

Chronicity of Anterior Cruciate Ligament Injury Does Not Adversely Affect the Clinical Outcomes of Primary Repair in Appropriately Selected Patients

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Purpose: To determine the association between surgical delay, anterior cruciate ligament (ACL) tissue quality, failure rates, and clinical outcomes at a minimum 2-year follow-up after arthroscopic ACL primary repair (ACLPR).

Methods: Consecutive patients with complete, proximal (type I/II) ACL tears who underwent arthroscopic ACLPR and had a minimum 2-year follow-up were included. Surgical delay was stratified into 3 categories: acute (≤ 21 days), subacute (22–90 days), and chronic (> 90 days). Intraoperative tissue quality was assessed according to synovial sheath integrity (grade 1, completely intact; grade 2, $> 50\%$ intact; grade 3, $< 50\%$ intact) and rupture pattern (1-bundle, 2-bundle, and complex tear). Failure was defined as instrumented laxity > 3 mm anterior tibial translation side-to-side difference, pivot shift grade ≥ 2 , and/or subjective instability. Clinical and patient-reported outcomes were compared and Patient Acceptable Symptom State thresholds established.

Results: Between 2008 and 2021, 276 of 298 (loss to follow-up, 7.4%) patients (mean age, 39.7 ± 10.7 years; females, 50.3%) who underwent ACLPR with a follow-up of 2.9 ± 1.0 years (2.0–6.5 years) met the inclusion criteria. Sixty-eight (24.6%) ACLPR were acute, 152 (50.1%) subacute, and 56 (20.3%) chronic. Surgical delay was not significantly correlated with worse tissue quality (grade 2, $P = .79$; grade 3, $P = .06$) or increased failure risk ($P = .57$). ACLPR failure occurred in 28 patients (10.1%), with no significant differences among groups (acute, 10.2%; subacute, 11.2%; chronic, 7.1%; $P = .76$). Reoperation rates ($P = .62$) and anterior tibial translation side-to-side difference ($P = .90$), as well as patient-reported outcomes (all $P > .28$) and Patient Acceptable Symptom State threshold achievements (overall: International Knee Documentation Committee, 84.7%; Lysholm, 83.3%; Forgotten Joint Score-12, 87.3%; and ACL-Return to Sport after Injury, 88.5%) were comparable across groups (all $P > .05$).

Conclusions: Injury chronicity did not adversely affect failure rates or clinical outcomes at minimum 2-year follow-up after ACLPR. Therefore, in the case of a proximal tear location and sufficient tissue quality, surgical delay alone should not be considered a contraindication for ACLPR.

Level of Evidence: Level III, retrospective comparative case series.

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Anterior cruciate ligament (ACL) reconstruction (ACLR) remains the gold standard for surgically treating ACL injuries.¹⁻³ However, a resurgence of interest in ligament-preserving techniques has been observed in recent years, particularly in patients with proximal tears and preserved tissue quality.^{1,3-10} While early studies have showed promising short-term and maintained midterm outcomes,^{1,8,11-13} widespread adoption of ACL primary repair (ACLPR) remains limited. A major barrier to this adoption is the prevailing belief that early surgical intervention is critical for repairability and successful outcomes. However, current literature often defines “repairable” cases by using arbitrary time-based cutoffs, typically within 21 days post-injury, despite limited empirical evidence supporting these thresholds.^{8,14-18}

Acute management allows for a more timely management of concomitant injuries and reduces long-term complications such as subsequent meniscal injuries.¹⁹⁻²⁴ However, expeditious management is not always feasible in clinical practice due to delays in diagnosis, administrative and payer logistics, operating room availability, or patient-related factors.^{14,25,26} Nevertheless, a key concern surrounding delayed ACLPR is the potential deterioration of ACL tissue quality over time, which could compromise repairability and increase the risk of failure.²⁷⁻²⁹ This is

particularly relevant given that it has been suggested that an intact synovial sheath may be associated with lower risk of failure after ACL repair.³⁰ In contrast, this must be balanced with performing surgery during the acute inflammatory phase, which has been posited to increase the risk of arthrofibrosis.^{22,31,32} Regardless, these concerns require further validation, as they contrast with multiple studies reporting low failure rates and favorable clinical outcomes after ACLPR even when performed beyond the traditionally defined “acute” window.^{1,11,18,33}

Given the paucity of literature concerning the potential importance of tissue integrity, surgical timing and clinical outcomes after ACLPR, additional data is warranted to help provide guidance for clinical decision making and whether a critical time window exists for performing ACLPR. As such, the purpose was to determine the association between surgical delay, ACL tissue quality, failure rates, and clinical outcomes at a minimum 2-year follow-up after arthroscopic ACLPR. It was hypothesized that surgical delay is not associated with intraoperative tissue quality and, consequently, does not significantly affect failure rates or clinical outcomes at a minimum 2-year follow-up following ACLPR.

