

KIPA2023_01 Allocation Simulation Analysis Report

Report for the Data Request from the OPTN Kidney and Pancreas
Committees

Contents

BACKGROUND	3
Baseline Scenario	3
Cohort	3
Strategic Goal	4
Continuous Distribution Formula	8
Scenario Rating Scales	9
Scenario Weights	13
Scenario Modifiers	15
SIMULATION SUBMODELS	16
History Generation	17
Donor Arrival Generation	19
Placement Mechanism (Acceptance Model) Background	19
Posttransplant Models	23
Operational Validation	24
RESULTS	25
Kidney	25
Pancreas	30
Organ Analysis	34
Kidney: Transplant Rates	37
Kidney: Distance Traveled for Transplanted Organs	45
Kidney: Posttransplant	56
Pancreas and Kidney-Pancreas: Transplant Rate	58
Pancreas and Kidney-Pancreas: Distance Traveled for Transplanted Organs	63
Kidney Additional	66



Pancreas and Kidney-Pancreas Additional 103
 Kidney-Pancreas: Transplant Rate 118
 Kidney-Pancreas: Distance Traveled for Transplanted Organs 122
 Kidney-Pancreas Additional 125

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BACKGROUND

The OPTN Kidney and Pancreas Committees are currently working on adopting the continuous distribution framework for kidney, pancreas, kidney-pancreas, and pancreas islets allocation. At the March 14, 2023, OPTN Kidney Committee meeting, the committee requested simulations for four different scenarios, plus current rules; at the March 6, 2023, OPTN Pancreas Committee meeting, the committee requested four different scenarios for pancreas and kidney-pancreas allocation. Each model, a run of the Organ Allocation Simulation software, represents a different set of weights for each of the attributes that will define continuous distribution.

Baseline Scenario

The simulation runs of the current allocation rules are used as a baseline scenario for all simulation comparisons and as a means of tuning the overall simulation and its sub-models.

The current allocation rules for kidney-pancreas allocation (OPTN Policy 11.5.A) give organ procurement organizations (OPOs) a choice between two pathways for kidney-pancreas donors. However, the simulator must follow a deterministic allocation order for all donors. At the March 15, 2022, meeting of the OPTN OPO Committee, OPO representatives indicated that current practice generally follows the pathway of offering both kidney and pancreas to the complete kidney-pancreas match run before offering the kidney to the kidney-alone match run. Accordingly, the baseline and all alternative simulation scenarios for this request also follow this pathway.

Cohort

The cohort for all simulation runs is all transplanted kidneys and pancreata from March 15, 2021, through March 15, 2022, and all kidney and pancreas candidates who were active during the same period, including *all* multiorgan candidates. Multiorgan candidates are included to ensure that historic match runs are accurately recreated in the simulation, which would not be possible if these candidates were excluded. Other than kidney-pancreas transplants, multiorgan *transplants* are not simulated. Therefore, results referring to “kidney-alone” transplants should be interpreted as transplants without a pancreas, and likewise results referring to “pancreas-alone” transplants should be interpreted as transplants without a kidney. This is particularly relevant when interpreting results on subpopulations of candidates that are disproportionately multiorgan (eg, pediatric pancreas candidates).

The simulation period was chosen to correspond with the implementation of the current "circle"-based allocation policy, and allow for 1 full year of donated organs from which to sample. Tables 1 and 2 show characteristics of the candidate cohort, and Table 3 shows characteristics of the donor cohort.

Strategic Goal

The strategic goal is to increase equity in access to transplants.

Table 1: Characteristics for the entire simulation cohort

Characteristic	Adult KI N = 135195 ¹	Pediatric KI N = 2793 ¹	Kidney-Pancreas N = 3229 ¹	Pancreas N = 1020 ¹
Age at Listing				
0-<18	0 (0%)	2,793 (100%)	5 (0.2%)	84 (8.2%)
18-<35	14,226 (11%)	0 (0%)	792 (25%)	254 (25%)
35-<50	36,273 (27%)	0 (0%)	1,671 (52%)	478 (47%)
50-<65	58,717 (43%)	0 (0%)	753 (23%)	194 (19%)
65+	25,979 (19%)	0 (0%)	8 (0.2%)	10 (1.0%)
Sex				
Female	51,301 (38%)	1,066 (38%)	1,396 (43%)	518 (51%)
Male	83,894 (62%)	1,727 (62%)	1,833 (57%)	502 (49%)
BMI	29.0 (25.1, 33.2)	19.0 (16.9, 22.7)	26.4 (23.4, 29.4)	25.1 (21.9, 28.8)
Blood Type				
A	38,358 (28%)	924 (33%)	1,007 (31%)	391 (38%)
AB	3,899 (2.9%)	90 (3.2%)	107 (3.3%)	41 (4.0%)
B	21,929 (16%)	393 (14%)	548 (17%)	112 (11%)
O	71,009 (53%)	1,386 (50%)	1,567 (49%)	476 (47%)
cPRA²				
0-60%	112,766 (83%)	2,473 (89%)	2,730 (85%)	820 (80%)
>60-80%	6,247 (4.6%)	81 (2.9%)	141 (4.4%)	39 (3.8%)
>80-98%	8,289 (6.1%)	105 (3.8%)	214 (6.6%)	81 (7.9%)
>98-99.5%	2,369 (1.8%)	41 (1.5%)	48 (1.5%)	27 (2.6%)
>99.5-99.9%	2,129 (1.6%)	43 (1.5%)	35 (1.1%)	28 (2.7%)
>99.9-100%	3,395 (2.5%)	50 (1.8%)	61 (1.9%)	25 (2.5%)
EPTS²				
0-20%	29,672 (22%)	582 (99%)	223 (14%)	0 (NA%)
>20-40%	28,009 (21%)	7 (1.2%)	752 (47%)	0 (NA%)
>40-60%	27,469 (20%)	1 (0.2%)	400 (25%)	0 (NA%)
>60-80%	26,190 (19%)	0 (0%)	177 (11%)	0 (NA%)
>80-100%	23,798 (18%)	0 (0%)	50 (3.1%)	0 (NA%)
Unknown	57	2,203	1,627	1,020

¹ Values are given as number (percentage), median (IQR), or number.

² Determined at the later of listing date or simulation start.

Table 2: Waiting list characteristics for the entire simulation cohort

Characteristic	Adult KI N = 135195 ¹	Pediatric KI N = 2793 ¹	Kidney-Pancreas N = 3229 ¹	Pancreas N = 1020 ¹
OPTN Region				
1	6,705 (5.0%)	103 (3.7%)	96 (3.0%)	42 (4.1%)
2	16,629 (12%)	343 (12%)	453 (14%)	145 (14%)
3	17,548 (13%)	280 (10%)	385 (12%)	66 (6.5%)
4	14,974 (11%)	248 (8.9%)	229 (7.1%)	50 (4.9%)
5	27,607 (20%)	647 (23%)	433 (13%)	91 (8.9%)
6	3,584 (2.7%)	91 (3.3%)	89 (2.8%)	7 (0.7%)
7	10,339 (7.6%)	259 (9.3%)	518 (16%)	240 (24%)
8	5,847 (4.3%)	185 (6.6%)	138 (4.3%)	35 (3.4%)
9	9,899 (7.3%)	240 (8.6%)	274 (8.5%)	147 (14%)
10	8,117 (6.0%)	158 (5.7%)	186 (5.8%)	113 (11%)
11	13,946 (10%)	239 (8.6%)	428 (13%)	84 (8.2%)
Qualifying Time (Years)²				
No Qualifying Time	15,308 (11%)	559 (20%)	445 (14%)	164 (16%)
>0-1	21,222 (16%)	760 (27%)	824 (26%)	191 (19%)
>1-2	23,277 (17%)	486 (17%)	766 (24%)	171 (17%)
>2-5	47,060 (35%)	672 (24%)	887 (27%)	282 (28%)
>5-10	23,898 (18%)	247 (8.8%)	263 (8.1%)	158 (15%)
>10	4,430 (3.3%)	69 (2.5%)	44 (1.4%)	54 (5.3%)
Time on Dialysis (Years)²				
0-1	14,636 (11%)	417 (15%)	582 (18%)	0 (0%)
>1-2	17,514 (13%)	285 (10%)	621 (19%)	0 (0%)
>2-5	38,541 (29%)	365 (13%)	741 (23%)	0 (0%)
>5-10	20,527 (15%)	115 (4.1%)	219 (6.8%)	0 (0%)
>10	3,998 (3.0%)	36 (1.3%)	34 (1.1%)	0 (0%)
Not on Dialysis	39,979 (30%)	1,575 (56%)	1,032 (32%)	1,020 (100%)

¹ Values are given as number (percentage).² Determined at the later of listing date or simulation start.

Table 3: Characteristics for the entire simulation donor cohort

Characteristic	Kidney N = 9340 ¹	Kidney-Pancreas N = 899 ¹	Pancreas N = 11 ¹
Age	41 (30, 52)	23 (18, 30)	22 (10, 30)
Sex			
Female	3,379 (36%)	280 (31%)	5 (45%)
Male	5,961 (64%)	619 (69%)	6 (55%)
BMI	28 (24, 33)	23 (21, 26)	23 (18, 24)
Blood Type			
A	3,441 (37%)	301 (33%)	3 (27%)
AB	315 (3.4%)	17 (1.9%)	0 (0%)
B	1,087 (12%)	110 (12%)	0 (0%)
O	4,497 (48%)	471 (52%)	8 (73%)
KDPI	48 (26, 69)	13 (6, 25)	39 (29, 55)

¹ Values are given as median (IQR) or number (percentage).

Continuous Distribution Formula

$$Score_i = \sum_j R_j(x_{i,j}(cand_i, don)) * W_j * M_j(don), \text{ where}$$

i : candidate,

j : metric,

R_j : the rating scale for metric, j ,

$x_{i,j}$: candidate i 's value for metric, j ,

W_j : weight for metric, j , and

M_j : donor weight modifier for metric, j .

Scenario Rating Scales

Kidney

Each component has a rating scale. The committee chose the following rating scales for kidney-alone candidates:

1. Medical urgency: A binary score.
 - Candidates meeting the policy definition of medically urgent receive a rating score of 1.
 - All other candidates receive a rating score of 0.
2. Posttransplant outcomes: The posttransplant outcomes component is split into DR mismatch and expected posttransplant survival (EPTS)/kidney donor profile index (KDPI) subcomponents.
 - DR mismatch:
 - Candidates with 0 HLA-DR mismatches to a donor receive a rating score of 1.
 - Candidates with 1 HLA-DR mismatch to a donor receive a rating score of 0.7.
 - Candidates with 2 HLA-DR mismatches to a donor receive a rating score of 0.
 - EPTS/KDPI: Each candidate has a calculated EPTS and each donor has a calculated KDPI.
 - Candidates with EPTS scores $\leq 20\%$ will receive 1 point for KDPI $\leq 20\%$ kidneys; this will be accomplished using a combination of rating scale points and donor modifiers.
 - Pediatric candidates will be assigned an EPTS of 0.
3. Candidate biology: The candidate biology component is split into blood type and calculated panel-reactive antibody (cPRA) subcomponents.
 - Blood type: Blood type screening as defined under current policy will be used in addition to blood type points, defined below.
 - Blood type: Blood type points are calculated based on the ratio of candidates with a blood type to donors they are compatible with, taking screening into account, and are scaled to a 0-1 score.

- Candidates with blood type A receive a rating score of 0.64827.
 - Candidates with blood type AB receive a rating score of 0.
 - Candidates with blood type B receive a rating score of 1.
 - Candidates with blood type O receive a rating score of 0.77192.
 - cPRA: Each candidate has a cPRA score for their sensitization.
 - The candidate's rating score for cPRA is $((100000^{cPRA}) - 1)/99999$.
4. Patient access: The patient access component is split into pediatric, prior living donor, kidney-after-liver safety net, and qualifying time subcomponents.
- Pediatric: A binary score.
 - Candidates younger than 18 years at time of listing receive a rating score of 1.
 - All other candidates receive a rating score of 0.
 - Prior living donor: A binary score.
 - Prior living donors of *any* organ receive a rating score of 1.
 - All other candidates receive a rating score of 0.
 - Safety net: A binary score
 - Candidates meeting the policy for kidney-after-liver safety net receive a rating score of 1.
 - All other candidates receive a rating score of 0.
 - Qualifying time: Each candidate has a qualifying time in years on the waiting list.
 - The candidate's qualifying time rating score is calculated as $0.1 * (time\ in\ years)$.
5. Placement efficiency: Candidates receive a score based on a piecewise linear function of the distance in nautical miles (NM) of their listed transplant center from the donor hospital.
- Candidates 0-50 NM from the donor hospital (inner plateau) receive a rating score of 1.
 - Candidates 51-250 NM from the donor hospital receive a rating score calculated as $1 - 0.15/200 * (NM - 50)$.
 - Candidates 251-500 NM from the donor hospital receive a rating score calculated as $0.85 - 0.6/250 * (NM - 250)$.
 - Candidates 501-5181 NM from the donor hospital receive a rating score calculated as $0.25 - 0.25/4681 * (NM - 500)$.

Pancreas

The committee chose the following rating scales for pancreas, kidney-pancreas, and pancreas islets candidates:

1. Candidate biology: The candidate biology component contains a cPRA component.
 - cPRA: Each candidate has a cPRA score for their sensitization.
 - The candidate's rating score for cPRA is $((100000^{cPRA}) - 1)/99999$
2. Patient access: The patient access component is split into pediatric, prior living donor, and qualifying time subcomponents.
 - Pediatric: A binary score.
 - Candidates younger than 18 years receive a rating score of 1.
 - All other candidates receive a rating score of 0.
 - Prior living donor: A binary score.
 - Prior living donors of *any* organ receive a rating score of 1.
 - All other candidates receive a rating score of 0.
 - Qualifying time: Each candidate has a qualifying time in years on the waiting list. The candidate's qualifying time rating score is a piecewise function of qualifying time.
 - Candidates with less than 5 years receive a rating score calculated as $0.18 * (\text{time in years})$.
 - Candidates with more than 5 years receive a rating score calculated as $0.004 * (\text{time in years} - 5) + 0.9$.
3. Placement efficiency: The placement efficiency component is split into proximity efficiency and whole pancreas subcomponents.
 - Proximity efficiency: Candidates receive a score based on a piecewise linear function of the distance in NM of their listed transplant center from the donor hospital.
 - Candidates 0-50 NM from the donor hospital (inner plateau) receive a rating score of 1.
 - Candidates 51-250 NM from the donor hospital receive a rating score calculated as $1 - 0.75/200 * (NM - 50)$.

- Candidates 251-5181 NM from the donor hospital receive a rating score calculated as $0.25 - 0.25/4931 * (NM - 250)$.
- Whole pancreas: A binary score.
 - Candidates listed for whole pancreas transplant as opposed to pancreas islets receive a rating score of 1.
 - All other candidates receive a score of 0.

Scenario Weights

Table 4: Simulation scenario weights for kidney

Subcomponent	Scenario 1	Scenario 2	Scenario 3	Scenario 4
	1:1	1.3:1	1.6:1	2:1
Medical Urgency				
Medical Urgency	15%	15%	15%	15%
Posttransplant Outcomes				
DR Mismatch	5.60%	8.10%	4.50%	8.20%
EPTS ≤ 20 /KDPI	6.60%	5.10%	9.60%	7.70%
EPTS > 20/KDPI	6.60%	5.10%	9.60%	7.70%
Candidate Biology				
Blood Type	14.60%	15.20%	9.80%	14.30%
cPRA	6.40%	5.80%	6.20%	5.40%
Patient Access				
Prior Living Donor	15.10%	15%	15.10%	15%
Pediatrics	15.10%	15.90%	16.70%	14.10%
Kidney-After-Liver Safety Net	5%	5%	5%	5%
Qualifying Time	5.60%	5.30%	7.70%	6.70%
Placement Efficiency				
Proximity Efficiency	11%	9.60%	10.40%	8.60%

Table 5: Simulation scenario weights for pancreas

Subcomponent	Scenario 1	Scenario 2	Scenario 3	Scenario 4
	1:1	1.3:1	1.6:1	2:1
Candidate Biology				
cPRA	20%	17%	18%	19%
Patient Access				
Prior Living Donor	20%	17%	18%	19%
Pediatrics	20%	17%	18%	19%
Qualifying Time	15%	17%	14%	11%
Placement Efficiency				
Proximity Efficiency	15%	22%	22%	22%
Whole Pancreas	10%	10%	10%	10%



Scenario Modifiers

Table 6: Simulation donor weight modifiers for kidney

Subcomponent	KDPI 0%-20%	KDPI 21%-34%	KDPI 35%-85% & Donor Age < 18 y	KDPI 35%-85% & Donor Age ≥ 18 y	KDPI 86%-100%
Medical Urgency					
Medical Urgency	1	1	1	1	1
Posttransplant Outcomes					
DR Mismatch	1	1	1	1	1
EPTS ≤ 20 /KDPI	1	0	0	0	0
EPTS > 20/KDPI	0	0	0	0	0
Candidate Biology					
Blood Type	1	1	1	1	1
cPRA	1	1	1	1	1
Patient Access					
Prior Living Donor	1	1	1	1	0
Pediatrics	1	1	1	0	0
Kidney-After-Liver Safety Net	0	1	1	1	1
Qualifying Time	1	1	1	1	1
Placement Efficiency					
Proximity Efficiency	1	1	1	1	3

Table 7: Simulation donor weight modifiers for all pancreas

Subcomponent	Donor Age ≤ 45 y & Donor BMI ≤ 30	Donor Age > 45 y or Donor BMI > 30
Candidate Biology		
cPRA	1	1
Patient Access		
Prior Living Donor	1	1
Pediatrics	1	1
Qualifying Time	1	1
Placement Efficiency		
Proximity Efficiency	1	1
Whole Pancreas	1	-1

SIMULATION SUBMODELS

Simulation of the organ allocation system requires a number of submodels, which are described here. All simulated scenarios share the same set of submodels.

History Generation

Transplant recipients in the historical cohort do not have a complete history from the standpoint of the simulation. Through simulation we hope to create novel match runs, so transplant recipients require a waitlist history for the simulation period after their transplant: a model of what would have happened had they not received a transplant.

Histories were generated for candidates who underwent transplant with an organ from a deceased donor allocated through the OPTN process. Living donor recipients and those who underwent transplant in another country did not have histories generated; in the simulation, they were removed from the list at their time of transplant like any other removal. The availability of living donors and foreign transplants are external to the simulated system.

Each listing for recipients who were listed at multiple centers was treated independently. Each recipient will have a history generated based on the last records available for the listing of each center; although this is the same individual, the value for each of their records at the two (or more) centers are not *required* to match.

There are two time-varying fields important for allocation policies in this simulation analysis: cPRA and EPTS.

cPRA is updated when the candidate's transplant center enters new unacceptable antigen information. For this history generation model, we assumed that candidates who received a transplant had an already advantageous cPRA value and so their transplant programs did not make any updates to their unacceptable antigen information. That is, the recipients keep their cPRA value at transplant.

Raw EPTS is calculated as:

$$\begin{aligned} \text{Raw EPTS} &= 0.047 * \max(\text{Age} - 25, 0) \\ &- 0.015 * \text{Diabetes} * \max(\text{Age} - 25, 0) \\ &+ 0.398 * \text{Prior Solid Organ Transplant} \\ &- 0.237 * \text{Diabetes} * \text{Prior Organ Transplant} \\ &+ 0.315 * \log(\text{Years on Dialysis} + 1) \\ &- 0.099 * \text{Diabetes} * \log(\text{Years on Dialysis} + 1) \\ &+ 0.130 * (\text{Years on Dialysis} = 0) \\ &- 0.348 * \text{Diabetes} * (\text{Years on Dialysis} = 0) \\ &+ 1.262 * \text{Diabetes} \end{aligned}$$

For the purpose of calculating EPTS in a generated patient history, we assumed Diabetes and Prior Organ Transplant statuses do not change. Given this, the only values

that changed were Years on Dialysis and Age. The raw EPTS was simply calculated every day of the simulation period posttransplant.

Waitlist removal was modeled with a matching algorithm. An attempt was made to match each transplant recipient to a candidate who did not receive a transplant during the cohort period; potential candidates were removals from the list or those who were still waiting. The matching was based on:

- Kidney:
 - Sex
 - Age at listing \pm 5 years of transplant candidate
 - Waitlist organ
 - At least 80% of the waiting time as the transplant candidate

- Pancreas and Kidney-Pancreas
 - Sex
 - Age at listing \pm 10 years of transplant candidate
 - Waitlist organ

After matching to create a group of potential candidates and checking that there were at least 10 unique candidates, a single candidate and date on their waitlist history that met the criteria was randomly selected. This sampled waitlist history was then applied to the transplant recipient at their transplant date. If this sampled removal history was:

- still waiting on the list historically, then the transplant recipient did not have a generated removal
- removed historically, but not within the remaining simulation period, then the transplant recipient did not have a generated removal
- removed within the remaining simulation period, then the transplant recipient had a generated removal of the same reason as the selected candidate.

After the matching algorithm, there were 31 kidney recipients and 1 kidney-pancreas recipient who could not be matched based on too few matching records. These recipients were assumed to remain on the list for the entire simulation period.

Donor Arrival Generation

Novel simulated match runs are created in part via randomization of the donated organ arrivals. We used a sampling approach to create different simulation iterations based on donor arrival date. All donors were sampled as follows:

- The donor arrival dates were sampled without replacement, reshuffling the donor arrival dates. This was used for four simulation iterations and was intended to closely match the historical record.
- The donor arrival dates were sampled with replacement. This was used for three iterations and was intended to broaden the range of possible match runs.
- Donor arrival dates were sampled uniformly from the entire cohort period. This was used for three iterations and was intended to create more variability. This sampling scheme may “smooth out” trends for donor arrival.

Placement Mechanism (Acceptance Model) Background

The placement mechanism (PM) in a simulation study of the organ allocation system is a submodel that determines who (if anyone) on a match run will accept a deceased donor organ for transplant. A PM can take many forms. For this KIPA2023_01 data request, we used an “accept/decline” style PM: a PM that offers an organ to candidates sequentially on the match run until a candidate accepts the organ, determined by probabilities calculated from one or more logistic regression models along with a random number generator, or until the match run is exhausted, in which case the organ is not used.

Note that because only transplanted organs are included in the cohort, nonuse of organs is not a validation/analysis metric. The “goal” of the PM is to place all organs somewhere on the match run; however, given the stochastic nature of the acceptance model framing, this is not guaranteed. There will always be some probability that an organ may be declined by every candidate; this is a model artifact, not a model result, and may result in fewer transplants performed in the simulation than were actually performed.

The same PM will be used for all requested simulations. This framing introduces an important assumption: the accept/decline behavior of candidates is invariant across allocation policies (ie, probability of acceptance under different allocation systems is reasonably approximated by the same logistic regression model[s]). This assumption is likely not entirely true in practice. However, the degree to which this assumption is violated in our simulations will depend greatly on the degree of allocation change under consideration and on what variables we allow to inform the PM model.

Since offer acceptance behavior depends, at least in part, on the allocation system in effect, the logistic regression model used to calculate the probability that a candidate will accept an organ will be trained using match-run data for the baseline allocation system. Organ nonuse will not be modeled; only match runs that ultimately resulted in an acceptance will be included in the model building.

We represented each individual “accept/decline” decision made by a candidate on a match run as a record in a logistic regression model. The probability that a candidate will accept an organ for transplant likely depends on characteristics of both the donor and the candidate. The SRTR database provides a large number of possible donor and candidate characteristics which could be used to inform our model. However, we need to be very careful, given that our simulation framing assumes the same accept/decline behavior across allocation policies.

For KIPA2023_01, the potential acceptance models will attempt to capture two features of the acceptance decision that were not present in the model used for KI2022_01:

- center variability
- center rank

Center variability background

Center variability attempts to characterize the notion that acceptance behavior varies widely across centers, and that incorporating this into the model will create a system closer to the historical system. Note that this does not mean the results of the simulation analysis are meant to be interpreted at the center level; these features are being accounted for in an attempt to make the aggregate metrics closer to the historical results.

Center variability is included in potential acceptance models via two concepts: offer acceptance ratio (OAR) and center-level covariate. The OAR is a model external to this simulation analysis based on the SRTR program-specific report (PSR) models. The OARs for each center were calculated based on the results of the external PSR model as applied to the simulation cohort; this factor in various forms is included for potential inclusion. Additionally, a model simply incorporating a covariate for each center is considered.

Center rank background

The design calls for the same acceptance model to be used across simulated potential allocation policies, which introduces an assumption into the simulated results: acceptance behavior, as predicted by the model, is invariant across allocation policies. This

assumption has been used in past modeling to exclude metrics that are a direct result of the allocation policy (eg, offer number). Empirical evidence suggests that a potential transplant recipient's offer number can mean different things across allocation policies, which violates the invariance assumption.

Offer number, and other allocation-related metrics, differ from other potential covariates in that they do not have a biological/medical heuristic to justify why the behavior would be the same across policies. For example, a donation after circulatory death donor is thought to mean the same thing from a biological/medical perspective to a candidate regardless of the specifics of the allocation policy. Empirical evidence suggests that a candidate's offer number and center number (ie, the number of transplant centers that have received an offer up to that point in the match run) violates the invariance assumption. However, for another allocation-related metric, center rank, there is good reason to believe that this metric is more in line with the invariance assumption.

A potential transplant recipient's center rank is their relative priority among other potential transplant recipients listed at the same transplant center. There are a number of proposed mechanisms that indicate why the impact of center rank on probability of acceptance might be invariant across allocation policies.

1. **Offer Decline vs. Organ Decline:** It is possible for a center to not merely decline an organ offer for this or that candidate, but to also decline that organ full stop. Center rank tells us how many times a specific center has declined an organ offer, and the greater the center rank, the more likely that center is declining the organ full stop, as opposed to merely declining it for specific candidates. This kind of behavior likely holds regardless of allocation policy.
2. **Candidate Readiness:** Transplant programs, especially kidney transplant programs, can have many waiting candidates. Not all of these candidates are necessarily ready for transplant if they received a suitable offer. Those candidates at the top of a center's list (ie, those with the lowest center rank) are most likely to be ready for transplant, because the transplant center knows that those candidates are the ones most likely to receive offers soon. This kind of behavior will likely hold for the allocation policies under consideration, where center rank is stable across different offered organs.
3. **Decision Theory:** When evaluating an organ offer, the transplant program must weigh the pros and cons of accepting that organ offer now, or else continuing to wait for a better offer in the future. How this decision is made depends upon a potential transplant recipient's center rank. Those with the highest priority may deem it worth declining a lower-quality organ and waiting a short time for a better

offer, whereas those with lower priority may deem it worth accepting a lower-quality organ instead of waiting a long time for a better offer. This kind of behavior will also likely hold for the allocation policies under consideration, where center rank is stable across different offered organs.

Potential acceptance models

We considered four ways of accounting for center variability in the potential acceptance models. Each of the types of models below was assessed with and without accounting for center rank:

- No center variability metrics
 - Without center rank, this amounts to the acceptance model from KI2022_01 and functions as a calibration model
 - Comparison to this model ensures the updated models are actually an improvement
- Overall OAR
 - Each center's overall OAR is included as a covariate
- All OAR
 - Each center's overall OAR is included as a covariate as well as an OAR covariate based on subsets of offered organs
- Center-level covariate

Each of the eight potential models above were built independently for these four subgroups:

- kidney and 18 years or older at listing,
- kidney and younger than 18 years at listing,
- kidney-pancreas, and
- pancreas.

Additionally, we ran three simple calibration simulations using only match-run position: 1st, 5th, and 10th on the list. Each of these PMs (along with the other submodels) were used in an operational validation simulation analysis, and the model with a center-level covariate and accounting for center rank was selected (see the "Operational Validation" section).

Posttransplant Models

Each simulation produces a unique group of patients who undergo transplant, some of whom may not yet have received a transplant in reality. To represent posttransplant outcomes in these simulated groups of transplant recipients, predicted probabilities at 1 year and 10 years posttransplant of all-cause graft failure and of death after transplant were estimated with Cox proportional hazards survival models.

Patients who underwent transplant between January 1, 2007, and November 2, 2021, were included in the cohort to fit the survival models. Patients were followed until the earliest of graft failure, death, or November 2, 2021. Patients who did not experience death or graft failure were assumed to be alive until November 2, 2021, even if their date of last follow-up was prior to November 2, 2021. Living donor transplants were excluded.

Separate models were fit for four different outcomes:

1. Kidney graft failure, including patient death. This outcome is defined as the earliest of death, relisting, retransplant, resuming dialysis, or center-reported graft failure.
2. Kidney recipient death.
3. Pancreas graft failure, including patient death. This outcome is defined as the earliest of death, relisting, or retransplant as there has only recently been a consistent OPTN definition of graft failure.
4. Pancreas recipient death.

The model cohort was split into an 80% training dataset and a 20% validation dataset. Elastic net Cox proportional hazard models with alpha of 0.99999 were fit with the 80% training dataset for variable selection. Variables identified from PSRs as predicting graft failure or death, and additional variables hypothesized to be associated with these outcomes, were included. Models were stratified on demographic or clinical predictors with evidence of violating the proportional hazards assumption to the extent possible. Continuous variables were transformed with linear splines. After variable selection with the elastic net models, center-level random effects were estimated with a Cox proportional hazard frailty model with an offset for the linear predictor from the elastic net model.

The linear predictor from the elastic net models and the center-level random effect were used to predict the probability of an outcome at 1-year and 10-years post-transplant. For each model, strata-specific baseline cumulative hazards at 1-year and 10-years posttransplant were estimated, multiplied by the patient-level linear predictor

and center-level random effect and transformed to a probability of event at 1-year or 10-years posttransplant for each patient. Using the 20% validation dataset, the sum of the probabilities of events from the models was compared to the observed number of events to estimate a multiplier for adjusting the baseline hazard. For example, if there were 120 predicted events, but only 100 observed events, the multiplier (or divisor) is 1.2, and each individual probability is divided by 1.2 to bring the baseline percents closer to those observed in reality.

For the simulated transplants, individual-level probabilities were estimated using the model parameters and divided by the multipliers. These individual-level probabilities were averaged across population subgroups of interest and multiplied by 100 to get the predicted percent of patients within a subgroup who would experience the event by 1-year or 10-years posttransplant.

Operational Validation

The potential acceptance models described in the “Potential acceptance models” section were evaluated using simulation. This process is called operational validation (OV) and was used for acceptance model selection as well as for characterization of the overall simulation model’s quality. The acceptance model with a center-level covariate and accounting for center rank was selected.

Each potential acceptance model was used (in conjunction with the other submodels) to simulate the cohort period, and the simulated results were compared to historic results as measured by the primary assessment metrics for the overall simulation study. Each figure in this final analysis report has an analog in the OV simulation analysis. Additionally, we analyzed results specifically related to the quality of model fit but not directly needed for the final analysis.

The OV simulations were run on a sample of the whole cohort. The initial sampling took place with donors during the logistic regression modeling process, described in the “Placement Mechanism (Acceptance Model) Background” section. The donors were split into train, test, and validation datasets, where the first two were used directly for the acceptance model building, and the final validation dataset was reserved for these operational validation simulations.

As mentioned above, the OV simulations were also used to characterize the quality of the overall simulation model, that is, all submodels working together. Observations relating to the overall reliability of the simulated results are noted in figure captions as appropriate in the by organ, kidney transplant rate, kidney distance traveled for transplanted organs, pancreas and kidney-pancreas transplant rate, and pancreas and kidney-

pancreas distance traveled for transplanted organs results sections below. Figures in these sections without OV notes had estimated results close to the historic results and did not require additional details. Figures in the kidney additional, pancreas and kidney-pancreas additional, and all kidney-pancreas results sections were not summarized as a part of the OV analysis; however, each of these figures was evaluated in the OV stage to ensure the simulated results did not exhibit any noticeable deficiencies. During the OV stage, we determined that offer number and center number were not reliable enough to present analytic results.

RESULTS

Kidney

Patient access

Question 1: Do the proposed CD policies maintain the high level of access that pediatric candidates receive in the current system? All proposed continuous distribution policies maintain a high level of access to kidney transplant for pediatric candidates. The simulation of current policy showed a kidney transplant rate of 0.74 transplants per patient-year among candidates younger than 18 years. The continuous distribution policies showed kidney transplant rates between 0.82 and 0.83 transplants per patient-year among candidates younger than 18 years. Overall kidney transplant rates were stable for other age groups as well from the simulation of current policy to the continuous distribution policies (Figure 4).

