



Title	Double-bundle anterior cruciate ligament reconstruction using autologous hamstring tendon hybrid grafts in a patient with hypermobile Ehlers-Danlos Syndrome : A case report
Author(s)	Hishimura, Ryosuke; Kondo, Eiji; Matsuoka, Masatake; Iwasaki, Koji; Kawaguchi, Yasuyuki; Suzuki, Yuki; Onodera, Tomohiro; Momma, Daisuke; Iwasaki, Norimasa
Citation	Knee, 35, 81-86 https://doi.org/10.1016/j.knee.2022.02.005
Issue Date	2022-03
Doc URL	http://hdl.handle.net/2115/88229
Rights	© 2022, Elsevier. Licensed under the Creative Commons Attribution-NonCommercial-NoDerivatives 4.0 International http://creativecommons.org/licenses/by-nc-nd/4.0/
Rights(URL)	http://creativecommons.org/licenses/by-nc-nd/4.0/
Type	article (author version)
File Information	Knee 35 81-86.pdf



[Instructions for use](#)

1 **Double-bundle anterior cruciate ligament reconstruction using autologous hamstring**
2 **tendon hybrid grafts in a patient with hypermobile Ehlers-Danlos Syndrome: a case**
3 **report**

4
5 Ryosuke Hishimura¹, MD, PhD, Eiji Kondo², MD, PhD, Masatake Matsuoka¹, MD, PhD,
6 Koji Iwasaki³, MD, PhD, Yasuyuki Kawaguchi⁴, MD, PhD, Yuki Suzuki¹, MD, PhD,
7 Tomohiro Onodera¹, MD, PhD, Daisuke Momma², MD, PhD,
8 and Norimasa Iwasaki¹, MD, PhD

9
10 ¹ Department of Orthopaedic Surgery, Faculty of Medicine and Graduate School of Medicine,
11 Hokkaido University, North 15 West 7, Kita-Ku, Sapporo 060-8638, Japan

12 ² Centre for Sports Medicine, Hokkaido University Hospital, North 15 West 7, Kita-Ku,
13 Sapporo 060-8638, Japan

14 ³ Department of functional reconstruction for the knee joint, Hokkaido University, North 15,
15 West 7, Kita-ku, Sapporo, Hokkaido 060-8638, Japan

16 ⁴ Sports and Arthroscopy Center, Hanna Central Hospital, Ikoma, Nara, Japan

17
18 **Corresponding author**

- 19
- Name: Eiji Kondo, MD, PhD
 - Institutional address: Centre for Sports Medicine, Hokkaido University Hospital,
20 North 15 West 7, Kita-Ku, Sapporo 060-8638, Japan
 - Phone: (+81) –11–706–5937
 - Email: eijik@med.hokudai.ac.jp
- 21
22
23
24
25

26 **Declarations:**

27 • **Conflict of interest**

28 The authors declare no conflicts of interest associated with this study.

29 • **Funding**

30 We receive no specific funding from any funding bodies to carry out the work.

31 • **Ethical approval**

32 The protocol of this study was approved by the Institutional Review Board of our
33 medical institution.

34 • **Informed consent**

35 Informed consent for the use of medical information was obtained from all patients
36 in this study.

37 • **Acknowledgements**

38 Special thanks to the physical therapists of Hokkaido University Hospital for their
39 expertise.

40 • **Authors' contribution**

41 EK was involved in the design of the study, performed the clinical assessment,
42 analysis and interpretation of data, and drafted and revised the manuscript. RH and
43 MM were involved in the design of the study, assisted with data interpretation, and
44 revised the manuscript for important intellectual content. KI, YK, YS, TO, DM, and
45 NI were involved in the design of the study and the data acquisition and revised the
46 manuscript critically for important intellectual content. All authors have read and
47 approved the final manuscript.

48 • **Number of words for your article excluding abstract and references**

49 1759 words

50

51 **ABSTRACT**

52 **Background:** Ehlers-Danlos syndrome (EDS) is a connective tissue disorder characterized by
53 skin hyperextensibility, joint hypermobility, and tissue friability. Hypermobility type Ehlers-
54 Danlos syndrome (hEDS) is considered one of the EDS subtypes characterized by generalized
55 joint hypermobility. Although there have been a few case reports which described surgical
56 considerations for anterior cruciate ligament (ACL) reconstructions in patients with other types
57 of EDS, no reports have described those in patients with hEDS.