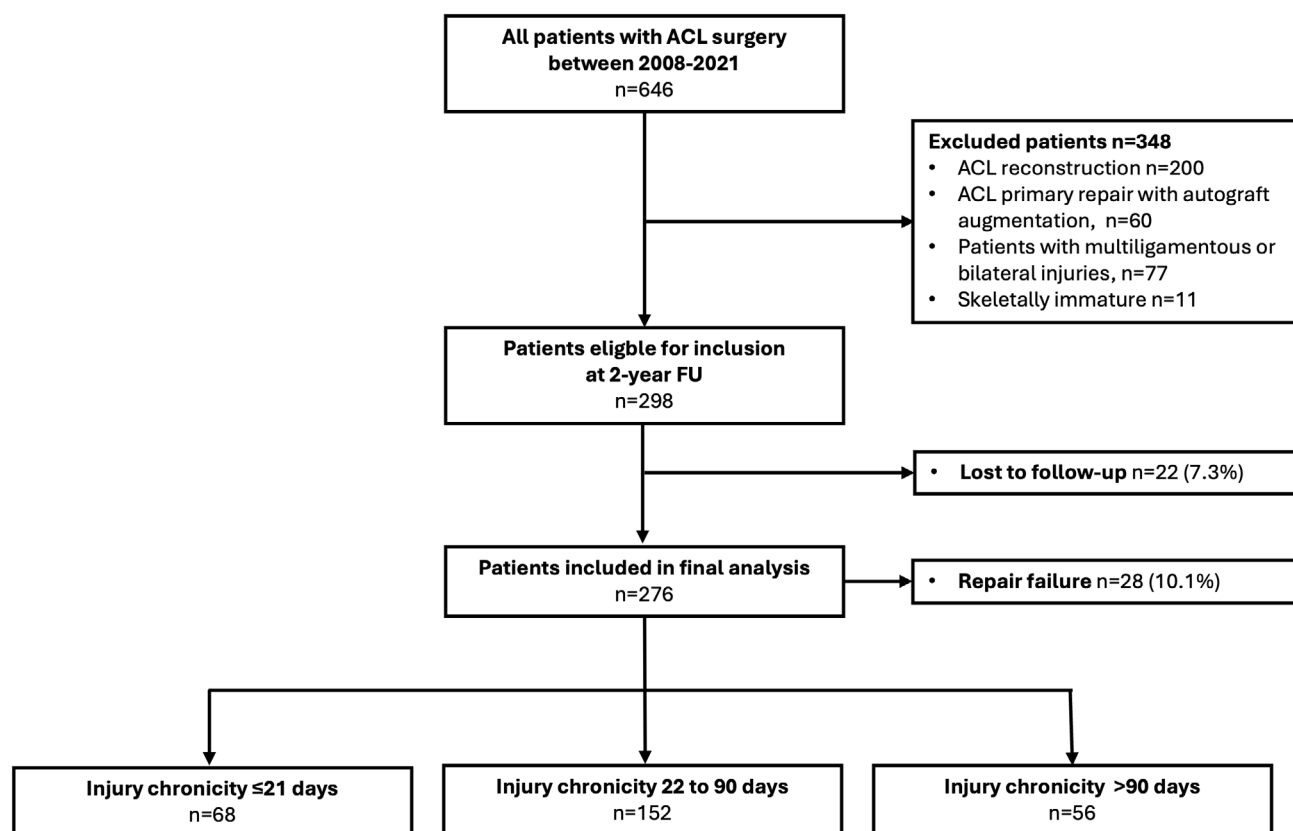


FIGURE 1 Study flow chart. (ACL, anterior cruciate ligament; n, number of patients.)

METHODS

Patient Selection and Study Setting

This study received Institutional Review Board approval prior to initiation (2017-0404). The study was performed according to the ethical standards in the 1964 Declaration of Helsinki and its later amendments or comparable ethical standards. Patients who underwent surgery for proximal, complete, isolated ACL injuries between January 2008 and October 2021 and were prospectively enrolled in an institutional registry met the inclusion criteria at minimum 2-year follow-up (Figure 1). Patients were excluded if they were skeletally immature, underwent ACLR or ACLPR with autograft augmentation, had ipsilateral multiligamentous knee injuries, had bilateral ACL injuries, or underwent extra-articular stabilization. Although type of repair (with or without suture augmentation), concomitant cartilage and meniscal injuries were considered during the indication process, in this cohort, none of these were felt to be absolute contraindications or exclusion criteria in this study. The surgical indication for ACLPR was based on clinical examination, including the presence of subjective instability, an anterior tibial translation side-to-side difference (ATT SSD) greater than 3 mm measured

using a Lachmeter (digital Rolimeter; Aircast Europa, Neubeuern, Germany) and magnetic resonance imaging confirmation of an ACL tear.³⁴⁻³⁶ The clinical decision to proceed with ACLPR followed the principles of the ACL Preservation First treatment algorithm^{35,37} and was confirmed intraoperatively based on tear type and tissue quality presentation. Patients with modified Sherman type I and II ACL tears^{35,38} and good to excellent tissue quality, defined as sufficient tissue integrity for intrasubstance suturing, were indicated for anatomic double suture anchor ACLPR.³⁹ Patients with nonrepairable tears, defined by insufficient remnant tissue length (for re-approximation to the native anatomic origin) or poor tissue quality, were treated with ACLR. ACLPR with all-soft tissue hamstring or quadriceps tendon autograft augmentation was performed when either the anteromedial or posterolateral bundle could be partially preserved and refixated in addition to the autograft reconstruction.^{35,40,41}

To assess the effect of surgical delay, patients were stratified into 3 groups according to time between injury and ACLPR:²⁷

- Acute: ≤ 21 days after injury
- Subacute: 22 to 90 days after injury
- Chronic: > 90 days after injury

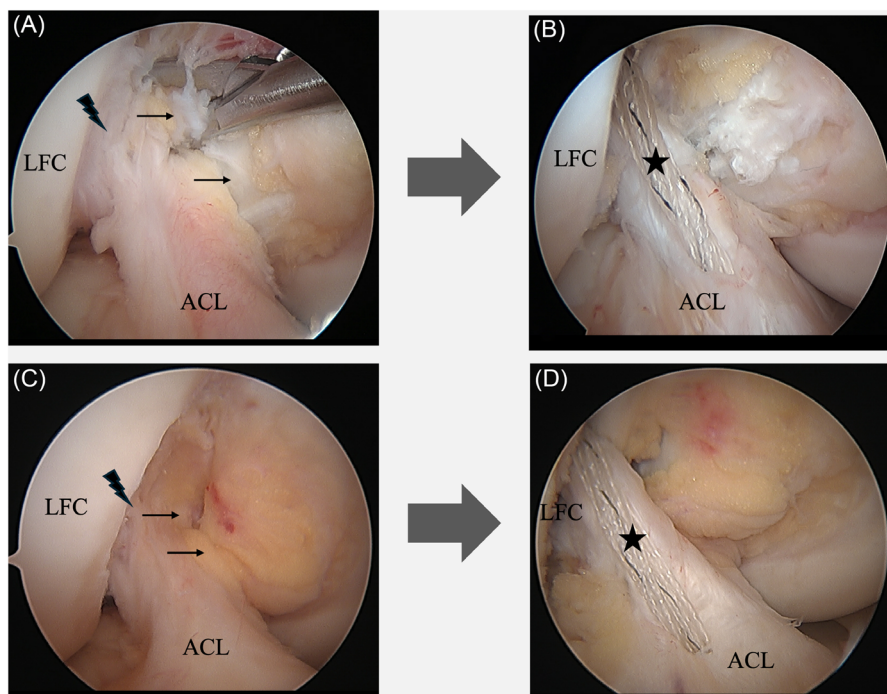


FIGURE 2 Arthroscopic images (anterolateral portal) showing 2 cases of chronic ACL injury and yet, type I tear location and excellent tissue quality with a broad stump and more than 50% remaining synovial sheath. (A) Patient 1, right knee, surgery 239 days post injury, arthroscopic evaluation of injury pattern, ACL gets released from PCL using arthroscopic scissors. (B) Patient 1, right knee; final surgical result after double suture anchor repair with suture augmentation. (C) Patient 2, right knee; surgery 376 days post injury, arthroscopic evaluation of injury pattern, ACL scarred to the PCL. (D) Patient 2, right knee, final surgical result after double suture anchor repair with suture augmentation. (ACL, anterior cruciate ligament; LFC, lateral femoral condyle; ←, ACL scarred to PCL; ↘, ACL tear location; ★, suture augmentation.)

