study reported median BMI data (Appendix I, Table 2). The combined mean BMI of 149 subjects was 23.8 kg/m^2. Fourteen studies reported concurrent injury data with 2 studies reporting no concurrent injury (Appendix I, Table 2). Concurrent injuries reported included meniscal tear, chondral injury, and collateral ligament injuries (Appendix I, Table 2). Across studies that reported concurrent injuries, there were 146 concomitant meniscectomies performed among 312 total participants (48%). The mean time elapsed from ACL injury to ACLR was reported in 10 studies (Appendix I, Table 2). These studies included 1375 subjects with a mean time from ACL injury to ACLR of 6.9 months.

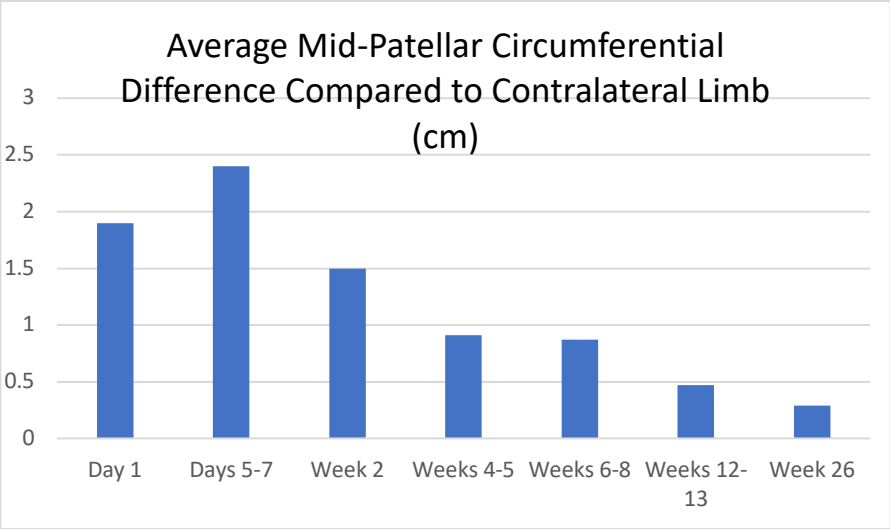
Question 1: What measurements are used to evaluate knee effusion post-ACLR in the clinic and clinical research?

Table 4 of Appendix I provides the knee joint effusion measurement methods used in the included studies. Circumferential measurement was used in 20 of the 34 studies (Appendix I, Table 4). The location of measurement varied among studies with the midpoint of the patella being the most common (8 studies) marker for measurement. Other anatomical landmarks used for circumferential knee joint effusion measurement were the knee joint space, 5 cm above the superior pole of the patella, 1 cm above the superior patellar border, 2 cm above the superior pole of the patella, the proximal margin of the patella, the apex of the patella, and the base of the patella. Four studies did not indicate the specific location of the circumferential measurement. The contralateral limb was used as a control reference point in 13 of 20 studies using circumferential measurement. Other studies referenced a preoperative or postoperative measurement of the injured knee. Other objective clinical measures used in knee joint effusion assessment were the bulge/stroke test (4 studies), the ballottement test (1 study), and an un-named standardized scale ranging from 1-4 (1 study) (Appendix I, Table 4). Imaging techniques were used to measure knee joint effusion in two studies with MRI and CT, respectively (Appendix I, Table 4). The CT scan was reported to measure effusion 5cm proximal to the knee joint line. Drechsler et al. was the only study to measure effusion via water displacement using a knee volumeter.[25] Sub-sections of subjective knee forms including the International Knee Documentation Committee (IKDC) Form, the Lysholm Knee Score, and the modified Noyes form were used to assess effusion in 6 studies (Appendix I, Table 4). Three studies categorized knee joint effusion subjectively as present or absent, none or mild, and excellent, good, or moderate, respectively (Appendix I, Table 4). Descriptions of measurements included in this review can be found in Appendix II.

Question 2: For patients up to one-year post-ACLR, what is the normal recovery timeline regarding knee effusion?