58 **Case presentation:** We report a case of ACL injury in an 18-year-old male patient with hEDS.
59 The patient was successfully treated with an anatomic double-bundle ACL reconstruction using
60 autologous hamstring tendon hybrid grafts which consist of hamstring tendons connected in a
61 series with commercially available polyester tape. The autogenous tendon portion of the
62 anteromedial and posterolateral bundles were composed of 4 and 2 strands of hamstring
63 tendons, respectively. After 2 weeks of knee joint immobilization, continuous passive motion
64 exercise of the knee joint and partial weight-bearing was allowed. A hinged knee brace was
65 used for a period of 5 months postoperatively. Second-look arthroscopy at 30 months showed
66 that the ACL graft had no laceration and an excellent coverage of the synovium. At 36 months
67 after surgery, the side-to-side differences in the anterior laxity was remarkably improved. The
68 operated knee showed negative Lachman test and had a full range of motion.

69 **Conclusions:** To the best of our knowledge, this represents the first report of anatomic double-
70 bundle ACL reconstruction in patients with hEDS and demonstrates excellent clinical and
71 functional outcomes.

72 **Introduction**

73 Ehlers-Danlos syndrome (EDS) is a connective tissue disorder characterized by skin
74 hyperextensibility, joint hypermobility, vascular fragility, and tissue fragility [1, 2]. The overall
75 incidence has been reported as approximately 1.0 per 5000 in the general population [2]. EDS
76 was classified into six types as the following; classical, hypermobile, vascular, kyphoscoliosis,
77 arthrochalasia, and dermatosparaxis [3].

78 The hypermobile EDS (hEDS) has been described in those with musculoskeletal disorders
79 including joint hypermobility, joint subluxations/dislocations, and ligament and tendon rupture
80 [1, 4]. There were some reports regarding joint laxity and pain in the patient with hEDS [5, 6].
81 Orthopedic surgeons may encounter joint trauma patients with hEDS due to joint instability
82 associated with inferior biomechanical properties of the innate collagen-containing structures.
83 According to previous studies, the treatment of knee injury in patients with hEDS can be
84 challenging [5, 6].

85 There have been only a few case reports which described the surgical considerations for
86 anterior cruciate ligament (ACL) reconstructions in patients with EDS [7-9]. However, it
87 remains controversial whether operative or conservative treatment of ACL injury yields a better
88 functional outcome. In particular, no reports have described surgical consideration and graft
89 selection for ACL reconstruction in patients with hEDS.

90 Recently, we encountered a case of ACL injury in a patient with hEDS. We successfully
91 treated the patient by double-bundle ACL reconstruction using hamstring tendon hybrid
92 autografts [10-13]. To the best of our knowledge, this is the first report of double-bundle ACL
93 reconstruction in patients with hEDS.

94

95 **Case report**

96 An 18-year-old male sustained an acute twisting injury to his left knee by slipping on ice. The
97 patient was first diagnosed by a pediatric physician as hEDS at 2-years-old with a history of
98 poor wound healing and elastic skin after inguinal hernia surgery. The patient at the age of 18
99 visited our affiliate hospital on the day of the accident. Physical examination showed knee
100 effusion, a positive Lachman test, and an anterior drawer test. Anteroposterior and lateral plain
101 radiographs of the left knee demonstrated no fracture (Fig.1A, B). Magnetic resonance imaging
102 (MRI) of the left knee detected a complete rupture of the ACL with a bone bruise of the lateral
103 femoral condyle (Fig.1C, D). Considering the inherent joint laxity in a patient with hEDS, there
104 was concern whether the ACL reconstruction could restore sufficient stability of the affected
105 knee. Immediately after injury, conservative treatment was chosen for the time being. Although
106 conservative treatment was continued by a rigid hinged knee brace for a period of 5 months,
107 the patient had repeated episodes of giving way in activities of daily living (ADL) as well as
108 participation with university theater club.

109 Six months after injury, the patient was referred to our hospital for surgical treatment. The left
110 knee showed not only a positive Lachman test and anterior drawer test but also a positive pivot-
111 shift test. The anterior laxity was measured using a Kneelax3 (MR Systems, Haarlem, The
112 Netherlands) with 30° of knee flexion under an anterior drawer force of 133 N. The anterior
113 laxity of the left knee was 18.4 mm, showing predominant laxity compared to that of the right
114 knee (the right side was 13.6 mm). The preoperative side-to-side differences in the anterior
115 laxity was calculated as + 4.8 mm. According to Beighton criteria [2], which is often used to
116 assess joint hypermobility, the total score was 6 points. Considering the predominant laxity of
117 the affected knee and the decrease in ADL, we made the decision to proceed with ACL
118 reconstruction of the left knee.