Treatment Algorithm and Surgical Technique

All surgeries were performed by the senior author (G.S.D.), a fellowship-trained sports medicine orthopaedic surgeon, following informed consent from all patients. In case of delayed ACLPR (subacute or chronic injury), the ACL remnant was frequently found scarred to the posterior cruciate ligament (PCL), intercondylar notch wall, or flipped anteriorly.⁴² If the tear type and tissue quality met the defined criteria for ACLPR, the ACL was carefully released using an arthroscopic scissor as needed (Figure 2).⁴² Arthroscopic anatomic ACLPR was performed using dual suture anchor fixation (4.75 mm BioComposite SwiveLock suture anchor, Arthrex, Naples, FL, USA).³⁹ In brief, both ACL bundles were sutured using a Bunnell-type pattern (anteromedial bundle, 3 to 4 passes; posterolateral bundle, 2 to 3) with a Scorpion suture passer (Arthrex) and fixed independently using the aforementioned suture anchors. Beginning in 2015, suture augmentation using FiberTape (Arthrex) was selectively introduced for patients at higher risk of failure. This technique was later adopted for all patients. The augmentation suture was loaded into the anteromedial bundle suture anchor, passed through a 2.4 mm tibial drill hole at the anterior one-third of the distal ACL footprint, tensioned independently in full extension to avoid over-constraining the knee, and fixed with another suture anchor.⁴³

Rehabilitation

Full weight-bearing with unrestricted passive range of motion (ROM) as tolerated was permitted immediately after surgery for all patients that underwent isolated ACLPR. If a meniscal repair was performed concomitantly, weight-bearing was limited to toe-touch (20% weight bearing) with ROM 0 to 90 degrees for up to 4 weeks. A brace locked in extension was recommended for the first 2 to 4 weeks to prevent knee buckling when ambulating. Once patients could comfortably perform 20 consecutive straight leg raises without lag, the brace was unlocked, and gradually weaned until they achieved unrestricted walking.

Likelihood of ACLPR and Assessment of ACL Tissue Quality

Likelihood of ACLPR was defined by the proportion of patients who underwent ACLPR relative to the total number of patients treated for ACL injury in each specific cohort.

Irrespective of the clinical indication, which was primarily based on the structural integrity of the ACL tissue to hold sutures, and to further characterize tissue quality and adjust for potential confounders in the survival analysis, 2 evaluators (F.v.R.P., S.C.R.) independently assessed the arthroscopic findings, including ligament tear location,^{35,38} synovial sheath integrity grade, and rupture pattern.²⁶ ACL tear location was defined according to the modified Sherman classification (tear location described as percentage of distal-proximal length; I, >90%; II, 75%-90%; III, 25%-75%; IV, 10%-25%; V, <10%).³⁵ Synovial sheath integrity was graded as grade 1 (completely intact), grade 2 (>50% intact), or grade 3 (<50% intact) and rupture patterns as grade 1 (1-bundle tear), grade 2 (2-bundle tear), or grade 3 (complex tear) (Figure 3).²⁶ Importantly, the term “bundle” does not refer to the anteromedial or posterolateral functional bundles, as only complete ACL tears were included; instead, it describes the specific macroscopic rupture pattern of the ligament. This classification system has shown high inter-observer reliability for tear pattern (0.96) and synovial sheath integrity (0.90) and intra-observer reliability (0.74-0.94).

Clinical Outcome Assessment

Patients underwent routine postoperative follow-up at 1, 4, and 8 weeks, as well as at 3, 6, and 9 months, and 1 and 2 years. All clinical assessments were performed by the senior author (G.S.D.) and included ATT SSD measurements using the Lachmeter, ROM, as well as Lachmann and pivot shift grading. Patient-reported outcome measurements (PROMs) were also collected, including the subjective International Knee Documentation Committee (IKDC),⁴⁴ Lysholm score (Lysholm),⁴⁵ Forgotten Joint Score-12 (FJS-12),⁴⁶ ACL-Return to Sport after Injury (ACL-RSI) score,⁴⁷ and Tegner activity scale (Tegner).⁴⁸ Clinical study follow-up was not continued for patients that experienced repair failure since these patients were subsequently treated with revision to ACLR, non-operatively or with revision ACLPR⁴⁹ and therefore clinical outcome would not represent that outcome of ACLPR. Patient satisfaction was assessed based on the dichotomous Patient Acceptable Symptom State (PASS) anchor question: “Taking into account all the activities you have during your daily life, your level of pain, and also your functional impairment, do you consider that your current state is satisfactory?” Answers of “yes” to this question indicated subjective patient satisfaction, whereas answers of “no” indicated dissatisfaction.

