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Comparable outcomes with anti-thymocyte globulins versus basiliximab in kidney transplantation from controlled circulatory death donors

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Due to organ shortage, donation after circulatory death (DCD) has increased. As DCD kidney grafts have higher rates of delayed graft function (DGF), the French national protocol mandates the use of hypothermic machine perfusion and routine anti-thymocyte globulin (ATG) induction therapy. However, evidence favoring ATG over interleukin-2 receptor antagonists, such as basiliximab, remains scarce. We retrospectively analysed a single-center cohort of 158 low immunological risk patients who underwent DCD kidney transplantation between 2015 and 2023. Patients transplanted before March 2020 received ATG (n = 64), while those transplanted thereafter (during and after the COVID-19 pandemic) received basiliximab (n = 94). Baseline characteristics were comparable, except for recipient age (lower in the basiliximab group), and cold ischemia times were similar. There were no

differences in primary non-function, DGF rates (17% after ATG versus 12% after basiliximab), biopsy-proven rejection, one-year renal function or graft survival. ATG was associated with prolonged EBV and BK viremia without increased complications. Hospital stays were similar, but ATG induction was 1.7 times more expensive. These findings were confirmed in an independent French multicenter cohort (n = 506). In conclusion, basiliximab appears to be a cost-effective alternative to ATG for low-immunological-risk patients receiving DCD kidney grafts, for whom ATG is not clearly indicated.

KEYWORDS

antithymocyte globulin, basiliximab, DCD (donation after circulatory death), delayed graft function, induction

Introduction

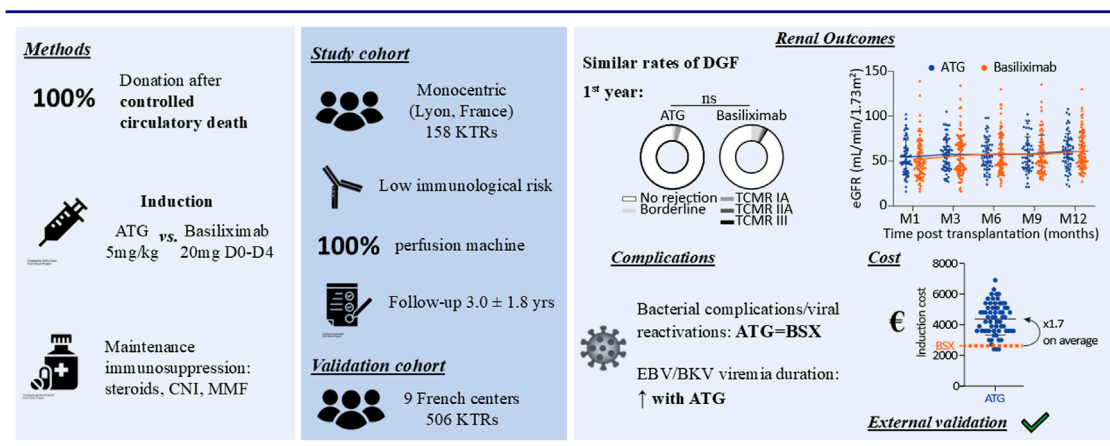
Kidney transplantation is the preferred treatment for patients with end-stage renal disease (ESRD), offering both improved quality of life [1] and significantly better survival [2, 3] for only a fraction of the costs of hemodialysis. However, due to the shortage of organ available there is a growing imbalance between the number of patients waiting for a graft and the number of transplantations performed each year [4]. As a result, many patients die each year while waiting for a compatible graft [4, 5].

To address the problem of organ shortage and optimize access to transplants, various strategies have been implemented to expand the donor pool. These include regenerative medicine approaches and xenotransplantation - currently still in the research phase [6, 7] - as well as the already established use of living donors and the extension of criteria for transplantation from deceased donors. In France, the “Maastricht 3 program”, launched in 2015, enabled the procurement of organs from donors after controlled circulatory death (DCD) [8]. This program has significantly contributed to increase the availability of kidney transplants. Between 2014 and 2024, the total number of

kidney transplants from deceased donors in France rose by 16.2% (2718 in 2014 vs. 3159 in 2024), with DCD donors accounting for nearly all this increase, while the number of donations after brain dead remained stable [4]. A similar trend has been observed in the United States [5].

However, due to the unavoidable warm ischemia time before organ retrieval, DCD transplants are inherently associated with an increased risk of delayed graft function (DGF) [9, 10]. In France, several measures have been proposed to mitigate the risk of DGF, and, more critically, primary non-function (PNF). First, all grafts from DCD donors must undergo hypothermic machine perfusion, which has been shown to reduce the risk of DGF [11, 12] particularly in donors aged over 60 [13]. Second, cold ischemia time (CIT), which is a known variable associated with DGF [12–14], is limited to 18 h (with a strong recommendation to keep it below 12 h). Third, at the time the program was set up, the French regulatory agency recommended the systematic use of depleting induction therapy with polyclonal antibodies (either anti-thymocyte globulins (ATG) or anti-lymphocyte globulins) to mitigate ischemia-reperfusion injury [15] and to promote early graft function [16] by allowing delayed introduction of calcineurin inhibitors. Interestingly, the

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GRAPHICAL ABSTRACT

combination of hypothermic machine perfusion and polyclonal antibodies may have synergistic effects in reducing graft immunogenicity and lowering rejection rates following transplantation with a DCD graft. Hypothermic perfusion facilitates the release of tissue-resident leukocytes into the perfusion fluid [17], while polyclonal antibodies deplete circulating passenger leukocytes. Given that several allorecognition pathways rely directly on donor passenger leukocytes [18–20], this approach could contribute to a longer-term reduction in rejection.

Notably, the expected short and long-term efficacy of polyclonal antibodies after DCD transplantation has never been prospectively compared with interleukin-2 receptor antagonists (IL-2RA) such as basiliximab or daclizumab. Therefore, we retrospectively analyzed prospectively collected data from a single center to compare the short-, medium-, and long-term outcomes of ATG versus basiliximab induction in kidney transplant recipients from DCD donors and assess their cost-effectiveness. These findings were subsequently evaluated in an independent validation cohort.