Question 2: Do the proposed CD policies maintain a high level of access for the extremely highly sensitized (cPRA 99.9+)? *Under currently policy, the highly sensitized have very high access to transplant; Do the proposed CD policies result in reduced access for the highly sensitized (cPRA 98-99.9; using the buckets used in the previous addendum report) and overall lower disparities in access across cPRA groups?*

Simulation models have shown limited ability to calibrate to historic transplant rates across cPRA groups, and therefore cannot be used to make definitive conclusions about *disparities* or equitability of transplant rates across cPRA groups. However, comparisons within a cPRA group across *scenarios* have been robust to sensitivity analyses, and inference across scenarios within a cPRA group are more well supported. Within this limitation, continuous distribution scenarios show lower adult kidney transplant rates for all cPRA groups over 80% compared to the simulation of current policy: this includes for patients with cPRA from >80% to 99.9%, who have historically experienced slightly greater

access than other cPRA groups, as well as for patients with cPRA of >99.9% to 100%, a group that has historically experienced lower transplant rates than all other cPRA groups (Figure 5).

Among pediatric candidates, continuous distribution scenarios showed higher transplant rates compared to the simulation of current policy for the cPRA groups from 80% to 99.5%, but were not notably different within other cPRA groups (Figure 6).

Question 3: Do the proposed CD policies transplant those with the highest qualifying times at a rate equal to or higher than current policy?

Adult kidney transplant rates by qualifying time were not dramatically different across continuous distribution scenarios compared to the simulation of current policy. For those adult kidney candidates with the longest qualifying time (more than 5 years), the transplant rate was highest under the “1.6:1” scenario (not surprising, as this scenario gives the greatest weight to qualifying time). Among adult kidney candidates who were waiting more than 5 years, the only continuous distribution scenario that showed the lowest transplant rates was “1.3:1”, which gave the least weight to qualifying time (Figure 7).

Among pediatric kidney candidates, transplant rates were higher under continuous distribution scenarios compared to the simulation of current policy for all waiting time groups (Figure 8).

Question 4: Do the proposed CD policies maintain a high level of access for prior living donors?

The continuous distribution scenarios showed higher transplant rates for prior living donors compared to the simulation of current policy, and in all cases transplant rates for prior living donors were notably higher than transplant rates for candidates who were not prior living donors (Figure 65).

Question 5: Do the proposed CD policies result in appropriate access for safety net candidates?

While the transplant rates for kidney-after-liver safety net candidates were lower under the continuous distribution scenarios compared to the simulation of current policy, transplant rates for kidney-after-liver safety net candidates were still notable higher than for candidates who were not kidney-after-liver safety net under all scenarios (Figure 66).

Question 6: Do the proposed CD policies maintain a high level of access for medically urgent candidates?

The number of candidates in the simulation cohort that

ever had a medically urgent status (n = 24) is too small to reasonably examine access across the simulated scenarios for candidates with this status.

Placement efficiency

Question 1: On average, how far are organs traveling? Under the simulation of current policy, the median travel distance for kidneys was 158 NM. The median travel distance for kidneys was slightly higher under the continuous distribution scenarios compared to the simulation of current policy. The longest median travel distance was 179 NM under the “2:1” scenario, which had the lowest weight placed on proximity efficiency (Figure 2).

Question 2: What is the distribution of travel distance? The distribution of kidney travel distances under the simulation of current policy shows a notable boundary at 250 NM, with relatively few kidneys travelling beyond 250 NM. Under all the continuous distribution scenarios, many more kidneys were travelling between 250 and 500 NM, although still relatively few were travelling beyond 500 NM (Figure 3).

Question 3: Are higher KDPI kidneys traveling shorter distances? In other words, is the increased donor modifier having the intended effect? For adult kidney travel distance, the distribution of distances under continuous distribution for kidneys with KDPI > 85% did not look notably different from the distributions for kidneys with KDPI ≤ 85% (Figure 14). However, KDPI > 85% is the only category where the median travel distance is less under all continuous distribution scenarios than under the simulation of current policy (Figure 13).

Question 4: When organs travel further are they traveling farther to reach vulnerable populations? (i.e. pediatrics, extremely highly sensitized) The distribution of travel distances shows notably longer travel distances for pediatric candidates under continuous distribution as compared to the simulation of current policy (Figure 12), which is also reflected in substantially longer median travel distances for pediatric candidates under continuous distribution compared to the simulation of current policy (Figure 11).

The distributions of kidney travel distance for the highest adult cPRA categories (>99.5% to 99.9% and >99.9% to 100%) show notably shorter travel distances under the continuous distribution scenarios compared to the simulation of current policy (Figure 18), which is also reflected in substantially lower median travel distances for highest

cPRA adult kidney transplants under continuous distribution compared to the simulation of current policy (Figure 17). For pediatric kidney transplants, the travel distances from the simulation of current policy to the continuous distribution scenarios are not substantially different for the highest cPRA categories (>99.5% to 99.9% and >99.9% to 100%), while for all lower cPRA categories the travel distances are substantially greater under continuous distribution compared to the simulation of current policy (Figures 20 and 19).

Candidate biology

Question 1: Do the proposed policies maintain access for O and B candidates? & Question 2: Do the proposed policies result in fewer disparities in access to transplant across blood types? *Committee expressed that decreased access for B and O candidates would not be tolerable.*

Adult kidney transplant rates did not differ from the simulation of current policy to any of the continuous distribution scenarios for candidates with A, B, or O blood type. Kidney transplant rates for adult candidates with blood type AB were lower under all continuous distribution scenarios than the simulation of current policy, although these rates under continuous distribution scenarios for AB candidates were closer to those for adult candidates with other blood types (Figure 9).

Posttransplant outcomes

Question 1: Do the proposed policies result in decreased graft failure and higher survival (short and long term)? One-year (Figure 21) and 10-year (Figure 22) kidney graft failure under all continuous distribution scenarios were consistent with or lower than the simulation of current policy.

Question 2: Do the proposed policies balance longevity matching and qualifying time? *In other words are we able to transplant EPTS 0-20% candidates with low KDPI kidneys without dropping their access while still transplanting those that have the longest qualifying times*

Adult kidney transplant rates were slightly higher for EPTS 0-20% candidates under continuous distribution compared to the simulation of current policy, and these candidates maintained the highest transplant rates of all EPTS categories (Figure 48). For candidates waiting 5 years or more, the adult kidney transplant rates were highest under the "1.6:1" scenario and lowest under the "1.3:1" scenario (Figure 7); for pediatric kidney

candidates at any duration of qualifying time, transplant rates were slightly higher under continuous distribution compared to the simulation of current policy (Figure 8). For candidates on dialysis 5 years or less, variations in transplant rate were relatively minor across continuous distribution scenarios compared to the simulation of current policy; only under the “1.6:1” policy did the transplant rate for candidates on dialysis 2 years or less drop slightly. For candidates on dialysis more than 5 years, the transplant rates were notably higher under the “1.6:1” scenario, which gives the highest weight to qualifying time (7.7%), compared to the other continuous distribution scenario and simulation of current policy. For candidates on dialysis 5 to 10 years, the scenario “1.3:1”, which gives the least weight to qualifying time (5.3%), showed a noticeably lower transplant rate compared to the simulation of current policy (Figure 50).

Other

Question 1: Do the proposed policies help diminish any disparities in access to transplant for subpopulations (Sex, Race, Ethnicity, Age, Rural/ Urban, Geography, cPRA, Blood type, EPTS, Medical urgency, Time on dialysis groups, Safety net candidates)? *The proposed CD policies aim to balance priority for patient access groups but may inadvertently result in decreased access for some subpopulations in an effort to prioritize others.*

There were few notable changes in kidney transplant rates from the simulation of current policy to the continuous distribution scenarios among population groups that have not already been discussed. The small changes in transplant rate by sex from the simulation of current policy to the continuous distribution scenarios bring the rates for females and males closer together (Figure 30). Transplant rates by race did not show large differences under the continuous distribution scenarios compared to the simulation of current policy; however, under all continuous distribution scenarios except “1.6:1”, which gave the most weight to qualifying time, transplant rates for Black and Native American candidates were slightly lower than under the simulation of current policy (Figure 32). Transplant rates by ethnicity did not show large differences under the continuous distribution scenarios compared to the simulation of current policy; however, under all continuous distribution scenarios, transplant rates for Latino candidates were slightly higher than under the simulation of current policy (Figure 34).

Transplant rates by rural or urban residence did not show large differences under the continuous distribution scenarios compared to the simulation of current policy; however, under the “1.6:1” continuous distribution scenario, transplant rates for nonmetropolitan (rural) candidates were slightly lower than under the simulation of

current policy or other continuous distribution scenarios (Figure 36). Transplant rates by OPTN region did not show large differences under the continuous distribution scenarios compared to the simulation of current policy; in the instances where there were slightly lower transplant rates under continuous distribution in a region compared to the simulation of current policy, it was most marked in regions that already showed the highest simulated transplant rates under current policy (Figures 38, 39, 40, 41, 42, 43, 44 and 45)

Question 2: Are there any unintended consequences on waitlist outcomes (additional time waiting, higher cumulative incidence of death etc.) for any subpopulations (Sex, Race, Ethnicity, Age, Rural/ Urban, Geography, cPRA, Blood type, EPTS, Medical urgency, Time on dialysis groups, Safety net candidates)? No population subgroup showed a difference in cumulative incidence of waitlist mortality from the simulation of current policy to any of the continuous distribution scenarios (Figures 31, 33, 35, 37, 46, 47, 49, 51).

For almost every population subgroup, of all the scenarios simulated, including current policy, the median qualifying time at transplant was highest under the "1.6:1" scenario that gives the most weight to qualifying time and lowest under the "1.3:1" scenario that gives the least weight to qualifying time (Figures 55, 56, 57, 58, 59, 60, 61, 62, 63, 64).

Pancreas

Placement efficiency

Goal: Maintain or reduce KP/PA travel distances relative to the current system (using travel distance as a proxy for anticipated impact on pancreas utilization).

Question 1: What is the distribution of organ travel distance (assess separately for KP and PA)? While the organ travel distance distributions for kidney-pancreas and pancreas show less of a hard boundary at 250 NM under the continuous distribution scenarios compared to the simulation of current policy (Figure 3), kidney-pancreas and pancreas median travel distance was lower under continuous distribution scenarios compared to the simulation of current policy – particularly for scenarios "1.3:1", "1.6:1", and "2:1" which have the highest weights on proximity efficiency (Figure 2).

Question 2: When KP/PA travel farther, are they doing so to reach highly sensitized candidates, pediatric candidates, and/or candidates with long qualifying times?

While variation across the simulation iteration makes it difficult to draw strong conclusions, pediatric and older adult candidates showed longer median travel distance for kidney-pancreas and pancreas under continuous distribution scenarios compared to the simulation of current policy. By contrast, median travel distance was not notably different for other age groups from the simulation of current policy to the continuous distribution scenarios (Figure 27). Variation across the simulation iterations also make strong conclusions difficult for the highest cPRA categories. However, the cPRA categories above 80% showed greater median travel distance than the lower cPRA categories, and it was the cPRA categories above 80% that also showed greater travel distance under the continuous distribution scenarios as compared to the simulation of current policy (Figure 28). Median travel distance remains highest for kidney-pancreas and pancreas transplant to candidates waiting more than 2 years for all scenarios compared to candidates with less time waiting. Compared to the simulation of current policy, the median travel distance was slightly higher under the "1:1" scenario for candidates waiting more than 2 years and slightly lower under all other continuous distribution scenarios, although with enough variation across simulation iterations to make strong conclusions difficult (Figure 29).

Candidate biology

Goal: Equitable access to transplant across cPRA groups (to the extent possible).

Question 1: How does access to transplant for highly sensitized candidates (cPRA 80-97%; cPRA 98-100%) compare with access under the current system? How does access to transplant compare across cPRA groups?

There were not substantial differences in transplant rates under the continuous distribution scenarios compared to the simulation of current policy for cPRA groups $\leq 98\%$ or for cPRA $>99.9-100\%$. Transplant rates for cPRA groups $>98\%$ to 99.5% and $>99.5\%$ to 99.9% were notably higher under the continuous distribution scenarios compared to the simulation of current policy (Figure 24)

Question 2: How does access to transplant by candidate blood type compare with access under the current system (expect no change given no ABO attribute but would like to confirm)? Ideally look at this separately for KP and PA since they have different blood type screening rules (this stratification would be new).

There were not substantial differences in transplant rates from the simulation of current policy to the continuous distribution scenarios for any of the blood types, either for combined pancreas and kidney-pancreas transplants (Figure 26) or for kidney-pancreas transplants alone (Figure 85).

Patient access

Goal: (1) Increase access to transplant for pediatrics and prior living donors (note: we recognize that OASIM cannot model PLD). (2) Maintain similar candidate waiting times relative to the current system.

Question 1: How does overall access to KP vs PA transplant compare with access under the current system? (ex. would we expect KP transplants to increase and PA to decrease?) Overall kidney-pancreas and pancreas transplant rates were relatively consistent from the simulation of current policy to the continuous distribution scenarios, with kidney-pancreas rates only slightly lower under continuous distribution and pancreas rates only slightly higher under continuous distribution compared to the simulation of current policy (Figure 1).

Question 2: How does access to transplant for pediatric candidates compare with access under the current system? Kidney-pancreas and pancreas transplant rates were higher for pediatric candidates under all the continuous distribution scenarios compared to the simulation of current policy. All other age groups showed relatively consistent transplant rates from the simulation of current policy to the continuous distribution scenarios (Figure 23).

Question 3: How does access to transplant by candidate qualifying time compare with access under the current system? *Do candidates with the highest qualifying times receive transplants at a rate similar to current policy? Higher than current policy?*

Ideally look at this separately for KP and PA, and would like to look at both qualifying time and time on the waitlist for KP (since KP qualifying time includes time on dialysis prior to listing).

There is not a substantial difference in kidney-pancreas and pancreas transplant rates by waiting time from the simulation of current policy to the continuous distribution scenarios. For candidates with more than 2 years of waiting time, the kidney-pancreas and pancreas transplant rates were slightly higher under the "1:1", "1.3:1", and "1.6:1"

continuous distribution scenarios compared to the simulation of current policy (Figures 25 and 84).

Other

Question 1: Do the proposed CD policies result in any new/unintended disparities in access to transplant for any of the following subpopulations: Geography, Age, Race, Ethnicity, Sex? There are not substantial differences in kidney-pancreas and pancreas transplant rates from the simulation of current policy to the continuous distribution scenarios by sex (Figure 67), race (Figure 68), or ethnicity (Figure 69). Native American candidates showed very slightly lower kidney-pancreas and pancreas transplant rates only under the "2:1" continuous distribution scenario (Figure 68), and Latino candidates only under the "1:1" continuous distribution scenario (Figure 69) compared to the simulation of current policy.

Differences in kidney-pancreas and pancreas transplant rates by OPTN region from the simulation of current policy to the continuous distribution scenarios was not large for any region. Some regions showed slightly higher transplant rates under continuous distribution and some regions slightly lower transplant rates compared to the simulation of current policy, although no regions moved substantially out of the range of rates experienced by other regions (Figures 70 and 71).

Organ Analysis

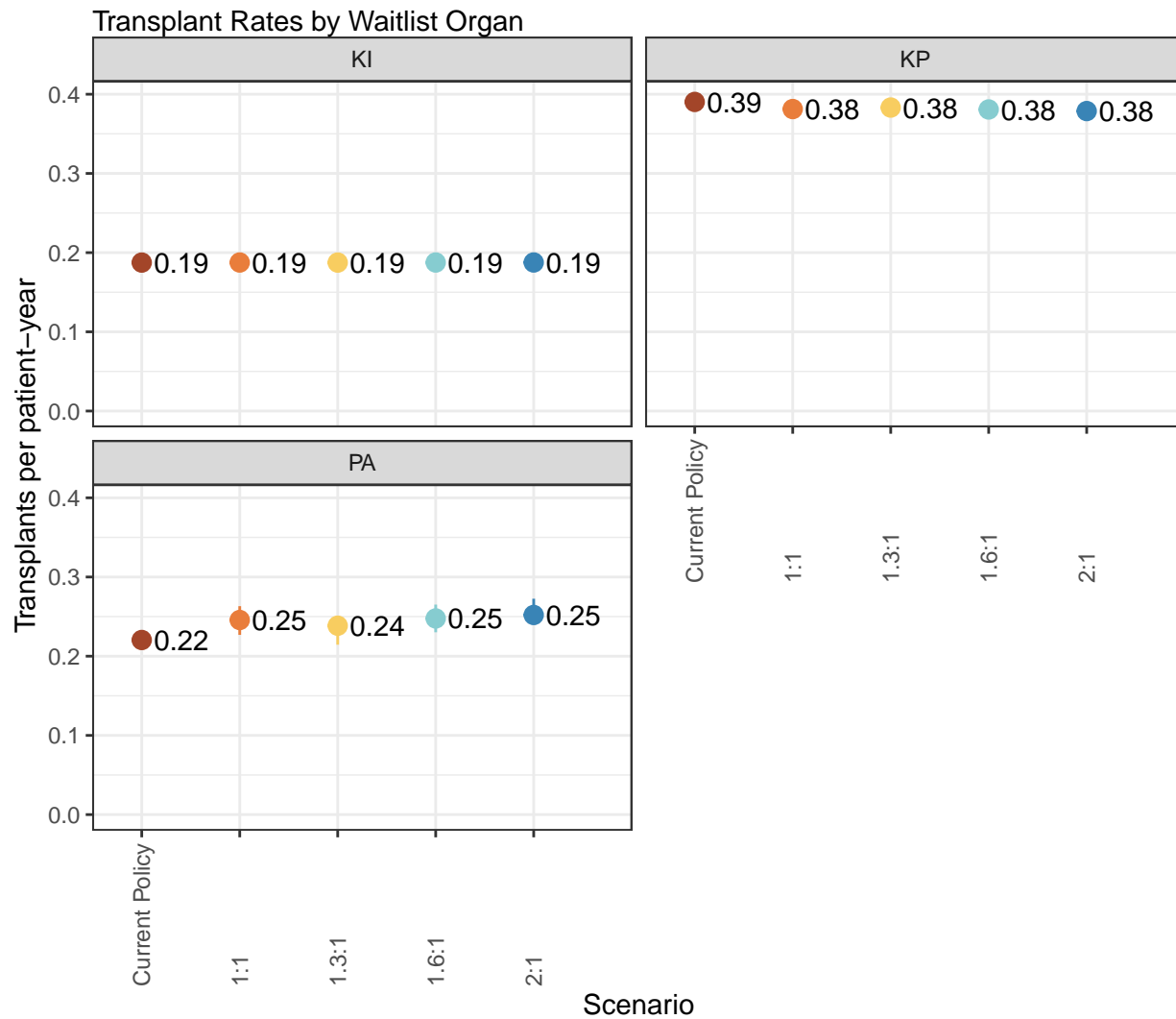


Figure 1: Transplant Rates by Waitlist Organ. Person-time is calculated in days for all candidates from the start of their simulation period (simulation start or listing) to transplant, waitlist removal, or simulation end. Operational validation historic comparison: estimated rates were lower than historic results for the kidney group and much lower for the kidney-pancreas group.

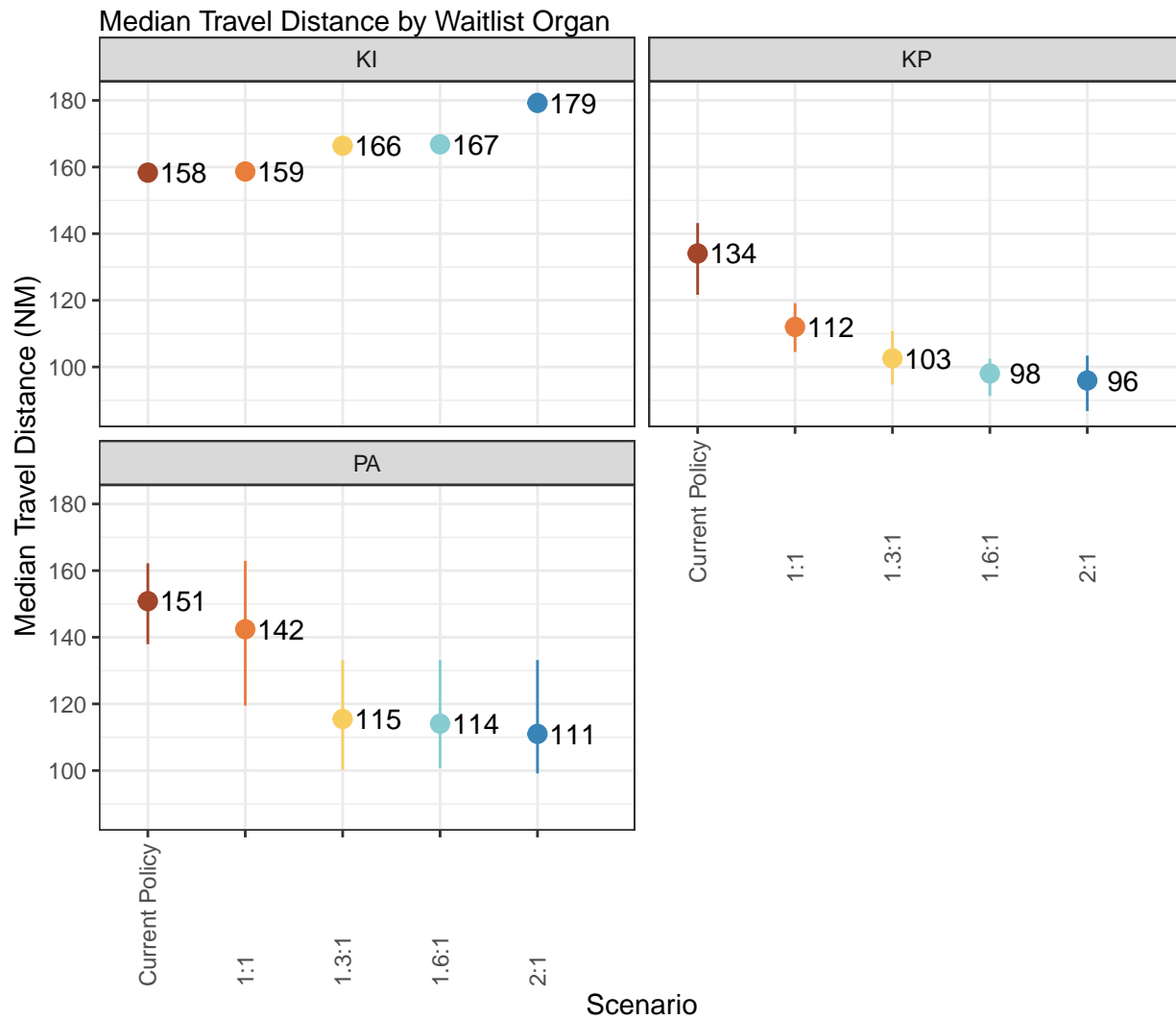


Figure 2: Median Travel Distance by Waitlist Organ. Travel distance is between the donor hospital and the transplant center, in nautical miles. Operational validation historic comparison: estimated median travel distances were much higher than historic results for the kidney group and slightly higher for the kidney-pancreas group.

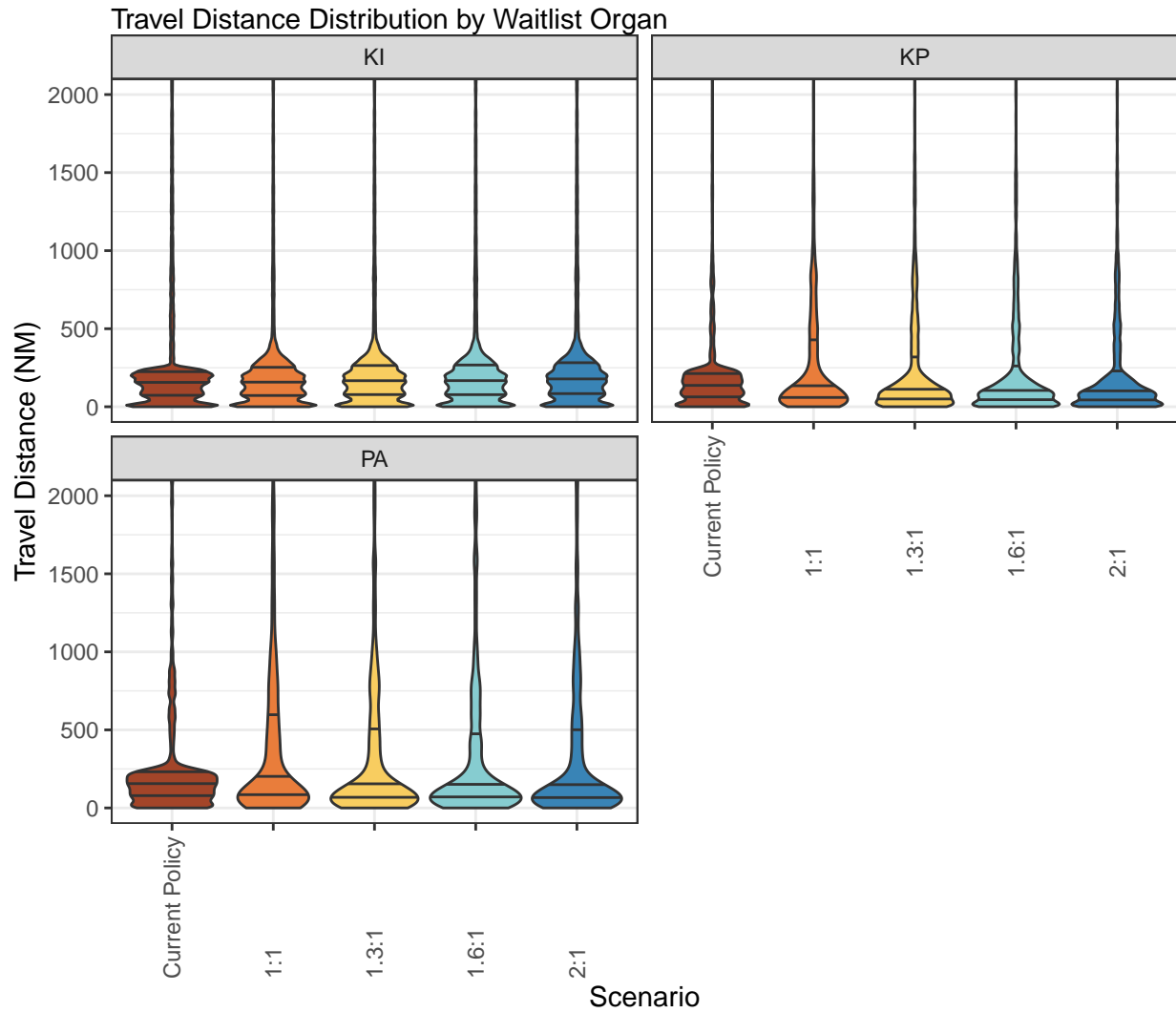


Figure 3: Travel Distance Distribution by Waitlist Organ. Distribution of travel distance. Travel distance is between the donor hospital and the transplant center, in nautical miles.



Kidney: Transplant Rates

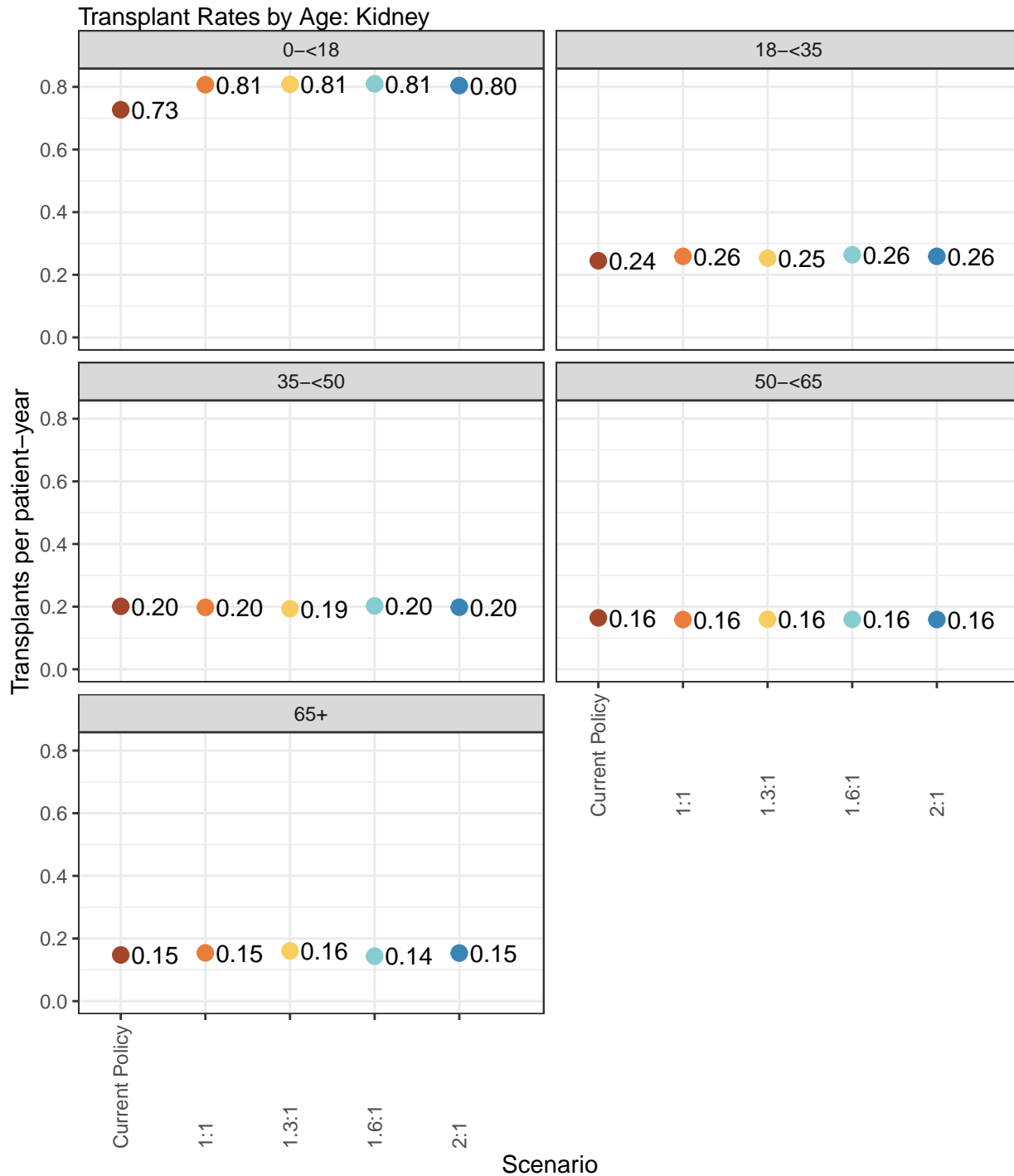


Figure 4: Transplant Rates by Age: Kidney. Age at listing. Person-time is calculated in days for all candidates from the start of their simulation period (simulation start or listing) to transplant, waitlist removal, or simulation end. Operational validation historic comparison: estimated rates were comparable to historic results for the middle age ranges of 18-35 and 35-50, while the 0-18 age group had much higher rates, and the 50-65 and 65+ groups had slightly lower rates.