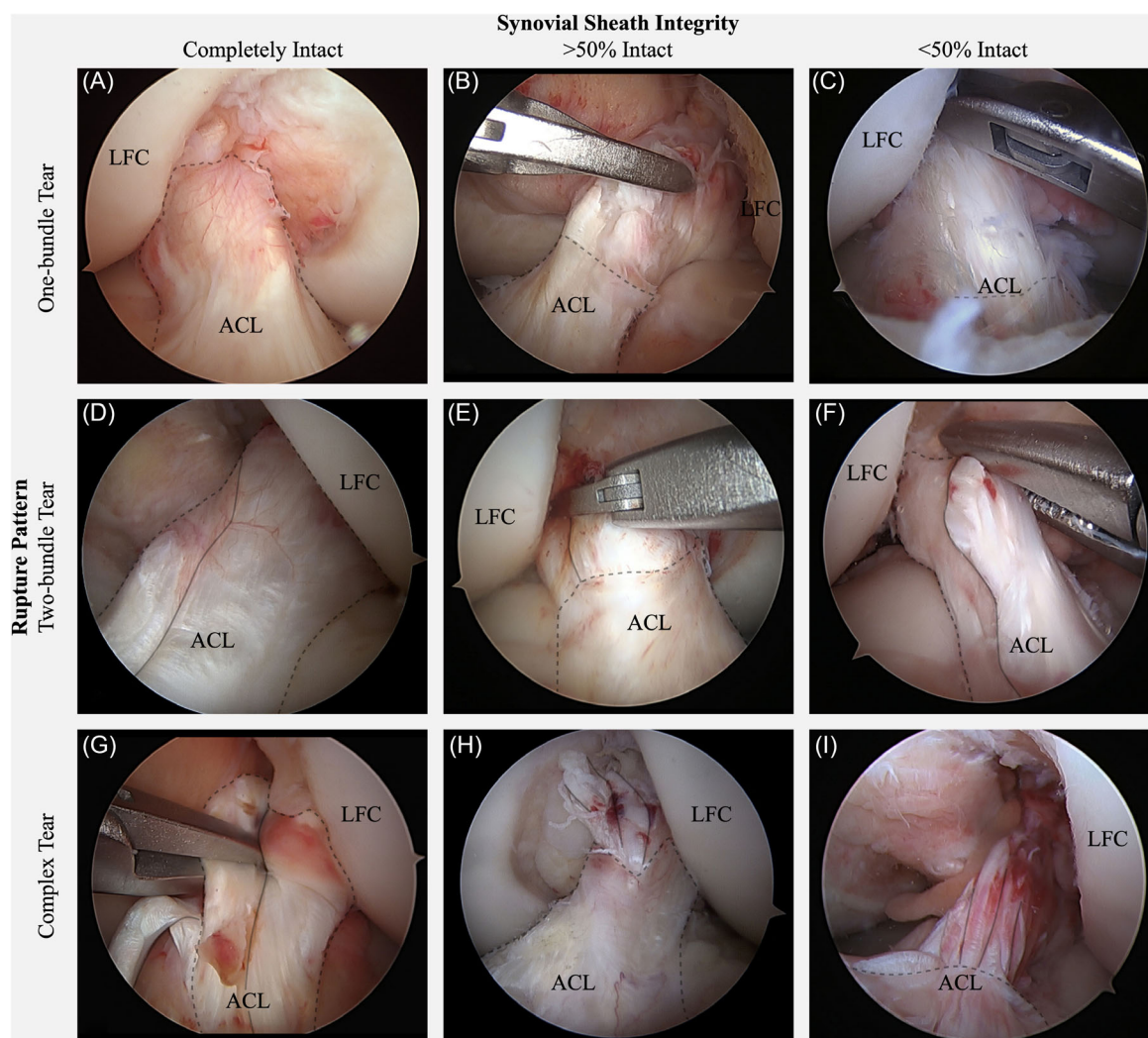


FIGURE 3 Arthroscopic images (anterolateral portal) showing cases of ACL injuries with modified Sherman type I or II tear location but varying tissue quality, defined by synovial sheath integrity (indicated by dashed line) and tear pattern (indicated by solid line). Importantly, the term “bundle” does not refer to the anteromedial or posterolateral functional bundles, as only complete ACL tears were included; instead, it describes the specific macroscopic rupture pattern of the ligament. (A) Right knee, 1-bundle tear with completely intact synovial sheath. (B) Left knee, 1-bundle tear with >50% intact synovial sheath. (C) Right knee, 1-bundle tear but <50% intact synovial sheath and exposed ligament fibers; (D) Left knee, 2-bundle tear (clearly separated after mobilization of the ACL) with completely intact synovial sheath. (E) Right knee, 2-bundles tear (1 bundle hold with grasper) and >50% intact synovial sheath. (F) Right knee, 2-bundles tear with <50% intact synovial sheath (anterior part of ACL hold with grasper without synovial sheath). (G) Left knee, complex tear pattern but synovial sheath completely intact. (H) Left knee, particularly proximal complex tear pattern with >50% intact synovial sheath. (I) Left knee, complex tear pattern with <50% intact synovial sheath. (ACL, anterior cruciate ligament; LFC, lateral femoral condyle; ←, limit of synovial sheath.)

Outcome Measures

Primary outcome measures included failure defined as objective laxity (ATT SSD ≥ 3 mm, grade ≥ 2 Lachman, and/or grade ≥ 2 pivot shift test) or subjective instability with confirmed re-rupture on magnetic resonance imaging.

Secondary outcome measures comprised reoperation rates, clinical outcomes (objective ATT SSD, negative Lachmann, and pivot shift rates), as well as PROMs

(IKDC, Lysholm, FJS-12, ACL-RSI, and Tegner) and PASS threshold achievement.

Statistical Analysis

A priori sample size estimation was based on detecting an absolute difference of 10 percentage points in ACLPR failure rates between the 3 groups (acute, subacute, and chronic ACLPR). A total sample of approximately 240 patients (equal

sized groups) was required to achieve 80% power at a 2-sided α level of 0.05 using a chi-square test for 3 proportions. Normality of distribution of the samples was tested with Shapiro-Wilk test. Normality distributed data in this study are expressed as means with standard deviation or median and interquartile range when appropriate. Two-way analysis of variance for nominal scaled data or Pearson's Chi-Square test for ordinal data was used ($P < .05$) to test for between-group differences in primary and secondary outcome measures. Regression analysis was conducted to evaluate the relationship between surgical delay and the likelihood of failure after ACLPR. Additionally, confounding variables (tear location, synovial sheath integrity, tear pattern, patient age, Tegner score) were evaluated in the survival analysis. For PASS achievement analysis, PASS was used as the binary outcome variable (0 = "no," 1 = "yes"). Receiver operating characteristic analyses were performed to quantify each PROM's (IKDC, Lysholm, FJS-12, and ACL-RSI) discriminatory capacity for identifying PASS status. Area under the curve values were calculated with standard nonparametric methods. Optimal thresholds were derived using Youden's J statistic, which maximizes the sum of sensitivity and specificity. Patients were classified as "passing" when their scores met or exceeded the derived threshold. Analyses included all individuals with complete PROM and PASS data. Significance comparing achieving versus not achieving the

PASS threshold determined using the Mann-Whitney *U*-test. Sex-stratified analyses were carried out to evaluate potential differences in clinicodemographic and outcome measures, and to assess whether sex acted as a confounder for ACLPR failure in cox and regression analyses. Statistical analyses were performed by using BlueSky Statistics (BlueSky Statistics, 2024 BlueSky Statistics Version 10.3.4, R package version 8.95, 2024, Chicago, USA) with support of the institutional biostatistics institute.