119 At the seven months after injury, anatomic double-bundle ACL reconstruction using
120 hamstring tendon hybrid autografts was performed with the trans-tibial tunnel technique [10,

121 11]. Arthroscopic examination showed complete rupture of the ACL without remnant tissue
122 (Fig. 2A). The ipsilateral semitendinosus and gracilis tendons were harvested. In the graft
123 preparation, the doubled semitendinosus and gracilis tendons were created as an anteromedial
124 (AM) bundle, and the doubled semitendinosus tendon was created as a posterolateral (PL)
125 bundle (Fig. 2C). Thus, the autogenous tendon portion of the AM and PL bundles was
126 composed of 4 and 2 strands of tendons, respectively. A commercially available polyester tape
127 (Leeds-Keio artificial ligament; Neoligaments, Leeds, England) was mechanically connected
128 in a series at an unlooped end of the folded tendon [12, 13]. An Endobutton CL BTB (Smith &
129 Nephew, Andover, MA) was attached to the looped end [14]. The diameter of the AM and PL
130 grafts were 7 mm and 6.5 mm, respectively.

131 To insert a guidewire for the tibial PL tunnel, we used a hole-in- one guide (Wire-navigator,
132 Smith & Nephew, Tokyo, Japan) [10]. Then, a guidewire was drilled in the tibia. A guidewire
133 for AM bundle reconstruction was inserted in the same manner. Two tibial tunnels were made
134 with a cannulated drill. To create two femoral tunnels, a guidewire was drilled at the femoral
135 attachment of the AM bundle by using an offset guide (Transtibial Femoral ACL Drill Guide;
136 Arthrex, Naples, FL,). Then, a guidewire was inserted at the PL bundle attachment on the femur.
137 Two femoral sockets were created with cannulated drills. Finally, the grafts for the AM and PL
138 bundles were fixed with 30 N tension to each graft using two tensiometers (Yufu Itonaga Co.,
139 Ltd., Tokyo, Japan) at 10° of knee flexion (Fig. 2B). The plain radiograph after ACL
140 reconstruction was shown in Fig. 3.

141 Considering its intrinsic joint laxity, accelerated rehabilitation was not applied to this patient.
142 After 2 weeks of knee joint immobilization, continuous passive motion exercise of the knee
143 joint and partial weight-bearing were allowed after 3 months. A hinged knee brace with 30°
144 extension block was applied for a period of 3 months after surgery. A knee brace was used for
145 a period of 5 months postoperatively. At 24 months after surgery, MRI showed a thick double-

146 bundle of the ACL graft (Fig. 4A, B). Thirty months later, second-look arthroscopy and staple
147 removal were performed. It showed that the ACL graft had no laceration and an excellent
148 coverage of the synovium (Fig. 4C) [15]. After 36 months postoperatively, the side-to-side
149 anterior laxity was improved from + 4.8 mm to - 4.2 mm. Lysholm knee score was 100 points.
150 The objective International Knee Documentation Committee was determined as grade A. Knee
151 injury and Osteoarthritis Outcome Score was 94.4, 92.8, 98.0, 85.0, and 87.5 in Pain, other
152 Symptoms, Function in daily living, Function in Sport and Recreation, and knee related Quality
153 of Life, respectively. The left knee showed a negative Lachman test, a negative pivot-shift test,
154 and had a full range of motion with no loss of hyperextension (5°). This patient subsequently
155 had no flexion contracture and could sit comfortably in the Japanese style (seiza). However,
156 there was early extension deficit during the first 6-8 weeks which can lead to a "more stable
157 knee", which is not always an advantage for the patient without knee joint laxity. The patient
158 had returned to a preinjury level of daily activity and participated in theater club activities.

159

160 **DISCUSSION**

161 We reported a case with ACL injury in the patient with hEDS. Anatomic double-bundle ACL
162 reconstruction using hamstring tendon hybrid autografts was performed in this case and had a
163 favorable clinical outcome as a short-term result.

164 There was concern about using an autograft-native tissue procedure, considering its intrinsic
165 joint laxity. Previous reports which demonstrated that patients with EDS showed spontaneous
166 tendon ruptures that pointed toward weaker tendon biomechanical properties [6, 16].
167 Considering the weakness of an autograft-native tissue procedure in patients with EDS, the use
168 of allografts could be a feasible option. However, in Japan, the use of allografts is severely
169 restricted.