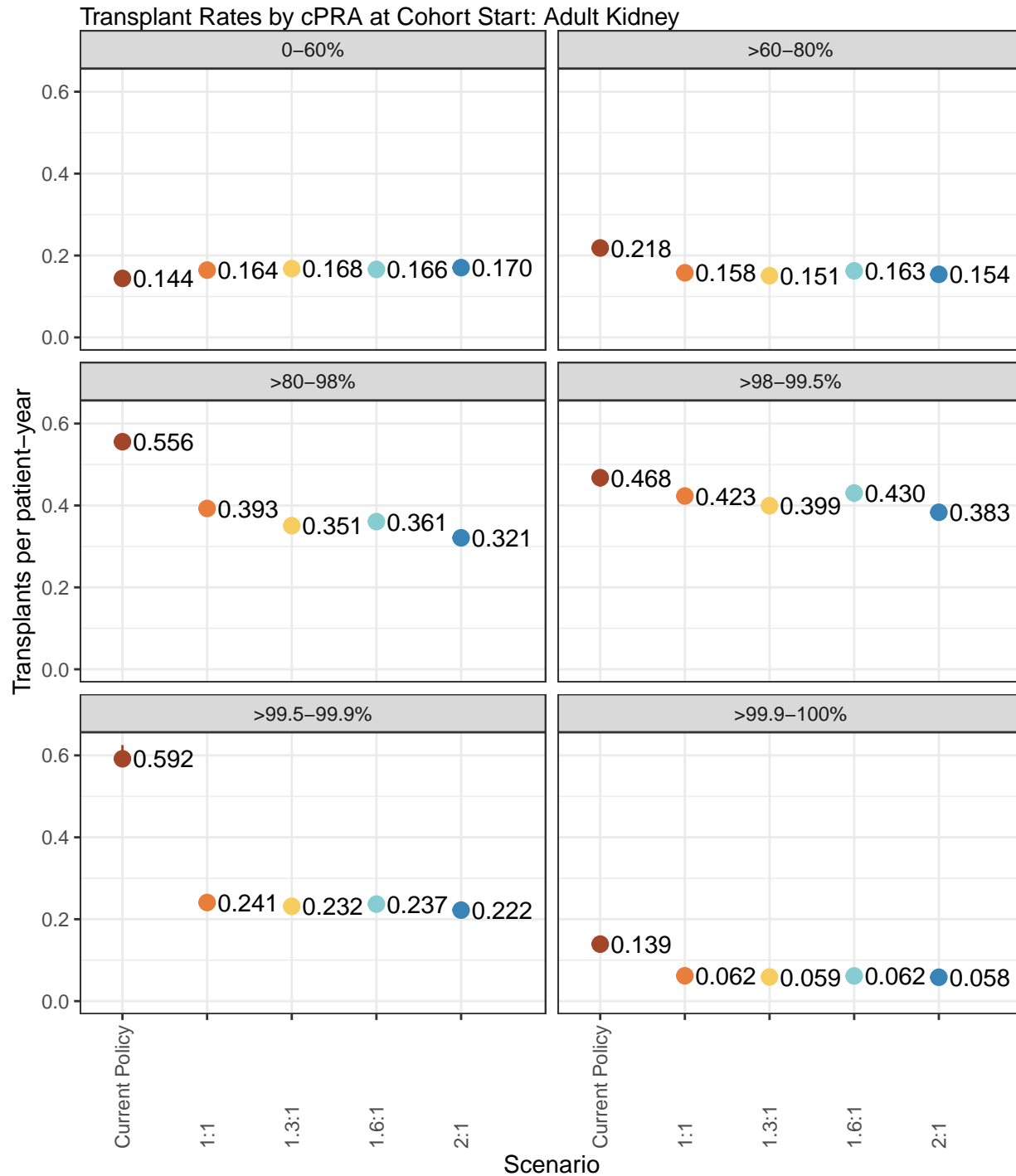


Figure 5: Transplant Rates by cPRA at Cohort Start: Adult Kidney. cPRA at cohort start is the last value the candidate had prior to the simulation start or their value at listing. Person-time is calculated in days for all candidates from the start of their simulation period (simulation start or listing) to transplant, waitlist removal, or simulation end. Operational validation historic comparison: estimated rates were comparable to historic results for all groups with cPRA > 60%, while the 0-60% cPRA group had slightly lower rates.

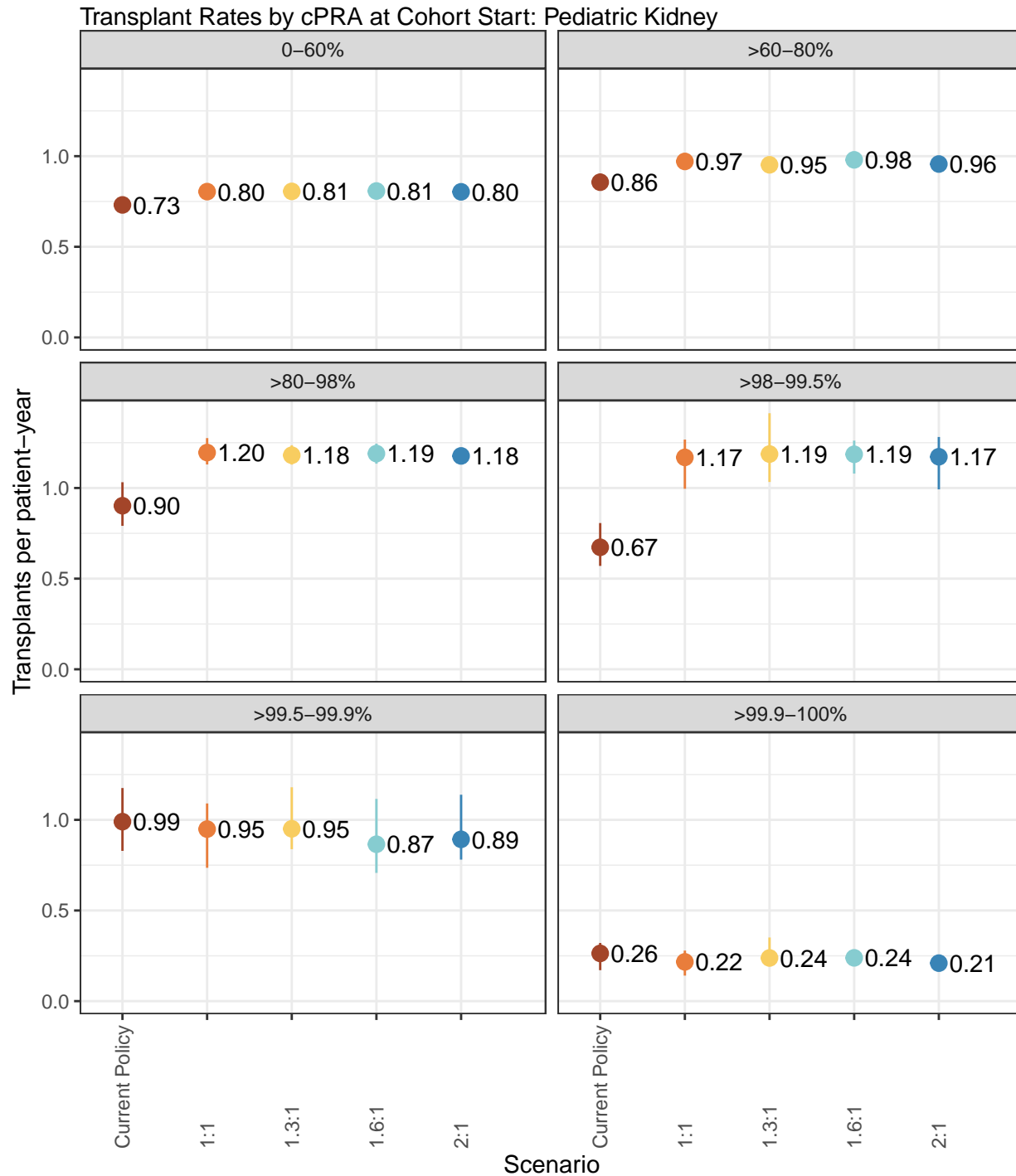


Figure 6: Transplant Rates by cPRA at Cohort Start: Pediatric Kidney. cPRA at cohort start is the last value the candidate had prior to the simulation start or their value at listing. Person-time is calculated in days for all candidates from the start of their simulation period (simulation start or listing) to transplant, waitlist removal, or simulation end. Operational validation historic comparison: consistent with the pediatric results seen in Figure 4, estimated rates were higher than historic results for all pediatric cPRA groups. There was a clear trend with increasing cPRA group: the cPRA 0-60% group had rates much higher than historic results and the >99.9-100% group slightly higher.

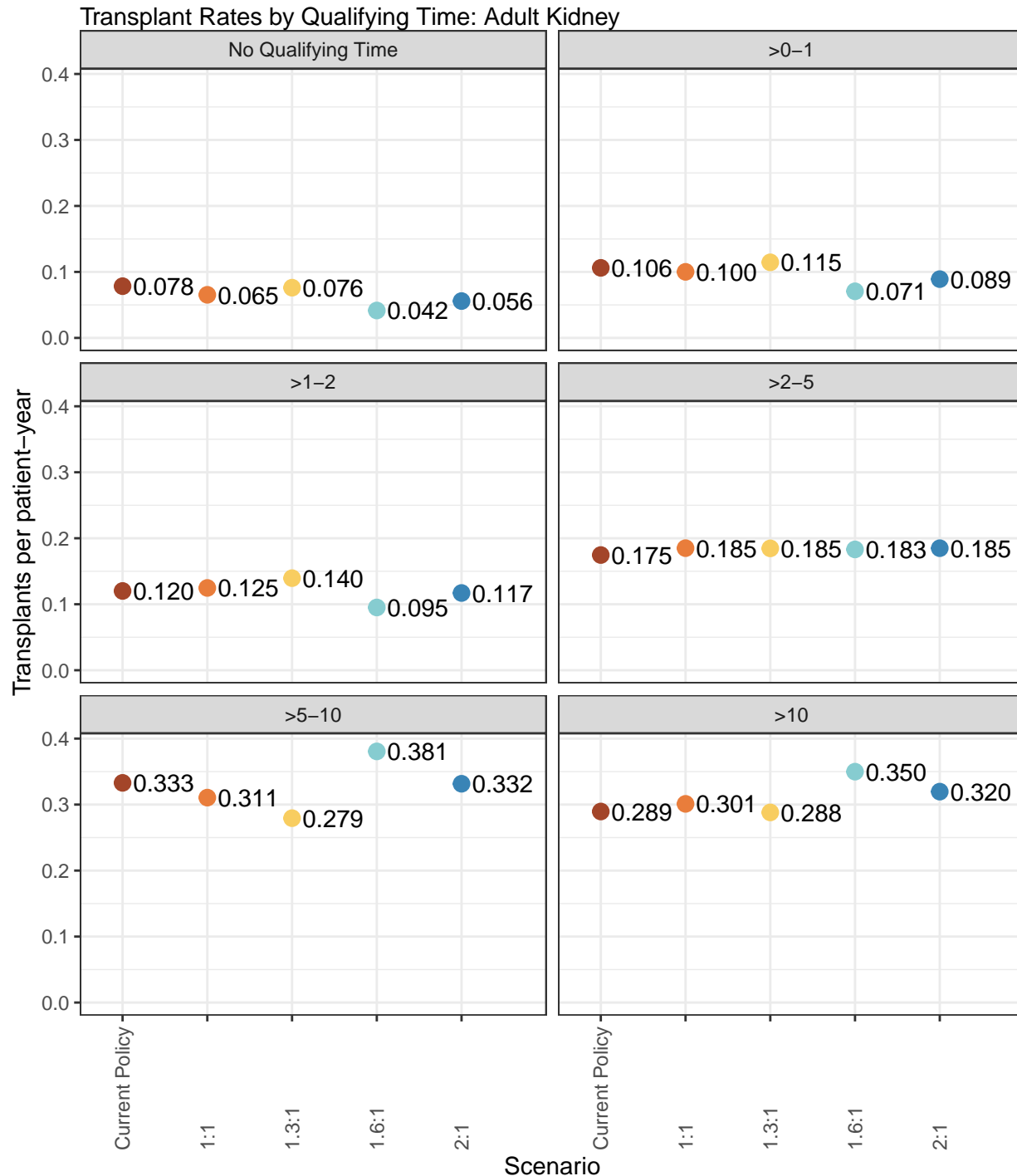


Figure 7: Transplant Rates by Qualifying Time: Adult Kidney. Qualifying time is time in years from qualifying date to simulation start. Person-time is calculated in days for all candidates from the start of their simulation period (simulation start or listing) to transplant, waitlist removal, or simulation end. Operational validation historic comparison: estimated rates were much lower than historic results for the no qualifying time group and lower for qualifying time >5-10 and >10 years of qualifying time groups.

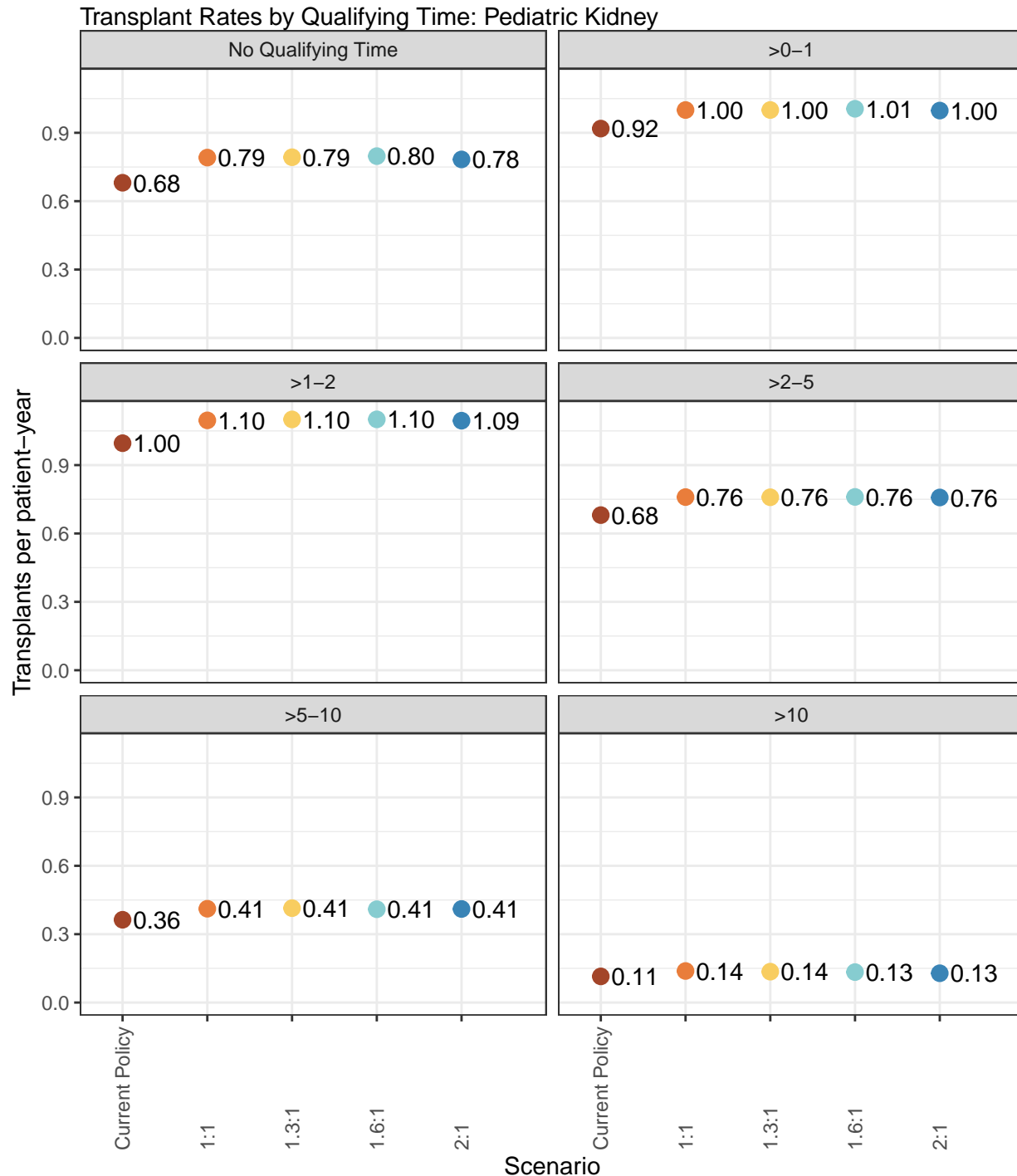


Figure 8: Transplant Rates by Qualifying Time: Pediatric Kidney. Qualifying time is time in years from qualifying date to simulation start. Person-time is calculated in days for all candidates from the start of their simulation period (simulation start or listing) to transplant, waitlist removal, or simulation end. Operational validation historic comparison: estimated rates were much higher than historic results for the no qualifying time, >0-1, >1-2, and >2-5 years of qualifying time groups and slightly higher for the >5-10 group.

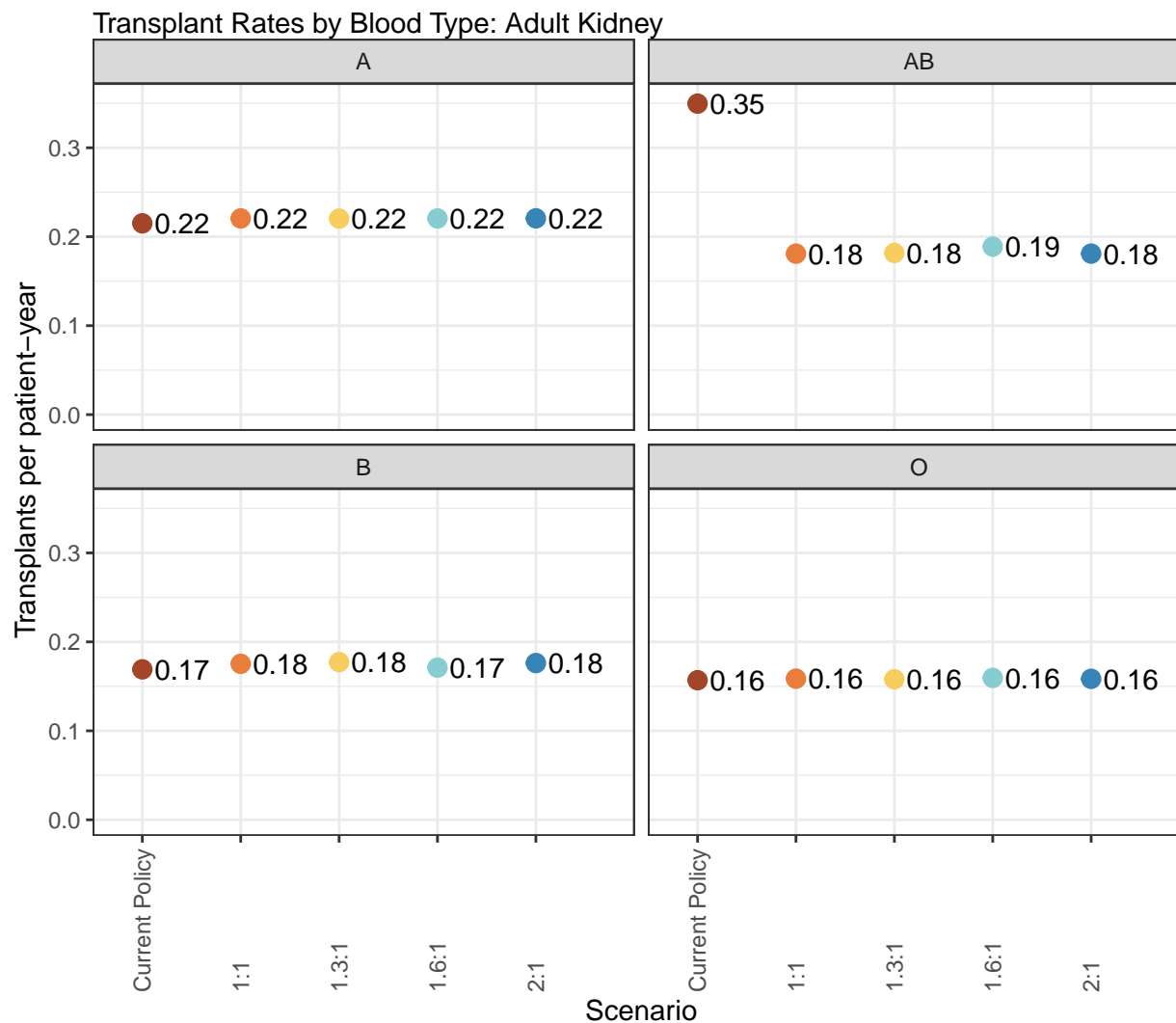


Figure 9: Transplant Rates by Blood Type: Adult Kidney. Person-time is calculated in days for all candidates from the start of their simulation period (simulation start or listing) to transplant, waitlist removal, or simulation end. Operational validation historic comparison: estimated rates were much lower than historic results for the A and AB blood type groups and B and O slightly lower than historic rates.

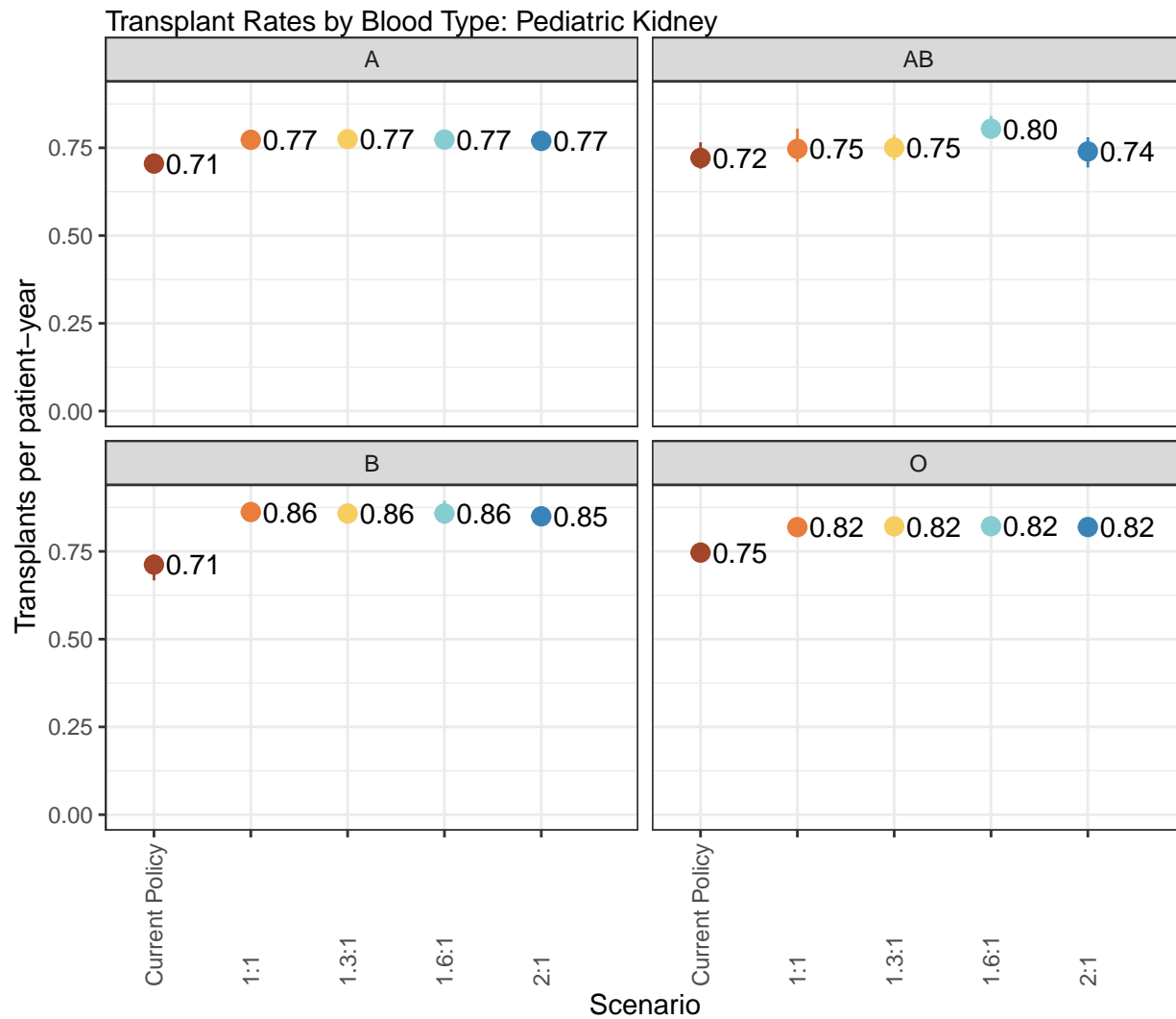


Figure 10: Transplant Rates by Blood Type: Pediatric Kidney. Person-time is calculated in days for all candidates from the start of their simulation period (simulation start or listing) to transplant, waitlist removal, or simulation end. Operational validation historic comparison: estimated rates were higher than historic results for all blood type groups.



Kidney: Distance Traveled for Transplanted Organs

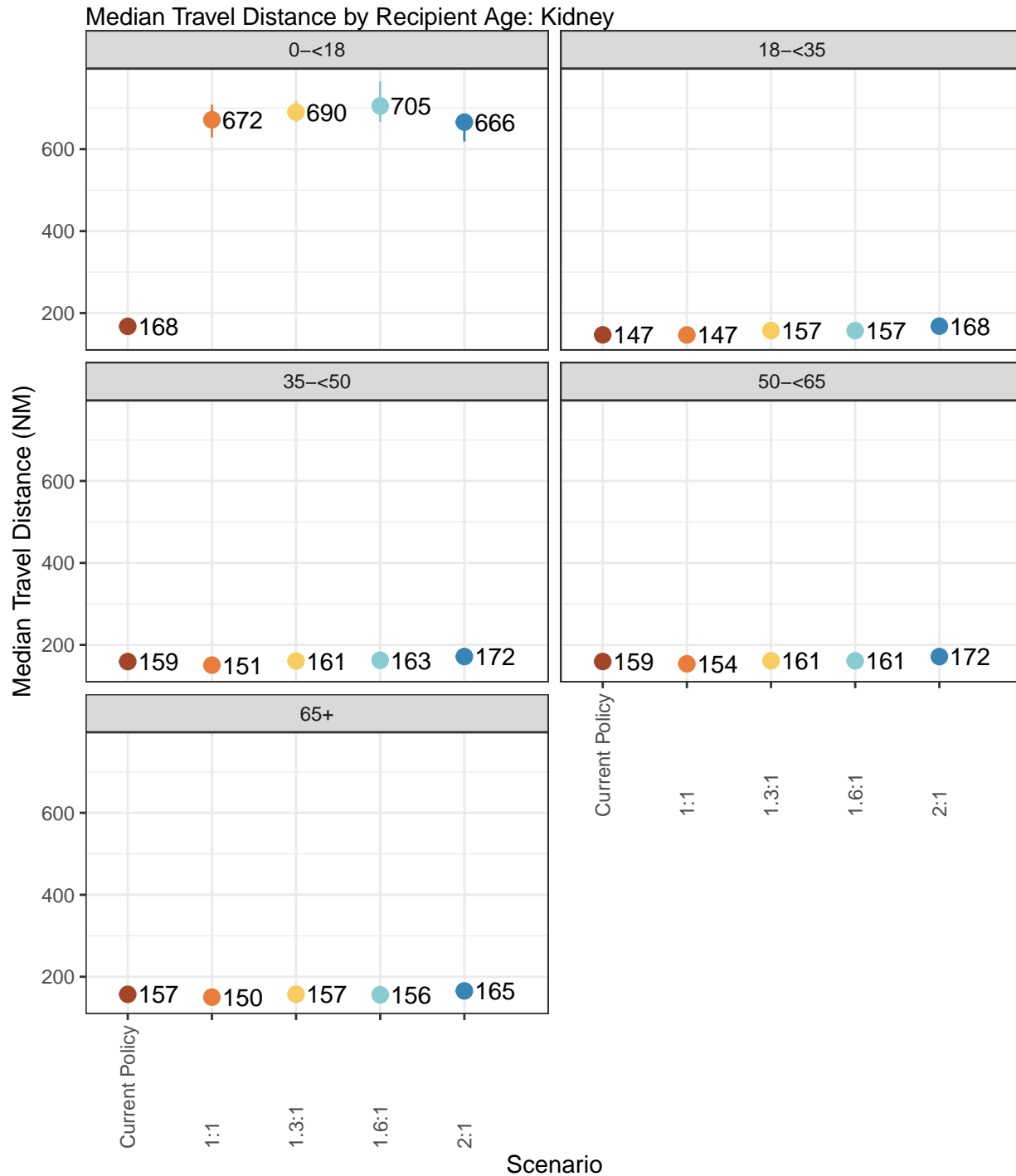


Figure 11: Median Travel Distance by Recipient Age: Kidney. Travel distance is between the donor hospital and the transplant center, in nautical miles. Operational validation historic comparison: consistent with the overall kidney results seen in Figure 2 estimated median travel distances were higher than historic results for all age groups.

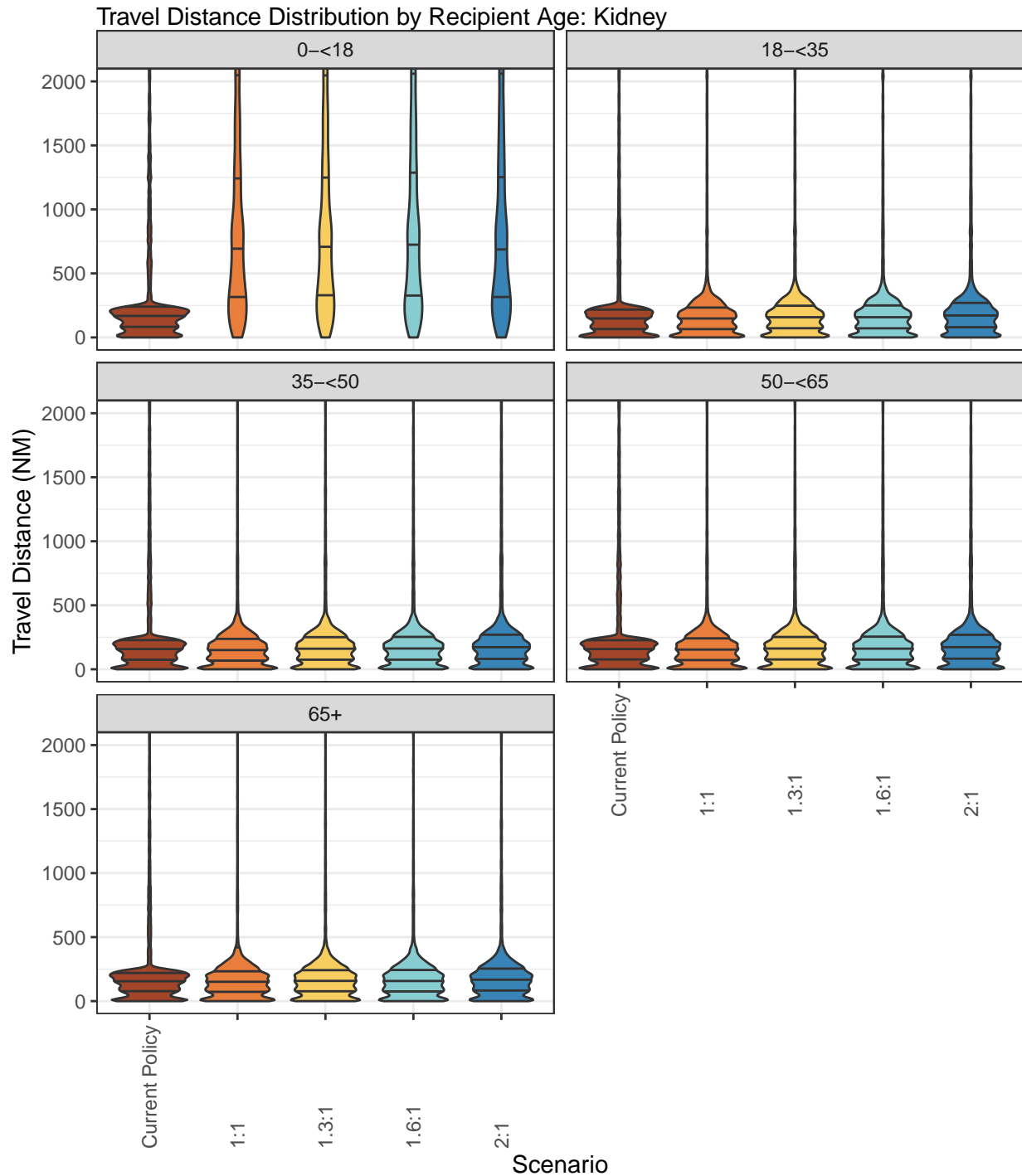


Figure 12: Travel Distance Distribution by Recipient Age: Kidney. Distribution of travel distance. Travel distance is between the donor hospital and the transplant center, in nautical miles.