Patients and methods

Study design

The study cohort consisted in a monocentric cohort of kidney transplant patients from Lyon University Hospital, France. It was used to retrospectively compare the impact of induction treatment in patients receiving kidneys from controlled circulatory death donors. All patients receiving a kidney transplantation from a DCD donor between January 1, 2015 and December 31, 2023 were enrolled. Data were prospectively collected. The validation cohort (DIVAT, Données Informatisées et Validées en Transplantation) included 506 adult recipients of DCD kidney transplants from 9 French centers [Necker (Paris), Saint Louis (Paris), Foch (Suresnes), le Kremlin-Bicêtre, Saint-Etienne, Nantes, Nancy, Montpellier, Nice] between January 1, 2015, and December 31, 2023.

Inclusion and exclusion criteria

In France, the Maastricht III program, which defines the rules for transplants using controlled DCD donors, imposes strict conditions. Donors must be strictly under the age of 70 and must not have acute organ failure. The agonic phase must last less than 3 h and the functional warm ischemia phase (time interval during which the organs are hypoperfused and then no longer perfused at all due to circulatory failure) less than 120 min for the kidneys. *Ex vivo* hypothermic perfusion is mandatory and must last at least 2 hours, while CIT must be < 18h. Recipients can only receive a first, HLA-compatible transplant.

Patients who received both available induction treatments were excluded from the analysis.

Definition of delayed graft function

Delayed graft function was defined as the need for at least one hemodialysis session after the transplantation.

Histological evaluation

Light microscopy was performed on systematic or “for cause” kidney biopsy samples fixed in formalin-acetic alcohol after staining with haematoxylin and eosin. Histological lesions were scored according to the Banff 2022 classification [21].

Statistical analysis

Qualitative variables were expressed as percentages and compared with the chi-square test or Fisher’s exact test when the conditions of application of chi-square were not met. Quantitative variables were expressed as mean \pm SD and compared using Student’s t-test. All tests were two-sided. When repeated measurements of the same parameter were performed over time, two-way ANOVA or mixed effects model were used with Sidak’s multiple comparisons test. No imputation was performed. Analyses were performed using variable-specific complete-case analyses, excluding only observations with missing data for the variable under consideration. Incidence and survival data were analysed by Kaplan-Meier curve and compared using a log-rank test. A multivariable Cox proportional hazards model was used to assess patient and graft survival in the validation cohort. All data were analysed using Prism (GraphPad) or the R software. All analyses were performed using R Statistical Software (v4.5.1); R Core Team [22].

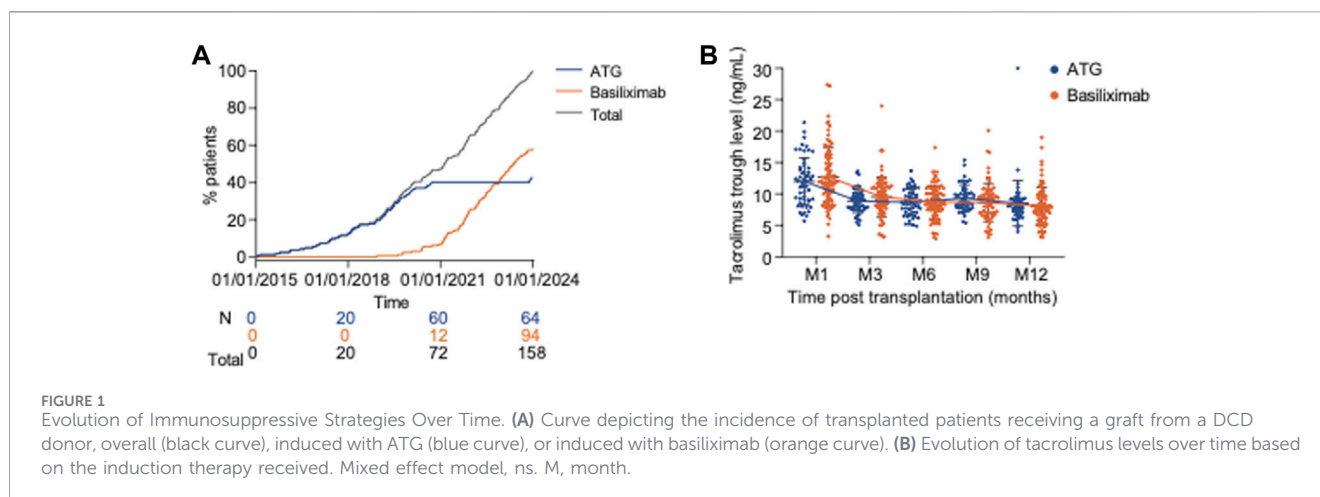
Study approval

The study was carried out in accordance with French legislation on biomedical research and the Declaration of Helsinki. All patients gave informed consent for the utilization of clinical data [Données Informatiques Validées en Transplantation (DIVAT cohort)] for research purpose (www.divat.fr, CNIL (Commission Nationale de l’Informatique et des Libertés) no. 914184, ClinicalTrials.gov: NCT02900040).

Results

Impact of the COVID-19 pandemic on induction therapy selection for DCD kidney transplants

Between January 2015 and December 2023, 163 patients received a transplant from a DCD donor. All received induction treatment with ATG (Thymoglobulin, Sanofi®, target dose 5 mg/kg) or an IL-2RA, basiliximab (Simulect, Novartis®, 20 mg day 0 and day 4). As they did not tolerate ATG, 5 patients were switched to basiliximab and received both molecules; they were therefore excluded from the study. Of the remaining 158 patients, the vast majority of those transplanted before the onset of COVID-19 pandemic in France (March 2020) have received ATG as an induction, as specified in the National protocol [23]. To limit the risk of COVID-19 induced mortality in the post-transplantation period [24, 25], almost all patients transplanted after March 2020 were induced with basiliximab (Figure 1A). However, the change in induction treatment was not accompanied by changes in



the maintenance immunosuppressive regimen. In particular, the target residual doses of calcineurin inhibitors were the same for all patients (Figure 1B; of note, the few patients ($n = 5$; 3%) on ciclosporin were excluded from this analysis), regardless of the induction treatment.

Taking advantage of this situation, we underwent the present study aiming at comparing the effect of induction on the prognosis of transplants with DCD donors. Therefore, transplant outcomes (in terms of renal parameters and complications) were compared between the 64 patients induced with ATG and the 94 patients induced with basiliximab, whose characteristics are presented in Table 1. Briefly, the mean recipient age was 56.2 ± 11.7 and 52.0 ± 12.6 years and the mean donor age was 50.6 ± 12.6 and 50.8 ± 13.6 years, in ATG and basiliximab groups, respectively. The type of initial kidney disease leading to end-stage renal disease was similar in both groups. The mean follow-up was 3.0 ± 1.8 years; nine patients died during follow-up.

