Comparison of knee extensor strength after anterior cruciate ligament reconstruction using either quadriceps tendon or hamstring tendon autografts

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Abstract

Purpose The aim was to assess the consequences of quadriceps tendon (QT) harvest on knee extensor strength after anterior cruciate ligament reconstruction (ACL-R) compared to hamstring tendon (HT) autograft. Secondary objectives were to evaluate flexor strength recovery and search for correlation between strength status and functional outcome.

Methods This a retrospective cohort of 44 patients who underwent ACL-R using either QT (25) or HT (19). Median age was 31.1 years. We assessed thigh muscle strength thanks to concentric iso kinetic evaluation (peak torque) at $60°.s^{-1}$, $180°.s^{-1}$, $240°.s^{-1}$ and eccentric at $30°.s^{-1}$, 7 months on average after surgery. Muscle strength values were compared to the uninjured leg in order to calculate a percentage of deficit as well as unilateral hamstring/quadriceps (H/Q) ratios. KOOS score was obtained at a mean follow-up of 18 months.

Results Extensor strength deficit (concentric $60°.s^{-1}$) was one average 33.1% in the QT group and 28.2% in the HT group ($p=0.42$). Difference of flexor strength deficit (concentric $60°.s^{-1}$) was close to be significant with 5% and 12% of deficit in the QT and HT group, respectively ($p=0.1$), and statistically significant for high angular velocity (14% versus 3% at $240°.s^{-1}$, $p=0.04$). H/Q ratios were comparable in both groups ranging from 0.62 to 0.78. Quadriceps muscle strength deficit was negatively correlated with the KOOS score (Pearson coefficient $=-0.4$; $p=0005$).

Conclusion QT autograft harvest does not yield significant quadriceps muscle weakness after ACL-R, which appear to be a pejorative factor for functional outcome.

Level of evidence IV, Retrospective study.

Keywords Anterior cruciate ligament · Quadriceps tendon · Muscle strength · Iso kinetic

Introduction

The use of quadriceps tendon (QT) autograft for anterior cruciate ligament (ACL) reconstruction has been first described by MacIntosh [1] and later Marshall [2] in the 1970s using a continuous graft of quadriceps and patellar tendon (PT). Then Blauth in 1984 [3] proposed a graft using only the QT. Its adequate biomechanical and morphological properties have been widely reported [4–6] as well as similar outcomes [7, 8] to classical graft such as hamstring tendon (HT) and patellar tendon (PT). As the graft choice for ACL reconstruction remains controversy, surgeon interest for QT autograft has exponentially increased for the last decade [9, 10]. Therefore, knowledges concerning this graft in terms of functional results [11, 12], donor site morbidity [13] and revision rate [11, 14] are already well established. The QT is now shown

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to be a good and reliable graft choice for primary ACL reconstruction in all patients. Nevertheless, consequences due to QT harvesting on extensor strength recovery have been little reported in current literature [15–18]. Quadriceps and hamstring muscles produce antagonist actions but ensure together a synergic work as dynamic knee stabilizers [19]. Iso kinetic strength assessment is essential to identify and treat thigh muscles unbalance and weakness [20]. Thus, muscle strength status after ACL reconstruction allows the clinician to drive and eventually correct the rehabilitation protocol during the last months before returning to sport activity. It might be influenced by many parameters and could also be a predictive factor for short-term functional outcome. Studies have already assessed the thigh muscle strength thanks to iso kinetic testing after ACL reconstruction using either QT or HT autograft [15, 16, 18, 21–24]. Various time span between surgery and iso kinetic evaluation, and different results among these studies make this subject unclear concerning late stage of rehabilitation. Protocol of iso kinetic assessment and judgment criteria vary from one study to another. It therefore requires to be standardized as suggested by Undehiem et al. [25] to avoid heterogeneous evaluations and make results comparable. The main purpose was to assess the consequences of quadriceps tendon (QT) harvest on knee extensor strength after anterior cruciate ligament reconstruction (ACL-R) compared to hamstring tendon (HT) autograft. Secondary objectives were to evaluate flexor strength recovery and search for correlation between strength status and functional outcome, age, body mass index or surgery delay. We hypothesized that QT autograft would not lead to significant extensor strength weakness compared to HT procedure and HT autograft would more likely result in reduced flexor strength.