170 In this case, we first considered the selection of a hamstring tendon, a bone-patellar tendon-

171 bone (BTB), and quadriceps tendon grafts as the autologous tendon graft. During the
172 remodeling phase, the structural properties of the graft deteriorate, and the reduced properties
173 are not completely restored even at 12 months after surgery [17-19]. Previous studies generally
174 confirmed that remodeling process of the graft was known to entail cellular repopulation,
175 revascularization and collagen deposition [20, 21]. Considering the graft remodeling phase,
176 each graft will be reconstructed with the similar ligamentization process. To overcome the
177 weakness of an autograft-native tissue, we focused on using hamstring tendon ‘hybrid’
178 autografts [22, 23]. It is well known that the weak points of a hamstring tendon graft fixed with
179 sutures to the bone are (1) low stiffness of the graft-suture-bone complex, (2) rapid relaxation
180 of graft tension after surgery, and (3) difficulty in tension control during graft fixation [23-25].
181 The “hybrid graft” was used to improve upon these weak points. Namely, the femur–hamstring
182 graft–tibia complex with polyester tapes involves the following advantages according to our
183 biomechanical studies [24, 26, 27]: (1) the maximal load of hamstring tendon hybrid graft was
184 significantly greater than that of the BTB grafts. (2) higher stiffness and stronger ultimate loads
185 than the hamstring complex with the suture method; (3) acceptably long and thick hybrid grafts
186 for double-bundle reconstruction can be fashioned by surgeons with a relatively short or thin
187 autogenous tendon; (4) the hybrid graft can be more resistance to graft tension relaxation, and
188 easily fixed to the bone, applying a tension quantified using a tensiometer to the graft.

189 Although there are no reports of the results of ACL reconstruction in hEDS, several papers
190 regarding the other types of EDS were reported. Choi et al. [8] reported that single-bundle ACL
191 reconstruction using Achilles tendon allograft was performed in a patient with the classical type
192 of EDS. At 2 years postoperatively, the patient continued to participate in regular preinjury
193 activities. Williams et al. [7] demonstrated the effectiveness of single-bundle ACL
194 reconstruction using the hamstring autograft combined with a Ligament Advanced
195 Reinforcement System (LARS) in a patient with an unknown type of EDS. At one year post

196 surgery, the patient had resumed sport activities.

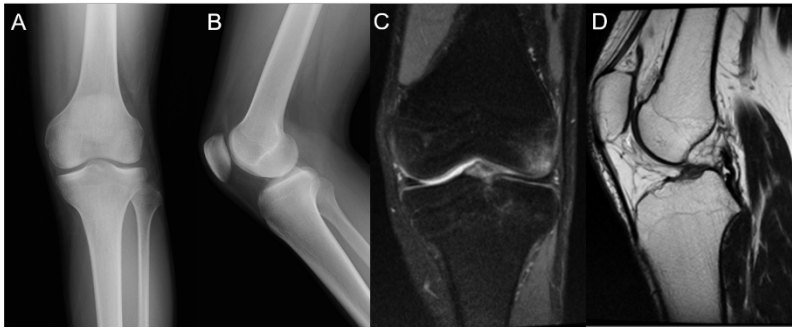
197 Several biomechanical studies have shown that double-bundle ACL reconstruction produces
198 better stability in the knee, compared with single-bundle reconstruction [28-30]. However,
199 controversy remains regarding the clinical utility of anatomic double-bundle reconstruction in
200 comparison with single-bundle reconstruction [31]. Recently, many comparative studies have
201 demonstrated significant superiority in anterior and/or rotatory stability of the knee after
202 double-bundle reconstruction [11, 32, 33]. Therefore, we considered that double-bundle ACL
203 reconstruction procedure with hamstring tendon hybrid autografts could obtain suitable
204 anterior and rotatory stability of the knee in a case of hEDS. A single-bundle reconstruction
205 with an extra-articular stabilization may be one option to this case [34].

206

207 **Conclusion**

208 To the best of our knowledge, this represents the first report of anatomic double-bundle ACL
209 reconstruction using hamstring tendon hybrid autografts in patients with hEDS and
210 demonstrates excellent clinical and functional outcomes.

211



212

Fig. 1. Preoperative plain radiograph and magnetic resonance imaging (MRI) scan at three months after injury.

(a) Anteroposterior and (b) lateral radiographs of the left knee demonstrating no fracture and avulsion.

(c) Coronal fat saturated proton density image of the left knee. Bone bruise of the lateral femoral condyle was detected. (d) Sagittal T2-weighted image of the left knee. The complete discontinuity of the ACL shows a full-thickness tear.