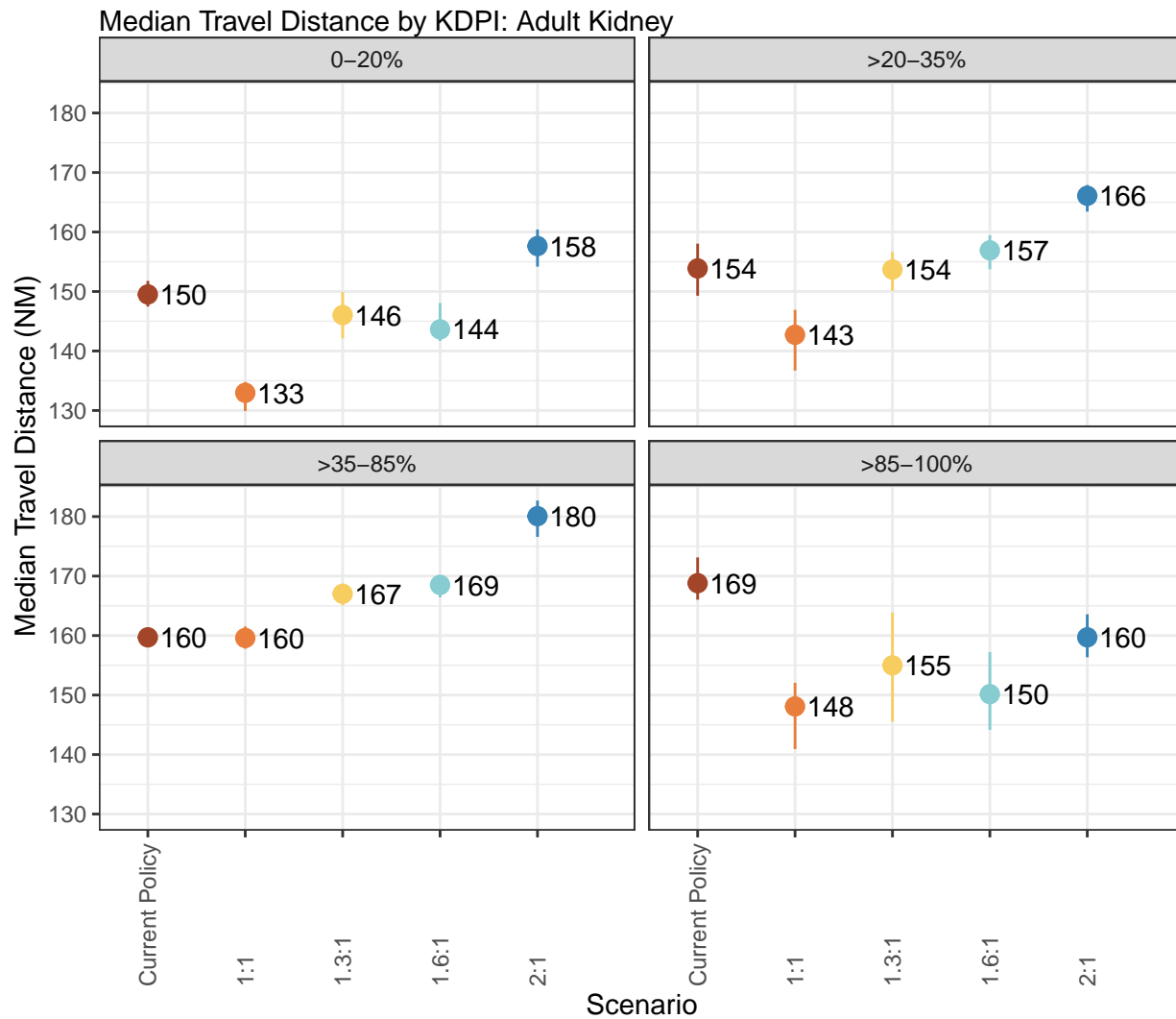


Figure 13: Median Travel Distance by KDPI: Adult Kidney. Travel distance is between the donor hospital and the transplant center, in nautical miles. Operational validation historic comparison: estimated median travel distances were slightly higher than historic results for the KDPI >85-100% group.

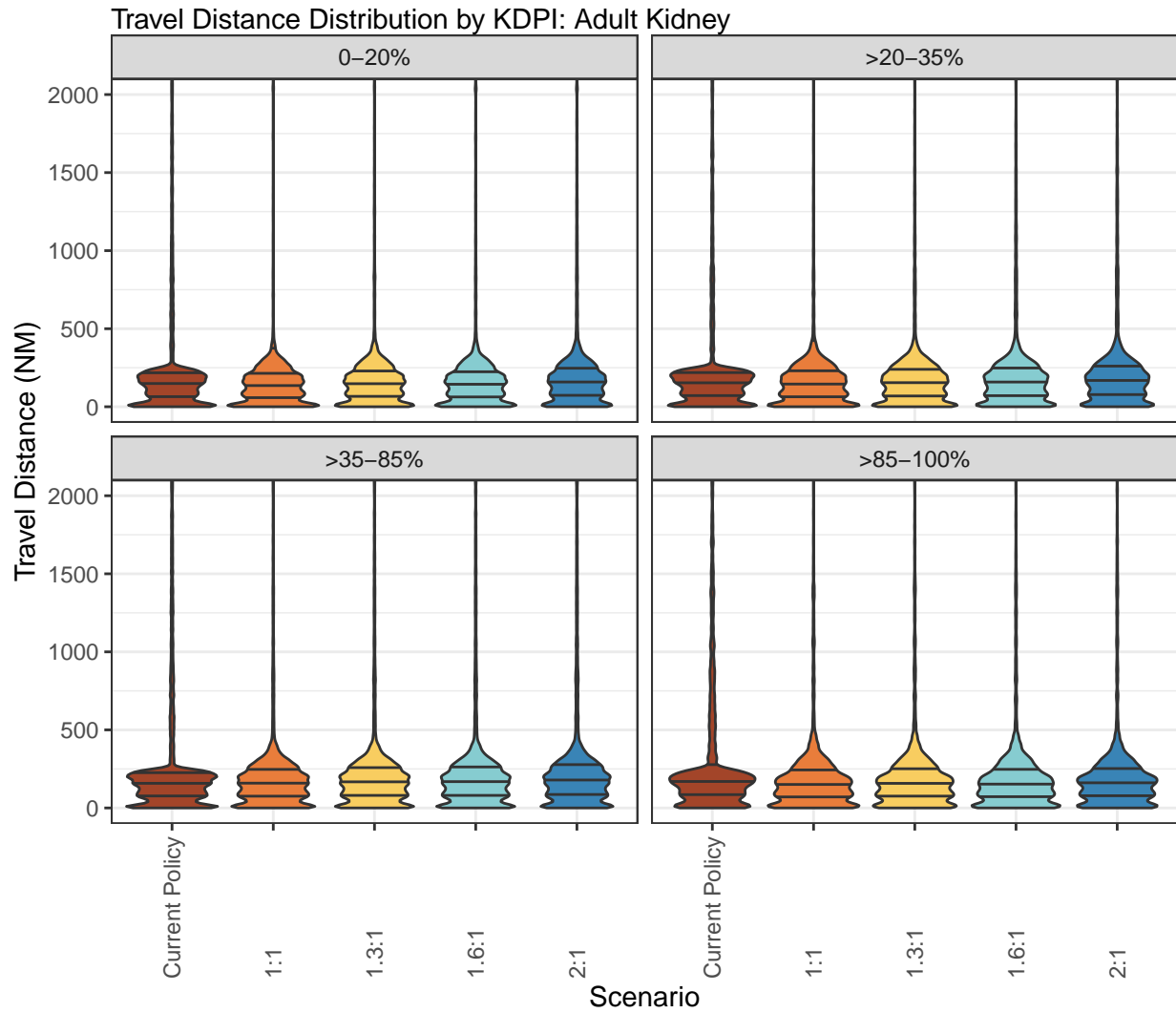


Figure 14: Travel Distance Distribution by KDPI: Adult Kidney. Distribution of travel distance. Travel distance is between the donor hospital and the transplant center, in nautical miles.

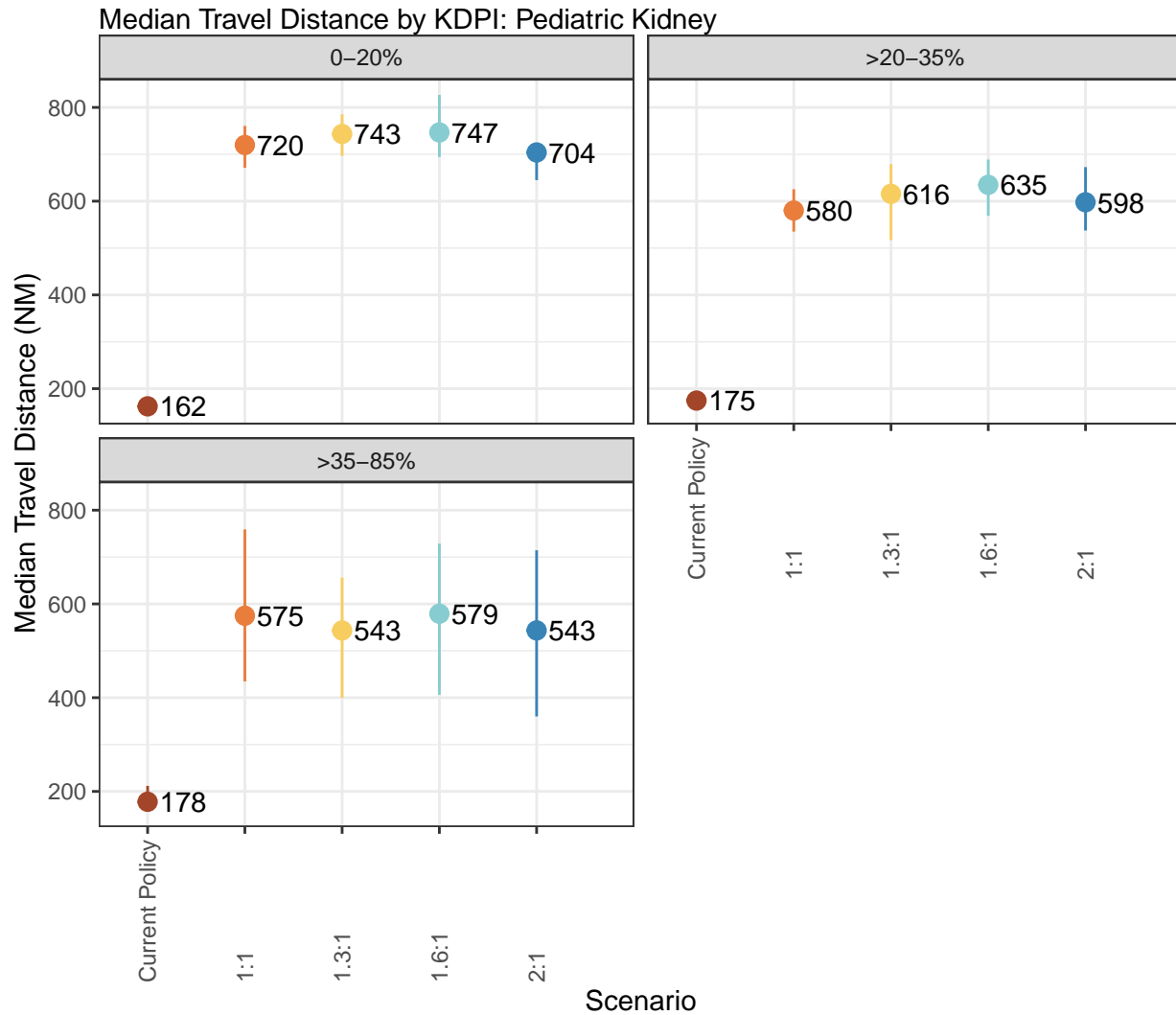


Figure 15: Median Travel Distance by KDPI: Pediatric Kidney. Travel distance is between the donor hospital and the transplant center, in nautical miles. Operational validation historic comparison: estimated median travel distances were slightly higher than historic results for the 0-20% and >20-35% KDPI groups, and slightly lower for the >35-85% KDPI group.

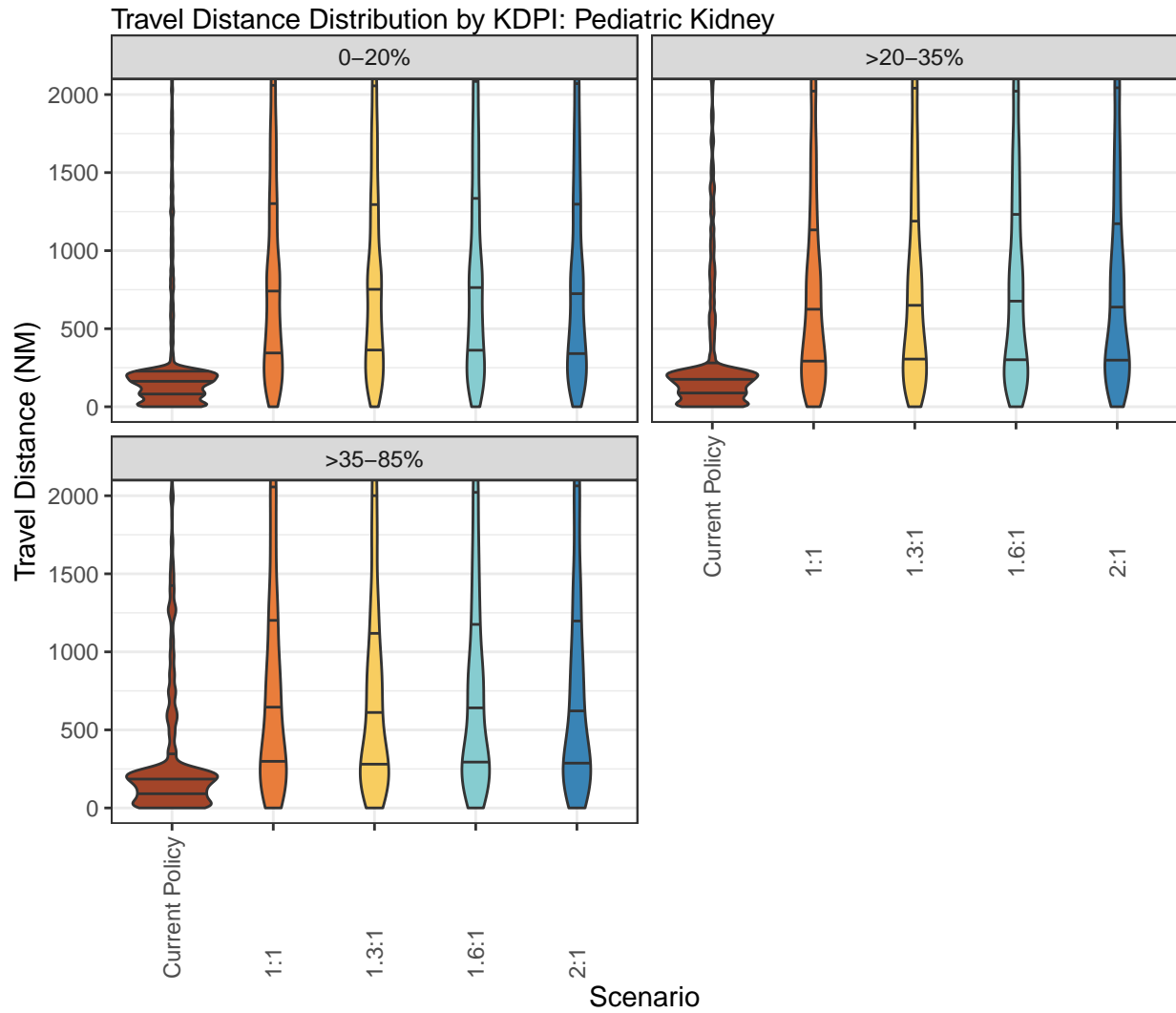


Figure 16: Travel Distance Distribution by KDPI: Pediatric Kidney. Distribution of travel distance. Travel distance is between the donor hospital and the transplant center, in nautical miles.

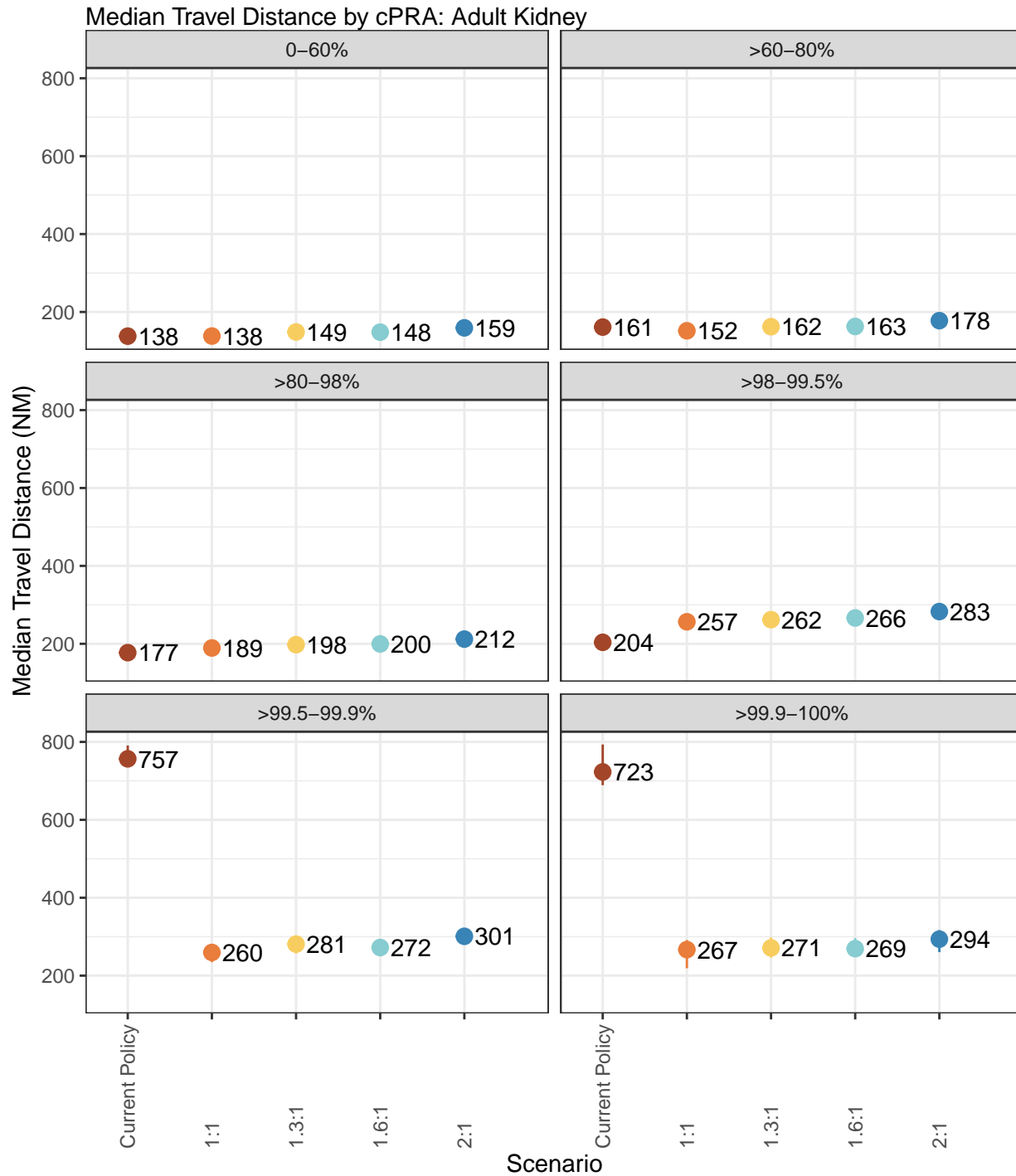


Figure 17: Median Travel Distance by cPRA: Adult Kidney. Travel distance is between the donor hospital and the transplant center, in nautical miles. Operational validation historic comparison: estimated median travel distances were slightly higher than historic results for the 0-60%, >60-80%, and >80-98% cPRA groups and higher for the >99.5-99.9% group.

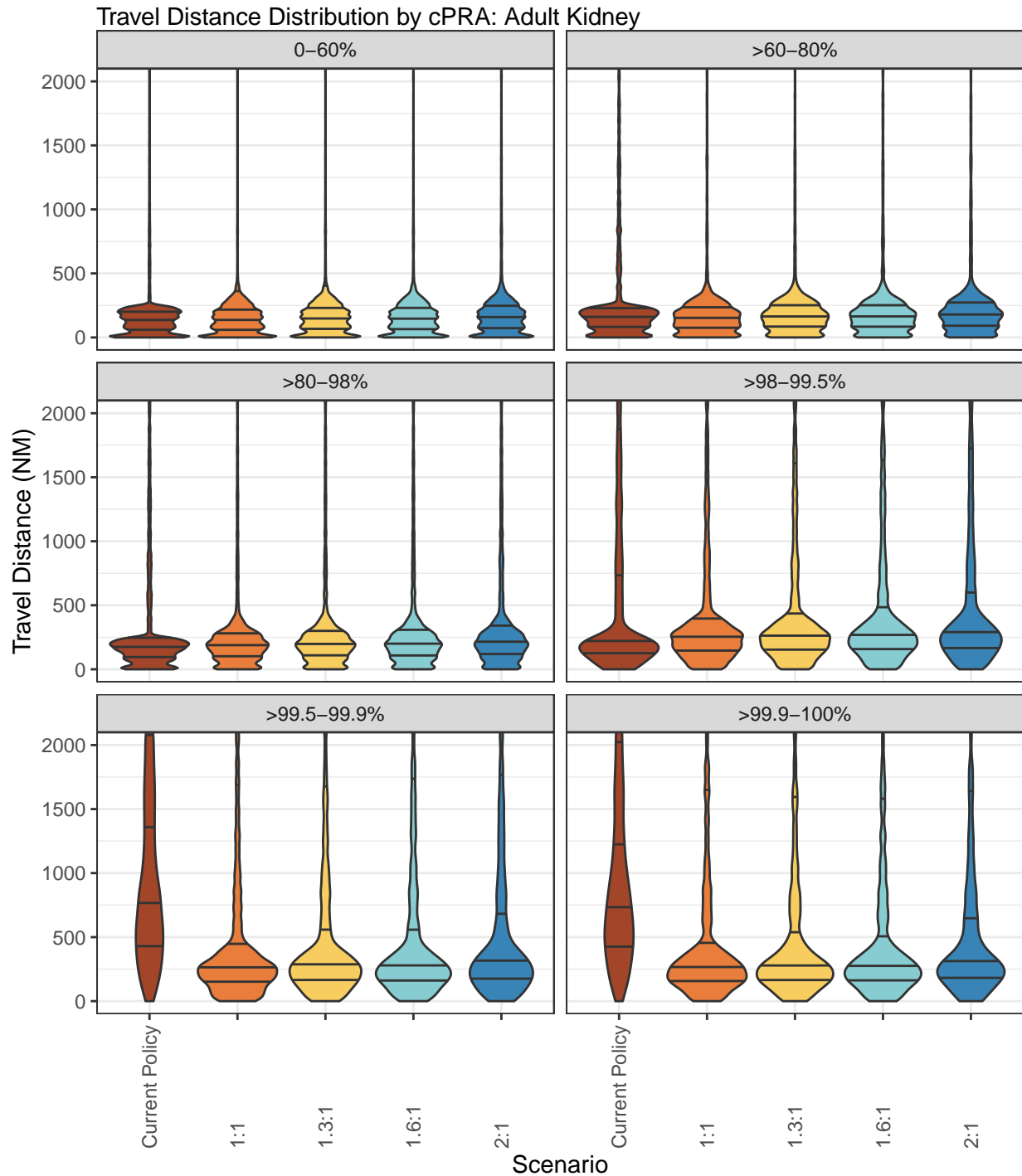


Figure 18: Travel Distance Distribution by cPRA: Adult Kidney. Distribution of travel distance. Travel distance is between the donor hospital and the transplant center, in nautical miles.

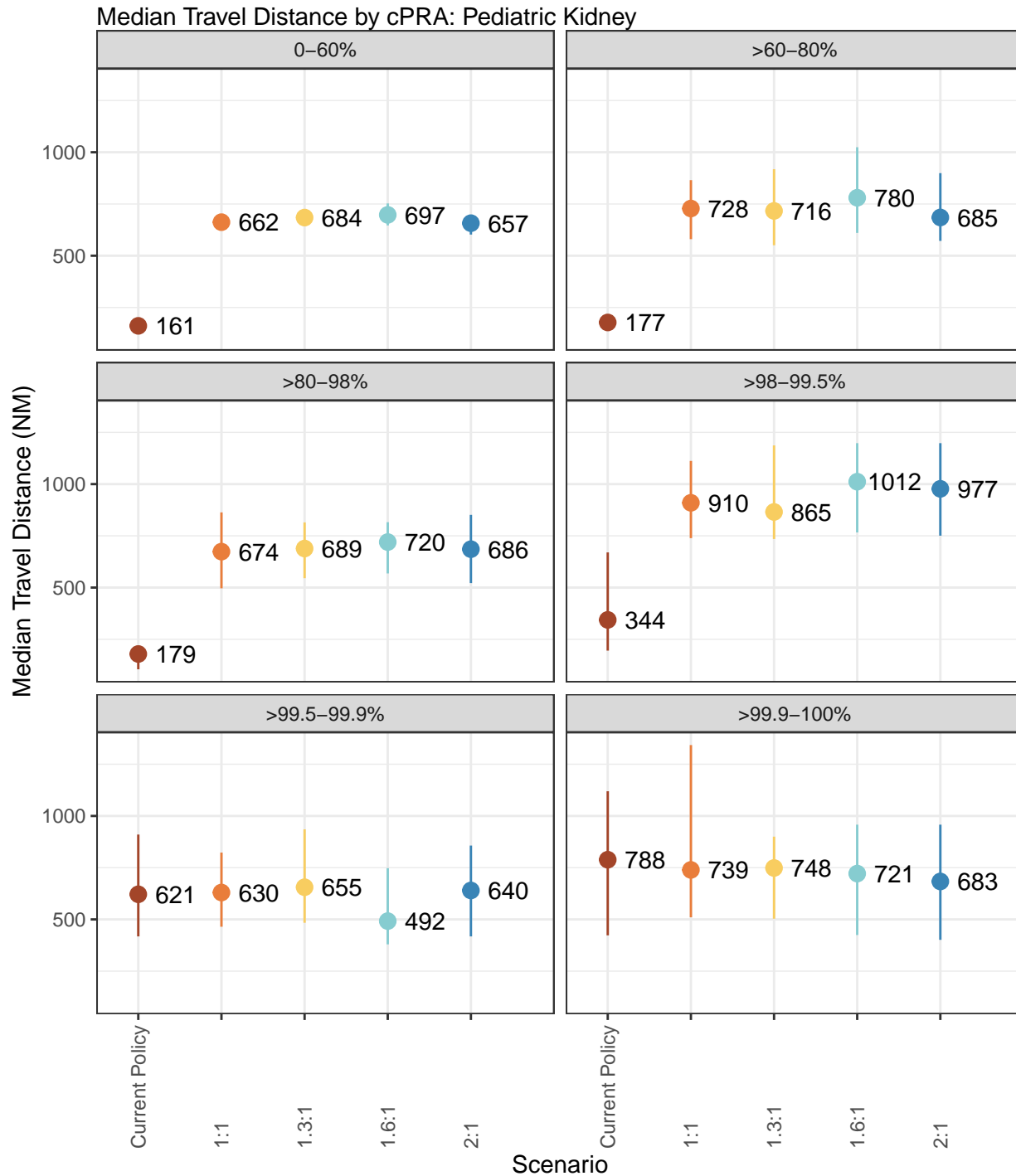


Figure 19: Median Travel Distance by cPRA: Pediatric Kidney. Travel distance is between the donor hospital and the transplant center, in nautical miles.

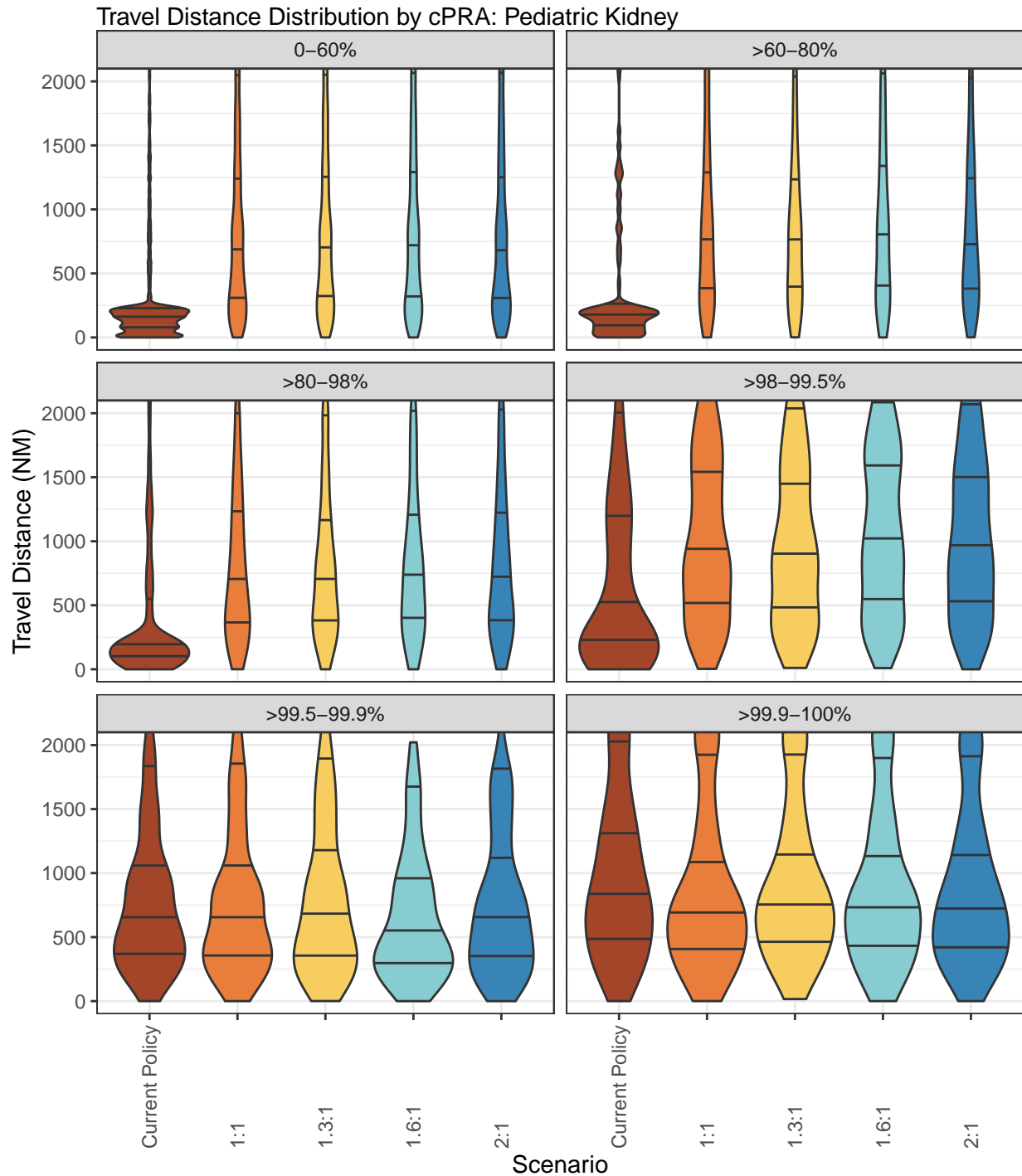


Figure 20: Travel Distance Distribution by cPRA: Pediatric Kidney. Distribution of travel distance. Travel distance is between the donor hospital and the transplant center, in nautical miles.