RESULTS

Baseline Demographics and Clinical Characteristics

Of the 646 patients who underwent surgery for complete, isolated ACL injuries between January 2008 and October 2021, 298 patients met the inclusion criteria at minimum 2-year follow-up. Of 276 included patients (mean follow-up was 2.9 ± 1.0 years [range, 2.0-6.5 years]; mean age, 39.7 ± 10.7 years; 50.3% female; preoperative Tegner, 6.4 ± 1.5), 68 patients (24.6%) underwent acute, 152 (55.1%) subacute, and 56 (20.3%) chronic ACLPR. A total of 22 patients (7.4%) could not be reached and were lost to follow-up. A detailed overview of baseline demographic and clinical characteristics is provided in Table 1.

TABLE 1 Baseline Demographic and Clinical Characteristics

	Acute ACLPR n = 68	Subacute ACLPR n = 152	Chronic ACLPR n = 56	P Value
Follow-up, y	2.9 ± 1.0	3.0 ± 0.9	2.9 ± 1.0	.72
Sex, Female, n (%)	37 (54.4)	80 (52.6)	22 (39.3)	.17
Age, y	41.0 ± 10.0	39.2 ± 1.9	39.5 ± 11.1	.51
Surgical Delay, d	16.0 (12.0-18.0)	39.0 (29.8-55.0)	191.0 (111.5-331.5)	<.01
BMI	25.1 ± 3.5	25.1 ± 3.9	25.6 ± 3.8	.71
Tegner Pre-injury	6.4 ± 1.2	6.5 ± 1.5	6.3 ± 1.9	.70
ACLPR + SA, n (%)	52 (77)	119 (78)	36 (64)	.11
Tear Location,* n (%)	64	148	55	.19
Type 1	43 (67.1)	107 (72.3)	45 (81.8)	
Type 2	21 (32.8)	41 (27.8)	10 (18.2)	
Medial Meniscus Injuries, n (%)	13 (19)	38 (25)	16 (29)	.45
Lateral Meniscus Injuries, n (%)	26 (38)	64 (42)	24 (43)	.84
Chondral Injuries, n (%)	19 (27.9)	42 (28.2)	14 (25.0)	.90

Note: Bold values denote statistical significance at $P < .05$.

ACLPR, anterior cruciate ligament primary repair; BMI, body mass index; d, days; n, number of patients; SA, suture augmentation; y, years.

*Tear location according to modified Sherman classification.^{35,38}

Likelihood of ACLPR and Assessment of ACL Tissue Quality

Patients with acute injury had a 4.6 higher likelihood of undergoing ACLPR compared with chronic cases (odds ratio = 4.6; 95% confidence interval: 2.7-8.0; $P < .01$). Acutely treated patients could receive ACLPR in 70.8% of cases, while 6.2% needed autograft augmentation of ACLPR and 22.9% ACLR. Similarly, 54.7% of patients treated subacutely could receive ACLPR (ACLPR with autograft augmentation, 12.9%; ACLR, 32.4%), which shows an increased likelihood of ACLPR compared with chronic cases (odds ratio = 2.3; 95% confidence interval 1.5-3.4; $P < .01$). In the chronic setting, patients were less often treated with ACLPR (34.6%) and more often with ACLR (54.3%) and ACLPR with autograft augmentation in 11.1%.

Synovial sheath integrity ($P = .40$) and rupture pattern ($P = .07$) did not differ significantly between all 3 groups (Table 2).

Primary Outcomes

Overall, 28 patients (10.1%) experienced ACL reinjury of which 24 cases (86%) were traumatic at a mean 2.0 ± 1.3 years after ACLPR. Failure occurred in 7 patients (10.2%) following acute ACLPR, 17 patients (11.2%) following subacute ACLPR, and 4 patients (7.1%) following chronic ACLPR, with no significant between-group differences ($P = .76$). The majority of patients (17/28, 60.7%) were treated with revision to ACLR. Non-operative

treatment was performed in 28.6% (8/28) and revision ACL repair in 3/28 cases (10.7%).

Cox regression survival analysis over a follow-up period of 2 to 5 years revealed no significant differences in repair survival among the 3 groups (continuous surgical delay, $P = .57$) (Figure 4). Categorical analyses comparing acute versus subacute and chronic treatment showed no significant correlation between surgical delay and time to failure (acute vs subacute $P = .83$; acute vs chronic $P = .51$).

Risk Factor Analysis

After adjusting for potential confounders including age, preoperative activity level (Tegner), and synovial sheath integrity, no significant differences in failure risk were observed among the 3 groups. However, younger age was a significant and independent risk factor for repair failure ($P < .01$). Surgical delay did not significantly correlate with worse severity of synovial sheath injury (grade 2, $P = .79$; grade 3 $P = .06$).

Secondary Outcome Measures

A total of 4 patients sustained traumatic, sport-related ACL injury on the contralateral side which were managed successfully with ACLPR. Twenty-two patients required subsequent ipsilateral meniscal repair or other additional procedures (e.g., minor chondroplasty, lysis of adhesions, removal of hardware). The remaining patients experienced

TABLE 2 Assessment of ACL Tissue Quality

	Acute ACLPR	Subacute ACLPR	Chronic ACLPR	P Value
Synovial sheath integrity, n (%)	62	144	54	.40
Grade 1	36 (58.1)	87 (60.4)	39 (72.2)	
Grade 2	17 (27.4)	42 (29.2)	12 (22.2)	
Grade 3	9 (14.5)	15 (10.4)	3 (5.6)	
Rupture Pattern, n (%):	62	144	54	.07
1 Bundle	47 (75.8)	113 (78.5)	50 (92.6)	
2 Bundles	7 (11.3)	21 (14.6)	3 (5.6)	
Complex Tear	8 (12.9)	10 (6.9)	1 (1.9)	

Note: The term "bundle" does not refer to the anteromedial or posterolateral functional bundles, as only complete ACL tears were included; instead, it describes the specific macroscopic rupture pattern of the ligament.
 ACL, anterior cruciate ligament; ACLPR, anterior cruciate ligament primary repair; n, number of patients.