213

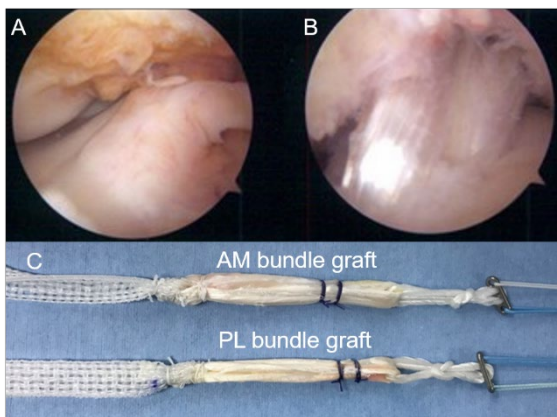
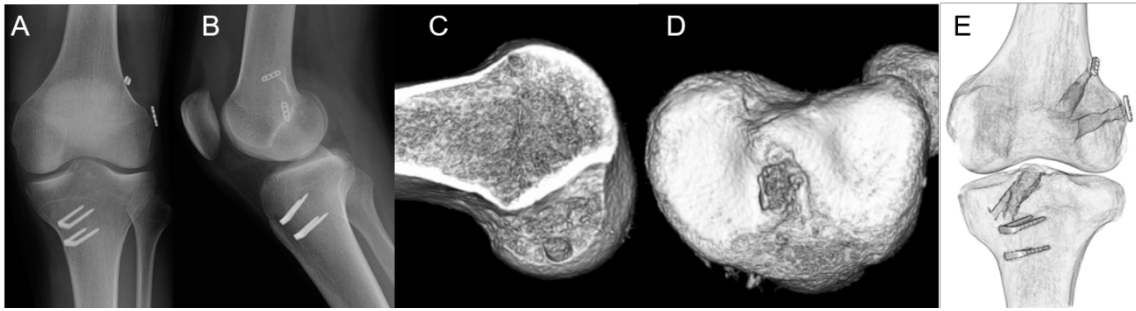


Fig 2. Arthroscopic observation of the ACL reconstruction and the intraoperative photograph of the hamstring tendon hybrid autograft.

(a) Arthroscopy showed complete rupture of the ACL without remnant tissue. (b) Two grafts transplanted across knee joint at time of surgery at 90° of knee flexion in arthroscopic view by use of lateral infrapatellar portal.

(c) AM and PL bundle grafts fashioned for anatomic ACL reconstruction. The tendon portion of the AM and PL bundles was composed of 4 and 2 strands of tendons, respectively.

214

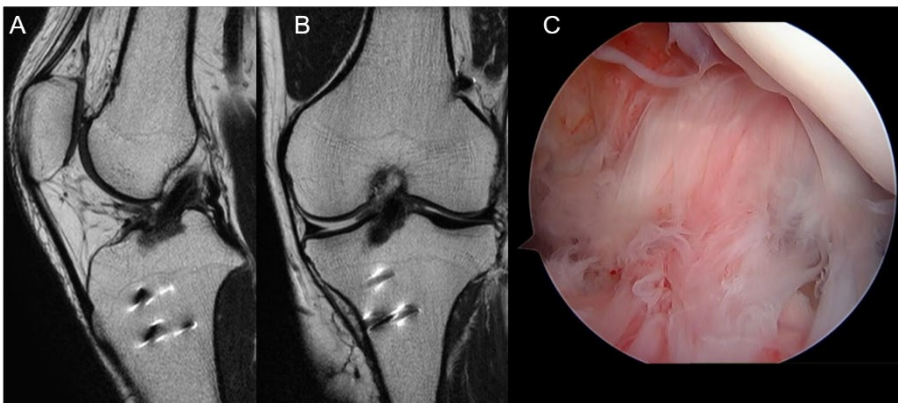


215

Fig. 3. Postoperative radiograph and imaging of computed tomography (CT) of the left knee. (a) Anteroposterior radiograph of the left knee joint. (b) Lateral view of the left knee joint. (c) Postoperative 3-dimensional CT image of the femur and (d) the tibia showed that the 2 tunnels were created at the expected positions. (e) The transparent 3-dimensional CT image of the left knee represents 2 tunnels intuitively.

216

217



218

Fig. 4. Magnetic resonance imaging (MRI) scan at 24 months postoperatively and intraoperative finding of second-look arthroscopic evaluation at 30 months postoperatively.