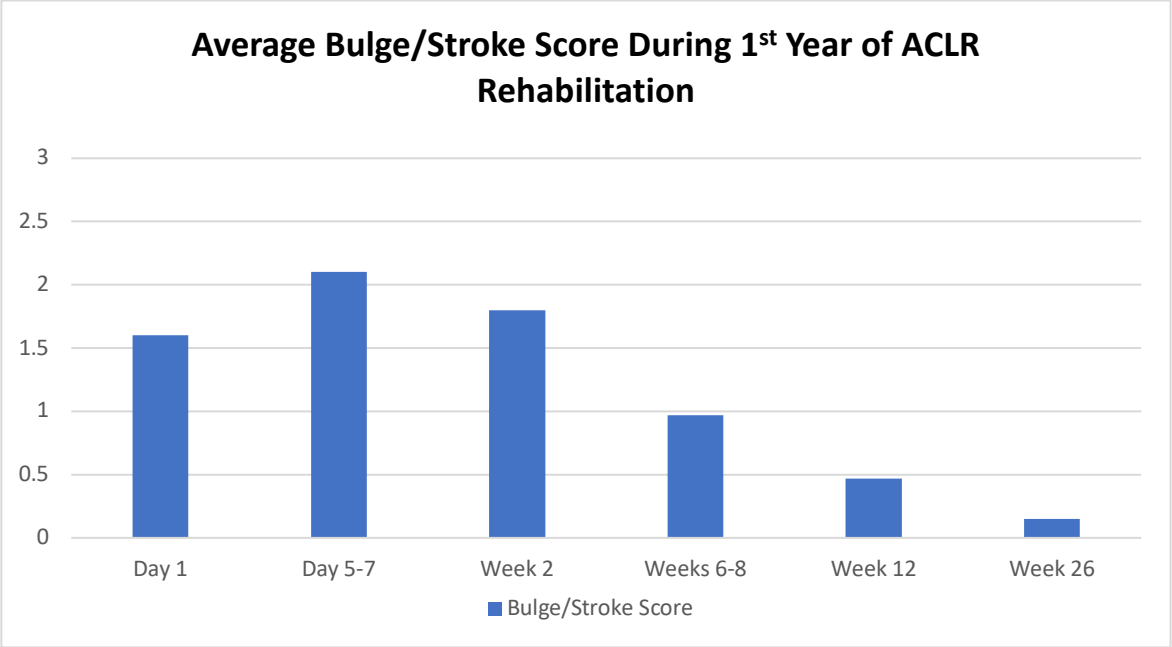
Table 4 of Appendix I provides the measurement time points and effusion data from each of the studies included in this review. Effusion measurement time points ranged from 1 day to 1-year post-ACLR in the included studies (Appendix I, Table 4). The most common measurement time points of effusion measurement are presented in Table 5 of Appendix I. Average knee effusion data were combined across four studies that used mid-patellar knee circumference (cm) and the contralateral limb as a comparison (Appendix I, Table 6). The average circumferential difference at day 1 was 1.9±1.5 cm and increased during the first week of recovery with a peak of 2.4±1.4 cm near 1-week post-ACLR.[26,27] The average circumferential difference then declined gradually, reaching 0.91±0.61 cm and 0.87±1.1 cm at the week 4-5 and week 6-8 time intervals, respectively.[16,28] Upon further measurements during weeks 12-13 and week 26, effusion diminished further with measurements of 0.47±0.84 cm and 0.29±0.63 cm, respectively.[26–28] A graphical representation of average effusion recovery as measured by mid-patellar circumferential difference compared to the contralateral limb can be seen in Figure 1 below.

Figure 1



The average effusion using the bulge/stroke test was found by combining data from two studies that used the same scale (Appendix I, Table 7).[26,27] Average knee effusion increased from day 1 (1.6±0.92) to week 1 (2.1±1.1).[26,27] After week 1, effusion scores decreased gradually decreased during the first year of ACLR recovery, reaching a minimum average value of 0.15±0.34 at week 26.[26,27] Other measures of effusion also demonstrated a decreasing trend during the first-year post ACLR but did not meet the criteria for data combination. A graphical representation of average effusion recovery as measured by the bulge/stroke test can be seen in Figure 2 below.

Figure 2



Question 3: For patients up to one-year post-ACLR, is knee effusion within the first year related to outcomes within 2 years after knee surgery?