Kidney: Posttransplant

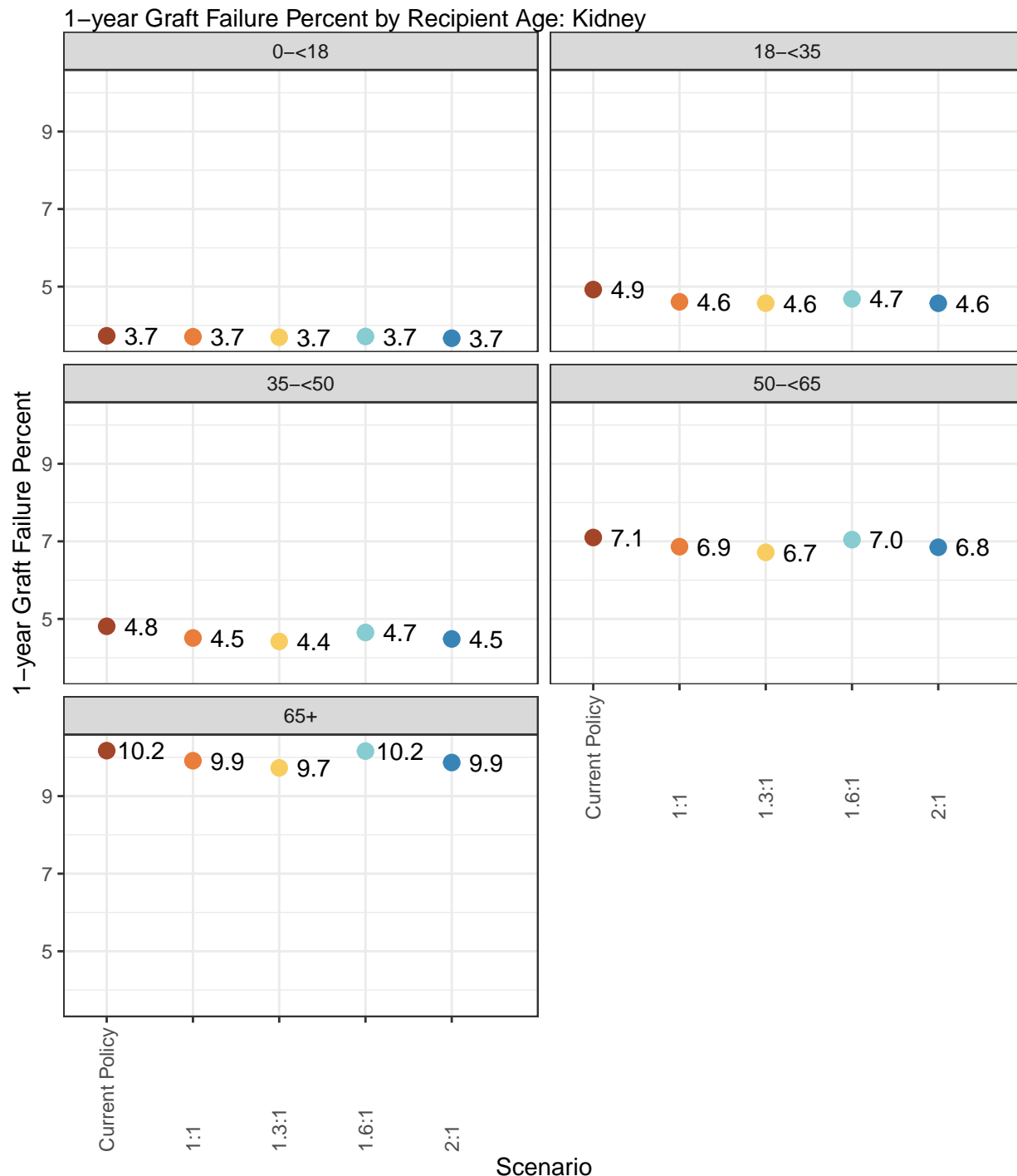


Figure 21: 1-year Graft Failure Percent by Recipient Age: Kidney. Age at transplant. All-cause graft failure.

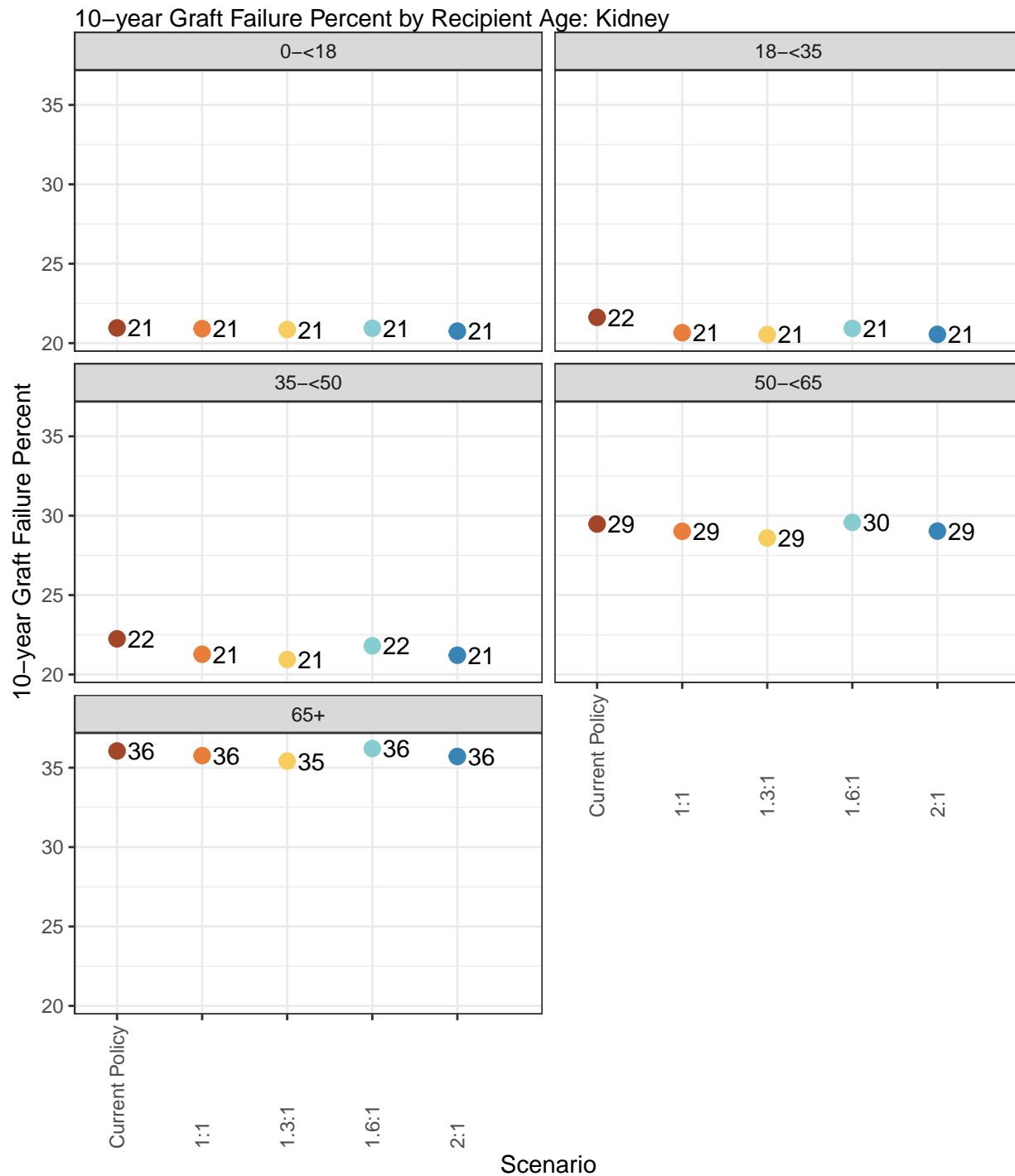


Figure 22: 10-year Graft Failure Percent by Recipient Age: Kidney. Age at transplant. All-cause graft failure.



Pancreas and Kidney-Pancreas: Transplant Rate

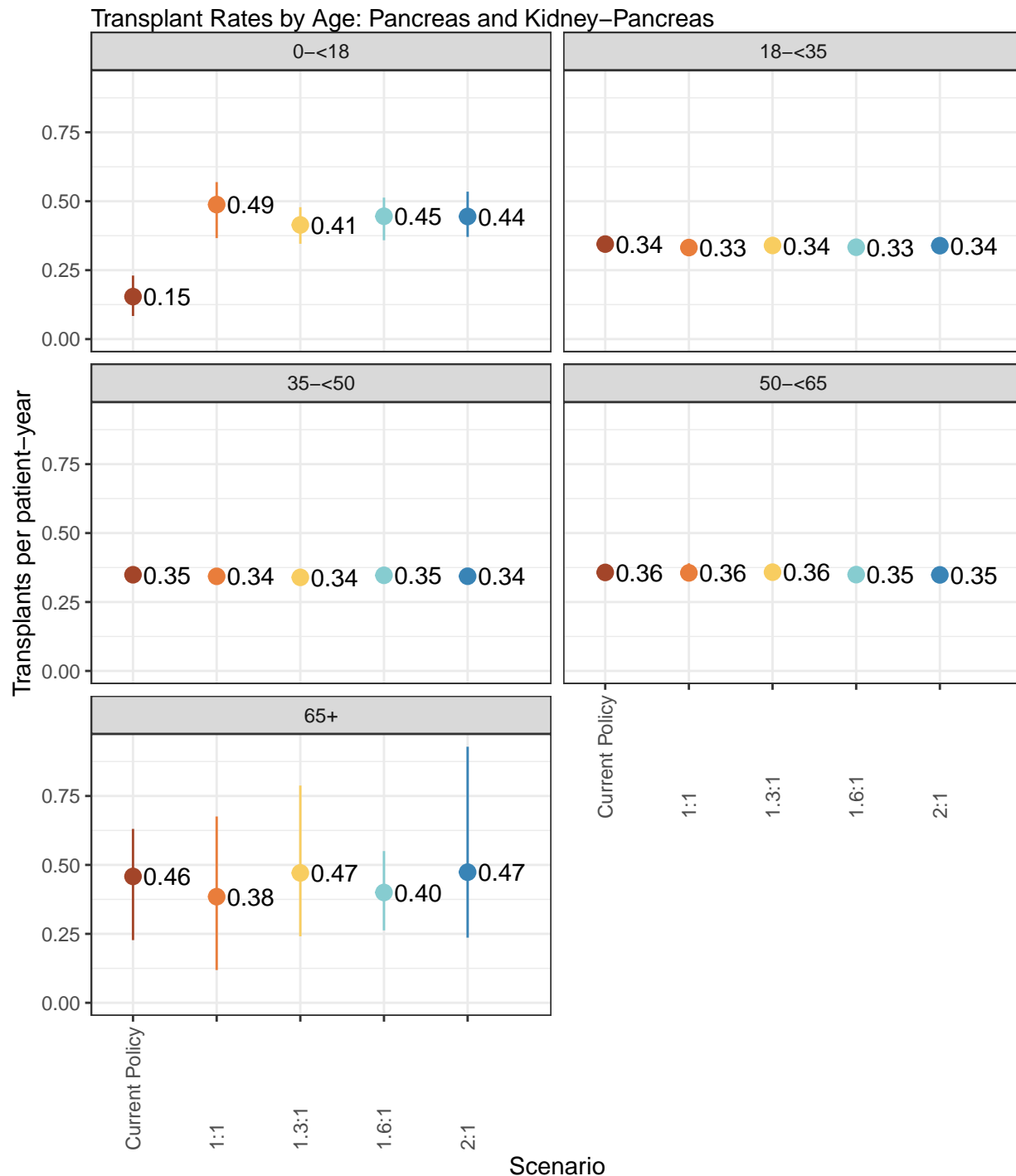


Figure 23: Transplant Rates by Age: Pancreas and Kidney-Pancreas. Age at listing. Person-time is calculated in days for all candidates from the start of their simulation period (simulation start or listing) to transplant, waitlist removal, or simulation end. Operational validation historic comparison: estimated rates were much lower than historic results for the 0-<18 age group.

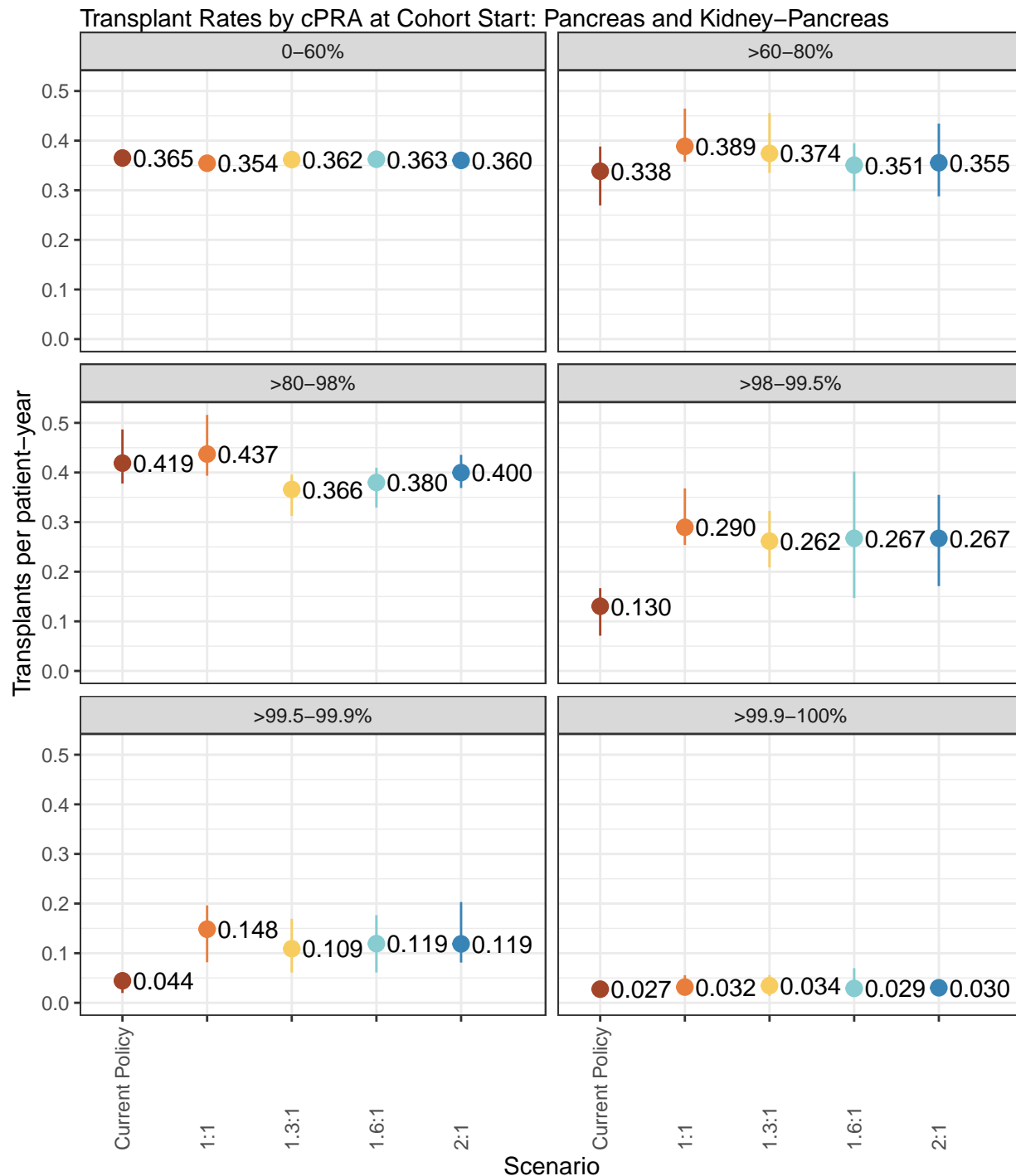


Figure 24: Transplant Rates by cPRA at Cohort Start: Pancreas and Kidney-Pancreas. cPRA at cohort start is the last value the candidate had prior to the simulation start or their value at listing. Person-time is calculated in days for all candidates from the start of their simulation period (simulation start or listing) to transplant, waitlist removal, or simulation end. Operational validation historic comparison: estimated rates were slightly lower than historic results for the 0-60% cPRA group.

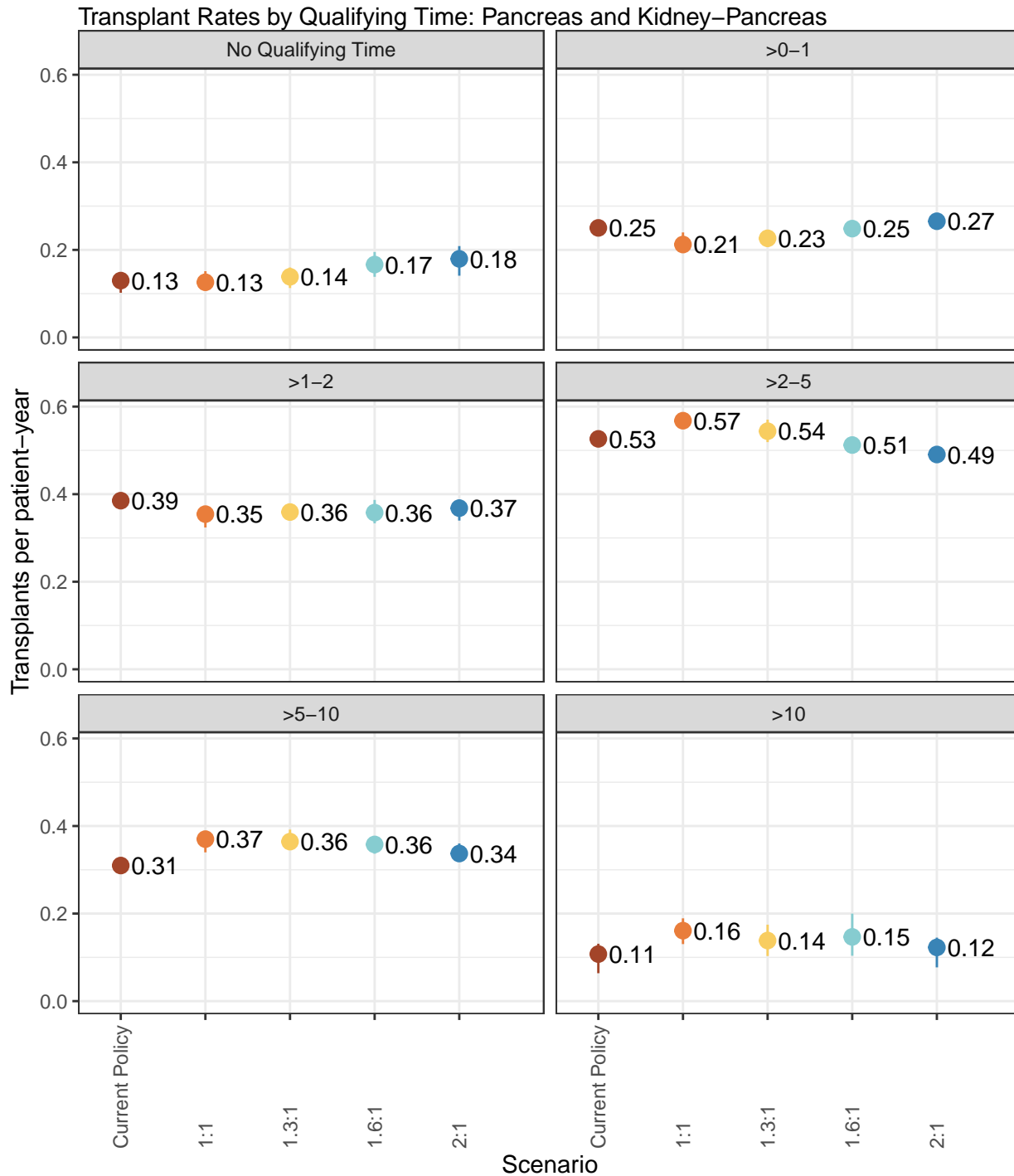


Figure 25: Transplant Rates by Qualifying Time: Pancreas and Kidney-Pancreas. Qualifying time is time in years from qualifying date to simulation start. Person-time is calculated in days for all candidates from the start of their simulation period (simulation start or listing) to transplant, waitlist removal, or simulation end. Operational validation historic comparison: estimated rates were much lower than historic results for the no qualifying time and >0-1 groups, and slightly lower for the >1-2 qualifying time group.

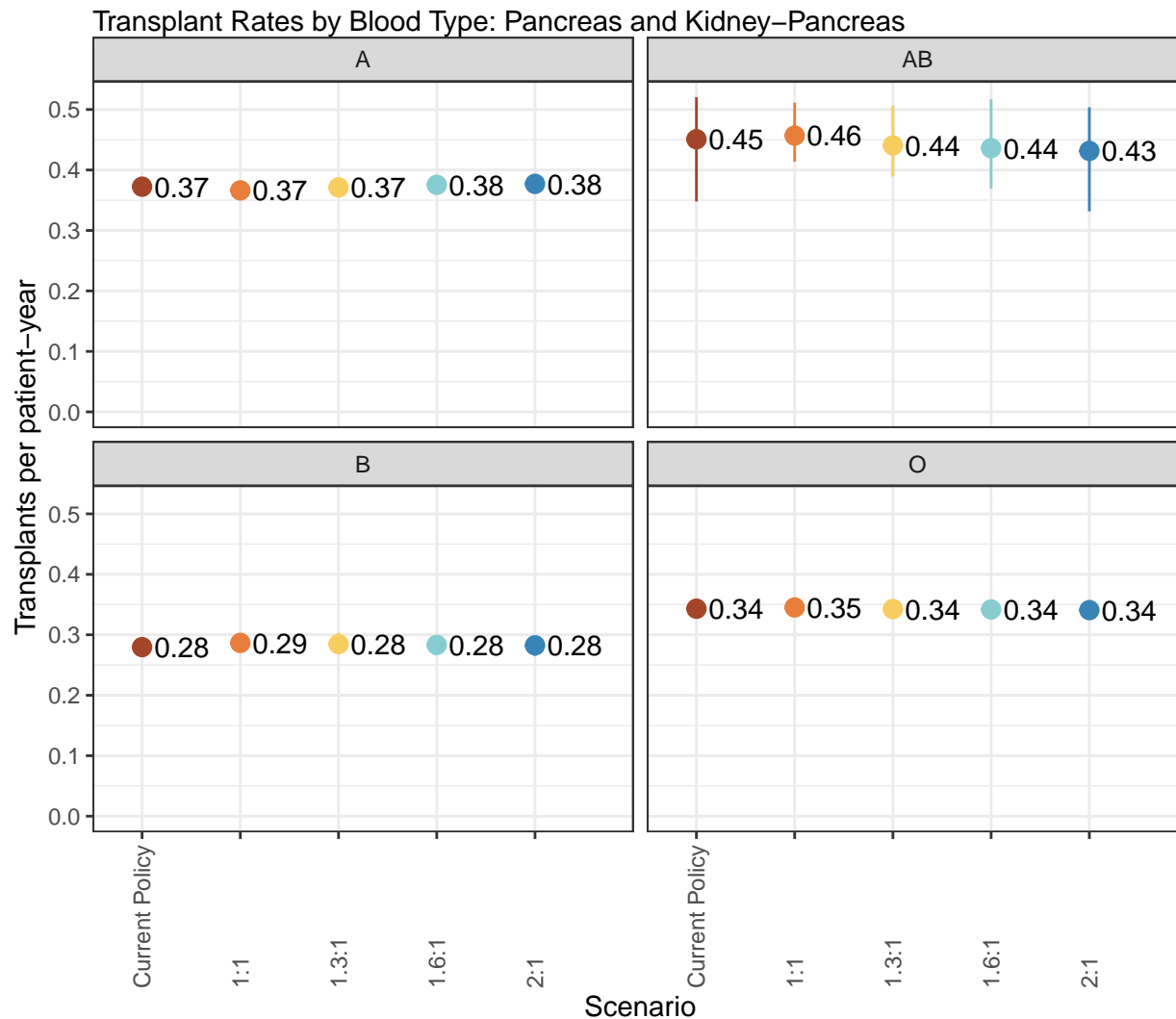


Figure 26: Transplant Rates by Blood Type: Pancreas and Kidney-Pancreas. Person-time is calculated in days for all candidates from the start of their simulation period (simulation start or listing) to transplant, waitlist removal, or simulation end. Operational validation historic comparison: estimated rates were lower than historic results for the A, B and O blood type groups.

Pancreas and Kidney-Pancreas: Distance Traveled for Transplanted Organs

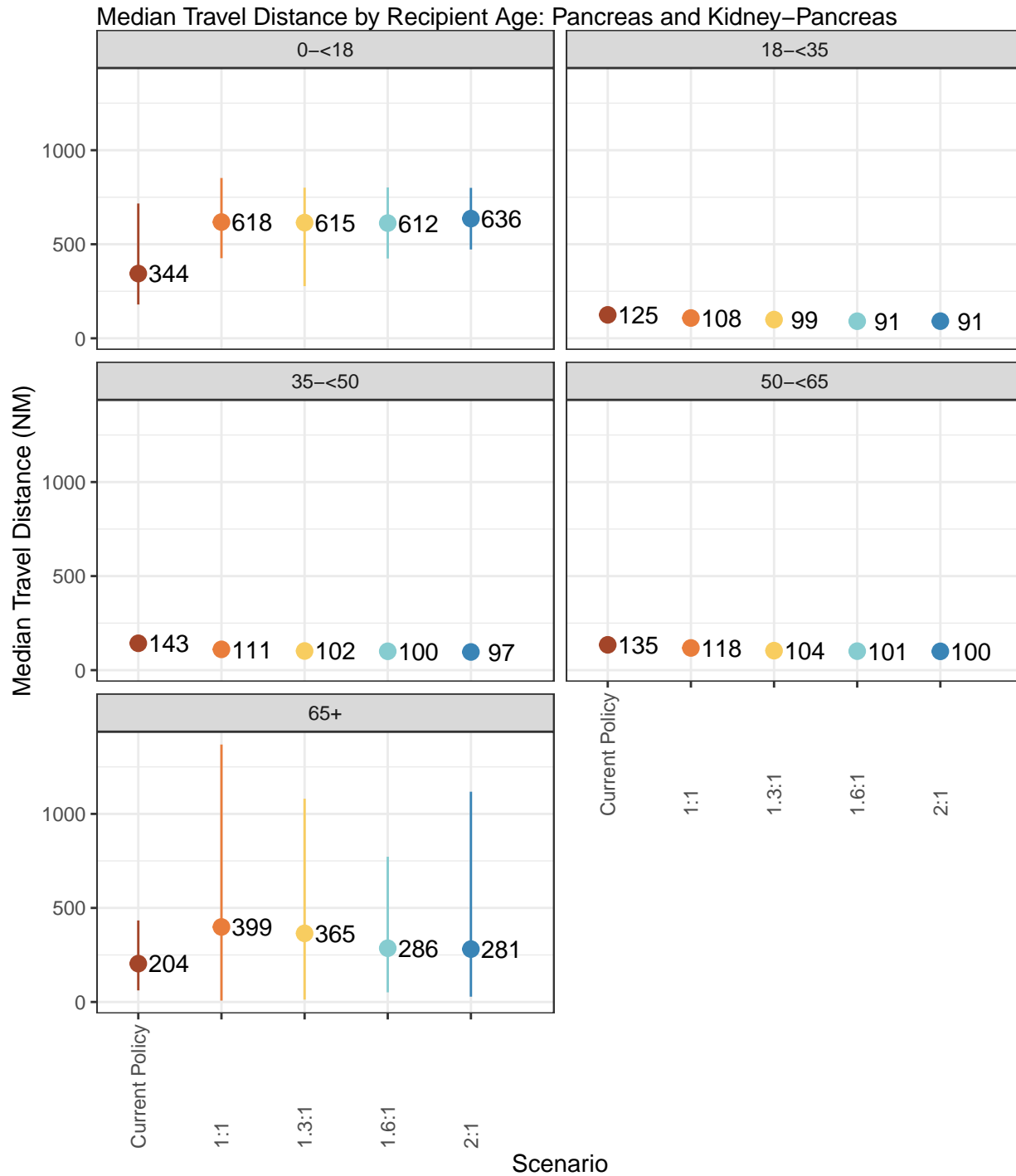


Figure 27: Median Travel Distance by Recipient Age: Pancreas and Kidney-Pancreas. Travel distance is between the donor hospital and the transplant center, in nautical miles.

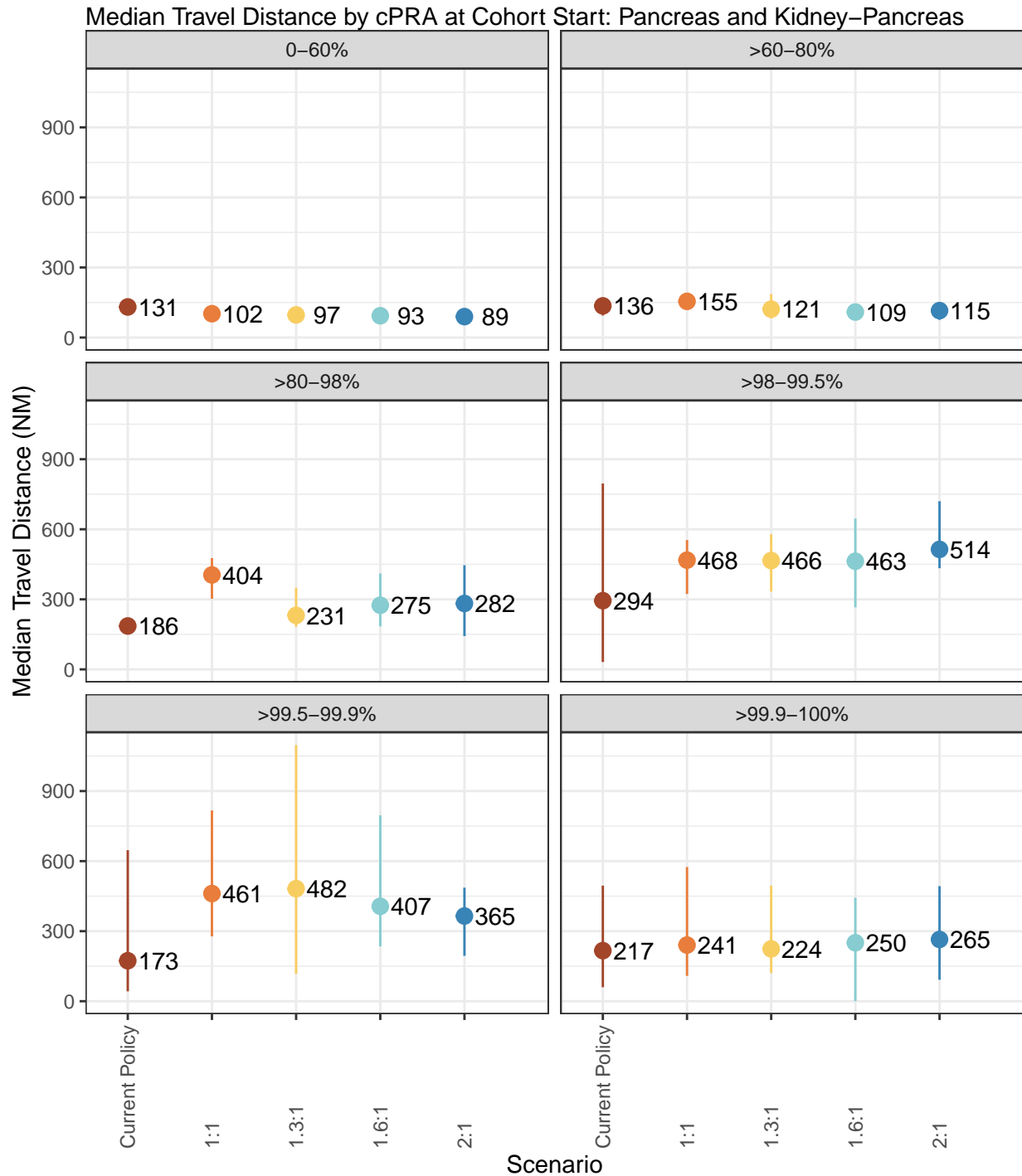


Figure 28: Median Travel Distance by cPRA at Cohort Start: Pancreas and Kidney-Pancreas. Travel distance is between the donor hospital and the transplant center, in nautical miles.