(a) Sagittal and (b) coronal T2-weighted image of the left knee showing the reconstruction to be a thick ACL graft.

(c) ACL graft had no laceration and was completely covered with the thin synovial and thick fibrous tissues.

219

220 **REFERENCES**

- 221 [1] Stanitski DF, Nadjarian R, Stanitski CL, Bawle E, Tsipouras P. Orthopaedic
 222 manifestations of Ehlers-Danlos syndrome. *Clin Orthop Relat Res* 2000(376):213-21.
 223 <https://doi.org/10.1097/00003086-200007000-00029>.
- 224 [2] Shirley ED, DeMaio M, Bodurtha J. Ehlers-Danlos Syndrome in Orthopaedics. *Sports*
 225 *Health: A Multidisciplinary Approach* 2012;4(5):394-403.
 226 <https://doi.org/10.1177/1941738112452385>.
- 227 [3] Beighton P, De Paepe A, Steinmann B, Tsipouras P, Wenstrup RJ. Ehlers-Danlos
 228 syndromes: revised nosology, Villefranche, 1997. Ehlers-Danlos National Foundation
 229 (USA) and Ehlers-Danlos Support Group (UK). *Am J Med Genet* 1998;77(1):31-7.
 230 [https://doi.org/10.1002/\(SICI\)1096-8628\(19980428\)77:1<31::AID-AJMG8>3.0.CO;2-O](https://doi.org/10.1002/(SICI)1096-8628(19980428)77:1<31::AID-AJMG8>3.0.CO;2-O) [pii]
 231 10.1002/(sici)1096-8628(19980428)77:1<31::aid-ajmg8>3.0.co;2-o.
- 232 [4] Tinkle B, Castori M, Berglund B, Cohen H, Grahame R, Kazkaz H, et al. Hypermobile
 233 Ehlers-Danlos syndrome (a.k.a. Ehlers-Danlos syndrome Type III and Ehlers-Danlos
 234 syndrome hypermobility type): Clinical description and natural history. *American Journal*
 235 *of Medical Genetics Part C: Seminars in Medical Genetics* 2017;175(1):48-69.
 236 <https://doi.org/10.1002/ajmg.c.31538>.
- 237 [5] Homere A, Bolia IK, Juhan T, Weber AE, Hatch GF. Surgical Management of Shoulder and
 238 Knee Instability in Patients with Ehlers-Danlos Syndrome: Joint Hypermobility Syndrome.
 239 *Clinics in Orthopedic Surgery* 2020;12(3):279. <https://doi.org/10.4055/cios20103>.
- 240 [6] Iacono V, Cigala F, Fazioli F, Rosa D, Maffulli N. Reconstruction of chronic patellar tendon
 241 tear with allograft in a patient with Ehlers-Danlos syndrome. *Knee Surg Sports Traumatol*
 242 *Arthrosc* 2009;18(8):1116-8. <https://doi.org/10.1007/s00167-009-1022-7>.
- 243 [7] Williams J, Hutt J, Rickman M. Anterior Cruciate Ligament Reconstruction in Ehlers-
 244 Danlos Syndrome. *Case Reports in Orthopedics* 2015;2015:1-3.
 245 <https://doi.org/10.1155/2015/160381>.
- 246 [8] Choi J, Naito K, Curry EJ, Li X. Anterior Cruciate Ligament Reconstruction With Achilles
 247 Tendon Allograft in a Patient With Ehlers-Danlos Syndrome. *Orthopaedic Journal of*
 248 *Sports Medicine* 2018;6(7):232596711878517. <https://doi.org/10.1177/2325967118785170>.
- 249 [9] Erdman MK, Warnick DE. Revision pediatric anterior cruciate ligament reconstruction
 250 after failure of iliotibial band technique treated with all-epiphyseal technique in a
 251 prepubescent with Ehlers-Danlos syndrome: a case report. *J Pediatr Orthop B*
 252 2017;26(5):470-6. <https://doi.org/10.1097/BPB.0000000000000298>.
- 253 [10] Yasuda K, Kondo E, Ichiyama H, Kitamura N, Tanabe Y, Tohyama H, et al. Anatomic
 254 reconstruction of the anteromedial and posterolateral bundles of the anterior cruciate
 255 ligament using hamstring tendon grafts. *Arthroscopy: The Journal of Arthroscopic &*
 256 *Related Surgery* 2004;20(10):1015-25. <https://doi.org/10.1016/j.arthro.2004.08.010>.
- 257 [11] Yasuda K, Kondo E, Ichiyama H, Tanabe Y, Tohyama H. Clinical Evaluation of Anatomic
 258 Double-Bundle Anterior Cruciate Ligament Reconstruction Procedure Using Hamstring
 259 Tendon Grafts: Comparisons Among 3 Different Procedures. *Arthroscopy: The Journal of*
 260 *Arthroscopic & Related Surgery* 2006;22(3):240-51.
 261 <https://doi.org/10.1016/j.arthro.2005.12.017>.
- 262 [12] Kondo E, Yasuda K, Miyatake S, Kitamura N, Tohyama H, Yagi T. Clinical comparison of
 263 two suspensory fixation devices for anatomic double-bundle anterior cruciate ligament
 264 reconstruction. *Knee Surg Sports Traumatol Arthrosc* 2011;20(7):1261-7.
 265 <https://doi.org/10.1007/s00167-011-1687-6>.
- 266 [13] Kondo E, Kitamura N, Onodera J, Yasuda K, Inagaki Y, Tanaka Y, et al. Prospective clinical
 267 comparisons of semitendinosus versus semitendinosus and gracilis tendon autografts for
 268 anatomic double-bundle anterior cruciate ligament reconstruction. *J Orthop Sci*
 269 2013;18(5):754-61. <https://doi.org/10.1007/s00776-013-0427-9>.
- 270 [14] Miyatake S, Kondo E, Tohyama H, Kitamura N, Yasuda K. Biomechanical evaluation of a
 271 novel application of a fixation device for bone-tendon-bone graft (EndoButton CL BTB) to
 272 soft-tissue grafts in anatomic double-bundle anterior cruciate ligament reconstruction.
 273 *Arthroscopy* 2010;26(9):1226-32. <https://doi.org/10.1016/j.arthro.2010.01.007>
 274 S0749-8063(10)00048-4 [pii].
- 275 [15] Kondo E, Yasuda K. Second-Look Arthroscopic Evaluations of Anatomic Double-Bundle
 276 Anterior Cruciate Ligament Reconstruction: Relation With Postoperative Knee Stability.