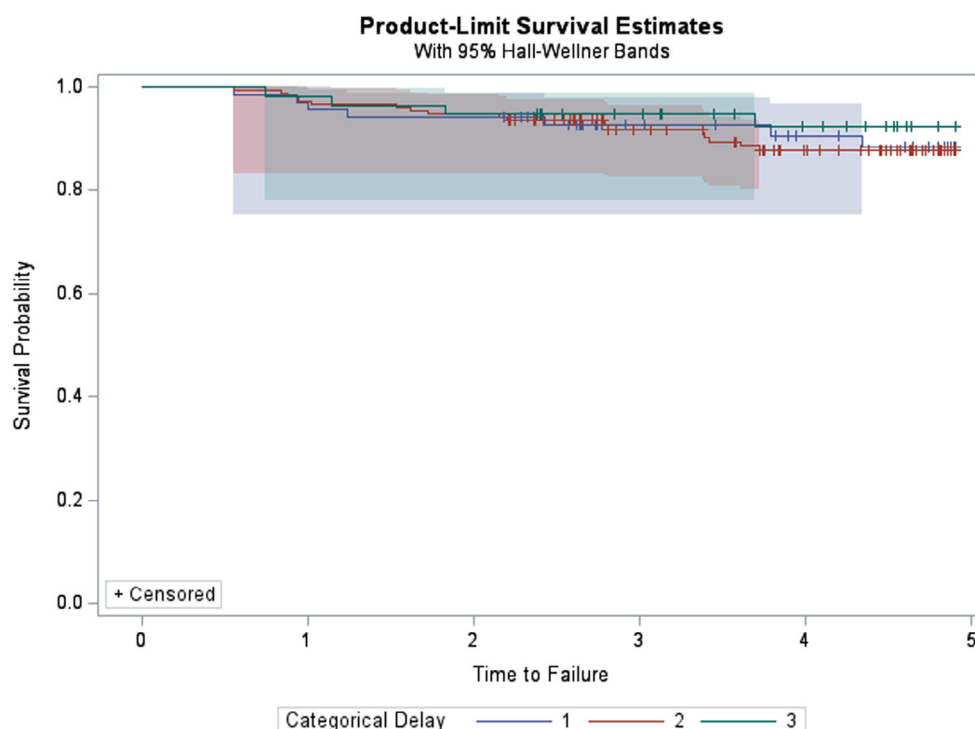


FIGURE 4 Censored survival analysis using cox regression in dependents of categorical surgical delay (acute, 1; subacute, 2; and chronic, 3). The graphic illustrates that there was no significant difference in survival among the 3 groups.

no procedure-related complications and did not require additional surgical procedures. No differences were found between the 3 groups regarding ATT SSD ($P = .90$), Lachmann test ($P = .36$), or Pivot shift test ($P = .21$), while all but 1 patient reached full ROM (Table 3).

PROMs were available in 241 out of 248 cases (97.2%) at 2-year follow-up (Table 4). On average all patients experienced significant improvements in the IKDC, Lysholm, Tegner, FJS-12, and ACL-RSI, which did not differ significantly between all 3 groups (all $P > .28$).

All PROMs showed strong discrimination for PASS status (Table 5). Area under the curve values ranged from 0.93 to 0.97, indicating excellent performance across instruments. The majority of patients met the PASS thresholds for all evaluated PROMs (all $P < .01$), including the subjective IKDC (84.7%), Lysholm (83.3%), FJS-12 (87.3%), and ACL-RSI scale (88.5%). PASS achievement was consistently high across all delay categories, with no significant differences between acute ACLPR, subacute ACLPR, and chronic ACLPR (Table 6). For IKDC, Lysholm, and FJS-12, PASS rates ranged from 81% to 88% across groups (all $P > .56$). ACL-RSI showed a similar pattern, with PASS attained by 87.5% of acute, 91.4% of subacute, and 82.2% of chronic patients ($P = .051$).

Sex-Stratified Analysis

Females exhibited a significantly lower body mass index (24.0 ± 3.7 vs 26.5 ± 3.5 ; $P < .01$) and a lower rate of lateral meniscus injuries (35.3% vs 47.4%; $P = .04$), whereas all other baseline demographic and clinical characteristics were comparable between sexes (all $P > .05$). Sex did not significantly influence primary outcomes (male vs female: ACLPR failure, $P = .10$; synovial sheath integrity, $P = .98$; rupture pattern, $P = .63$), reoperations, or clinical outcomes (all $P > .05$). Particularly, sex was not a significant confounder for ACLPR failure and therefore excluded from the final cox and logistic regression analysis. IKDC scores were significantly higher in males (90.1 ± 9.7 vs 87.3 ± 11.9 ; $P = .049$), while all other PROMs were similar (male vs female: Lysholm, 93.1 ± 11.4 vs 90.9 ± 12.1 , $P = .15$; Tegner postoperative, 6.1 ± 1.6 vs 5.8 ± 1.5 , $P = .14$; FJS-12, 87.4 ± 14.8 vs 82.6 ± 21.3 , $P = .054$; ACL-RSI, 71.4 ± 23.5 vs 74.5 ± 22.5 , $P = .32$). Although overall PASS rates were high in both sexes, men showed nonsignificant higher PASS achievement. For Lysholm, 88.5% of males and 78.7% of females achieved PASS ($P = .06$), and for FJS-12, 90.7% of males and 84.2% of females met the PASS

TABLE 3 Reoperations and Clinical Outcomes

	Acute ACLPR n = 68	Subacute ACLPR n = 152	Chronic ACLPR n = 56	P Value
Re-operation, n (%)	7 (10.3)	10 (6.6)	5 (8.9)	.62
Medial Meniscus	5 (7.3)	2 (1.3)	3 (5.4)	.08
Lateral Meniscus	1 (1.5)	2 (1.3)	1 (1.8)	.95
Minor Chondroplasty	1 (1.5)	0 (0)	2 (3.6)	.10
Lysis of Adhesions	1 (1.5)	2 (1.3)	0 (0)	.57
Removal of Hardware	0 (0)	2 (1.3)	0 (0)	.27
Time of Reoperation, y	1.5 ± 1.2	2.0 ± 1.3	3.1 ± 1.7	.19
Contralateral ACL Injury, n (%)	0 (0)	3 (2.0)	1 (1.8)	.51
ATT SSD (mm)	1.0 ± 1.5*	1.0 ± 1.1 [†]	1.1 ± 1.4 ^{††}	.90
Negative Lachmann Test, n (%)	50 (92.6)	88 (89.8)	31 (81.6)	.36
Negative Pivot Shift Test, n (%)	49 (90.7)	90 (91.8)	34 (89.5)	.21
Range of Motion, Angular Degree				
Knee Extension (°)	0 ± 0	0 ± 0	0 ± 2	.11
Knee Flexion (°)	139 ± 7	140 ± 5	140 ± 5	.76

Note: Outcomes were assessed only for patients with no reinjury.