Associations of knee effusion with other knee-related outcomes and between-group differences from 16 studies are listed in Table 8 of Appendix I. All associations found were measured within 1-year post ACLR. Cappellino et al. found that circumferential measurements at 3- and 6-months post-ACLR demonstrated a positive association with dynamic load asymmetry

during gait (r=0.909) and knee flexion range of motion (ROM) (r=0.866) when measured by clinical assessment at the same time points.[28] In the same study, effusion was not associated with several other measures including walking speed, pain, knee force, and quality of life.[28] Similarly, Drechsler et al. found that knee effusion measured at 1- and 3- months post-ACLR was not associated with quadriceps strength or muscle activation at the same time points.

When using a discriminant function analysis (DFA) to examine contributors to return to sport vs non-return to sport at 1-year post ACLR, Lentz et al. found that knee joint effusion was a strong contributor to return to sport status as effusion was negatively associated with the return to sport rate (0.519).[29] Morrissey et al. measured effusion via circumferential measurement at 2- and 6-weeks post-ACLR and observed that improved knee joint effusion was weakly correlated with decreased knee laxity (r=-0.159).[30] In the study by Madadi et al., the double fixation group had significantly greater effusion reduction, less anterior translation of the tibia but decreased stability according to the pivot shift test compared to the single fixation group.[31] This study did not directly assess the association of effusion reduction with knee laxity/stability. However, it was the authors' opinion that the decreased anterior tibial translation in the double fixation group was the main cause of the decreased effusion because the reliability of the KT-2000 measurement is higher than the pivot shift test.[31]

Table 8 of Appendix I displays studies that report between-group effusion measurement differences as well as knee-related outcomes that differ between groups. Groups that improved effusion also improved SF-36, increased subjective knee scores, decreased pain, decreased laxity, increased strength, increased ROM, improved Star Excursion Balance Test score, and increased return to sport rate within two years after ACLR.[15,26–29,32–37] Additionally, those with

improved knee effusion also demonstrated improved stair-climbing ability, decreased locking of the knee and decreased kinesiophobia.[23,29]

Discussion

Effusion Measurement Methods Post-ACLR

This systematic review detailed the measures of knee joint effusion used in clinical and research settings for patients after undergoing ACLR. The measurement methods varied across studies but can be primarily divided into the following six subgroups: circumferential measurement, bulge/stroke test, imaging, ballottement/dancing patella sign, subjective knee form score, and other (Appendix I, Table 4). Circumferential measurement was the most common form of measurement as this mode was used in 20 of the 34 studies included in this review (Appendix I, Table 4). The bulge/stroke test (4 studies) and IKDC subjective knee form (3 studies) were the next most common modes of measurement used (Appendix I, Table 4). In previous studies, circumferential measurement of the knee (ICC>0.8) and the bulge/stroke test (kappa=0.75) have been shown to have good and substantial interrater reliability, respectively.[12,38–40]

The majority of the studies from other systematic reviews that include effusion resolution post-ACLR also used circumferential measurements at various locations on the knee.[6,41,42] Van Grinsven et al. recommend using a circumferential measurement and the IKDC subjective knee form to assess effusion symptoms due to their favorable psychometric properties.[6] In the current review, the circumferential measurement location varied with the middle of the patella being the most common landmark used (8 studies). Van Grinsven et al. recommend a circumferential measurement landmark 1 cm above the superior patella although no rationale is provided.[6] The studies included in a review by Jaspers et al. measured knee circumference at the mid-patella or

superior to the patella as recommended by Van Grinsven et al.[41] The comparison for circumference measurement also varied in the studies from the current review with the contralateral limb being the most common. Van Grinsven et al. recommend a comparison to the contralateral limb while the studies included in the review by Jaspers et al. used the contralateral limb or a pre-operative measurement for comparison.[6,41]

The authors of this systematic review recommend the bulge/stroke test and/or a circumferential measurement for assessing effusion in patients recovering from ACLR. Interrater reliability has been established and there has been sufficient use in the literature to estimate the average recovery during the first year of recovery using these measures.[12,38] It is the authors' opinion that the contralateral limb may be the best comparison landmark compared to a pre-operative measurement of the injured knee due to the possibility of confounding effusion presenting secondary to the initial ACL injury.