277 Arthroscopy: The Journal of Arthroscopic & Related Surgery 2007;23(11):1198-209.
278 <https://doi.org/10.1016/j.arthro.2007.08.019>.

279 [16] Moretti B, Notarnicola A, Moretti L, Garofalo R, Patella V. Spontaneous bilateral patellar
280 tendon rupture: a case report and review of the literature. *Chir Organi Mov* 2008;91(1):51-
281 5. <https://doi.org/10.1007/s12306-007-0009-0>.

282 [17] Butler DL, Grood ES, Noyes FR, Olmstead ML, Hohn RB, Arnoczky SP, et al. Mechanical
283 properties of primate vascularized vs. nonvascularized patellar tendon grafts; changes over
284 time. *J Orthop Res* 1989;7(1):68-79. <https://doi.org/10.1002/jor.1100070110>.

285 [18] Clancy WG, Jr., Narechania RG, Rosenberg TD, Gmeiner JG, Wisnefske DD, Lange TA.
286 Anterior and posterior cruciate ligament reconstruction in rhesus monkeys. *J Bone Joint
287 Surg Am* 1981;63(8):1270-84.

288 [19] Kondo E, Yasuda K, Katsura T, Hayashi R, Kotani Y, Tohyama H. Biomechanical and
289 Histological Evaluations of the Doubled Semitendinosus Tendon Autograft After Anterior
290 Cruciate Ligament Reconstruction in Sheep. *The American Journal of Sports Medicine*
291 2011;40(2):315-24. <https://doi.org/10.1177/0363546511426417>.

292 [20] Amiel D, Kleiner JB, Akeson WH. The natural history of the anterior cruciate ligament
293 autograft of patellar tendon origin. *Am J Sports Med* 1986;14(6):449-62.
294 <https://doi.org/10.1177/036354658601400603>.

295 [21] Arnoczky SP, Tarvin GB, Marshall JL. Anterior cruciate ligament replacement using
296 patellar tendon. An evaluation of graft revascularization in the dog. *J Bone Joint Surg Am*
297 1982;64(2):217-24.

298 [22] Yasuda K, Tsujino J, Ohkoshi Y, Tanabe Y, Kaneda K. Graft site morbidity with autogenous
299 semitendinosus and gracilis tendons. *Am J Sports Med* 1995;23(6):706-14.
300 <https://doi.org/10.1177/036354659502300613>.