The type of induction therapy has no impact on renal graft function or immunological outcomes

The cold-ischemia time was comparable between the groups (787 ± 214 min in ATG group vs. 769 ± 264 min in basiliximab group; unpaired t-test, $p = 0.66$; Table 1), and all kidneys were preserved on a perfusion machine. The rate of PNF was low (5; 3.16%) and did not differ according to the induction received (1 [1.56%] patient in ATG group, vs. 4 [4.25%] patients in basiliximab group; Fisher's exact test, $p = 0.65$; Figure 2A). Among the remaining 153 patients, 15% experienced DGF, 11 in ATG group and 12 in basiliximab group (chi-square test, $p = 0.48$; Figure 2B). Thus, induction does not affect the early outcomes after transplantation.

Since some studies have indicated a lower risk of biopsy-proven rejection with ATG induction compared to IL-2RA [26], we sought to determine whether this also holds true for DCD transplants, considered more immunogenic [27]. In our cohort, patients had very low levels of immunization (19.6% with preformed anti-HLA antibodies, none with preformed donor-specific antibodies; chi-square test for comparison between groups, $p = 0.86$; Table 1),

and the number of HLA-A/B/DR mismatches was also similar between the groups (3.7 ± 1.1 and 3.7 ± 1.2 in ATG and basiliximab groups, respectively; chi-square test, $p = 0.86$; Table 1). Overall, 5 patients experienced full blown T-cell mediated rejection (2 and 1 grade IA, 0 and 1 grade IIA, 0 and 1 grade III, in ATG and basiliximab groups, respectively) during the first year of follow-up, whereas one patient with concomitant BK nephropathy was excluded from this analysis. Over the same period of 1 year of follow-up, 6 other patients had borderline lesions (1 in ATG group and 5 in basiliximab group). The intensity of inflammatory lesions (borderline lesions or TCMR) did not differ between the groups (chi-square test, $p = 0.45$; Figure 2C). Of these 11 patients, all but two (with borderline lesions) were treated with corticosteroids and the control biopsy performed at 192 ± 83 days showed resolution of inflammation in all cases. Two of these 9 treated patients developed post-transplant diabetes mellitus. In addition, three patients in the basiliximab group developed microvascular inflammation (MVI) without DSA.

The evolution of renal function and proteinuria during the first year was comparable regardless of induction (Figures 2D,E). Patients had a mean one-year estimated glomerular filtration rate of 61.0 ± 19.6 mL/min/1.73 m² and 61.3 ± 20.3 mL/min/1.73 m² in ATG and basiliximab groups, respectively (unpaired t-test, $p = 0.93$; Figure 2D). At 1 year, among patients with an available proteinuria measurement, 10 of 59 and 12 of 80 had significant proteinuria ≥ 50 mg/mmol creatininuria in ATG and basiliximab groups, respectively (chi-square test, $p = 0.76$; Figure 2E).

At the systematic one-year evaluation, 102 patients had a biopsy (41 in the ATG group and 61 in the basiliximab group, mean delay 383 ± 23 days post transplantation [range 275–455 days]). Among all biopsies for which the following Banff scores were available, there was no difference in terms of tubulointerstitial (i + t; evaluated on 91 biopsies) or microvascular (g + pt; 89 biopsies) acute inflammatory lesions, nor in chronic glomerular lesions (cg; 90 biopsies) or interstitial fibrosis/tubular atrophy (IFTA; 88 biopsies; Figure 2F). Very few patients developed *de novo* donor-specific antibodies (2 in ATG group, 1 in basiliximab group, log-rank test, $p = 0.36$).

Finally, to integrate all the risks (PNF, DGF, rejection...) that could potentially affect graft function on the long term, we

TABLE 1 Patients characteristics—Original cohort.

Mean \pm SD or n (%)	Whole cohort N = 158	ATG N = 64	BSX N = 94	p-value
Recipient characteristics at the time of transplantation				
Female	47 (30)	23 (36)	24 (26)	0.160
Age (years)	54 \pm 12.4	56 \pm 11.7	52 \pm 12.6	0.046
BMI (kg/m ²)	26.2 \pm 4.6	26.3 \pm 5.1	26.1 \pm 4.3	0.791
Blood group				0.044
A	64 (41)	20 (31)	44 (47)	
B	20 (13)	13 (20)	7 (8)	
O	65 (41)	26 (41)	39 (41)	
AB	9 (5)	5 (8)	4 (4)	
Renal disease				0.539
Diabete mellitus	24 (15)	10 (16)	14 (15)	
Glomerulonephritis	43 (27)	17 (27)	26 (28)	
Tubular-interstitial, genetic	12 (8)	20 (31)	19 (20)	
Vascular	22 (14)	11 (17)	11 (12)	
Uropathy	1 (1)	0	1 (1)	
Undetermined	34 (21)	11 (17)	23 (24)	
Anti-HLA antibody	31 (20)	13 (20)	18 (19)	0.857
DSA	0	0	0	NA
Donor characteristics				
Female	43 (27)	15 (23)	28 (30)	0.379
Age (years)	51 \pm 13.2	51 \pm 12.6	51 \pm 13.6	>0.999
BMI (kg/m ²)	25.3 \pm 5.3	25.5 \pm 5.3	25.1 \pm 5.3	0.642
Transplantation characteristics				
Cold ischemia time (min)	776 \pm 244	787 \pm 214	769 \pm 264	0.651
Perfusion machine	158 (100)	64 (100)	94 (100)	NA
No. of HLA A/B/DR mismatches	3.7 \pm 1.1	3.7 \pm 1.1	3.7 \pm 1.2	>0.999
Induction therapy dose (mg/kg for ATG, mg for BSX)	ND	4.9 \pm 0.6	40 \pm 2	NA
Maintenance immunosuppression at hospital discharge				
Tacrolimus	152 (96)	58 (91)	94 (100)	0.009
Cyclosporine	5 (3)	5 (8)	0	
MMF	154 (97)	63 (98)*	91 (97)	0.647
Steroids mTORi	157 (99)*	63 (98)*	94 (100)	0.405
Belatacept	2 (1)	0	2 (2)	0.515
	1 (1)	0	1 (1)	>0.999
CMV status				0.200
D ⁻ /R ⁻	29 (18)	14 (22)	15 (16)	
D ⁺ /R ⁻	21 (13)	5 (8)	16 (16)	
R ⁺	108 (69)	45 (70)	63 (68)	
EBV status				0.247
D ⁻ /R ⁻	1 (1)	0	1 (1)	
D ⁺ /R ⁻	3 (2)	0	3 (3)	
R ⁺	154 (97)	64 (100)	90 (96)	