Average Effusion Values 1-Year Post ACLR

Although there were several different effusion measurement types reported in the included studies, only mid-patellar circumferential measurement compared to the contralateral limb and the bulge/stroke test provided adequate data points to chart recovery during the first year of recovery post ACLR (Figures 1 and 2). When calculating the average effusion using a circumferential measurement in comparison to the contralateral limb, data from only 4 studies could be combined due to the reported locations of measurement, study type, and reporting of variance. Data from only two studies measuring effusion using the bulge/stroke test could be combined due to the method of reporting by Feller et al. and Lentz et al.[29,43]

The average effusion measurements decreased during the first year post-ACLR with the maximum effusion occurring at approximately 1-week post ACLR as measured by mid-patellar

circumference difference (2.4±1.4 cm) and by the bulge/stroke test (2.1±1.1).[26,27] This increase in effusion may be explained by the inflammatory phase of healing that typically occurs during the first week of healing to recruit an immune response.[44] However, the inflammatory phase transitions to the proliferative phase after the first week of healing and a decrease in effusion is expected.[44] The effusion measurements followed this pattern as a gradual reduction occurred after week 1, reaching a near-full resolution between 8 and 12 weeks post-ACLR.

The systematic review by Van Grinsven et al. established an evidence-based protocol for ACLR rehabilitation, in which the resolution of effusion was expected during the early phases of the protocol.[6] "Minimal swelling" was included in the criteria to begin phase 2 of the protocol which was recommended to begin 2 weeks post-ACLR.[6] Based on the results of the present review, a fair amount of effusion is likely to remain which suggests that the "minimal effusion" criteria may not be met 2-weeks post ACLR by a large percentage of patients. However, further research validating the findings of this review are required before recommending a change to established rehabilitation protocols. The systematic review by Jaspers et al. included one study (Engstrom et al.) that measures knee joint effusion using a mid-patellar circumferential measurement and uses a comparison to the contralateral limb.[41] This study was excluded from the present systematic review due to the inclusion of patients with concurrent high-grade MCL rupture.[45] Engstrom et al. found that the average effusion measurement among the subjects at 6-weeks post-ACLR was 1.3 cm which is slightly higher than the findings of the present review during the same time interval (0.87±1.1 cm).[45] However, it is unknown whether this is a clinically meaningful difference.

Based on the findings of this review, normal effusion recovery post-ACLR should gradually resolve with near full resolution taking place between 8-12 weeks (Figures 1 and 2)

Clinicians should measure patients' knee joint effusion post-ACLR using a circumferential measurement or the bulge/stroke test at regular intervals to monitor for abnormal increases in effusion and to compare their findings to average recovery data found in the literature.

Associations Between Effusion Values and Knee-Related Outcomes Post-ACLR

In a limited number of studies that reported associations between knee joint effusion and knee-related outcomes, effusion was found to have a strong positive association with dynamic load asymmetry during gait and a strong negative association with knee flexion ROM at 3- and 6- months post-ACLR.[28] A strong negative association was also found between effusion and return to sport rate at 1-year post-ACLR (Appendix I, Table 8).[29] Knee effusion is a hypothesized cause of arthrogenic muscle inhibition that has been demonstrated using an experimentally induced knee effusion followed by a landing task.[9] However, this finding is not supported by the studies included in this systematic review. Drechsler et al. observed that knee joint effusion was not associated with quadriceps activation when measured at 1- and 3- months post-ACLR.[25] Similarly, Cappelino et al. observed that effusion was not associated with decreased thigh atrophy or decreased knee force when measured at 1-, 3-, or 6- months post-ACLR.[28] Both thigh musculature atrophy and decreased knee force production are typical characteristics of arthrogenic muscle inhibition.[46] Measurements of effusion taken earlier in the recovery period when effusion is closer to its maximum average value (~1 week) may have an association with arthrogenic muscle inhibition. Unfortunately, none of the studies included in this review provide sufficient evidence to support or refute this hypothesis.

Madadi et al. draw a connection between decreased knee effusion and increased stability in the double fixation group as measured by decreased KT-2000 measurement.[31] However, this finding should be viewed skeptically as the double fixation group also demonstrated worse pivot

shift scores which indicates decreased stability. Given the contradictory findings in the study related to laxity, we cannot be confident in the stated relationship between effusion and laxity.[31]

Thirteen studies reported significant differences in effusion measurement between groups at various points during the first year of recovery, as well as between-group differences in other knee-related outcomes (Appendix I, Table 8). Eleven of these studies reported knee effusion differences between intervention and control groups, one study reported differences between return-to-sport and non-return-to-sport groups, and another study reported differences between groups using different femoral fixations of the ACL (Appendix I, Table 8). The group differences observed suggest that reducing knee effusion may have a multitude of benefits as stated above in the results section and in Appendix I, Table 8. However, these findings should be interpreted with caution as rigorous statistical analysis has not been performed to determine whether an association exists between knee effusion and these outcomes. None of the other systematic reviews that include knee effusion measurement sought to identify associations between effusion and knee-related outcomes.[6,41,42]