301 [23] Yasuda K, Tsujino J, Tanabe Y, Kaneda K. Effects of initial graft tension on clinical outcome
302 after anterior cruciate ligament reconstruction. Autogenous doubled hamstring tendons
303 connected in series with polyester tapes. *Am J Sports Med* 1997;25(1):99-106.
304 <https://doi.org/10.1177/036354659702500120>.

305 [24] Yamanaka M, Yasuda K, Tohyama H, Nakano H, Wada T. The effect of cyclic displacement
306 on the biomechanical characteristics of anterior cruciate ligament reconstructions. *Am J
307 Sports Med* 1999;27(6):772-7. <https://doi.org/10.1177/03635465990270061401>.

308 [25] Numazaki H, Tohyama H, Nakano H, Kikuchi S, Yasuda K. The effect of initial graft
309 tension in anterior cruciate ligament reconstruction on the mechanical behaviors of the
310 femur-graft-tibia complex during cyclic loading. *Am J Sports Med* 2002;30(6):800-5.
311 <https://doi.org/10.1177/03635465020300060801>.

312 [26] Kitamura N, Yasuda K, Tohyama H, Yamanaka M, Tanabe Y. Primary Stability of Three
313 Posterior Cruciate Ligament Reconstruction Procedures: A Biomechanical In Vitro Study.
314 *Arthroscopy: The Journal of Arthroscopic & Related Surgery* 2005;21(8):970-8.
315 <https://doi.org/10.1016/j.arthro.2005.05.025>.

316 [27] Miyata K, Yasuda K, Kondo E, Nakano H, Kimura S, Hara N. Biomechanical comparisons
317 of anterior cruciate ligament: reconstruction procedures with flexor tendon graft. *J Orthop
318 Sci* 2000;5(6):585-92. <https://doi.org/10.1007/s007760070010>.

319 [28] Kondo E, Merican AM, Yasuda K, Amis AA. Biomechanical Comparisons of Knee Stability
320 After Anterior Cruciate Ligament Reconstruction Between 2 Clinically Available
321 Transtibial Procedures. *The American Journal of Sports Medicine* 2010;38(7):1349-58.
322 <https://doi.org/10.1177/0363546510361234>.

323 [29] Kondo E, Merican AM, Yasuda K, Amis AA. Biomechanical Comparison of Anatomic
324 Double-Bundle, Anatomic Single-Bundle, and Nonanatomic Single-Bundle Anterior
325 Cruciate Ligament Reconstructions. *The American Journal of Sports Medicine*
326 2011;39(2):279-88. <https://doi.org/10.1177/0363546510392350>.

327 [30] Yagi M, Wong EK, Kanamori A, Debski RE, Fu FH, Woo SL. Biomechanical analysis of an
328 anatomic anterior cruciate ligament reconstruction. *Am J Sports Med* 2002;30(5):660-6.
329 <https://doi.org/10.1177/03635465020300050501>.

330 [31] Yasuda K, Tanabe Y, Kondo E, Kitamura N, Tohyama H. Anatomic double-bundle anterior
331 cruciate ligament reconstruction. *Arthroscopy* 2010;26(9 Suppl):S21-34.
332 <https://doi.org/10.1016/j.arthro.2010.03.014>
333 S0749-8063(10)00258-6 [pii].

- 334 [32] Kondo E, Yasuda K, Azuma H, Tanabe Y, Yagi T. Prospective clinical comparisons of
335 anatomic double-bundle versus single-bundle anterior cruciate ligament reconstruction
336 procedures in 328 consecutive patients. *Am J Sports Med* 2008;36(9):1675-87.
337 <https://doi.org/10.1177/0363546508317123>
338 0363546508317123 [pii].
- 339 [33] Lewis PB, Parameswaran AD, Rue J-PH, Bernard RB. Systematic Review of Single-Bundle
340 Anterior Cruciate Ligament Reconstruction Outcomes. *The American Journal of Sports*
341 *Medicine* 2008;36(10):2028-36. <https://doi.org/10.1177/0363546508322892>.
- 342 [34] Hurley ET, Fried JW, Kingery MT, Strauss EJ, Alaia MJ. Antero-lateral ligament
343 reconstruction improves knee stability alongside anterior cruciate ligament reconstruction.
344 *Knee Surg Sports Traumatol Arthrosc* 2021;29(3):764-71. [https://doi.org/10.1007/s00167-](https://doi.org/10.1007/s00167-020-06002-8)
345 [020-06002-8](https://doi.org/10.1007/s00167-020-06002-8)
346 10.1007/s00167-020-06002-8 [pii].
347
348