ACLPR, anterior cruciate ligament primary repair; ATT SSD, anterior-tibial translation side-to-side difference; n, number; ROM, range of motion; y, years.

*Reported in 40 (58%) patients.

[†]Reported in 70 (46%) patients.

^{††}Reported in 28 (50%) patients.

TABLE 4 Patient-Reported Outcome Measures

	Acute ACLPR n = 61	Subacute ACLPR n = 132	Chronic ACLPR n = 48	P Value
Subjective IKDC	89.0 ± 10.9*	87.5 ± 13.4**	88.8 ± 11.0***	.72
Lysholm	92.6 ± 10.4	92.5 ± 9.7	89.5 ± 17.3	.28
Tegner Score Post-op	5.9 ± 1.5	6.0 ± 1.6	6.0 ± 1.7	.80
Tegner Score Diff. (Pre vs Post)	−0.5 ± 1.3	−0.4 ± 0.9	−0.3 ± 1.1	.58
FJS-12	83.4 ± 21.0 [†]	85.5 ± 17.3 ^{††}	84.8 ± 19.8 [§]	.80
ACL-RSI	76.0 ± 24.5	69.8 ± 25.2 [¶]	72.2 ± 22.0 [#]	.31

ACL-RSI, Anterior Cruciate Ligament-Return to Sport after Injury; ACLPR, anterior cruciate ligament primary repair; FJS-12, Forgotten Joint Score-12; IKDC, International Knee Documentation Committee; Lysholm, Lysholm score.

*Reported in 58 patients.

**Reported in 129 patients.

***Reported in 48 patients.

[†]Reported in 56 patients.

^{††}Reported in 127 patients.

[§]Reported in 45 patients.

^{||}Reported in 53 patients.

[¶]Reported in 122 patients.

[#]Reported in 45 patients.

TABLE 5 PASS Thresholds at Minimum 2-Year Follow-up

	PASS Threshold	AUC (95% CI)	Achievement Rate, n (%)	P Value*
Subjective IKDC	77.6	0.97 (0.95-0.99)	199 (84.7)	< .01
Lysholm	84.5	0.93 (0.88-0.99)	200 (83.3)	< .01
FJS-12	61.5	0.94 (0.89-0.99)	199 (87.3)	< .01
ACL-RSI	40.8	0.97 (0.94-0.99)	192 (88.5)	< .01

Note: Significant values are in bold.
 ACL-RSI, ACL-Return to Sport after Injury; AUC, area under the curve; FJS-12, Forgotten Joint Score-12; Subjective IKDC, Subjective International Knee Documentation Committee; Lysholm, Lysholm score; PASS, Patient Acceptable Symptom State.
 *Significance comparing achieving versus not achieving the PASS threshold.

TABLE 6 PASS-Achievement by Surgical Delay at Minimum 2-Year Follow-up

	Acute ACLPR	Subacute ACLPR	Chronic ACLPR	P Value*
Subjective IKDC	51 (86.4)	111 (86.0)	38 (80.9)	.56
Lysholm	50 (83.3)	111 (84.1)	39 (81.2)	.90
FJS-12	48 (84.2)	109 (88.6)	42 (87.5)	.68
ACL-RSI	49 (87.5)	106 (91.4)	37 (82.2)	.05

ACLPR, anterior cruciate ligament primary repair; ACL-RSI, ACL-Return to Sport after Injury; FJS-12, Forgotten Joint Score-12; Lysholm, Lysholm score; PASS, Patient Acceptable Symptom State; Subjective IKDC, Subjective International Knee Documentation Committee.
 *P values reflect group differences comparing acute versus subacute versus chronic ACLPR in PASS achievement.

threshold ($P = .053$). No significant sex-related differences were observed for IKDC (86.6% vs 82.9%; $P = .39$) or ACL-RSI (89.7% vs 87.3%; $P = .74$).

DISCUSSION

The most important finding of this study was that surgical delay was not significantly associated with synovial sheath integrity or rupture pattern, failure rates, or clinical outcomes at short-term follow-up after ACLPR. In this cohort, the likelihood of performing ACLPR varied with surgical timing, yet injury chronicity did not affect arthrofibrosis rates, failure rates, or PROMs. Notably, ACLPR remained feasible across a broad range of time points, indicating that timing alone does not determine the success of ACLPR when tissue quality is preserved. These results further challenge the existing belief, supported by earlier studies,^{14,27} that ACLPR should only be performed within 4 weeks of injury.

Acute treatment is most commonly defined as occurring within 21 days (range: 15-28) post-injury.^{8,14-17,25} Due to delay in diagnosis, administrative and hospital logistics, and payer utilization approval, as well as a significant risk for arthrofibrosis following acute ACLR,^{22,31,32} performing

surgery within the acute phase is often not feasible in clinical practice leading to subacute treatment.^{50,51} In the current study, performing ACLPR within subacute and chronic timeframes were showed to be viable treatment options with acceptable failure and reoperation rates, preserved objective stability, and significant improvements in clinical outcome measures. This finding is clinically important as data from this study may encourage surgeons to consider proceeding with ACLPR for appropriately selected patients with proximal tear location and sufficient tissue quality that present in the subacute or chronic state after ACL injury.