Patients and method

This is an observational retrospective cohort study written in accordance with the principles of the Helsinki Declaration. Study ethics approval was obtained on 19/05/2020. All patients included gave their informed consent. Data collection started after registration to the national competent authority.

Patients

Forty-four patients who underwent ACL reconstruction using QT (25) and HT (19) in our institution between January 2017 and April 2018 have been included. All surgeries were performed by a single surgeon specialized and fully trained in arthroscopic knee surgery. Graft choice was left to patient's preference. The patients included had to be over 18 years old, had no history of previous ACL reconstruction and had to fulfill at least a 12 months clinical follow-up, with one iso kinetic evaluation 6 months after the surgery. Exclusion criteria were health's condition affecting one or both lower limb function and any pathology that makes iso kinetic test strictly forbidden (cardiovascular diseases mainly). At final verification, data were available for all patients: 27 men and 17 women who were on average 31.1 ± 11.7 years old.

Population characteristics and pre-operative data are summed up in Table 1.

Surgical procedure and rehabilitation

All procedures were arthroscopically assisted and performed under loco-regional or general anesthesia; patient was positioned in dorsal decubitus with a pneumatic thigh tourniquet. The intra-articular procedure was strictly identical in both groups. Tibial and femoral tunnels were defined

Table 1 Population characteristics

		Quadriceps tendon	Hamstring tendon	All	*p*-value
Number of patients		25	19	44	
Sex (*N*)	Male/female	20/5	7/12	27/17	**0.003**
Age (years) ± SD		31.6 ± 11	35 ± 12	33 ± 12	0.34
Time to iso kinetic evaluation (months) ± SD		7.3 ± 2	6.8 ± 1.5	7.1 ± 1.8	0.34
Follow-up: KOOS score (months) ± SD		17.5 ± 4.6	19 ± 4	18 ± 4.9	0.26
Side (N)	Left/right	15/ 10	6/13	21/23	0.06
Patient morphology	Size (cm) ± SD	174 ± 9	169 ± 10	171 ± 9	0.07
	Weight (kg) ± SD	72 ± 15	68 ± 12	72.4 ± 13	0.33
	Body mass index	23.4 ± 3	23.6 ± 2	23.5 ± 3	0.85
Time interval injury–surgery		93 ± 72	95 ± 124	95 ± 104	0.89
Meniscal lesion sutured		11	10	22	0.79

N Number, *SD* Standard deviation, *KOOS* Knee injury and Osteoarthritis Outcome Score

Bold value indicates *p*-value < 0.05

by positioning a wire using an outside-in method with an angulated guide. Tunnels were then drilled using cannulated reamers of diameters corresponding to the graft width. In the QT group, the quadriceps tendon was harvested with a patellar bone block as described by Cavaignac et al. [16] and fixed with bioabsorbable screws (Ligafix®, SBM™). The quadriceps tendon was then stitched using a decimal 2 OPTIM®. The bone defect of the proximal patella was filled in with autologous cancellous bone gathered from tibial tunnel drilling. In the HT group, graft harvest, preparation and fixation were performed according to Colombet et al. [26]: 4-strands semitendinosus graft fixed with adjustable endobuttons (Pullup XL, SBM™).

All patients followed the same standard rehabilitation protocol. Follow-up visits were proposed 45 days, 3 months, 6 months, 1 year and 2 years after the surgery. The rehabilitation protocol was performed in accordance with the national guidelines from 2008. It was divided into 5 periods running from the surgery day until the return to sport practice without any restriction 8 to 9 months later. Protocol details are presented in Table 2. In the case of meniscal suture, knee flexion while weight bearing was limited to 120° for two months postoperatively.

Evaluation method

Functional results evaluation consisted in patient self-reported outcome thanks to the KOOS (Knee Injury and Osteoarthritis Outcome Score) [27] and the Lysholm-Tegner score [28] at last follow-up.