Abbreviations: ATG, anti-thymocyte globulins; BSX, basiliximab; BMI, body mass index; DSA, donor-specific antibodies; ND, not determined; MMF, mycophenolate mofetil; mTORi, mechanistic target of rapamycin inhibitor; CMV, cytomegalovirus; EBV, Epstein-Barr virus; D/R, donor/recipient; *, death of a patient at day 17 of transplantation.

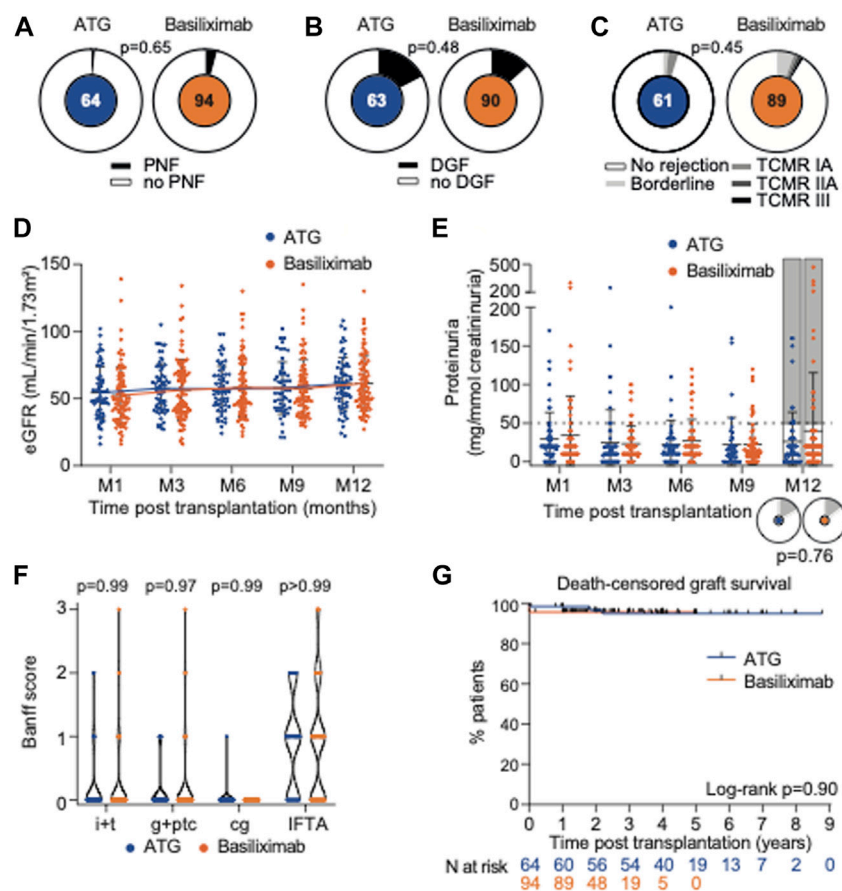


FIGURE 2 Comparison of renal functional and immunological outcomes in patients receiving ATG or basiliximab. (A–C) The prevalence of (A) primary non-function (PNF), (B) delayed graft function (DGF) and (C) rejection was compared between groups (A) in the entire cohort, (B) in patients without PNF and (C) in patients without PNF who were alive at the one-year follow-up. Fisher's test (A,B) and chi-square test (C), ns. (D,E) Evolution of (D) estimated glomerular filtration rate (eGFR) and (E) proteinuria levels over time based on the induction therapy received. Mixed effect models, ns. (F) Comparison of the Banff i + t, g + ptc, cg and IFTA scores between groups in the one-year biopsy. Two-way ANOVA, ns. (G) Kaplan-Meier survival curve for death-censored graft survival according to induction therapy. M; month. TCMR; T-cell mediated rejection.

compared the death-censored graft survival of the two groups and found no difference (log-rank test, $p = 0.90$; Figure 2G).

The type of induction therapy has no impact on infectious and cancer complications

Having demonstrated that graft survival was similar in the two groups of patients, we wanted to compare the safety of the two induction therapies.

Patient and graft survival were similar between the 2 groups (log-rank test, $p = 0.58$; Figure 3A). The number of bacterial complications (including bacteremia, pyelonephritis and bacterial pneumonia) during the first year was equivalent (chi-square test, $p = 0.46$; Figure 3B). Regarding viral complications, we observed no difference in the incidence of cytomegalovirus (CMV) viremia between the two groups (log-rank test, $p = 0.94$; Figure 3C). However, this result should be interpreted with caution because patients received protocolized prophylaxis against CMV with valganciclovir, the duration of which varied according to the serological status of the donor/recipient pair (6 months for the

high-risk seropositive donor/seronegative recipient group [D+/R-] and 3 months for intermediate-risk group [R+]). Although the difference was not statistically significant, there were more D+/R-high-risk pairs in the basiliximab than in the ATG group (16% vs. 8% respectively; Table 1). Regarding EBV, there were only 4 high-risk pairs (D+/R-) and all received basiliximab as induction. In the rest of patients (D+/R+ or D-/R+), the incidence of EBV reactivation was comparable between groups (log-rank test, $p = 0.75$; Figure 3D) and the maximum viral load was similar (mean maximum viral load 3.1 ± 0.7 log vs. 3.1 ± 0.6 log in the ATG and basiliximab groups, respectively; unpaired t-test, $p = 0.92$; Figure 3E), but the duration of viremia was significantly longer in patients who had received ATG (log-rank test, $p = 0.0028$; Figure 3F). Despite this difference, no patient of the cohort developed EBV-related post-transplant lymphoproliferative disease during the follow-up period. For the analysis focusing on BK virus, we excluded from the analysis the 5 patients who experienced PNF and remained on dialysis. The results were reminiscent to those obtained for EBV. The incidence of viremia (log-rank test, $p = 0.91$; Figure 3G), and maximum