Although there is a lack of robust data examining the relationship between effusion and knee-related outcomes, the findings of this review support that effusion resolution should remain a priority for clinicians and patients during early ACLR rehabilitation. Specifically, persistent effusion may result in dynamic load asymmetry which may begin to affect other areas of the body that undergo increased stress due to compensation.[28] Increased effusion may also decrease knee ROM which can limit patients' functional activity such as navigating stairs, squatting, or kneeling.[28] Lastly, excessive effusion during the first year of ACLR recovery may decrease an athlete's chances of returning to sport.[29]

Limitations

This systematic review has several limitations that should be considered when interpreting the findings. First, the average population across the included studies is not representative of the typical population who receives ACLR. A study by Herzog et al. tracked the incidence of reconstruction among commercially insured patients in the United States from 2002-2014.[47] The authors found that of 283,810 ACL reconstructions, 57.2% of the reconstructions were performed on male patients while the percentage of male patients included in this systematic review is significantly higher at 76%.[47] The large percentage of male subjects may result in a lack of generalizability to female patients who undergo ACLR. However, the average effusion measures presented in Tables 6 and 7 of Appendix I may provide a more even sex distribution except for the 4-5 week interval measured circumferentially due to the large study (969 subjects) by Bordes et al. that consisted of 79% men.[16] The study by Mayr et al. contributed significantly (73 subjects) to the average effusion reported but did not report sex distribution.[27] The other studies that contributed to the results found in Tables 6 and 7 consisted of an equal number of men (20 subjects) and women (20 subjects).[26,28]

Another limitation was the inability to combine data from a majority of the studies included in the review due to heterogeneity of measurement location, measurement reporting, and the comparison used. Of 34 included studies, only 4 studies contributed to the average circumferential measurements and 2 studies contributed to the average effusion measured using the bulge/stroke test.[16,26–28] This systematic review included lower levels of evidence including case series to capture the methods used to measure effusion in clinical practice and research. This inclusion of lower-level studies may affect the validity of the association reported between effusion and knee laxity due to the contribution from the study by Morrissey et al.[30] Risk of bias was also a limitation of the studies included in this review as 17 of the 19 studies contributing to

questions 2 and 3 had a high or unclear risk of bias (Appendix I, Table 3). Additionally, all of the studies that contributed to question 2 had a high or unclear risk of bias rating (Appendix I, Table 3). Lastly, only 6 of the 34 included studies stated direct associations between effusion and knee-related outcomes which indicates a need for further research to explore the impact of effusion recovery on outcomes.

Future Research

While this systematic review provided a broad overview of the various methods of effusion measurement used post-ACLR, future research may help study effusion measurement by standardizing measurement methods, increasing sample sizes, and increasing methodological rigor. This may allow for clinicians to interpret their patients' effusion measurements with more confidence compared to the averages found in the literature. Future research may also be conducted to establish mean effusion recovery in subsets of the population based on sex, time from injury, concomitant procedure, etc. Lastly, future studies that aim to draw any existing associations between effusion in early ACLR rehabilitation and knee-related outcomes may allow effusion to serve as a yellow flag to identify patients who are at increased risk for a poor functional outcome.

Conclusion

This systematic review found that the primary methods of effusion measurement used in clinical practice and research were the bulge/stroke test and circumferential measurement at a variety of locations with a comparison to either the contralateral limb or to a pre-operative measurement of the injured limb. The studies included in this review suggest that average effusion levels post-ACLR reach their peak near 1-week postoperatively and gradually decline until full resolution between 8- and 12-weeks post-operatively. Lastly, data from the included

studies indicate that persistent effusion may be associated with dynamic load asymmetry, decreased knee ROM, and decreased return to sport rate. However, due to the limitations indicated above, the findings of this review should be interpreted with caution and further studied in future research.