Iso kinetic muscle strength evaluation was performed by the same physiotherapist. The same machine (HUMAC® NORM™ isokinetic extremity system) with the same software for data treatment (HUMAC 2015®) was used for all patient. A unique protocol was carried out for all patient on both lower limb including Undheim et al. [25] recommendations for assessment standardization (concentric contraction at 60°.s^{-1} from 0° to 100° of knee flexion). After 15 min of soft warm up, 4 tests were performed consecutively with a one-minute rest between each test. The non-affected leg was tested before testing the operated one. Patients were asked to produce the maximum effort possible. Each series consisted of 3 repetitions of one cycle of maximal flexion–extension effort ranging from 0 to 100° of knee flexion. For each test, settings including the type of muscle contraction (concentric or excentric) as well as the angular velocity and range of motion were programmed. The 4 tests practiced were the followings: concentric at 240°.s^{-1}, concentric at 180°.s^{-1}, concentric at 60°.s^{-1} [25] and eccentric at 30°.s^{-1}. Reproducibility of the 3 cycles of each series was assessed with a variability coefficient that needed to be less than 0.10 to demonstrate high reproducibility. Peak torque from the best repetition of each test was reported for both extensor strength (quadriceps muscles) and flexion strength (hamstring muscles) and compared to the values from the non-affected leg to be then expressed as percentage of deficit.

Table 2 Rehabilitation program

Stage	Period	Objectives	Instructions
1	Surgery day–week 3	ROM: 0–70°	Walking with crutches for partial weight bearing
		Controlling pain and swelling	Isometric thigh strengthening
		Complete knee active extension	Passive ROM recovery
			Cryotherapy and massage
2	Week 3–month 2	ROM: 0–120°	No restriction for ROM recovery
		Painless	Moderate muscle strengthening
		Total weight bearing	Electrostimulation
		Walking without crutches and splint	Static proprioception by bipodal and unipodal weight bearing
			Cycling without resistance
3	Month 2–Month 4	Total ROM recovery	H/Q co contractions
		Good knee confidence	H strengthening without limitation
		Cycling	Q closed chain reinforcement
		Jogging on straight line	Neuromuscular control and dynamic proprioception exercises
			Cardiovascular rehabilitation
4	Month 4–Month 6	Return to endurance and powerful activities (running, cycling, crawl)	Intensify muscle strengthening
			Iso kinetic reinforcement
			Dynamic work: jumping, changing direction
5	Month 6–Month 8–9	Safe return to pivot-contact sport activity (training)	Stage 4 instructions
		Return to competition at month 9	Sport practice

ROM Range of motion, *H* Hamstring, *Q* Quadriceps

Unilateral hamstring(H)/quadriceps(Q) ratio and mixed ratio (H excentric 30°.s^{-1}/Q concentric 240°.s^{-1}) were calculated to estimate the thigh muscle strength balance.

Functional outcome and muscle strength data were recorded in the patient's medical files. Data collection was then based on those files and achieved by an independent investigator.

Statistical analysis

Statistical analyses were performed using XL STAT 2019 software. The quantitative variables were analyzed using the Student test, and the qualitative variables using the Chi^2 test. Correlation between two variables was assessed using the Pearson coefficient which had to be over 0.40 to consider the correlation as actual [29]. All p values were compared to a 0.05 alpha value to identify statistical differences. According to sample size calculation (power = 90%), 18 patients per group were needed to detect a projected difference > 10% of quadriceps strength deficit.

Results

Results for peak torque assessment and unilateral ratio calculation are summed up in Table 3. The average variability coefficient assessing was 0.06 in both groups.

No difference of extensor strength deficit between both groups was found for all tests. For concentric contraction at 60°.s^{-1}, the peak torque deficit was one average 33.1% (range: 18–70%) in the QT group and 28.2% (range: −2–74%) in the HT group (p = 0,42). Flexor strength deficit was more likely greater in the HT group compared to the QT one especially for high angular velocity corresponding to explosive muscle contraction (14% versus 3% at 240°.s^{-1}, p = 0.04). For concentric contraction at 60°.s^{-1}, a slight difference was observed with 5% and 12% of average flexor strength deficit in the QT and HT group respectively (p = 0.11).

H/Q ratio were, as expected, greater on the operated leg compared to the uninjured one due to systematic significant quadriceps weakness after surgery up to 69% for the worst case (Fig. 1). Ratios were comparable in both groups ranging on average from 0.64 to 0.78 in the QT group and from 0.62 to 0.77 in the HT group. No difference was found for the mixed ratio (1.44 versus 1.29 in the HT and TQ group respectively, p = 0.27).