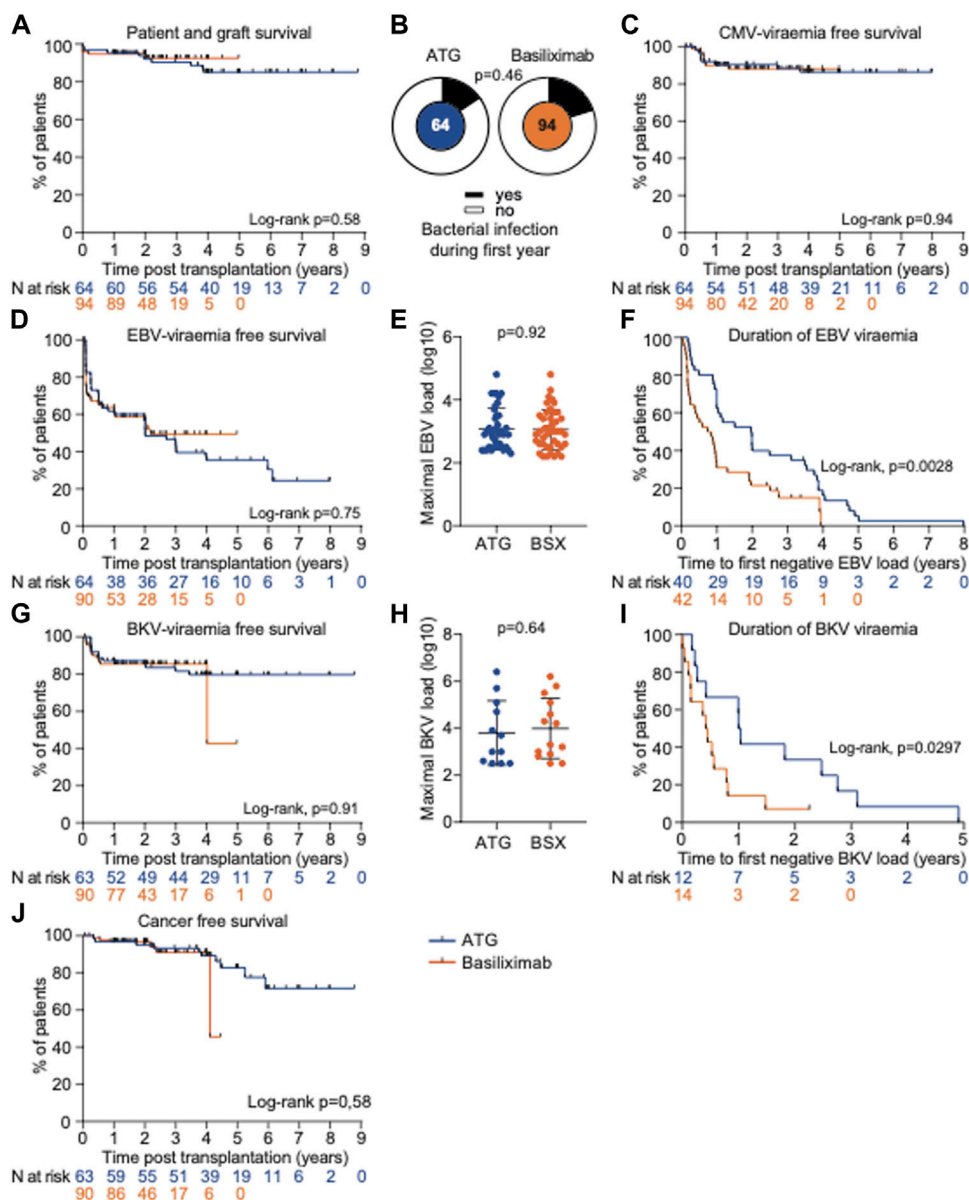


FIGURE 3

Comparison of infectious and cancer complications in patients receiving ATG or basiliximab. (A) Kaplan-Meier survival curve for patient and graft survival according to induction therapy. (B) The prevalence of bacterial infections during the first year was compared between each group in the entire cohort. Chi-square test, ns. (C,D) Kaplan-Meier survival curve for (C) CMV-viraemia and (D) EBV-viraemia free survival according to induction therapy in the entire cohort. (E) Comparison of the maximal EBV viral load between groups. Student's t-test, ns. (F) Kaplan-Meier curve of the delay between EBV reactivation and viral clearance according to induction therapy. (G) Kaplan-Meier survival curve for BKV-viraemia free survival according to induction therapy in patients without primary non function. (H) Comparison of the maximal BKV viral load between groups. Student's t-test, ns. (I) Kaplan-Meier curve of the delay between the first BKV viraemia and viral clearance according to induction therapy. (J) Kaplan-Meier survival curve for cancer free survival according to induction therapy.

viral loads (mean maximum viral load 3.8 ± 1.4 log vs. 4.0 ± 1.3 log in ATG and basiliximab groups, respectively; unpaired t-test, $p = 0.71$; Figure 3H), were similar in the two groups but patients from the ATG group exhibited longer duration of viremia (log-rank test, $p = 0.0297$; Figure 3I). However, this difference did not translate into a higher risk of BK virus-associated nephropathy (BKVAN), as only 4 patients developed BKVAN, 1 in the group ATG and 3 in the group basiliximab (log-rank test, $p = 0.41$).

Finally, the risk of cancer was equivalent in each group (log-rank test, $p = 0.58$; Figure 3J).

Validation of these results in an independent cohort

To assess the external validity of our findings, we analysed an independent validation cohort comprising 521 kidney transplant recipients from nine additional French centers who received a DCD graft between January 2015 and December 2023. Fifteen patients were excluded due to missing induction data. Among the 506 patients analysed, 408 received ATG and 98 received basiliximab. The characteristics of these patients are presented in

TABLE 2 Patients characteristics—Validation cohort.