Tissue quality did not differ significantly between the 3 groups. Of note, there was a higher prevalence of modified Sherman type I ACL tears with preserved synovial sheaths and more simple tear patterns in the chronic group, which may be important for the healing potential of the ACL.^{30,52} An often mentioned argument against delayed ACLPR is the assumption that ACL tissue quality may deteriorate over time.²⁷⁻²⁹ Murray et al. have shown in animal studies, due to prevention of clot formation,²⁸ that the ACL stumps retract over time, which may be most relevant for midsubstance tears.⁵³ If the tibial ACL remnant is flipped anteriorly, prolonged displacement can render ACLPR unfeasible due to ligament shortening.²⁹ However, in cases of proximal ACL tears, the tibial remnant frequently

adheres to the PCL, which prevents retraction, thereby maintaining the feasibility of ACLPR.^{42,53,54} Lo et al. reported that attachment of the ACL to the PCL was observed in 72% of the cases.⁵⁵ Crain et al. showed that this scarring may contribute to a degree of stability, which could explain the success of non-operative treatment in select cases.⁵⁶ The applicability of the current findings to modified Sherman types III-V is likely limited. For mid-substance and distal ACL tears, ACLPR is constrained by less robust tissue quality and more challenging biomechanics, and, apart from Bridge-Enhanced ACL Restoration, current evidence supporting repair in these tear patterns remains sparse.⁵⁷⁻⁶¹ Therefore, our results should not be directly extrapolated to Sherman III-V tears, in which ACLR will often remain the preferred treatment. Furthermore, although revision ACL repair, as showed in 3 cases in this cohort, may be feasible, such as recurrent proximal avulsions with excellent tissue quality, it has only been described in isolated case reports and should therefore be reserved for highly selected patients.⁴⁹

The synovial sheath protects the ACL from degradative effects of the synovial environment.^{52,62} Ateschrang et al. reported a significantly lower failure rate after dynamic intraligamentary stabilization in the case of 1 bundle tears with an intact synovial sheath compared with 2- or more-part injuries (4% vs 26.9% and 27.3%).³⁰ The importance of the combined factors of tear location, rupture pattern, and synovial sheath integrity for ACL injuries was described by Henle et al.²⁶ It can be proposed that those factors may play a more critical role in determining eligibility for ACLPR than the surgical delay.¹⁸ Since magnetic resonance imaging analysis does not always allow accurate assessment of tissue quality, diagnostic arthroscopy prior to treatment decision (graft harvesting for ACLR vs ACLPR) is crucial.¹⁴

Another frequently cited argument against delayed surgical repair of ACL injuries is the potential occurrence of secondary complications, particularly meniscal tears, due to chronic instability.¹⁹⁻²³ Significantly improved IKDC scores have been observed after early treatment of ACL injuries with concomitant meniscal injury,⁶³ while delayed treatment may decrease the possibility for meniscus repair.⁶⁴ Although the present study showed that chronic ACLPR can yield satisfactory results, early surgery is still generally advised to increase the likelihood of repair and prevent secondary cartilage or meniscal injuries.^{21,63,65} A commonly raised concern is that early surgery may increase the risk of arthrofibrosis.^{22,31,32} This study found no increased incidence of arthrofibrosis following acute ACLPR, with all 3 groups showing a low incidence including preservation of full ROM. In the current study, ACLPR was more feasible in the acute setting based on the higher percentage of repairable cases in this phase, suggesting that

earlier treatment may not only be protective against secondary injuries, but allow for a greater proportion of ACL tears to be repaired in this phase due to preserved synovial sheath integrity. Furthermore, the current study does not aim to advocate for delayed ACLPR despite showing feasibility; rather, it highlights that in cases where a chronic ACL injury is already present, ACLPR remains a viable option and should not be categorically excluded.

One consideration is whether patients treated with delayed ACLPR already adapted to functioning with an unstable knee, potentially contributing to a higher success rate after surgery. However, patients undergoing chronic ACLPR typically attempt non-operative treatment first, which is perceived as a reasonable approach in certain patient cohorts (optional delayed surgical treatment),^{66,67} but experienced persistent subjective instability. Consequently, as ACLPR can address symptoms of instability sufficiently, it should be considered as a viable treatment option for those patients with proximal tears in which the tissue length and quality is preserved. The failure rate of 7.1% in the context of a high proportion of patients meeting a clinically acceptable symptom state (PASS rates > 80%) emphasizes the value of ACLPR as a potential treatment option. This study contributes additional data to help refine the evolving indications for ACLPR, highlighting that one of the key indication criteria—acute timing of ACLPR—may unnecessarily exclude a substantial number of patients who could still be suitable candidates if other factors, such as a proximal tear location and good to excellent tissue quality, are present.

Limitations

This study has several limitations. First, the retrospective study design and the high median age of the patients may limit the generalizability of the findings.^{11,14} Second, the groups were unevenly distributed, with a disproportionately larger subacute cohort, which may have reduced the statistical power to detect small differences (risk for type II error) between groups (comparison of surgical delay groups and sex specific analysis). Furthermore, propensity matching to reduce treatment selection bias was not feasible, and the low number of ACLPR failures may have led to overfitting of the regression model. Third, given the absence of preoperative, baseline PROM data, within-patient change-based minimal important difference could not be robustly estimated. Fourth, intra-operative treatment decisions to perform ACLPR were made by an experienced surgeon, which introduces selection bias and limits external validity of these findings. Fifth, the underlying biological mechanisms that foster

synovial sheath integrity and ACL healing remain unknown. Sixth, the impact of coronal and sagittal deformity was not investigated.

CONCLUSIONS

Injury chronicity did not adversely affect failure rates or clinical outcomes at minimum 2-year follow-up after ACLPR. Therefore, in the case of a proximal tear location and sufficient tissue quality, surgical delay alone should not be considered a contraindication for ACLPR.

DISCLOSURES

The authors (K.N.K., J.P.L., G.S.D.) declare the following financial interests/personal relationships which may be considered as potential competing interests: K.N.K. reports a relationship with AllaiHealth Inc that includes: consulting or advisory and stock options; and is an Editorial Board member of Arthroscopy. Given his role as editor, he had no involvement in the peer review of this article and had no access to information regarding its peer review. Full responsibility for the editorial process for this article was delegated to another journal editor. J.P.L.: is on the Editorial Board for Arthroscopy. Given his role as editor, he had no involvement in the peer review of this article and had no access to information regarding its peer review. Full responsibility for the editorial process for this article was delegated to another journal editor. G.S.D. reports a relationship with Zimmer Biomet that includes: consulting or advisory and equity or stocks; reports a relationship with Miach Orthopaedics that includes: consulting or advisory, stock options, and funding grants; has patent with royalties paid by Arthrex and Zimmer Biomet; reports a relationship with OSSIO Inc. that includes: consulting or advisory and stock options. The other authors (M.M.M., S.C-R., F.R-P., G.C.D., F.M.T., R.J.O.) declare that they have no known competing financial interests or personal relationships that could have appeared to influence the work reported in this paper.

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