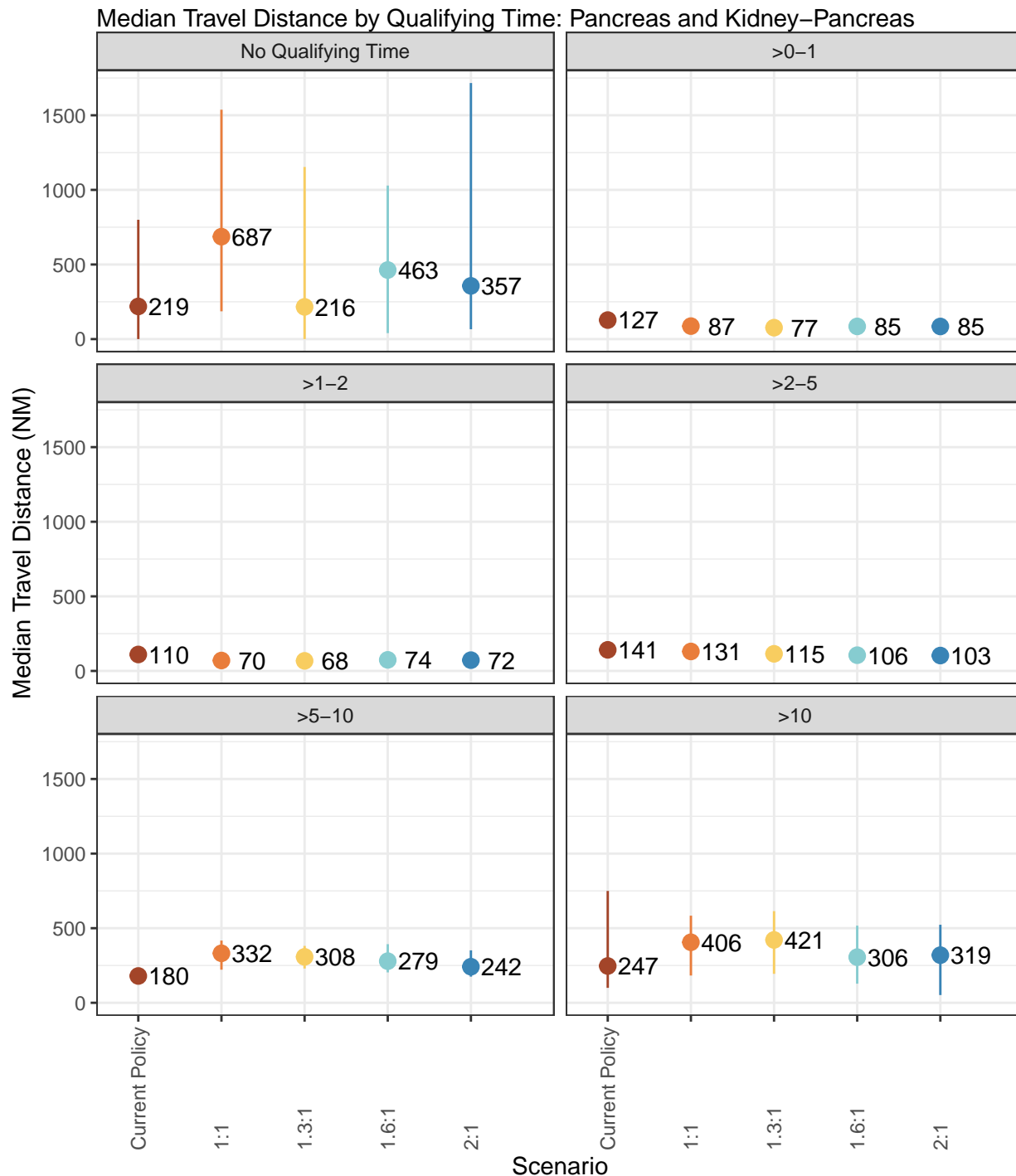


Figure 29: Median Travel Distance by Qualifying Time: Pancreas and Kidney-Pancreas. Qualifying time is time in years from qualifying date to transplant among those who underwent transplant. Travel distance is between the donor hospital and the transplant center, in nautical miles.

Kidney Additional

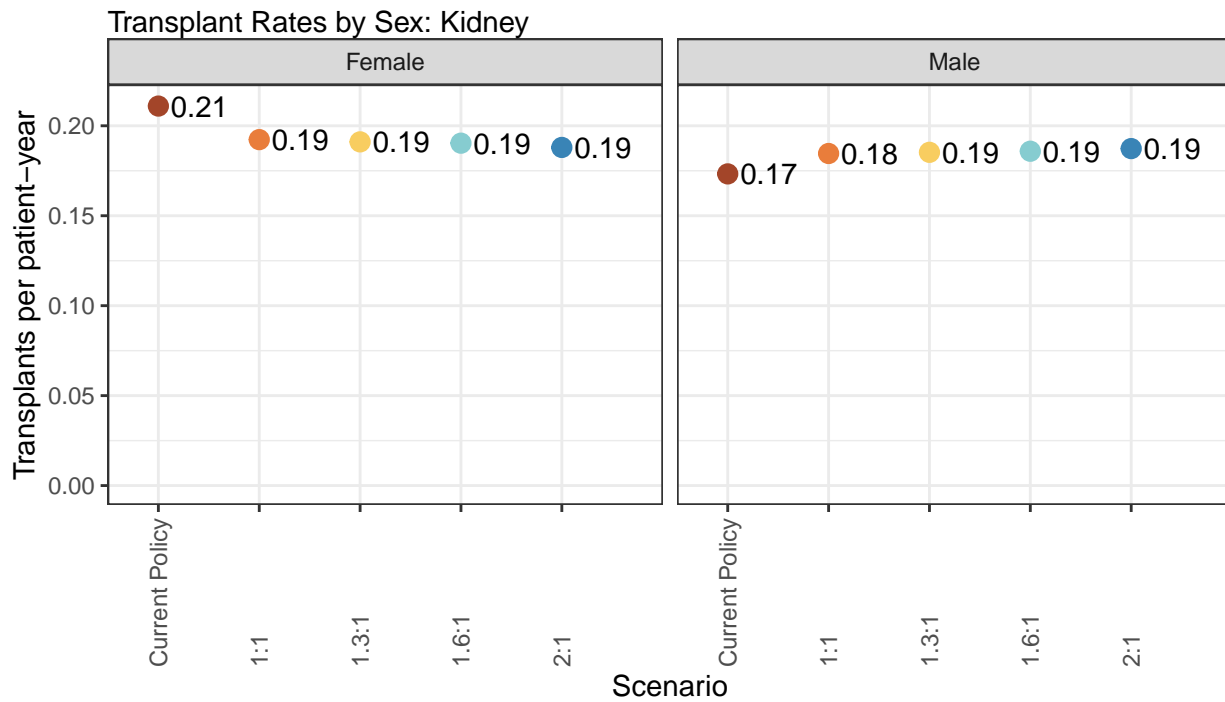


Figure 30: Transplant Rates by Sex: Kidney. Person-time is calculated in days for all candidates from the start of their simulation period (simulation start or listing) to transplant, waitlist removal, or simulation end.

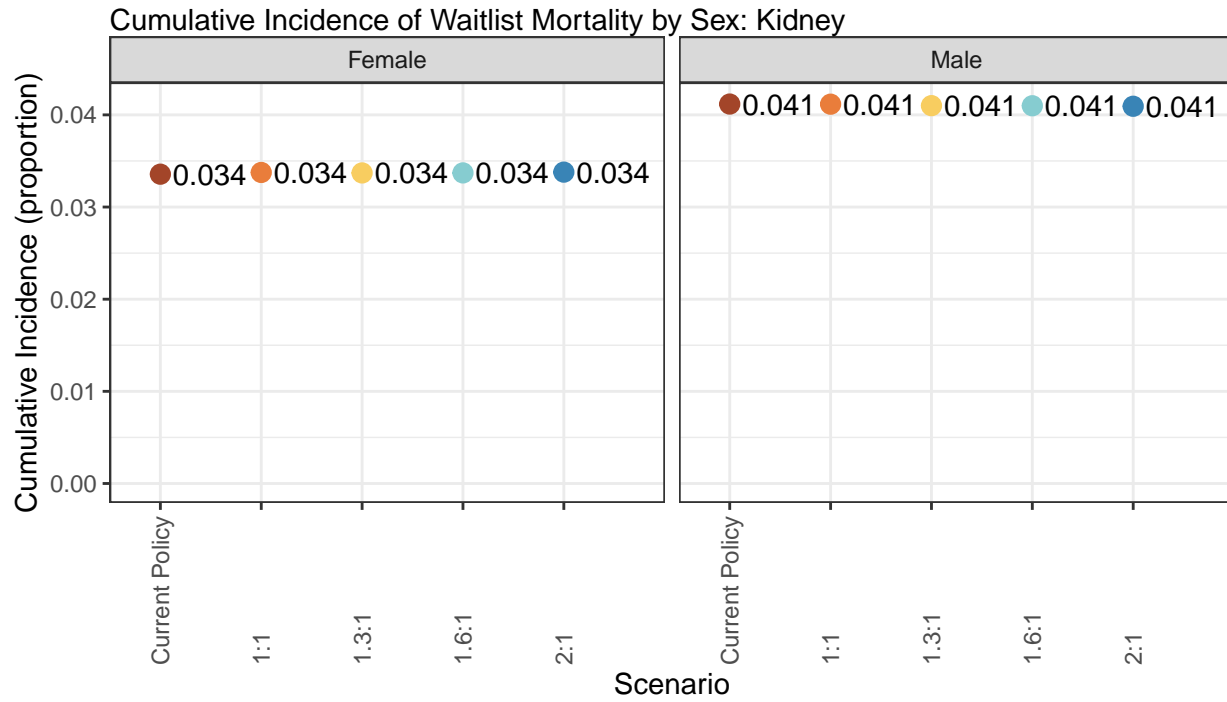


Figure 31: Cumulative Incidence of Waitlist Mortality by Sex: Kidney. Person-time is calculated in days for all candidates from the start of their simulation period (simulation start or listing) to transplant, waitlist removal, or simulation end. Cumulative incidence at 1 year from the start of the simulation period.

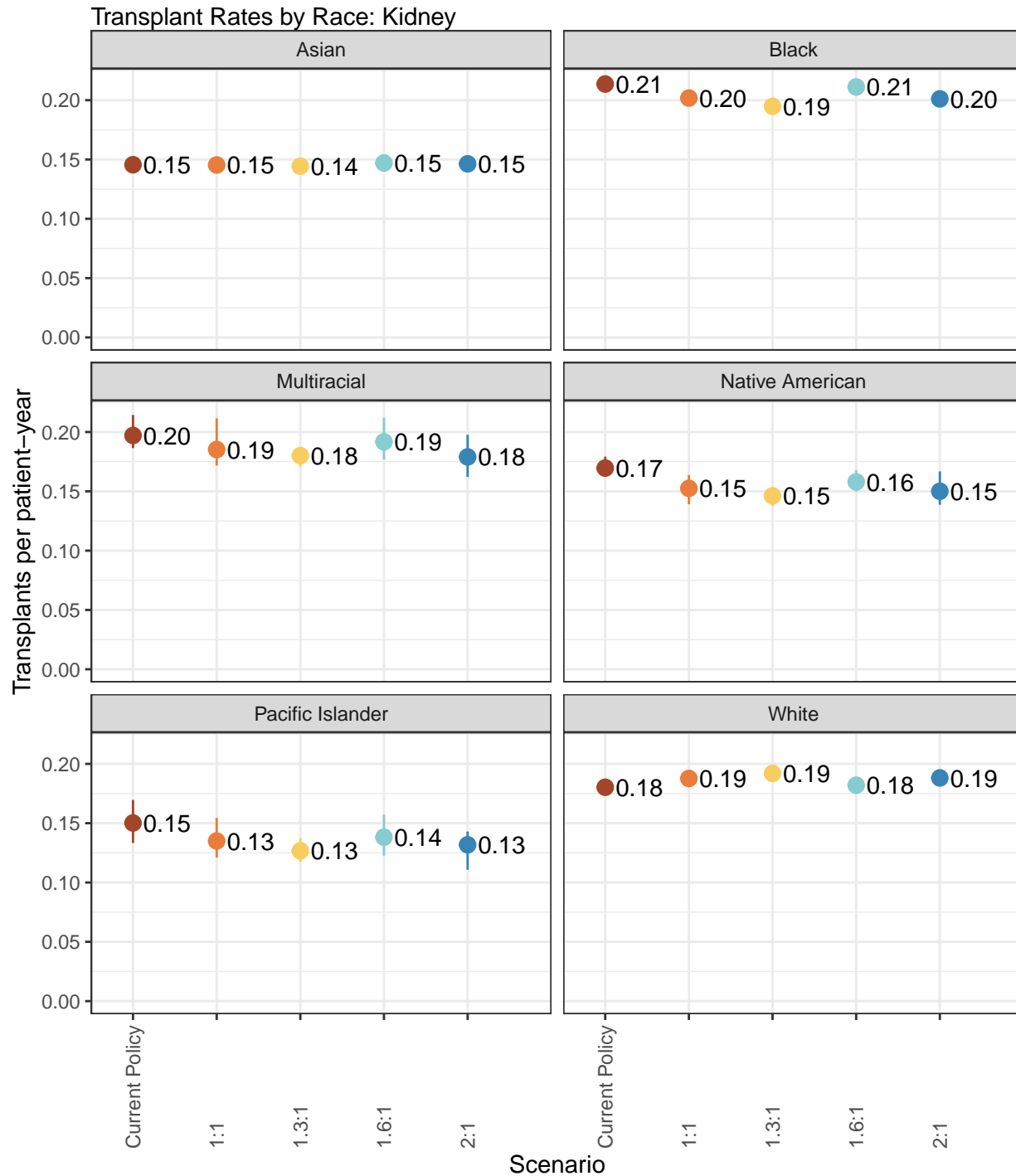


Figure 32: Transplant Rates by Race: Kidney. Person-time is calculated in days for all candidates from the start of their simulation period (simulation start or listing) to transplant, waitlist removal, or simulation end.

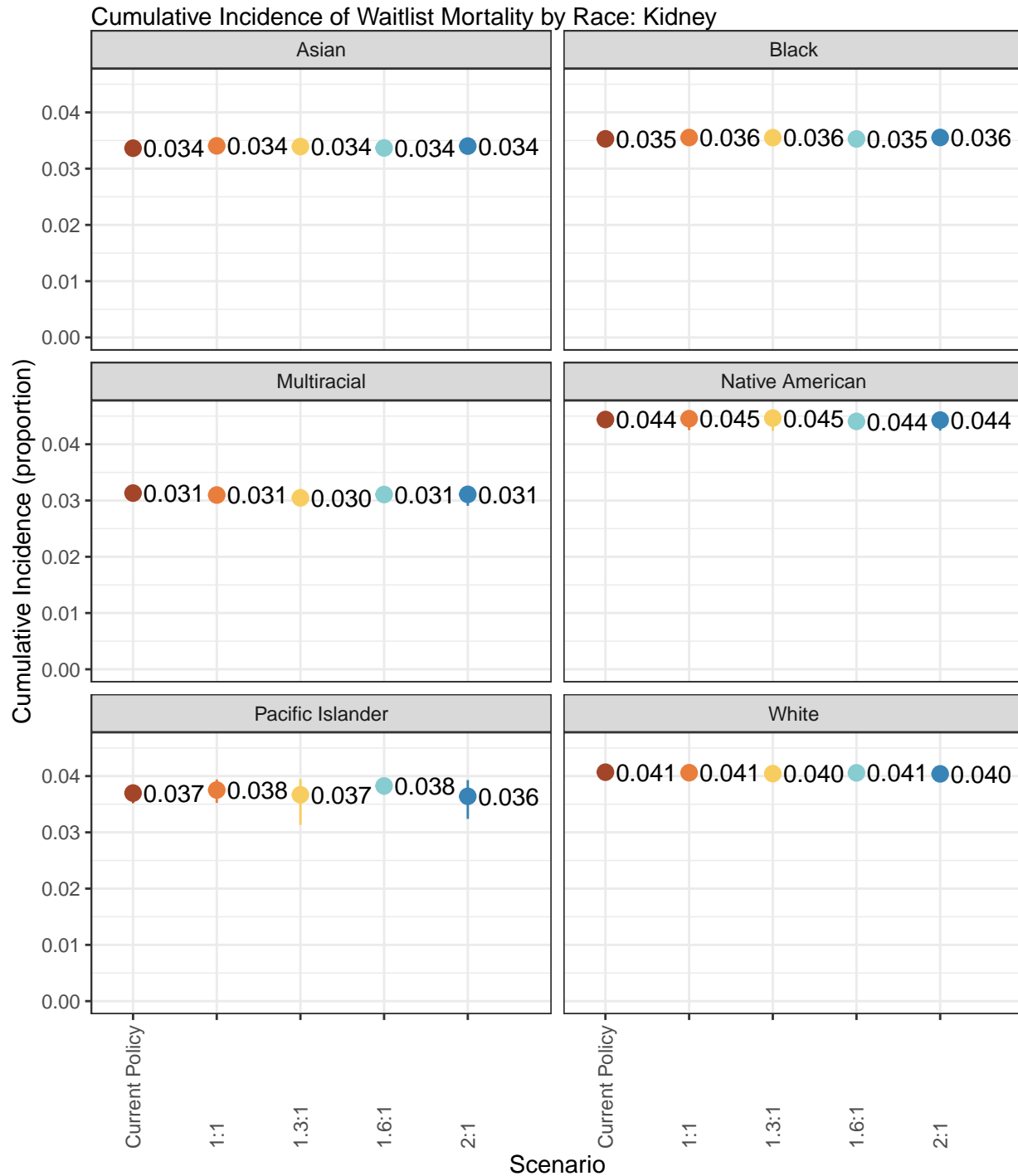


Figure 33: Cumulative Incidence of Waitlist Mortality by Race: Kidney. Person-time is calculated in days for all candidates from the start of their simulation period (simulation start or listing) to transplant, waitlist removal, or simulation end. Cumulative incidence at 1 year from the start of the simulation period.

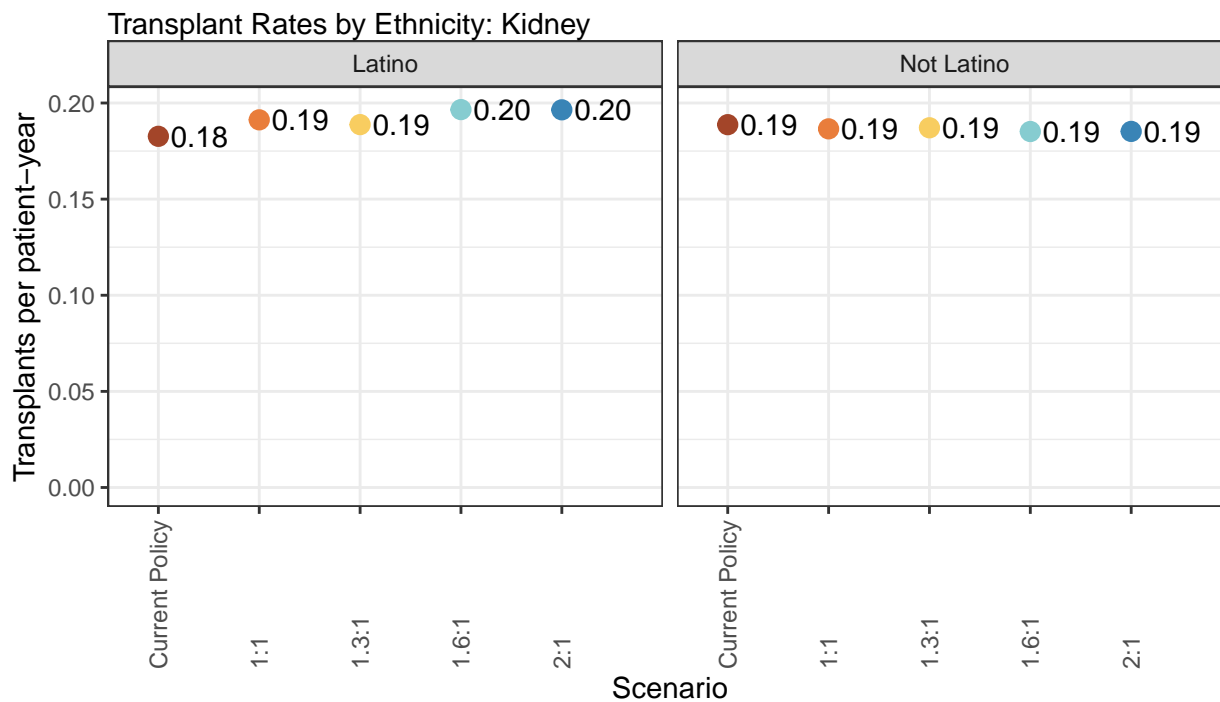


Figure 34: Transplant Rates by Ethnicity: Kidney. Person-time is calculated in days for all candidates from the start of their simulation period (simulation start or listing) to transplant, waitlist removal, or simulation end.

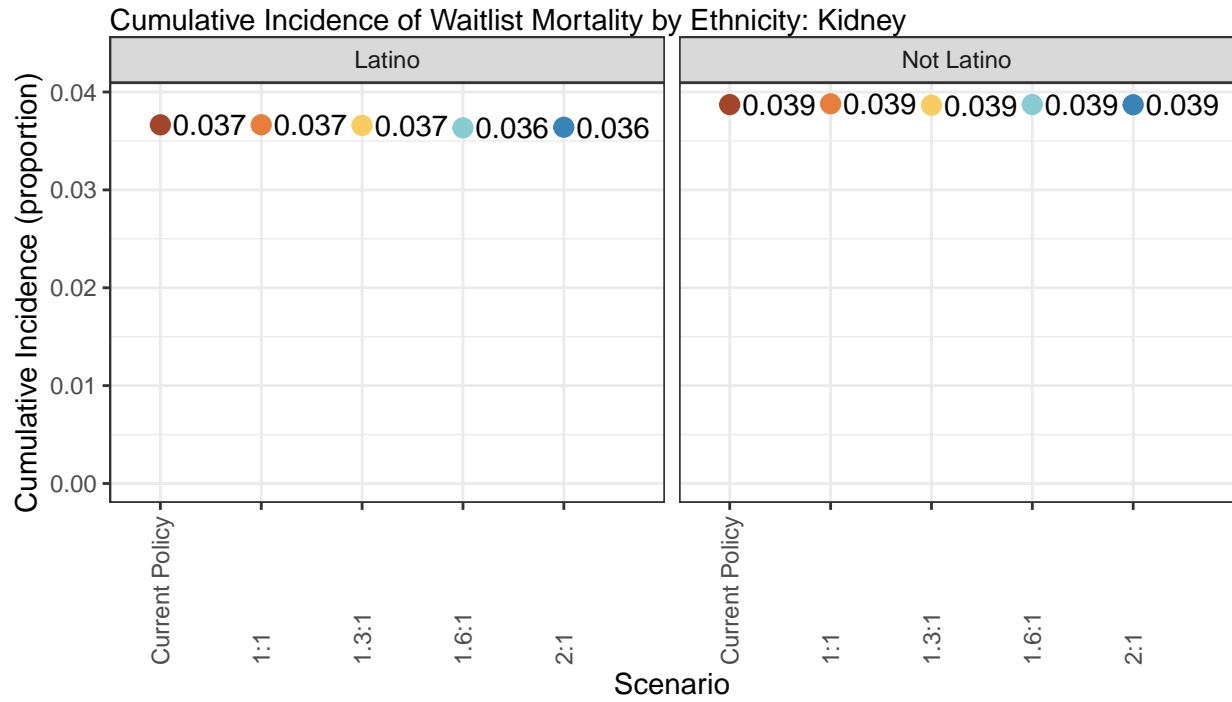


Figure 35: Cumulative Incidence of Waitlist Mortality by Ethnicity: Kidney. Person-time is calculated in days for all candidates from the start of their simulation period (simulation start or listing) to transplant, waitlist removal, or simulation end. Cumulative incidence at 1 year from the start of the simulation period.

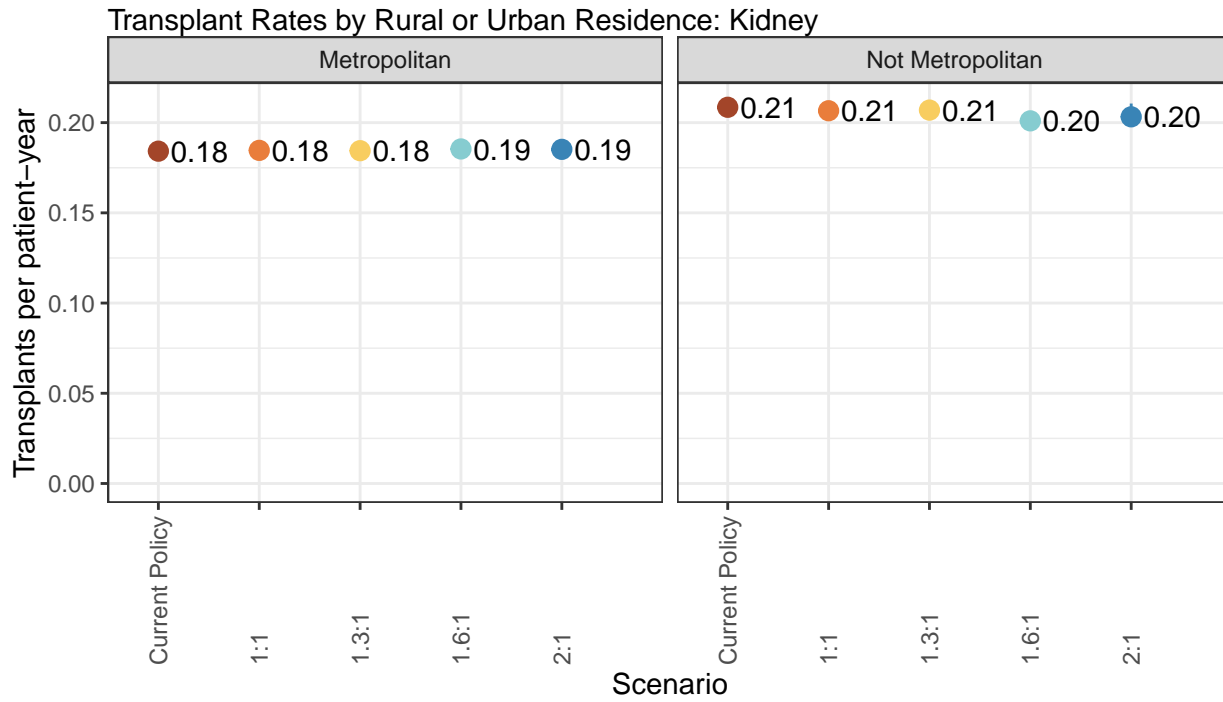


Figure 36: Transplant Rates by Rural or Urban Residence: Kidney. Person-time is calculated in days for all candidates from the start of their simulation period (simulation start or listing) to transplant, waitlist removal, or simulation end.

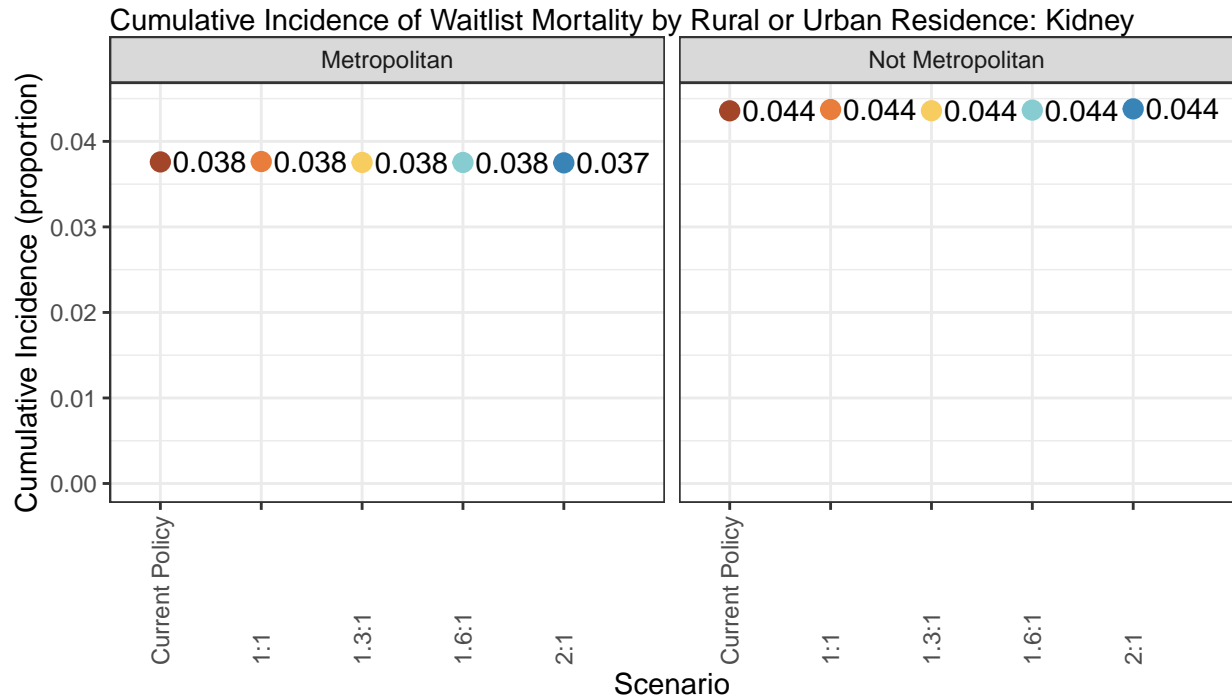


Figure 37: Cumulative Incidence of Waitlist Mortality by Rural or Urban Residence: Kidney. Person-time is calculated in days for all candidates from the start of their simulation period (simulation start or listing) to transplant, waitlist removal, or simulation end. Cumulative incidence at 1 year from the start of the simulation period.

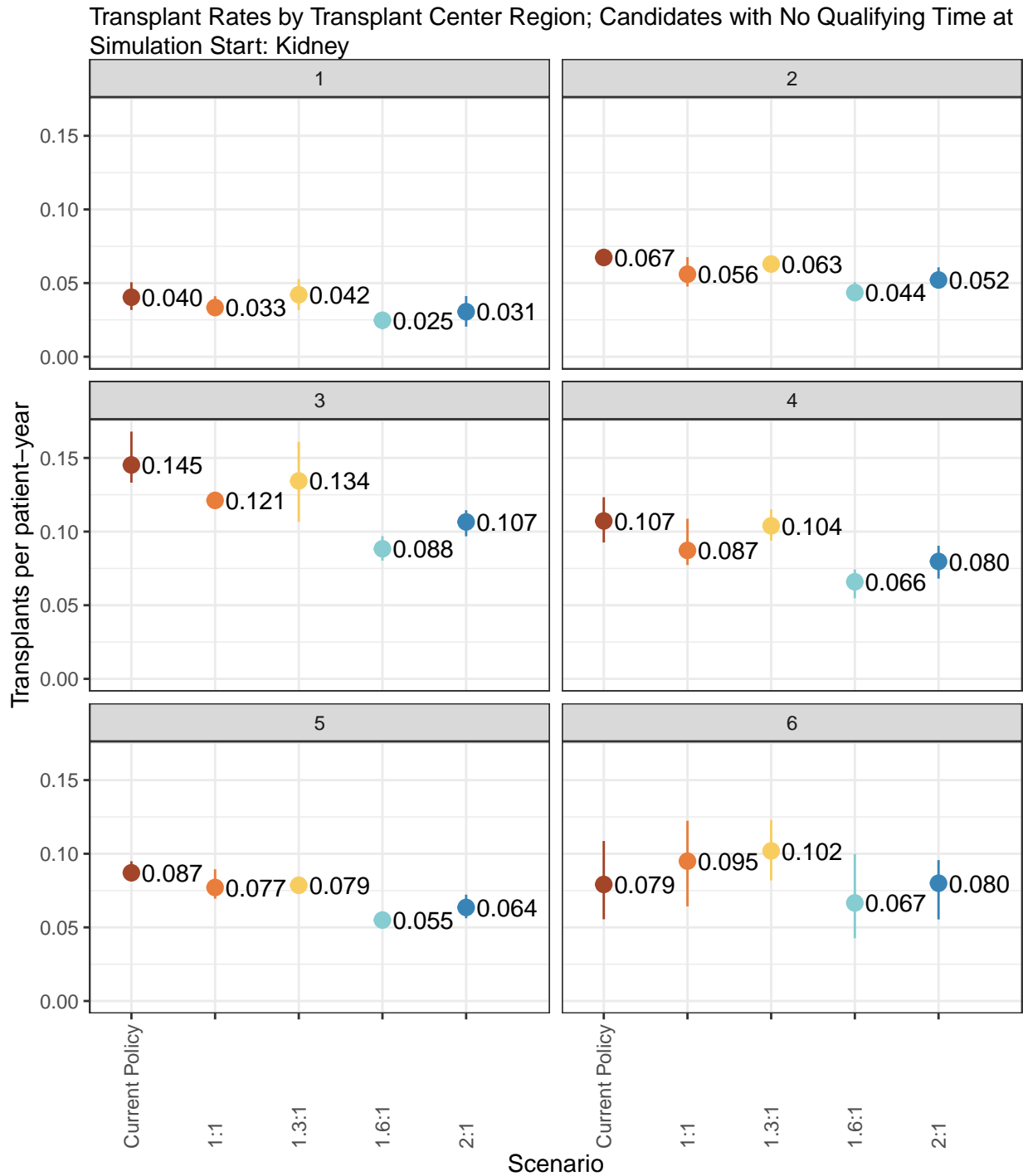


Figure 38: Transplant Rates by Transplant Center Region; Candidates with No Qualifying Time at Simulation Start: Kidney. Person-time is calculated in days for all candidates from the start of their simulation period (simulation start or listing) to transplant, waitlist removal, or simulation end. OPTN regions numbers 1 to 6.