Mean + SD or n (%)	Whole cohort N = 506	ATG N = 408	BSX N = 98	p-value
Recipient characteristics at the time of transplantation				
Female	176 (35)	150 (37)	26 (27)	0.073
Age (years)	54 ± 12.6	54 ± 12.6	52 ± 12.6	0.198
BMI (kg/m ²)	25.3 ± 4.4 ¹	25.4 ± 4.4 ¹	24.5 ± 4.4	0.049
Blood group				0.282
A				
B	218 (43)	171 (42)	47 (48)	
O	46 (9)	39 (10)	7 (7)	
AB	216 (43)	181 (44)	35 (36)	
ND	21 (4)	15 (3)	6 (6)	
	5 (1)	2 (1)	3 (3)	
Renal disease				0.888
Diabete mellitus	52 (10)	41 (10)	11 (11)	
Glomerulonephritis	120 (24)	97 (24)	23 (24)	
Tubular-interstitial, genetic	196 (39)	155 (38)	41 (42)	
Vascular	64 (13)	54 (13)	10 (10)	
Undetermined	74 (14)	61 (15)	13 (13)	
Anti-HLA antibody	266 (61 ²)	200 (60 ³)	66 (68 ⁴)	0.203
DSA	63 (15 ⁵)	47 (14 ⁶)	16 (16 ⁷)	1
Donor characteristics				
Female	144 (28)	121 (30)	23 (23)	0.274
Age (years)	52 ± 12.9 ⁸	52 ± 12.9	52 ± 13.4 ⁹	0.959
BMI (kg/m ²)	26.0 ± 5.5 ⁹	26.0 ± 5.6 ⁹	25.9 ± 5.5	0.846
Transplantation characteristics				
Cold ischemia time (min)	614 ± 247 ¹⁰	607 ± 250 ¹¹	643 ± 234 ¹²	0.181
Perfusion machine	450 (93 ¹³)	373 (93 ¹⁴)	77 (92 ¹⁵)	0.580
No. of HLA A/B/DR mismatches	3.5 ± 1.1 ¹⁶	3.5 ± 1.1	3.5 ± 1.1 ¹⁶	0.879
Maintenance immunosuppression at hospital discharge				
Tacrolimus	441 (87)	343 (84)	98 (100)	<0.001
Cyclosporine	63 (12)	63 (15)	0	
MMF	485 (96)	401 (98)	84 (86)	<0.001
Steroids mTORi	497 (98)	405 (99)	92 (94)	0.002
Belatacept	17 (3)	2 (1)	15 (15)	<0.001
	0	0	0	
CMV status				0.016
D ⁻ /R ⁻	124 (24)	94 (23)	30 (31)	
D ⁺ /R ⁻	86 (17)	63 (15)	23 (23)	
R ⁺	292 (58)	248 (61)	44 (45)	
ND	4 (1)	3 (1)	1 (1)	

(Continued)

TABLE 2 Continued

Mean + SD or n (%)		Whole cohort N = 506	ATG N = 408	BSX N = 98	p-value
EBV status					<0.001
	D ⁻ /R	1 (0)	1 (0)	0	
	D ⁺ /R	30 (6)	16 (4)	14 (14)	
	R ⁺	472 (93)	389 (95)	83 (85)	
	ND	3 (1)	2 (1)	1 (1)	

Abbreviations: ATG, anti-thymocyte globulins; BSX, basiliximab; BMI, body mass index; DSA, donor-specific antibodies; ND, not determined; MMF, mycophenolate mofetil; mTORi, mechanistic target of rapamycin inhibitor; CMV, cytomegalovirus; EBV, Epstein-Barr virus; D/R, donor/recipient.

¹ND for 1 recipient.

²ND for 73 recipients.

³ND for 72 recipients.

⁴ND for 1 recipient.

⁵ND for 83 recipients.

⁶ND for 82 recipients.

⁷ND for 1 recipient.

⁸ND for 1 donor.

⁹ND for 2 donors.

¹⁰ND for 6 grafts.

¹¹ND for 4 grafts.

¹²ND for 2 grafts.

¹³ND for 23 grafts.

¹⁴ND for 9 grafts.

¹⁵ND for 14 grafts.

¹⁶ND for 1 D/R pair.

Table 2. Of note, a higher proportion of patients in this cohort were immunised, with 61% having preformed anti-HLA antibodies and 15% having day-0 DSA. Furthermore, 7% of grafts in both groups were not preserved using a perfusion machine.

The distribution of induction regimens was more balanced over time than in the study cohort (Figure 4A). The rates of PNF, DGF (after exclusion of PNF), and rejections occurring during the first-year post-transplantation were similar between groups (Figures 4B,C). Kidney function and proteinuria at 1 year were also comparable between patients receiving ATG or basiliximab (Figure 4D).

Protocol biopsies were less systematically performed in this cohort, with fewer than one third of patients undergoing a one-year biopsy; therefore, no biopsy analysis at 1 year is reported.

Importantly, death-censored graft survival did not differ between the groups (log-rank test, $p = 0.44$; Figure 4E). Multivariable Cox regression adjusted for recipient age, HLA-A/B/DR mismatches and cold ischemia time confirmed that survival was comparable between basiliximab and ATG groups (HR 1.26, 95% CI 0.65–2.45; $p = 0.49$; Figure 4F).

From a safety perspective, the two groups were compared in terms of viral and malignancy-related complications. The incidences of CMV, EBV and BKV viremia were comparable (log-rank tests, $p = 0.26$, $p = 0.42$ and $p = 0.2$, respectively; Figures 5A–C). A non-significant trend towards an increased risk of cancer (all types combined) was observed in the ATG group (log-rank test, $p = 0.12$; Figure 5D).

ATG vs. basiliximab induction: comparable efficacy and risks, divergent costs

Basiliximab-treated patients exhibited slightly more early inflammatory kidney lesions without long-term graft impact,

while ATG-treated patients experienced prolonged EBV and BKV viremia without apparent severity. These non-significant differences balance the risks, offering no clear advantage for either agent. A pragmatic approach is to consider tolerance - measured here by the length of the initial hospital stay - and cost. Hospital stays were similar in both groups (mean 12 ± 6 days for ATG vs. 12 ± 7 days for basiliximab, $p = 0.80$; and 12 ± 8 days for ATG vs. 12 ± 7 days for basiliximab, $p = 0.48$; in the study and validation cohorts, respectively; Figure 6A). However, at our institution, ATG induction is, on average, 1.7 times (range 0.92–2.65) more expensive than basiliximab (€300 per ATG vial, median 15 vials per patient versus €1,315 per basiliximab vial, 2 vials per patient; Figure 6B). Therefore, we conclude that in the absence of a compelling clinical reason to prefer ATG, basiliximab appears to be a reasonable and cost-effective choice for induction in DCD kidney transplant recipients.