References

1. Barber-Westin SD, Noyes FR. Objective criteria for return to athletics after anterior cruciate ligament reconstruction and subsequent reinjury rates: a systematic review. *Phys Sportsmed*. 2011;39(3):100-110. doi:10.3810/psm.2011.09.1926
2. Musahl V, Karlsson J. Anterior cruciate ligament tear. *N Engl J Med*. 2019;380(24):2341-2348. doi:10.1056/NEJMcp1805931
3. Paterno MV. Incidence and predictors of second anterior cruciate ligament injury after primary reconstruction and return to sport. *J Athl Train*. 2015;50(10):1097-1099. doi:10.4085/1062-6050-50.10.07
4. MARS Group, Allen CR, Anderson AF, et al. Surgical predictors of clinical outcomes after revision anterior cruciate ligament reconstruction. *Am J Sports Med*. 2017;45(11):2586-2594. doi:10.1177/0363546517712952
5. Filbay SR, Grindem H. Evidence-based recommendations for the management of anterior cruciate ligament (ACL) rupture. *Best Pract Res Clin Rheumatol*. 2019;33(1):33-47. doi:10.1016/j.berh.2019.01.018
6. van Grinsven S, van Cingel REH, Holla CJM, van Loon CJM. Evidence-based rehabilitation following anterior cruciate ligament reconstruction. *Knee Surg Sports Traumatol Arthrosc*. 2010;18(8):1128-1144. doi:10.1007/s00167-009-1027-2
7. Lynch AD, Logerstedt DS, Grindem H, et al. Consensus criteria for defining "successful outcome" after ACL injury and reconstruction: a Delaware-Oslo ACL cohort investigation. *Br J Sports Med*. 2015;49(5):335-342. doi:10.1136/bjsports-2013-092299
8. Coughlan GF, McLoughlin R, McCarthy Persson U, Caulfield BM. An investigation into the effects of a simulated effusion in healthy subjects on knee kinematics during jogging and running. *Clin Biomech (Bristol, Avon)*. 2008;23(8):1038-1043. doi:10.1016/j.clinbiomech.2008.04.010
9. Palmieri-Smith RM, Kreinbrink J, Ashton-Miller JA, Wojtys EM. Quadriceps inhibition induced by an experimental knee joint effusion affects knee joint mechanics during a single-legged drop landing. *Am J Sports Med*. 2007;35(8):1269-1275. doi:10.1177/0363546506296417
10. Cho YR, Hong BY, Lim SH, et al. Effects of joint effusion on proprioception in patients with knee osteoarthritis: a single-blind, randomized controlled clinical trial. *Osteoarthr Cartil*. 2011;19(1):22-28. doi:10.1016/j.joca.2010.10.013
11. Dagher E, Hays PL, Kawamura S, Godin J, Deng X, Rodeo SA. Immobilization modulates macrophage accumulation in tendon-bone healing. *Clin Orthop Relat Res*. 2009;467(1):281-287. doi:10.1007/s11999-008-0512-0
12. Sturgill LP, Snyder-Mackler L, Manal TJ, Axe MJ. Interrater reliability of a clinical scale to assess knee joint effusion. *J Orthop Sports Phys Ther*. 2009;39(12):845-849.