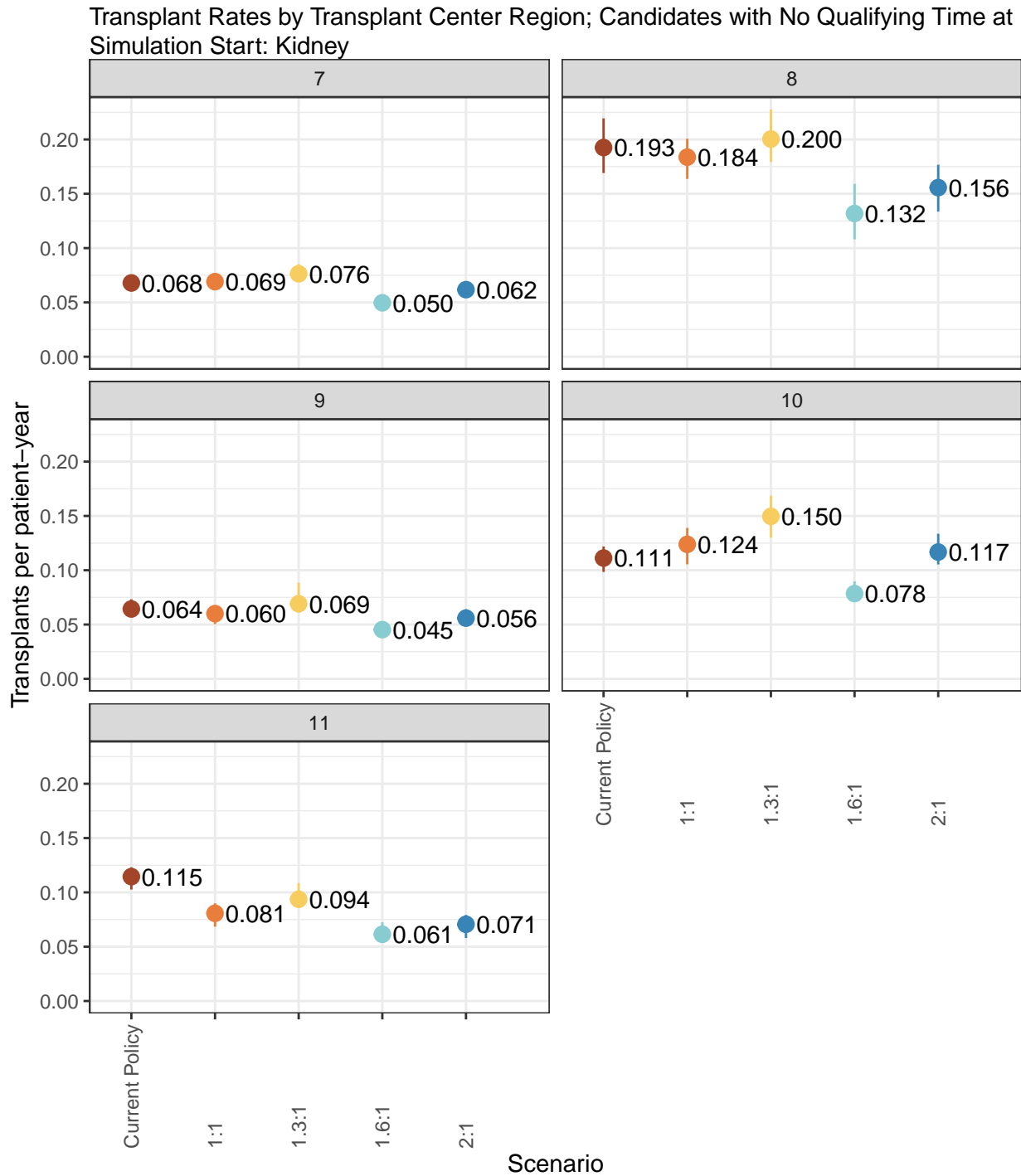


Figure 39: Transplant Rates by Transplant Center Region; Candidates with No Qualifying Time at Simulation Start: Kidney. Person-time is calculated in days for all candidates from the start of their simulation period (simulation start or listing) to transplant, waitlist removal, or simulation end. OPTN regions numbers 7 to 11.

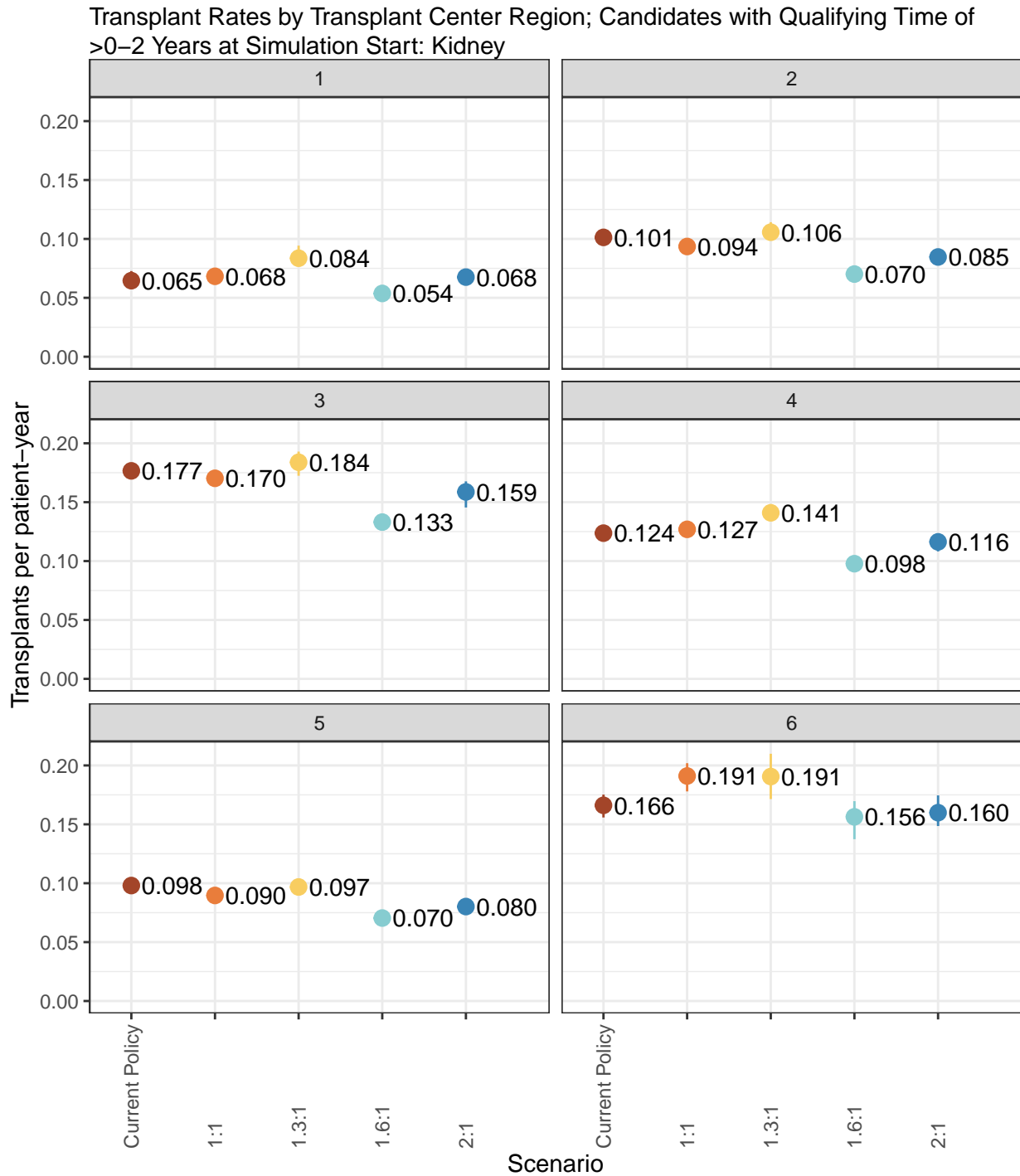


Figure 40: Transplant Rates by Transplant Center Region; Candidates with Qualifying Time of >0-2 Years at Simulation Start: Kidney. Person-time is calculated in days for all candidates from the start of their simulation period (simulation start or listing) to transplant, waitlist removal, or simulation end. OPTN regions numbers 1 to 6.

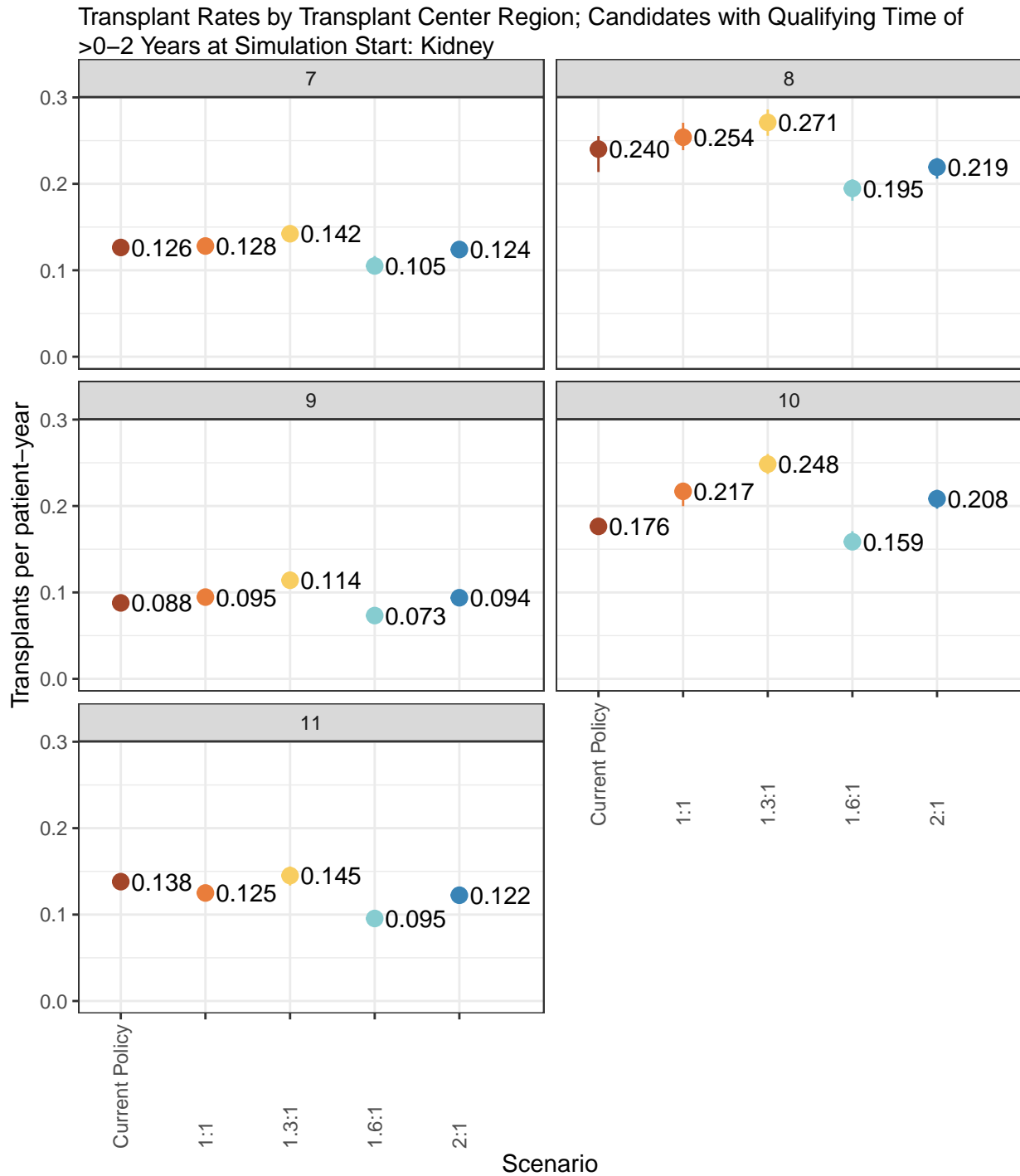


Figure 41: Transplant Rates by Transplant Center Region; Candidates with Qualifying Time of >0-2 Years at Simulation Start: Kidney. Person-time is calculated in days for all candidates from the start of their simulation period (simulation start or listing) to transplant, waitlist removal, or simulation end. OPTN regions numbers 7 to 11.

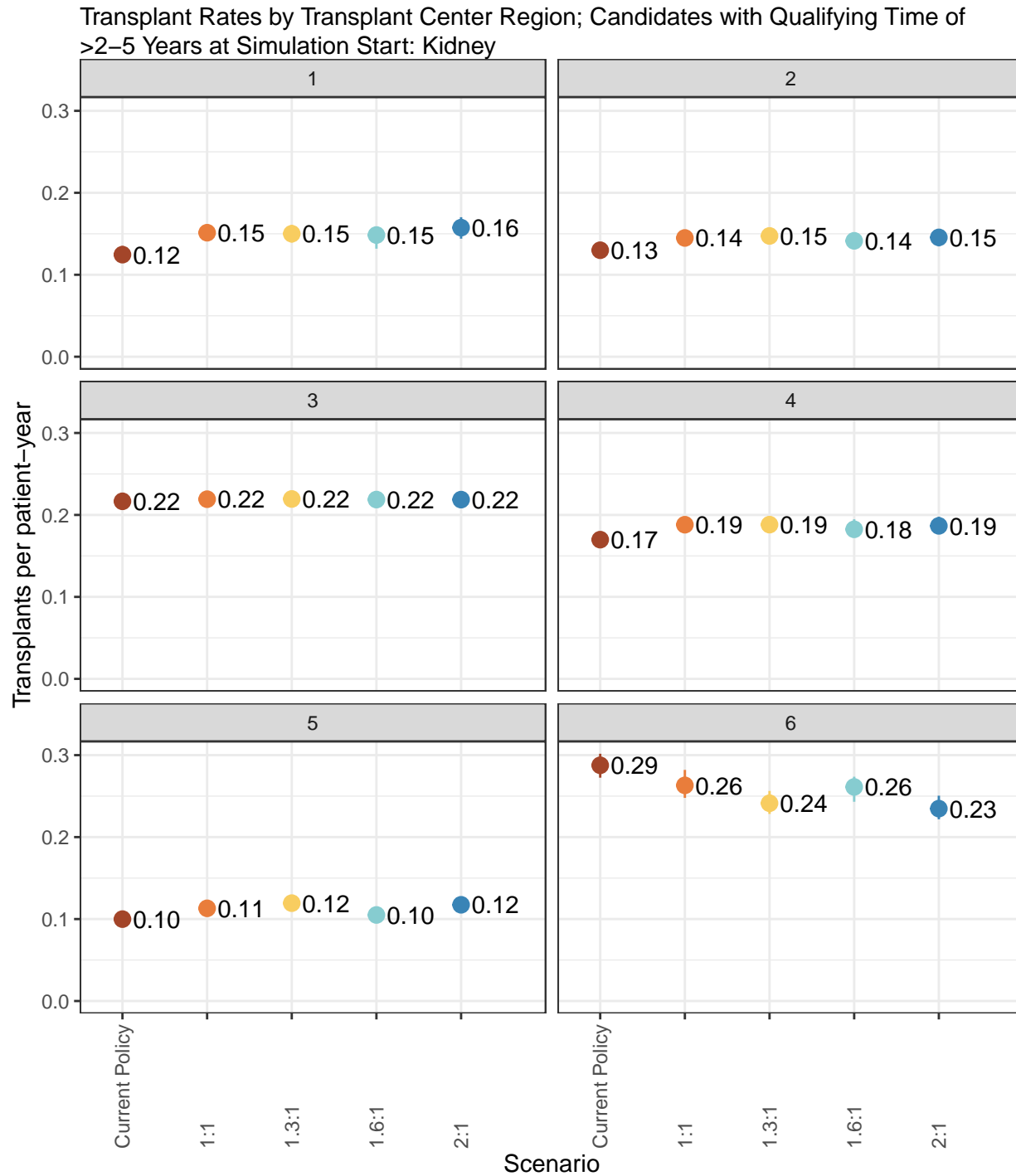


Figure 42: Transplant Rates by Transplant Center Region; Candidates with Qualifying Time of >2-5 Years at Simulation Start: Kidney. Person-time is calculated in days for all candidates from the start of their simulation period (simulation start or listing) to transplant, waitlist removal, or simulation end. OPTN regions numbers 1 to 6.

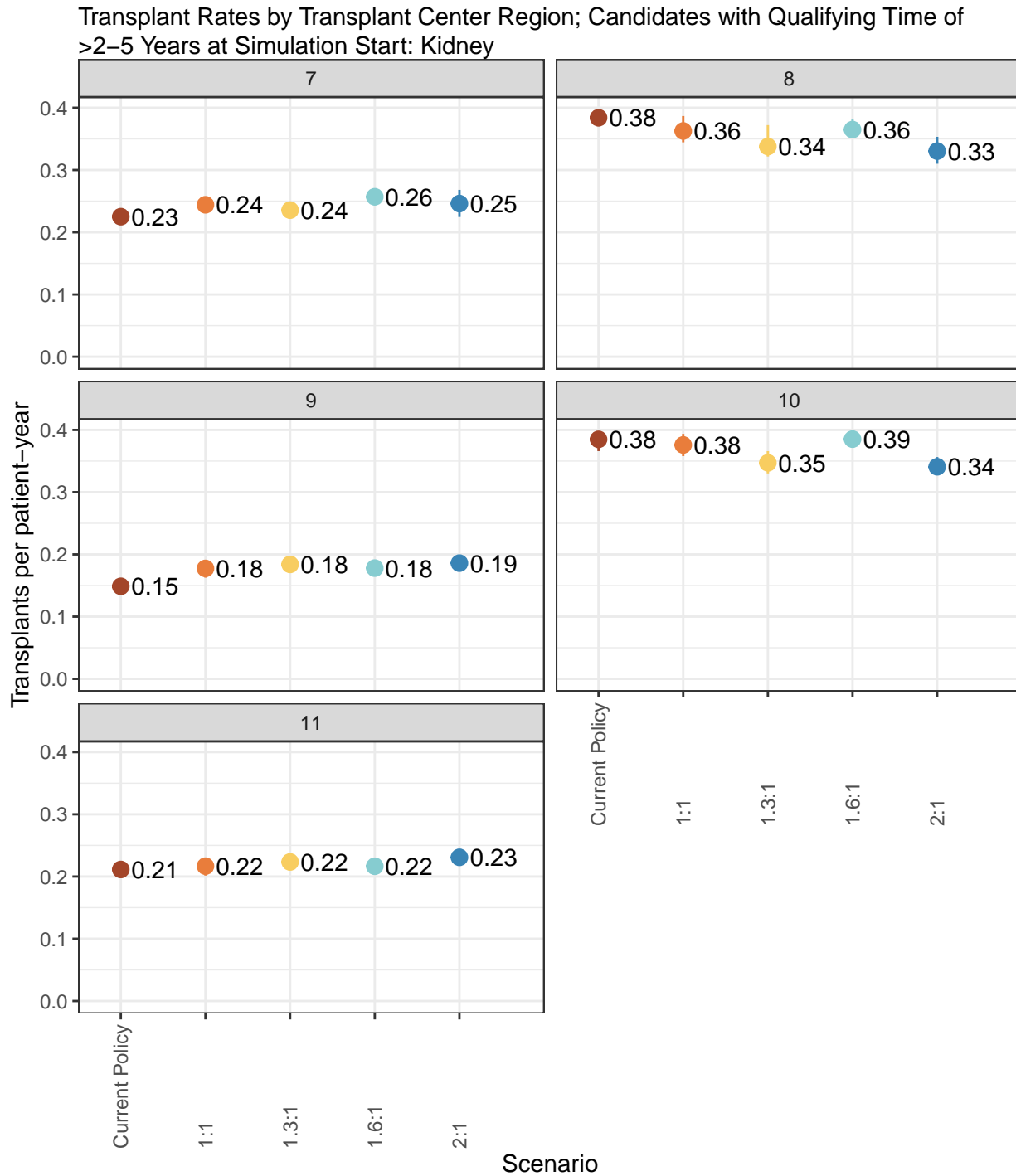


Figure 43: Transplant Rates by Transplant Center Region; Candidates with Qualifying Time of >2-5 Years at Simulation Start: Kidney. Person-time is calculated in days for all candidates from the start of their simulation period (simulation start or listing) to transplant, waitlist removal, or simulation end. OPTN regions numbers 7 to 11.

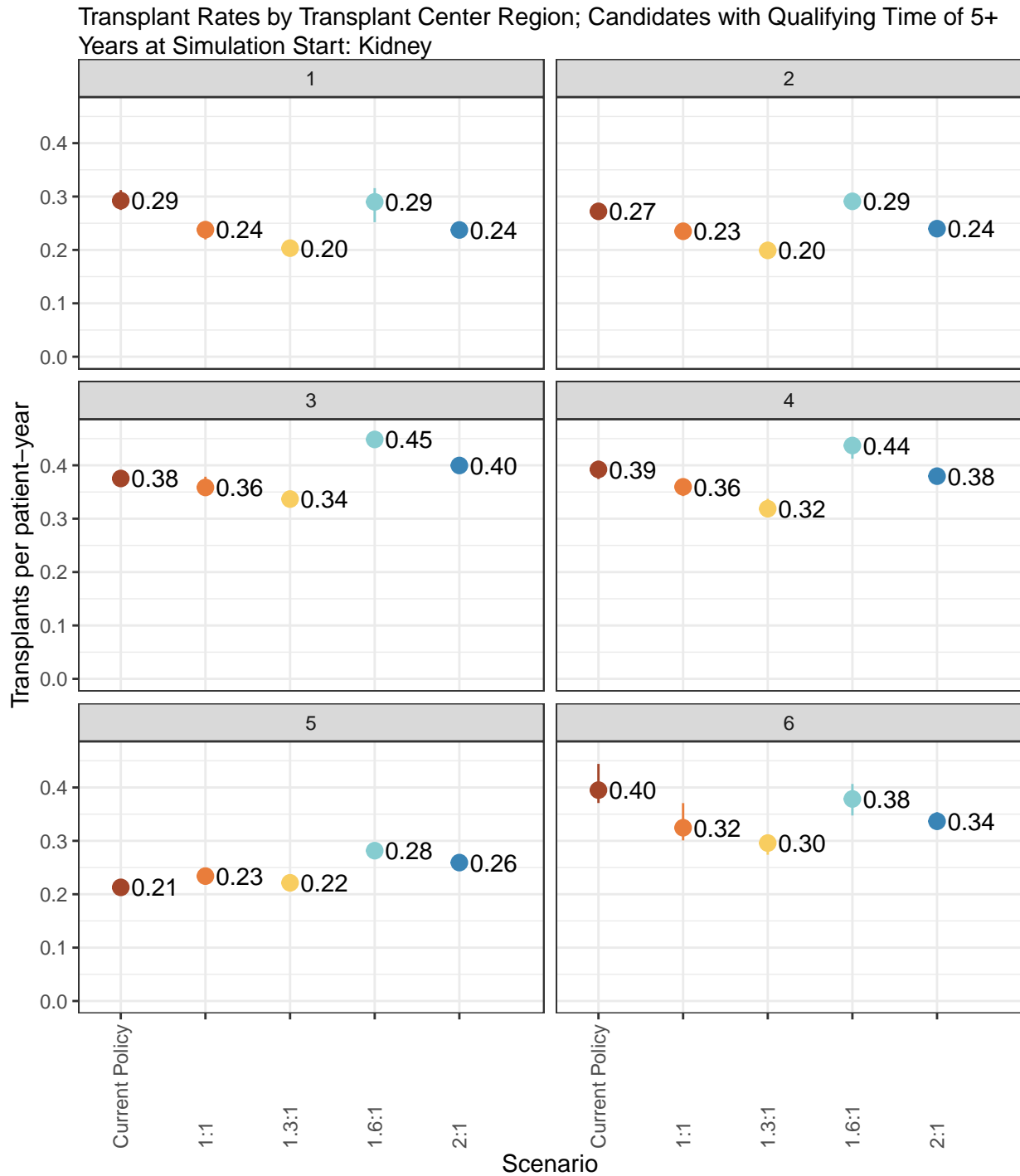


Figure 44: Transplant Rates by Transplant Center Region; Candidates with Qualifying Time of 5+ Years at Simulation Start: Kidney. Person-time is calculated in days for all candidates from the start of their simulation period (simulation start or listing) to transplant, waitlist removal, or simulation end. OPTN regions numbers 1 to 6.

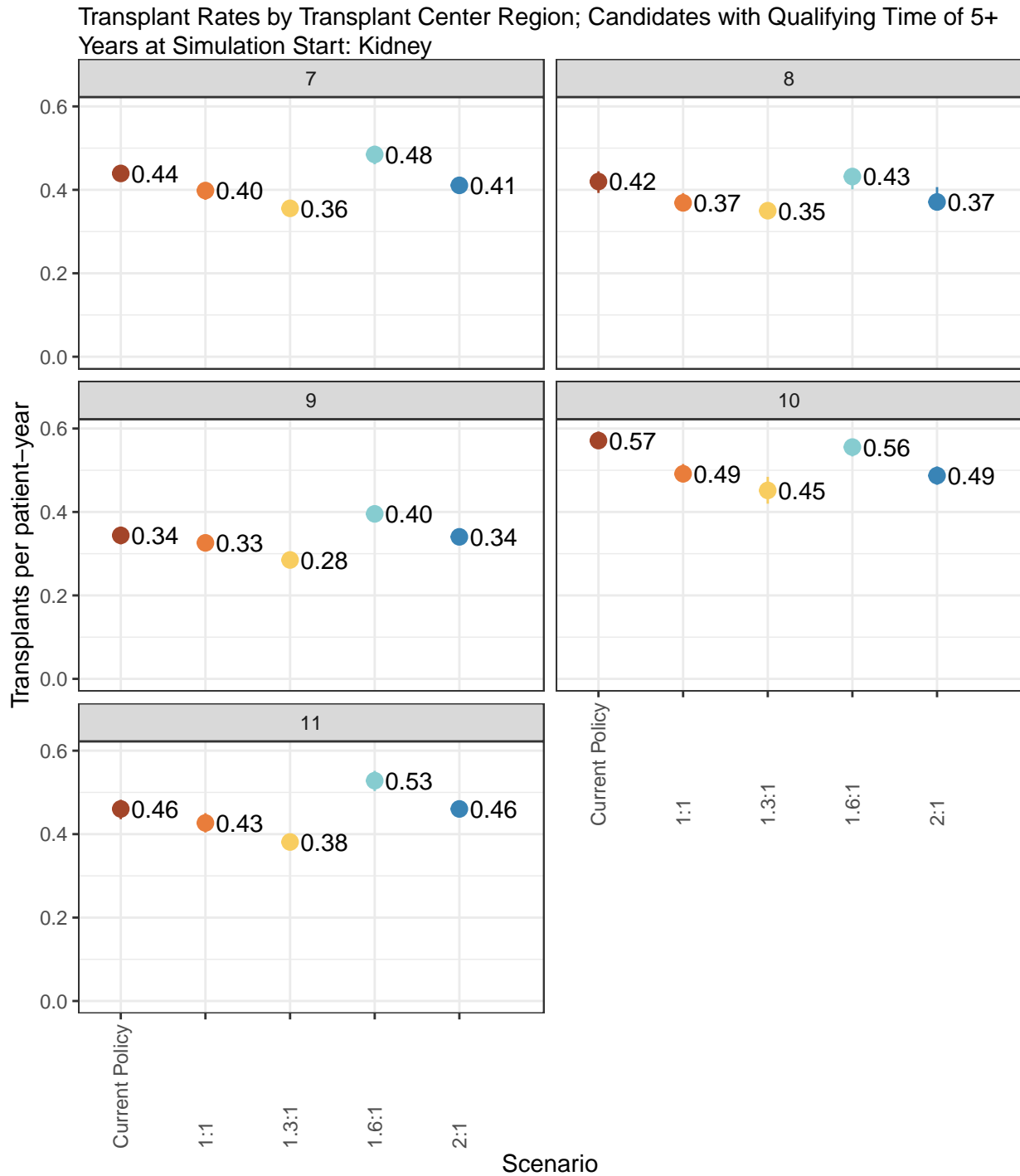


Figure 45: Transplant Rates by Transplant Center Region; Candidates with Qualifying Time of 5+ Years at Simulation Start: Kidney. Person-time is calculated in days for all candidates from the start of their simulation period (simulation start or listing) to transplant, waitlist removal, or simulation end. OPTN regions numbers 7 to 11.

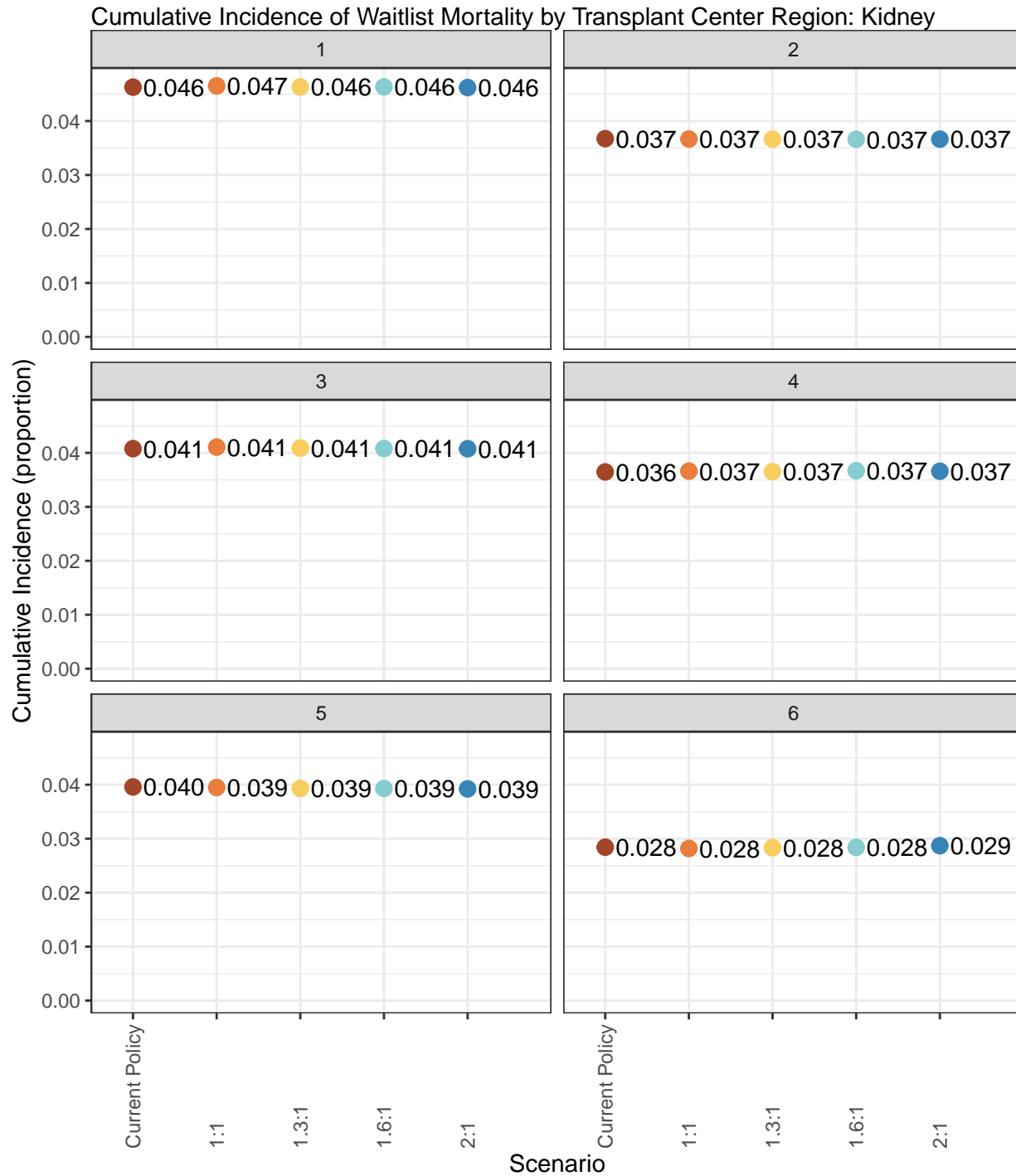


Figure 46: Cumulative Incidence of Waitlist Mortality by Transplant Center Region: Kidney. Person-time is calculated in days for all candidates from the start of their simulation period (simulation start or listing) to transplant, waitlist removal, or simulation end. Cumulative incidence at 1 year from the start of the simulation period. OPTN regions numbers 1 to 6.