Discussion

In this study, we demonstrate, in two independent cohorts including a total of 664 patients, that induction therapy with ATG or basiliximab is associated with similar outcomes following kidney transplantation from DCD donors in recipients with a low immunological risk. ATG did not provide any advantage in terms of DGF or rejection incidence. However, it was also not associated with a higher risk of infectious or cancer-related complications.

In fact, at the time the program was set up in France, the rationale for preferring ATG to basiliximab appeared to be weak, as highlighted by the British and European recommendations on this topic [28, 29]. Since then, two studies have specifically compared ATG and IL-2RA in DCD kidney transplantation. In the first study [30], IL-2-RA induction was not associated with a higher risk of DGF.

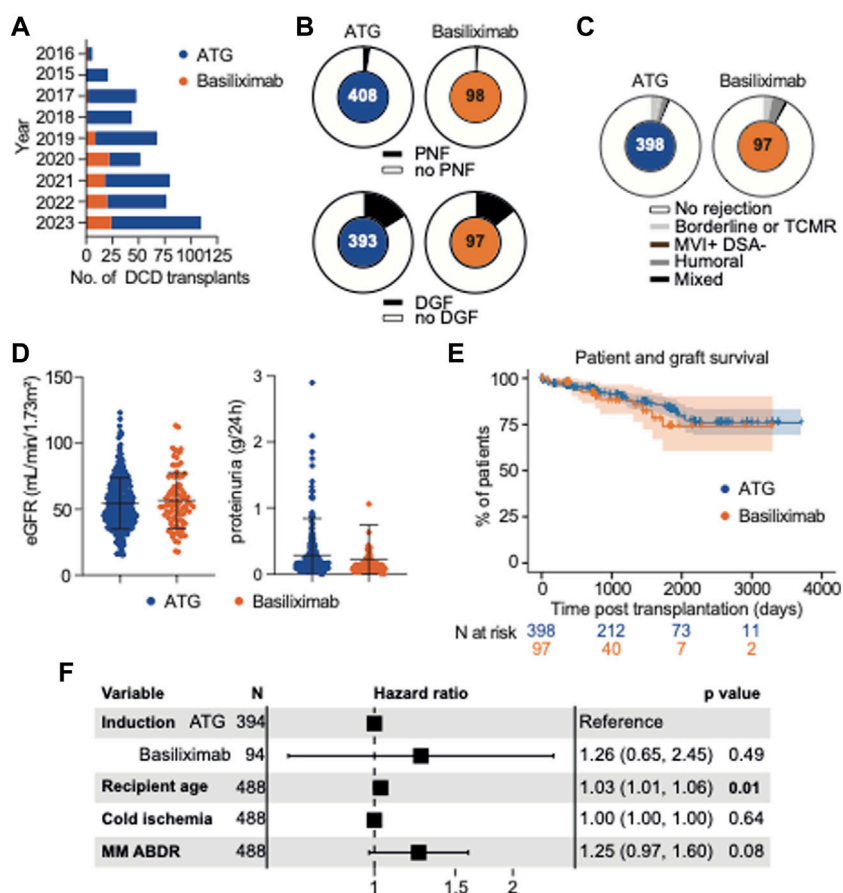


FIGURE 4 Renal functional and immunological outcomes in the validation cohort. (A) Histogram showing the annual number of DCD transplants by induction therapy in the validation cohort. (B) Prevalence of primary non-function (PNF) in the entire validation cohort and delayed graft function (DGF) in patients without PNF. Chi-square and Fisher’s exact test, ns. (C) Prevalence of rejection in patients without PNF during first year of follow-up. Chi-square test, ns. (D) Comparison of estimated glomerular filtration rate (eGFR) and proteinuria level at 1 year’s evaluation. Student’s t-test, ns. (E) Kaplan-Meier survival curve for death-censored graft survival according to induction therapy. (F) Forest plot representing the results of the multivariable Cox regression analysis. Abbreviations: MVI, microvascular inflammation; DSA, donor-specific antibodies.

In the second study [31], ATG was associated with a lower incidence of acute rejection but did not reduce the risk of DGF. Notably, the rates of DGF in both studies were very high, compared to our study which found around 15% DGF, with comparable rates between the groups. Limiting ischemia as much as possible seems to be crucial for these particular grafts, but our CIT were comparable to those previously published. Therefore, this difference is more likely due to the systematic use of normothermic regional perfusion [32] and hypothermic perfusion machine [11, 12], which was not the case in the two published studies. Consequently, our results on induction must be interpreted as part of a strict protocol, which imposes the two technical constraints mentioned above. They cannot therefore be extrapolated outside this specific framework.

One of the strengths of our study is that many patients of the cohort study (65.8% of those with a functioning graft at 1 year) had a screening renal biopsy 1 year post-transplantation, allowing for the detection of subclinical graft inflammation that would not have been seen based only on for cause biopsy and functional parameters [33]. Additionally, the relatively long follow-up period reinforces the robustness of our conclusions.

The theoretical benefit of ATG in mitigating ischemia-reperfusion injury is based on experimental data suggesting that these polyclonal cocktails also contain antibodies specific of adhesion molecules [34, 35] potentially limiting ischemia-reperfusion damage [15] by modulating the inflammatory infiltrate of the graft. As ischemia-reperfusion injury can theoretically still contribute to long-term graft remodeling, ATG should limit chronic graft dysfunction (which can be evaluated by cg and IF/TA lesions). However, our findings do not support any benefit of ATG, or this mechanism may not be relevant in DCD transplant recipients.