doi:10.2519/jospt.2009.3143
13. Gagnier JJ, Shen Y, Huang H. Psychometric Properties of Patient-Reported Outcome Measures for Use in Patients with Anterior Cruciate Ligament Injuries: A Systematic Review. *JBJS Reviews*. 2018;6(4):e5. doi:10.2106/JBJS.RVW.17.00114
14. Chambat P, Guier C, Sonnery-Cottet B, Fayard J-M, Thaunat M. The evolution of ACL reconstruction over the last fifty years. *Int Orthop*. 2013;37(2):181-186. doi:10.1007/s00264-012-1759-3
15. Jarit GJ, Mohr KJ, Waller R, Glousman RE. The effects of home interferential therapy on post-operative pain, edema, and range of motion of the knee. *Clin J Sport Med*. 2003;13(1):16-20. doi:10.1097/00042752-200301000-00004
16. Bordes P, Laboute E, Bertolotti A, et al. No beneficial effect of bracing after anterior cruciate ligament reconstruction in a cohort of 969 athletes followed in rehabilitation. *Ann Phys Rehabil Med*. 2017;60(4):230-236. doi:10.1016/j.rehab.2017.02.001
17. Dahlstedt L, Dalén N, Jonsson U. Goretex prosthetic ligament vs. Kennedy ligament augmentation device in anterior cruciate ligament reconstruction. A prospective randomized 3-year follow-up of 41 cases. *Acta Orthop Scand*. 1990;61(3):217-224. doi:10.3109/17453679008993504
18. Paulos LE, Rosenberg TD, Grewe SR, Tearse DS, Beck CL. The GORE-TEX anterior cruciate ligament prosthesis. A long-term followup. *Am J Sports Med*. 1992;20(3):246-252. doi:10.1177/036354659202000302
19. Sterne JAC, Savović J, Page MJ, et al. RoB 2: a revised tool for assessing risk of bias in randomised trials. *BMJ*. 2019;366:l4898. doi:10.1136/bmj.l4898
20. Sterne JA, Hernán MA, Reeves BC, et al. ROBINS-I: a tool for assessing risk of bias in non-randomised studies of interventions. *BMJ*. 2016;355:i4919. doi:10.1136/bmj.i4919
21. Risk of Bias Assessment tool for Non-randomized Studies (RoBANS): Development and validation of a new instrument | Colloquium Abstracts. https://abstracts.cochrane.org/2011-madrid/risk-bias-assessment-tool-non-randomized-studies-robans-development-and-validation-new. Accessed April 5, 2020.
22. Moher D, Liberati A, Tetzlaff J, Altman DG, PRISMA Group. Preferred reporting items for systematic reviews and meta-analyses: the PRISMA statement. *PLoS Med*. 2009;6(7):e1000097. doi:10.1371/journal.pmed.1000097
23. Sharifzadeh SR, Shahrezaee M, Okhovatpour MA, Boroujeni SA, Banasiri M. Comparison of the effectiveness of femoral fixation techniques (Aperfix and Endobutton) in anterior cruciate ligament surgery. *AMJ*. 2017;10(9). doi:10.21767/AMJ.2017.3138
24. Sarrafan N, Mehdinasab SA. Anterior cruciate ligament reconstruction using patellar tendon and quadriceps tendon: A comparative study. *Pak J Med Sci*. 2008;24(3):416-419.
25. Drechsler WI, Cramp MC, Scott OM. Changes in muscle strength and EMG median frequency after anterior cruciate ligament reconstruction. *Eur J Appl Physiol*. 2006;98(6):613-623. doi:10.1007/s00421-006-0311-9
26. Ediz L, Ceylan MF, Turktas U, Yanmis I, Hiz O. A randomized controlled trial of electrostimulation effects on effussion, swelling and pain recovery after anterior cruciate ligament reconstruction: a pilot study. *Clin Rehabil*. 2012;26(5):413-422. doi:10.1177/0269215511421029
27. Mayr HO, Hochrein A, Hein W, Hube R, Bernstein A. Rehabilitation results following anterior cruciate ligament reconstruction using a hard brace compared to a fluid-filled soft brace. *Knee*. 2010;17(2):119-126. doi:10.1016/j.knee.2009.07.002