With an average follow-up of 18 ± 4.9 months, KOOS score was on average 93.9 ± 9.5 in the QT group and 92.5 ± 10.6 in the HT group. Same values were found with the Lysholm-Tegner score.

Quadriceps muscle strength deficit was negatively correlated with the KOOS score (Pearson coefficient = −0.4;

Table 3 Muscle strength deficit and H/Q ratios

Type of contraction	Average extensor strength deficit			Average flexor strength deficit			H/Q unilateral ratios (operated leg)			H/Q unilateral ratios (non-operated leg)		
	QT group	HT group	*p*-value	QT group	HT group	*p*-value	QT group	HT group	*p*-value	QT group	HT group	*p*-value
Concentric 60°.s^{-1} (SD)	33% (±11)	28% (±12)	0.42	5% (±12)	12% (±13)	0.11	0.78 (±0,18)	0.77 (±0.3)	0.40	0.54 (±0.08)	0.56 (±0.05)	0.95
Concentric 180°.s^{-1} (SD)	28% (±15)	26% (±16)	0.54	5% (±11)	14% (±7)	**0.05**	0.78 (±0.13)	0.73 (±0.23)	0.47	0.58 (±0.11)	0.59 (±0.05)	0.96
Concentric 240°.s^{-1} (SD)	25% (±13)	25% (±17)	0.76	3% (±16)	14% (±14)	**0.04**	0.74 (±0.1)	0.70 (±0.17)	0.23	0.58 (±0.12)	0.58 (±0.07)	0.92
Eccentric 30°.s^{-1} (SD)	27% (±15)	17% (±19)	0.12	12% (±16)	7% (±15)	0.39	0.64 (±0.17)	0.62 (±0.29)	0.78	0.53 (±0.10)	0.53 (±0.11)	0.93

Bold value indicates p-value < 0.05

QT Quadriceps tendon, *HT* Hamstring tendon, *SD* Standard deviation, *H/Q* Hamstring strength/Quadriceps strength

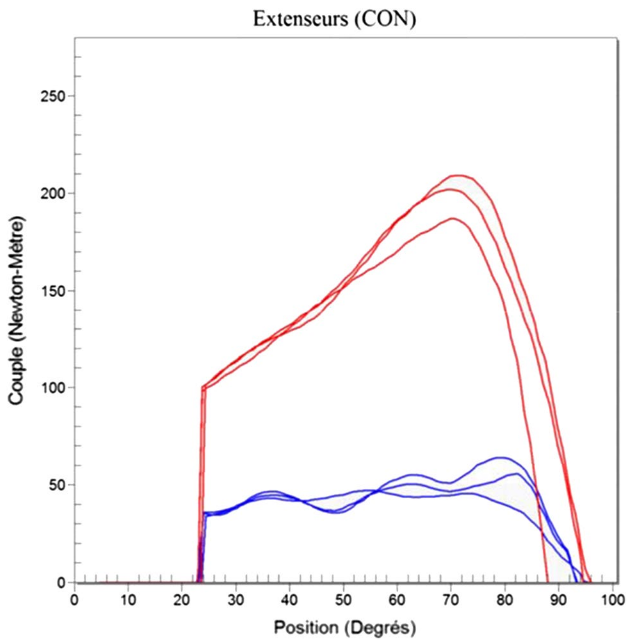

Fig. 1 Example of 69% extensor strength deficit (patient of QT group). Red curves: uninjured lower limb, blue curves: operated lower limb. (Color figure online)

$p = 0.005$). No correlation appeared between functional outcome and flexor strength, age, BMI and surgery delay, nor between extensor strength deficit and those 4 parameters (Table 4).

Discussion

This study suggests the relative safety of QT harvest for knee extensor muscle strength 6 months after ACL reconstruction. These findings meet those of Cavaignac et al. [16] and Lee et al. [15] at different timepoints after surgery (6 and 12 months respectively) with a side-to-side ratio nearing 30% and less than 10% of extensor and flexor strength deficit respectively without significant differences compared to HT autograft. Same levels of strength deficit are also described 6 months [24] and 12 months [18] after ACL reconstruction but with significant differences between QT and HT autograft. Despite various conclusion, these studies suppose that graft harvest from the QT is very little involved in quadriceps muscle weakness after ACL reconstruction since comparable level of strength deficit exists after HT procedure. The study of Kwack et al. [23] stands for this hypothesis reporting almost no difference of extensor peak torque 6 months after ACL reconstruction using QT autograft and QT allograft. This statement might be generalized to all knee extender mechanism grafts considering studies of ACL reconstruction using PT [17, 30]. Literature review including over 300 patients from 8 studies is presented in Table 5.