Interestingly, we also observed lower rates of T cell-mediated rejection in the basiliximab group compared to previous reports, despite no apparent differences in maintenance immunosuppression. One possible explanation is that perfusion may help clear ischemia-induced pro-inflammatory mediators and donor-derived immune cells, thereby reducing graft immunogenicity and potentially allowing for less intensive immunosuppression. These results confirm that ATG and IL-2RA give similar results in terms of rejection in patients at low immunological risk, as shown in

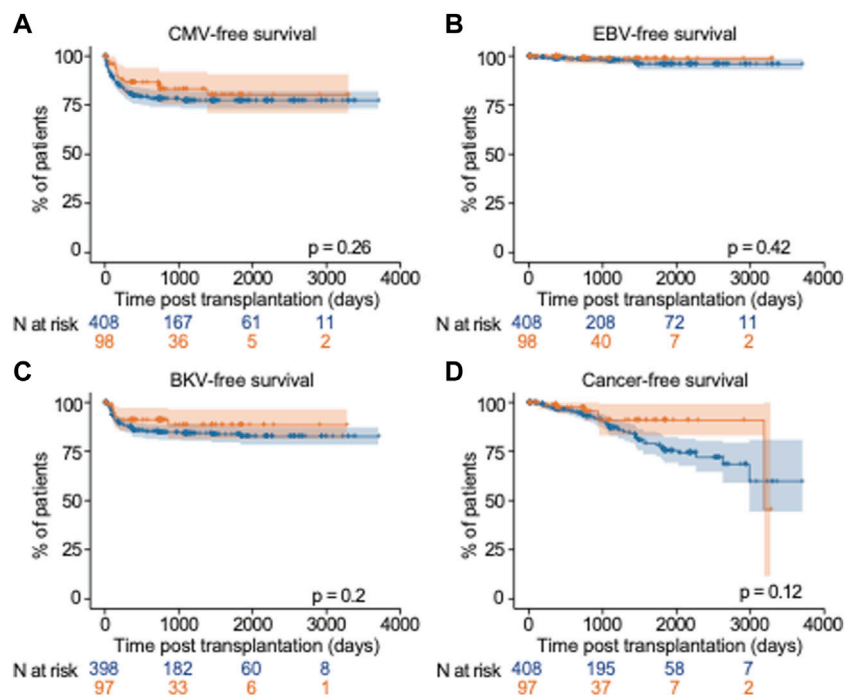


FIGURE 5
 Viral and cancer complications in the validation cohort. (A,B) Kaplan-Meier survival curve for (A) CMV-viraemia and (B) EBV-viraemia survival according to induction therapy in the entire cohort. (C) Kaplan-Meier survival curve for BKV-viraemia free survival according to induction therapy in patients without primary non function. (D) Kaplan-Meier survival curve for cancer free survival according to induction therapy.

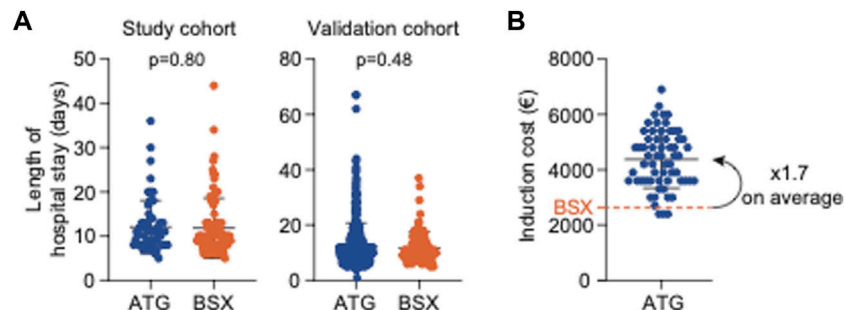


FIGURE 6
 Comparison of hospital stay duration in patients receiving ATG or basiliximab and treatment costs. (A) Comparison of the length of hospital stay between groups in the study (left) and the validation (right) cohorts. Student's t-test, ns. (B) Comparison of the costs of each treatment. The dashed line represents the fixed cost of induction with basiliximab.

previously published studies in kidney transplantation with brain-dead donors [36–38].

While we expected more infectious complications, particularly viral, in the ATG group [39–44], we did not observe any excess risk associated with the use of this induction therapy in our study. This result has probably various explanations, such as the lower dose of ATG used in our study (5 mg/kg versus 5–10 mg/kg in other studies), and the systematic use of anti-CMV prophylaxis in patients at risk.

Everything else being equal, it makes sense to prioritize a less expensive drug that does not require the use of animal for its production. While this study was not designed to assess

environmental impact, it is reasonable to assume that monoclonal antibodies have a lower ecological footprint. Since one of the key advantages of transplantation over hemodialysis is its lower societal cost—both financially and in terms of resource consumption (such as plastic disposables and other materials)—optimizing certain parameters, such as induction, could further strengthen this economic and environmental benefit.

Our study has some limitations. First, while the cohort sizes are sufficiently large to support statistical conclusions, the population is highly homogeneous, which limits the generalizability of our findings to more diverse groups, such as

older recipients or those at higher immunological risk. Second, the study is retrospective. However, as the choice of induction therapy in the study cohort was primarily determined by the transplantation period, clinician-driven selection bias was minimized. Notably, induction strategy was the only variable that differed between the two study periods. Furthermore, in the independent validation cohort, the use of induction therapy was more evenly distributed over time, with comparable results, suggesting that the potential bias mentioned above is likely negligible. Third, the follow-up duration may not have been sufficient to fully assess the long-term impact of induction therapy on late complications, such as cancer. Finally, although our study suggests a longer duration of BKV and EBV replication in the ATG group, these findings should be interpreted with caution due to the lack of standardized viral monitoring, which may have introduced bias into the results.

In conclusion, our study does not support selecting induction therapy based solely on DCD donor criteria, as it does not influence transplant outcomes. From a cost-effectiveness perspective, basiliximab should be the preferred choice for patients who do not require ATG to prevent the recurrence of their initial nephropathy. Further studies are needed to determine the optimal approach for high immunological risk recipients.

Data availability statement

The original contributions presented in the study are included in the article/supplementary material, further inquiries can be directed to the corresponding author.

Ethics statement

The requirement of ethical approval was waived by Comité Consultatif sur le Traitement de l'Information en matière de Recherche dans le domaine de la Santé for the studies involving humans because All patients gave informed consent for the utilization of clinical data [Données Informatiques Validées en Transplantation (DIVAT)] for research purpose at transplantation. The studies were conducted in accordance with the local legislation and institutional requirements. Written informed consent for participation was not required from the participants or the participants' legal guardians/next of kin because It was required at transplantation.

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Author contributions

MD, AK, GO, FB, EM, OT, and XC designed the study. All authors collected the clinical data. XC and MD analysed the data and formatted the results. XC, MD, and OT wrote the first draft of the manuscript. All authors reviewed the article and approved the submitted version.

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Conflict of interest

EM has received speaker fees from Sanofi.

The remaining author(s) declared that this work was conducted in the absence of any commercial or financial relationships that could be construed as a potential conflict of interest.

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