28. Cappellino F, Paolucci T, Zangrando F, et al. Neurocognitive rehabilitative approach effectiveness after anterior cruciate ligament reconstruction with patellar tendon. A randomized controlled trial. *Eur J Phys Rehabil Med*. 2012;48(1):17-30.
29. Lentz TA, Zeppieri G, Tillman SM, et al. Return to preinjury sports participation following anterior cruciate ligament reconstruction: contributions of demographic, knee impairment, and self-report measures. *J Orthop Sports Phys Ther*. 2012;42(11):893-901. doi:10.2519/jospt.2012.4077
30. Morrissey MC, Hudson ZL, Drechsler WI, Coutts FJ, King JB, McAuliffe TB. Correlates of knee laxity change in early rehabilitation after anterior cruciate ligament reconstruction. *Int J Sports Med*. 2000;21(7):529-535. doi:10.1055/s-2000-7414
31. Madadi F, Sarmadi A, Kahlaee AH, et al. A new hybrid fixation method in ACL reconstruction surgery. *Eur J Orthop Surg Traumatol*. 2010;20(2):137-140. doi:10.1007/s00590-009-0497-8
32. Benazzo F, Zanon G, Pederzini L, et al. Effects of biophysical stimulation in patients undergoing arthroscopic reconstruction of anterior cruciate ligament: prospective, randomized and double blind study. *Knee Surg Sports Traumatol Arthrosc*. 2008;16(6):595-601. doi:10.1007/s00167-008-0519-9
33. Chau JYM, Chan WL, Woo SB, et al. Hyaluronic acid instillation following arthroscopic anterior cruciate ligament reconstruction: a double-blinded, randomised controlled study. *J Orthop Surg (Hong Kong)*. 2012;20(2):162-165. doi:10.1177/230949901202000205
34. Felli L, Revello S, Burastero G, et al. Single intravenous administration of tranexamic acid in anterior cruciate ligament reconstruction to reduce postoperative hemarthrosis and increase functional outcomes in the early phase of postoperative rehabilitation: A randomized controlled trial. *Arthroscopy*. 2019;35(1):149-157. doi:10.1016/j.arthro.2018.07.050
35. Hughes L, Rosenblatt B, Haddad F, et al. Comparing the Effectiveness of Blood Flow Restriction and Traditional Heavy Load Resistance Training in the Post-Surgery Rehabilitation of Anterior Cruciate Ligament Reconstruction Patients: A UK National Health Service Randomised Controlled Trial. *Sports Med*. 2019;49(11):1787-1805. doi:10.1007/s40279-019-01137-2
36. Ruffilli A, Buda R, Castagnini F, et al. Temperature-controlled continuous cold flow device versus traditional icing regimen following anterior cruciate ligament reconstruction: a prospective randomized comparative trial. *Arch Orthop Trauma Surg*. 2015;135(10):1405-1410. doi:10.1007/s00402-015-2273-z
37. Straw R, Colclough K, Geutjens GG. Arthroscopically assisted ACL reconstruction. Is a drain necessary? *Knee*. 2003;10(3):283-285. doi:10.1016/s0968-0160(02)00150-3
38. Jakobsen TL, Christensen M, Christensen SS, Olsen M, Bandholm T. Reliability of knee joint range of motion and circumference measurements after total knee arthroplasty: does tester experience matter? *Physiother Res Int*. 2010;15(3):126-134. doi:10.1002/pri.450
39. Koo TK, Li MY. A guideline of selecting and reporting intraclass correlation coefficients for reliability research. *J Chiropr Med*. 2016;15(2):155-163. doi:10.1016/j.jcm.2016.02.012
40. McHugh ML. Interrater reliability: the kappa statistic. *Biochem Med (Zagreb)*. 2012;22(3):276-282. doi:10.11613/BM.2012.031
41. Jaspers T, Taeymans J, Hirschmüller A, Baur H, Hilfiker R, Rogan S. Continuous Passive Motion Does Improve Range of Motion, Pain and Swelling After ACL Reconstruction: A

Systematic Review and Meta-Analysis. *Z Orthop Unfall*. 2019;157(3):279-291. doi:10.1055/a-0710-5127

42. Martimbianco ALC, Gomes da Silva BN, de Carvalho APV, Silva V, Torloni MR, Peccin MS. Effectiveness and safety of cryotherapy after arthroscopic anterior cruciate ligament reconstruction. A systematic review of the literature. *Phys Ther Sport*. 2014;15(4):261-268. doi:10.1016/j.ptsp.2014.02.008
43. Feller JA, Webster KE, Gavin B. Early post-operative morbidity following anterior cruciate ligament reconstruction: patellar tendon versus hamstring graft. *Knee Surg Sports Traumatol Arthrosc*. 2001;9(5):260-266. doi:10.1007/s001670100216
44. Landén NX, Li D, Ståhle M. Transition from inflammation to proliferation: a critical step during wound healing. *Cell Mol Life Sci*. 2016;73(20):3861-3885. doi:10.1007/s00018-016-2268-0
45. Engström B, Sperber A, Wredmark T. Continuous passive motion in rehabilitation after anterior cruciate ligament reconstruction. *Knee Surg Sports Traumatol Arthrosc*. 1995;3(1):18-20. doi:10.1007/bf01553520
46. Rice DA, McNair PJ. Quadriceps arthrogenic muscle inhibition: neural mechanisms and treatment perspectives. *Semin Arthritis Rheum*. 2010;40(3):250-266. doi:10.1016/j.semarthrit.2009.10.001
47. Herzog MM, Marshall SW, Lund JL, Pate V, Mack CD, Spang JT. Trends in Incidence of ACL Reconstruction and Concomitant Procedures Among Commercially Insured Individuals in the United States, 2002-2014. *Sports Health*. 2018;10(6):523-531. doi:10.1177/1941738118803616