Etiology for extensor weakness after ACL reconstruction is multifactorial as many explanations have been proposed [29]. Some of them do not involve any role from graft harvesting even for QT autograft. Rest during the first weeks after surgery combined to reflex inhibition from intra-articular pain leads to muscle atrophy especially for type II fibers [31]. The loss of mechanoreceptors in the broken ACL, that cannot be restored by the reconstruction procedure, reduces gamma motor neurons function and, as a consequence, quadriceps reflex contraction [32]. This is, among others, a reason why some authors [33] recommend to conserve the remnant ACL, while performing reconstruction, to preserve its native mechanoreceptors. Finally, arthrogen quadriceps inhibition due to potential residual laxity might occur after ACL reconstruction in order to protect the graft from anterior tibial translation [34].

Table 4 Correlation between muscle strength and pre-/postoperative parameters

Correlation tested		Pearson coefficient	95% confidence interval	*p*-value
Extensor strength deficit (concentric 60°.s^{-1})	KOOS score	−0.41	[−0.634; -0.136]	**0.005**
	Lysholm-Tegner score	−0.32	[−0.563; -0.025]	**0.03**
	Age	0.08	[−0.220; 0.369]	0.59
	Time to surgery	−0.29	[−0.541; 0.006]	0.054
	Body mass index	0.05	[−0.244; 0.347]	0.72
	Flexor strength deficit	0.23	[−0.088; 0.517]	0.15
Flexor strength deficit (concentric 60°.s^{-1})	KOOS score	−0.06	[−0.348; 0.244]	0.71
	Lysholm-Tegner score	−0.05	[−0.342; 0.249]	0.74
	Age	−0.23	[−0.490; 0.075]	0.15
	Time to surgery	−0.20	[−0.467; 0.104]	0.2
	Body mass index	−0.14	[−0.421; 0.161]	0.36

Bold value indicates *p*-value < 0.05

KOOS Knee injury and Osteoarthritis Outcome Score

Table 5 Literature review

Authors	Years	Level of evidence	Effective	Evaluation	Analysis	Follow-up (months)	Extension strength deficit	Flexor strength deficit	Control group (CG)	Significant differences with CG
Pigozzi et al. [18]	2004	2	–	Counter movement jump test	LSI	6	11%	–	PT	$QT^{ES} > PT^{ES}$
Lee et al. [17]	2016	3	48	Iso. Con. 60/180°.s^{-1}	LSI	12	28%/26%	13%/5%	HT	$QT^{FS} > HT^{FS}$ at 180°.s^{-1} (6–12 months)
						24	19%/16%	8%/0.4%		
Cavaignac et al. [14]	2017	3	44	Iso. Con. 90°.s^{-1}	LSI	6.4	26%	8%	HT	No
Kwak et al. [19]	2018	4	45	Iso. Con. 60/180°.s^{-1}	LSI	6	50%/48%	–	QT allograft (QTa)	No except: $QTa^{ES} > QT^{ES}$ at 60°.s^{-1} (6 months)
						12	42%/38%	–		
						24	22%/17%	–		
Fischer et al. [20]	2018	3	61	Iso. Con. 60°.s^{-1}	LSI	5,5	30%	6%	HT	$QT^{ES} < HT^{ES}$ and $QT^{FS} > HT^{FS}$
						7.8	16%	2%		
Martin-Alguacil et al. [16]	2018	2	28	Iso. Con. 60/180/300°.s^{-1}	Repeated measures analyses of the covariance (ANCOVA)	3, 6 and 12	–	–	HT	greater increase of extensor peak torque in HT than QT with time
Hunnicut et al. [26]	2019	3	15	Iso. Con. 60/180°.s^{-1}	LSI	8	31%/22%	–	PT	No
Sinding et al. [15]	2020	2	42	Iso. Con. 60/180°.s^{-1}	LSI	12	26%/16%	4%/0%	HT	$QT^{ES} < HT^{ES}$ $QT^{FS} > HT^{FS}$

LSI Limb symmetry index, *ES* Extensor strength, *FS* Flexor strength, *QT* Quadriceps tendon, *HT* Hamstring tendon, *PT* Patellar tendon, Iso: Iso kinetic evaluation, Conc. = concentric contraction

One the other hand, others hypothesis for extensor weakness, extrapolated from patellar tendon studies [30, 35] are shown to be directly linked to QT harvest. First, the postoperative pain of the donor site bothers voluntary muscle contraction [36]. Then, according to Breitfuss et al. [35], suture and healing of a tendon after graft harvest might shorten its length. This morphological modification could result in an increased muscle tension which alter contraction efficiency. Last but not least, as suggested by Dauty et al. [30] for patellar tendon graft, QT harvest may modify the femoro-patellar cinematics and disturb the correct function of knee extensor muscles.

Some authors [24] consider the high H/Q ratio after QT procedure observed in the literature [16, 24] and in our study as an advantage for graft protection at its early stages of integration. This interpretation has to be considered carefully because this high value is much more consecutive to deep quadriceps weakness than hamstring muscle reliable strength. Knee extensor-flexor strength modified balance is indeed agonist to ACL function, but hamstring strength cannot be considered as an actual protection in case of instability accident during rehabilitation since the flexor strength is inferior to normal value in all cases. Furthermore, the quadriceps weakness after ACL reconstruction, which raises H/Q ratio, is correlated with poorest functional outcome no matter the graft type in the literature [37] as well as in our study. Coudouret et al. [38] support these results in a 2 years follow-up study including 127 patient undergoing ACL reconstruction with HT or PT graft. Over long term, quadriceps weakness even appear to be associated with osteoarthritis evolution after ACL reconstruction according to Tourville et al. [39].

No correlation between flexor strength recovery and functional outcomes has been demonstrated, even for HT procedures which seem to provide greater hamstring weakness compared to PT or QT autograft [37].

No significant correlation was established in our study between flexor and extensor weakness. As a matter of fact, quadriceps strength deficit is more likely due to an unbalanced thigh reinforcement than a global lack of rehabilitation. Considering the quadriceps strength as a prognostic factor for functional outcomes should bring surgeons and physiotherapist to evaluate rehabilitation program with more preferential quadriceps strengthening. However, it remains impossible to clarify whether the extensor weakness, or the poor functional outcome, is cause or consequence of the other. Good level of extensor reinforcement must be found avoiding overly aggressive quadriceps strengthening facing the risk of pain and knee effusion which compromise short-term results.

This study bears few limits. Our sample size was determined to identify substantial differences between groups regarding quadriceps strength. Number of subjects was indeed calculated to detect a projected difference of 10% of strength deficit. Differences between groups were inferiors to this subjective cutoff which was chosen according to the fact that a deficit below 10% can be considered as a subnormal strength [40]. Small differences might possibly be statistically significant in lager cohorts without meeting any clinical relevance as proved by excellent outcomes reported for QT autograft [11, 12]. Unbalance sex ratio and possible variabilities in adherence to rehabilitation program are two potential bias.

Studies one larger population are still needed to clarify the impact of QT harvest on extensor strength recovery after ACL reconstruction. According to data from the literature and our study, QT harvest acts as a minor role for quadriceps weakness which appear insufficient to jeopardize the surgery success.

Conclusion

ACL reconstruction using QT autograft doesn't yield significant quadriceps muscle weakness compared to HT autograft. Flexor strength appeared to be more likely preserved using QT compared to HT. Quadriceps muscle strength is positively correlated with mid-term functional outcome, whatever the graft type. This statement should be taken into account considering rehabilitation protocol.

Authors' contribution CH and BRD performed data extraction. MO, JC and RP designed the protocol. MO performed statistical analysis. AM performed the isokinetic tests. CH wrote the initial draft and edited the different versions of the draft. CH, BRD, AM, RP, JC and MO approved the submitted and final version.

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Declarations

Conflict of interest MO (Matthieu Ollivier) is an educational consultant for Stryker, New-clip and Arthrex. Other authors declare no con-flict of interest.

Ethical approval Study ethics approval was obtained on 19/05/2020 (CECIC Rhône-Alpes-Auvergne, IRB 5891).

Consent to participate All patients included gave their informed consent. Data collection started after registration to the CNIL France (National commission for Data Protection and Liberties).

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