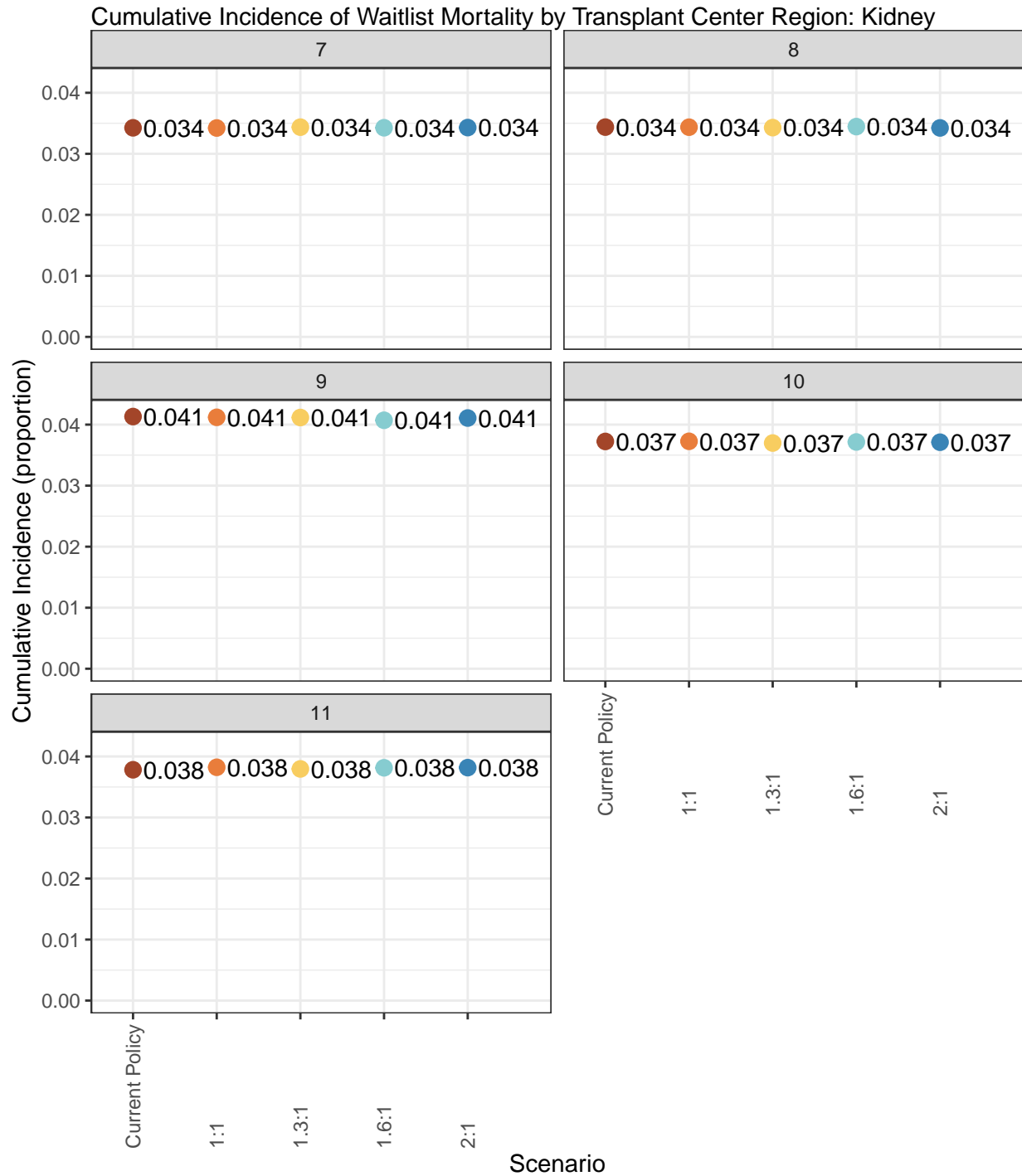


Figure 47: Cumulative Incidence of Waitlist Mortality by Transplant Center Region: Kidney. Person-time is calculated in days for all candidates from the start of their simulation period (simulation start or listing) to transplant, waitlist removal, or simulation end. Cumulative incidence at 1 year from the start of the simulation period. OPTN regions numbers 7 to 11.

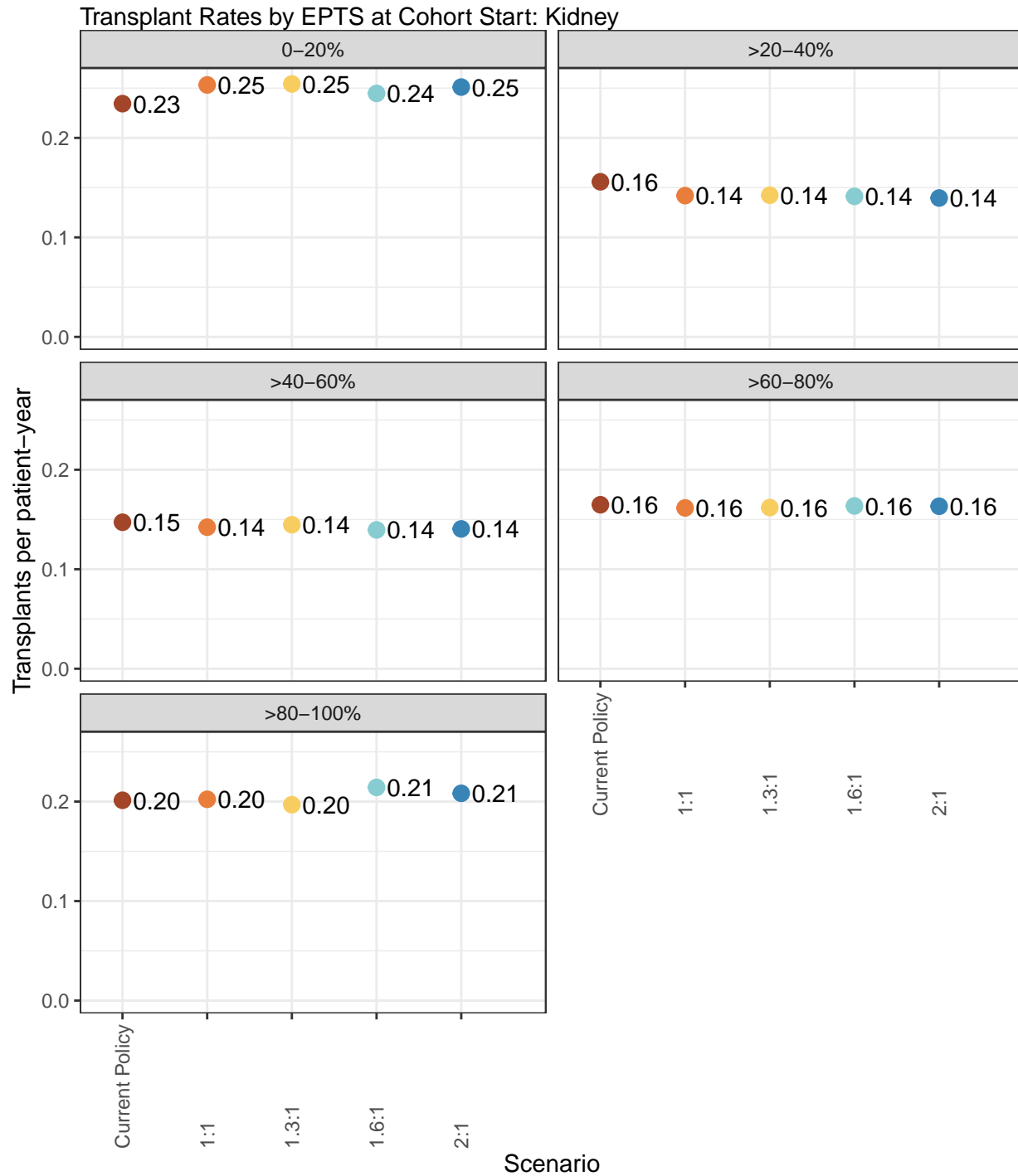


Figure 48: Transplant Rates by EPTS at Cohort Start: Kidney. EPTS at cohort start is the last value the candidate had prior to the simulation start or their value at listing. Person-time is calculated in days for all candidates from the start of their simulation period (simulation start or listing) to transplant, waitlist removal, or simulation end.

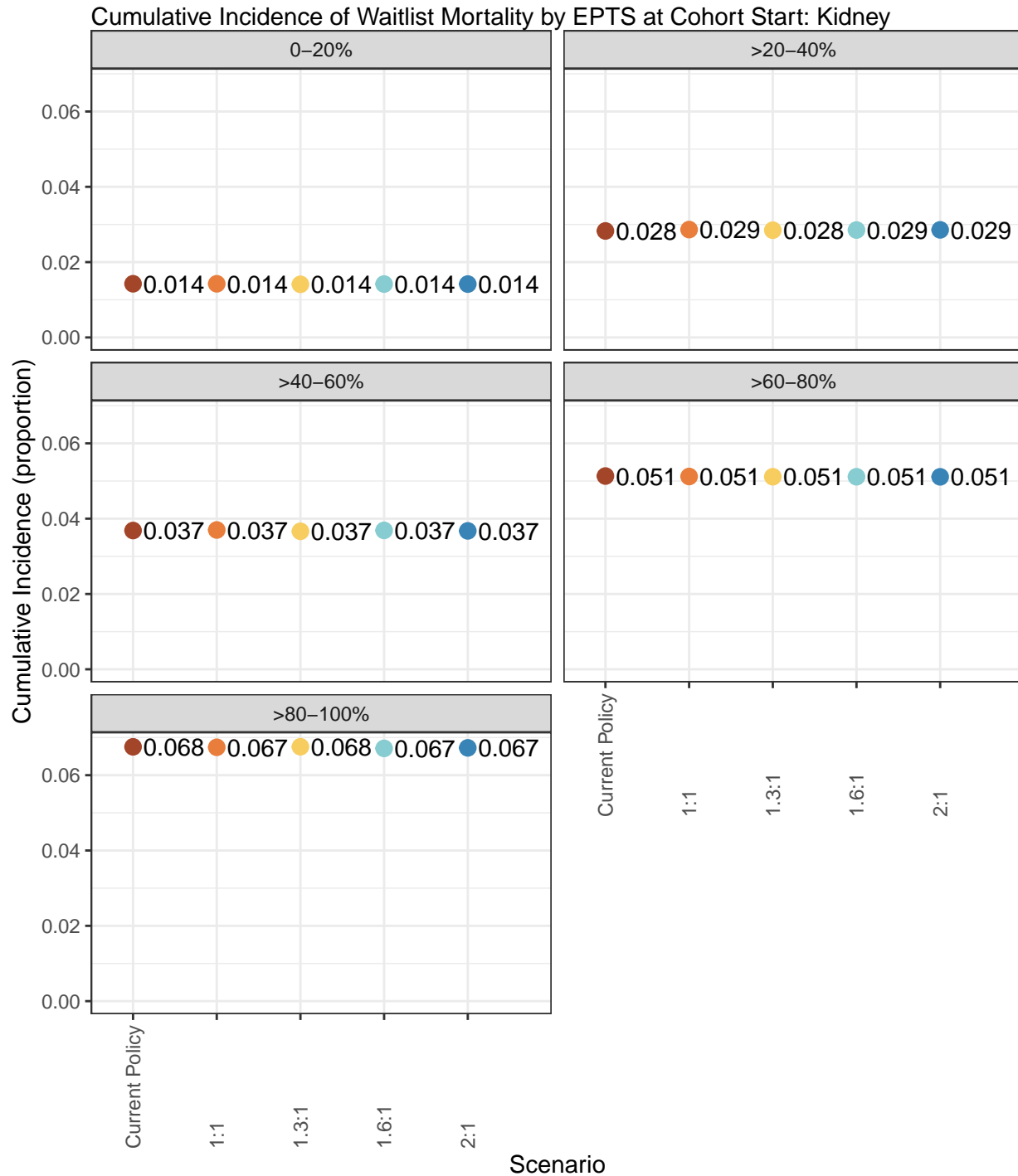


Figure 49: Cumulative Incidence of Waitlist Mortality by EPTS at Cohort Start: Kidney. EPTS at cohort start is the last value the candidate had prior to the simulation start or their value at listing. Person-time is calculated in days for all candidates from the start of their simulation period (simulation start or listing) to transplant, waitlist removal, or simulation end. Cumulative incidence at 1 year from the start of the simulation period.

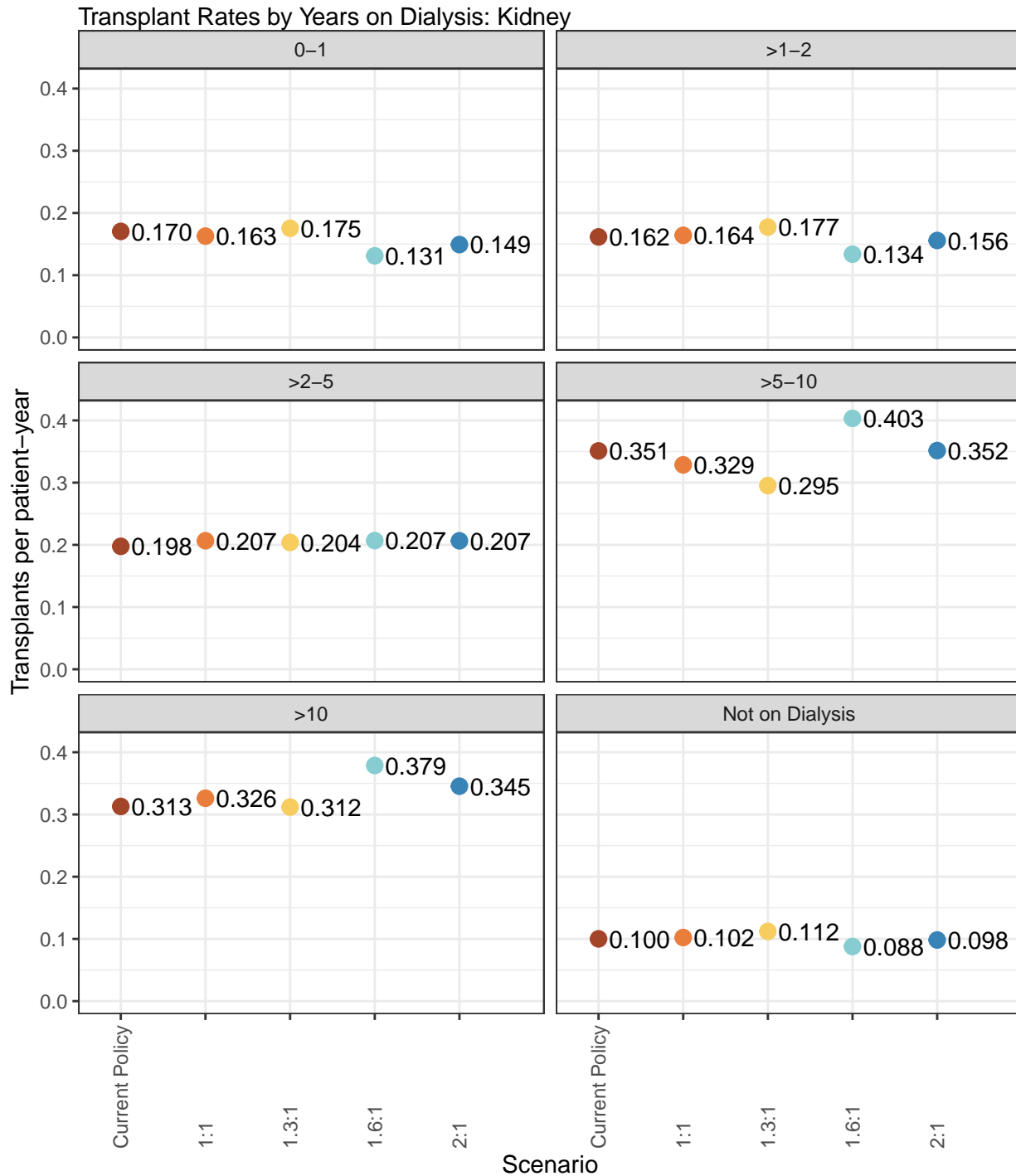


Figure 50: Transplant Rates by Years on Dialysis: Kidney. Person-time is calculated in days for all candidates from the start of their simulation period (simulation start or listing) to transplant, waitlist removal, or simulation end.

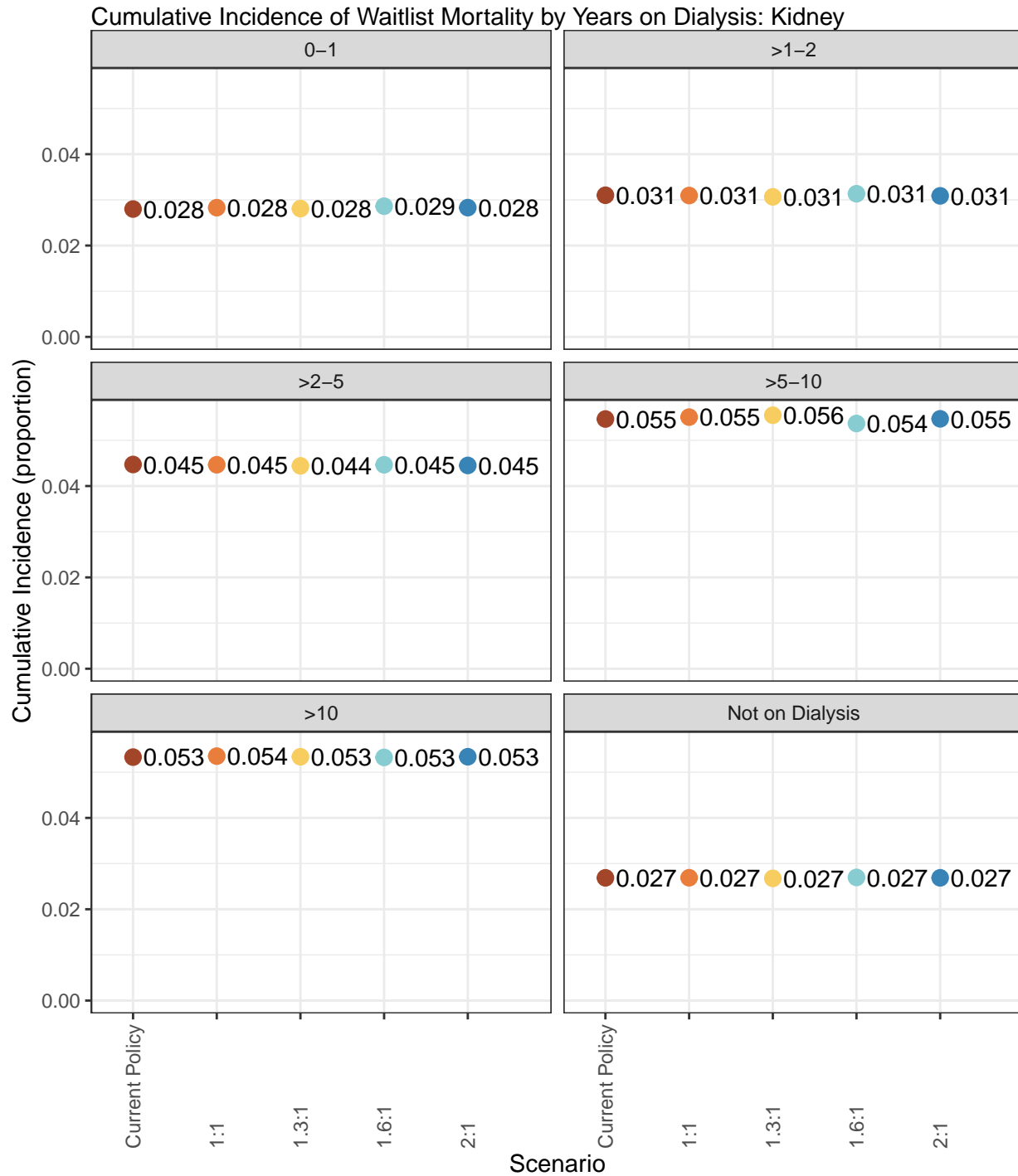


Figure 51: Cumulative Incidence of Waitlist Mortality by Years on Dialysis: Kidney. Person-time is calculated in days for all candidates from the start of their simulation period (simulation start or listing) to transplant, waitlist removal, or simulation end. Cumulative incidence at 1 year from the start of the simulation period.

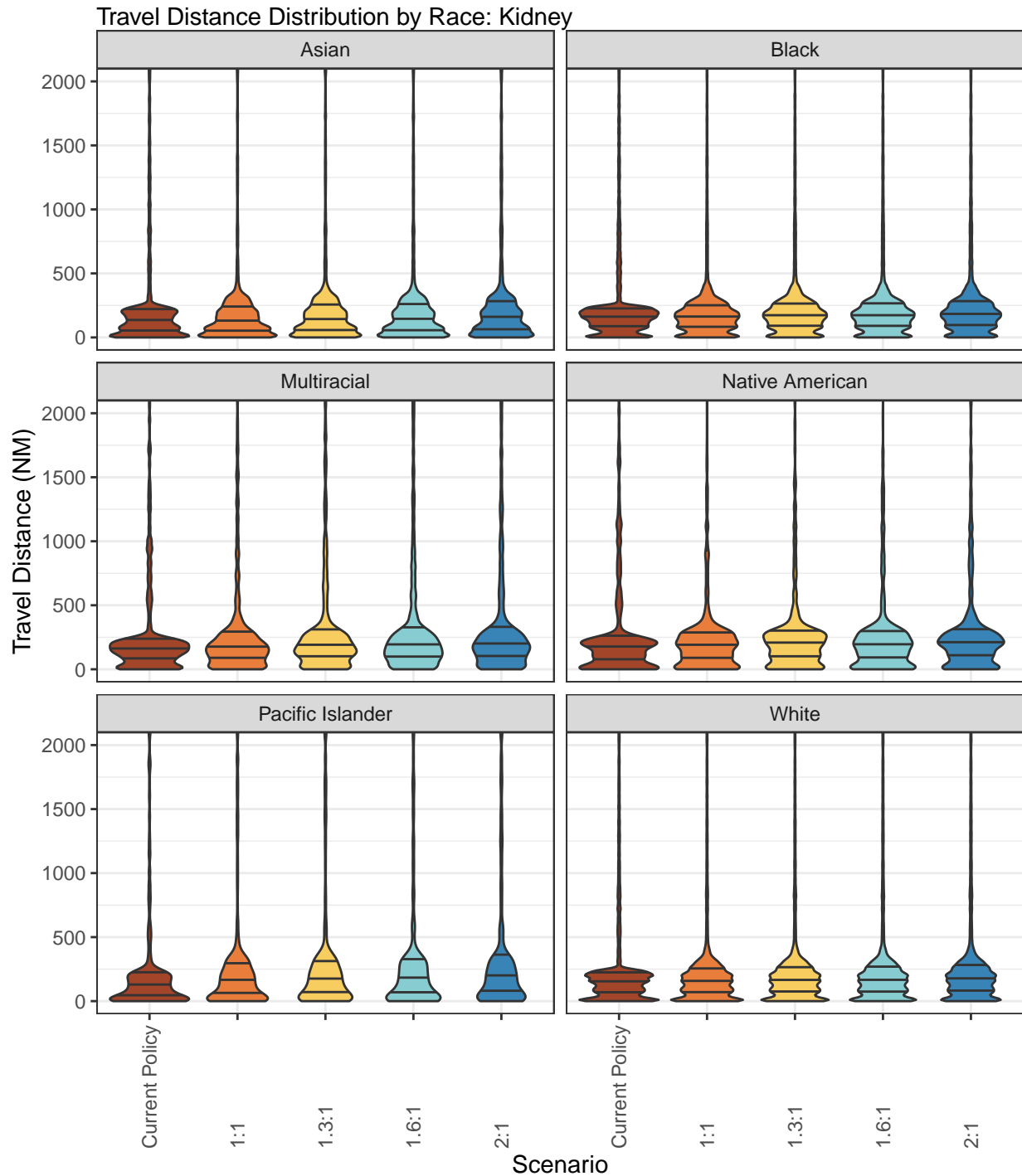


Figure 52: Travel Distance Distribution by Race: Kidney. Distribution of travel distance. Travel distance is between the donor hospital and the transplant center, in nautical miles.

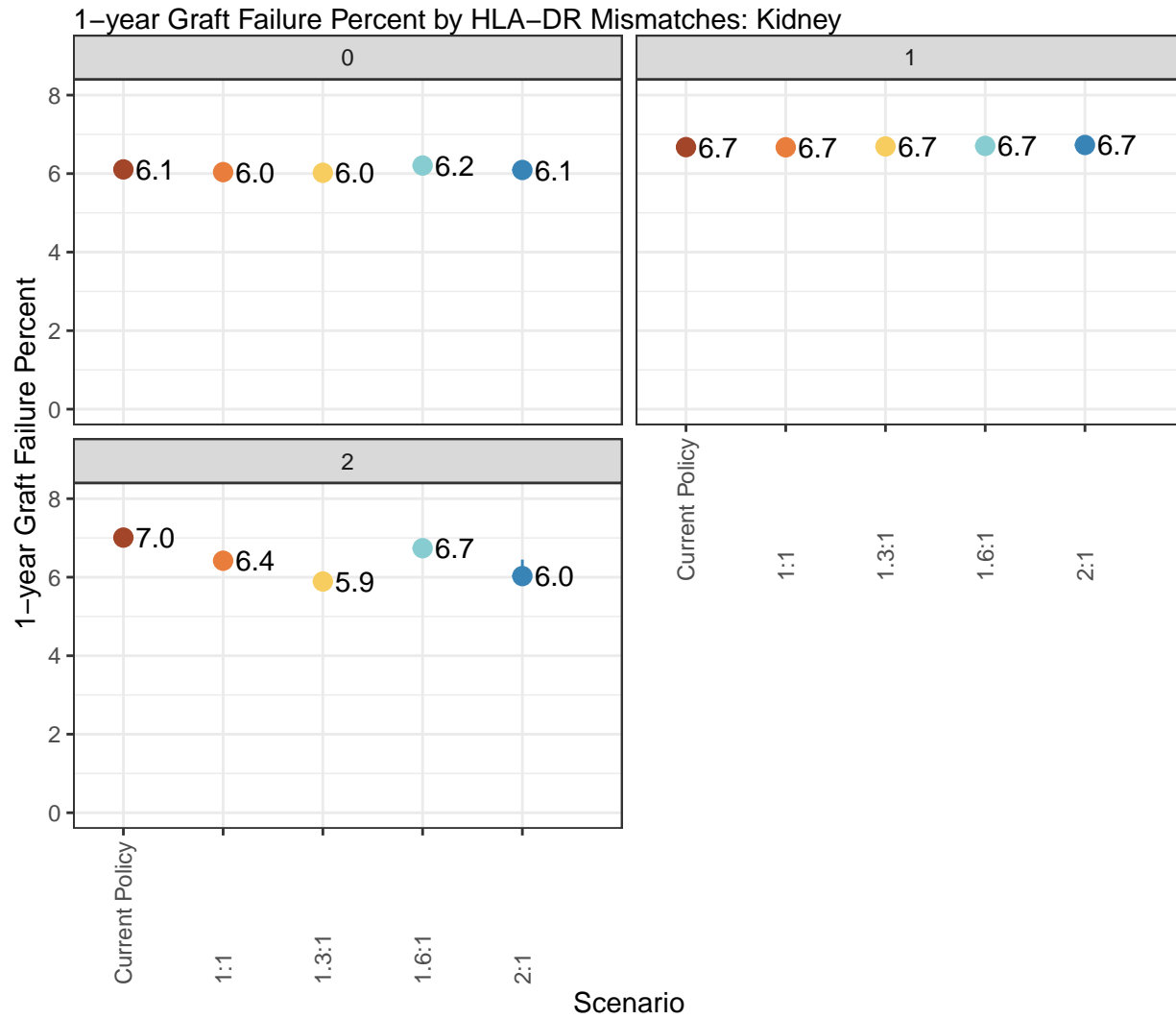


Figure 53: 1-year Graft Failure Percent by HLA-DR Mismatches: Kidney. HLA-DR Mismatches. All-cause graft failure.

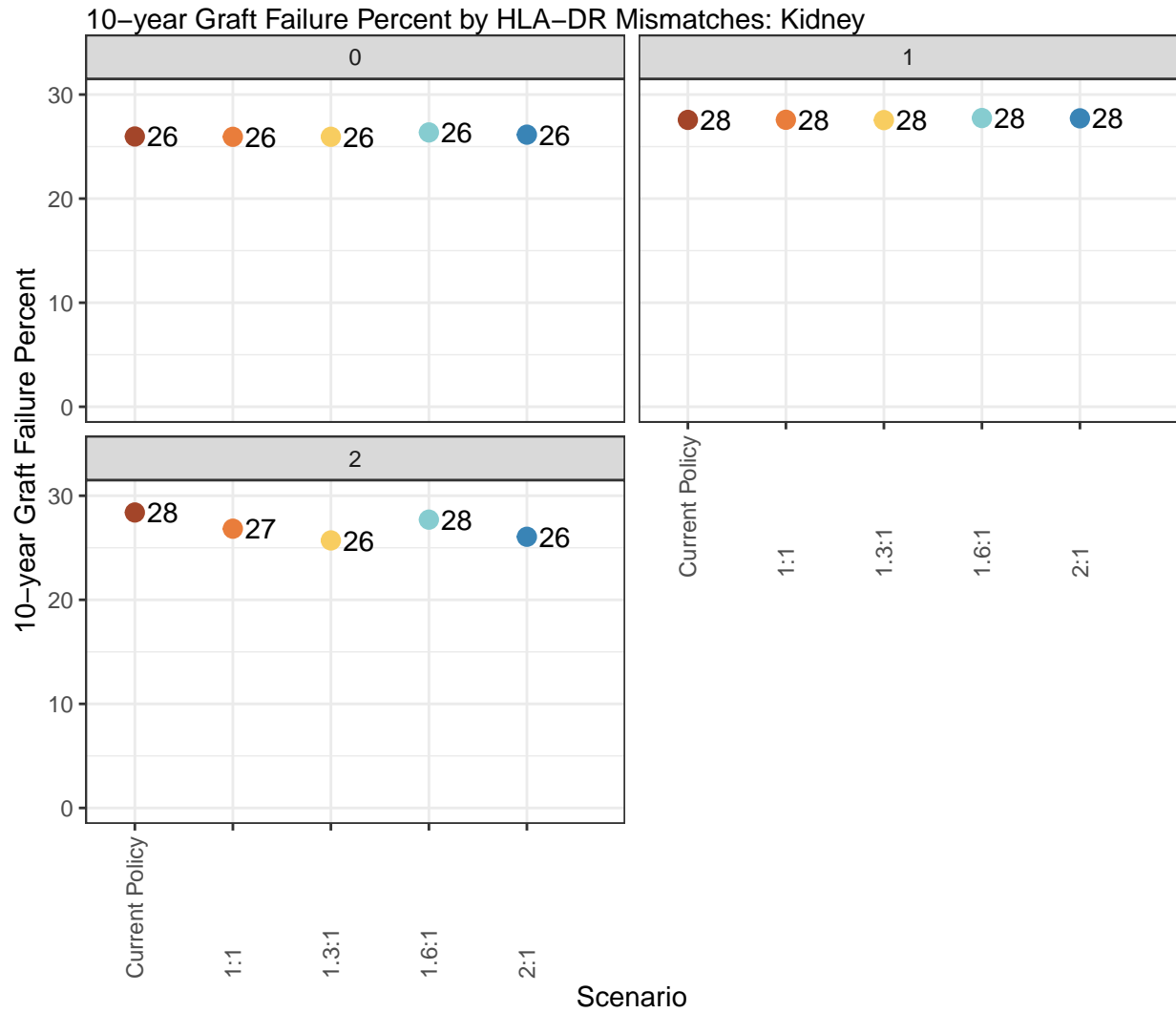


Figure 54: 10-year Graft Failure Percent by HLA-DR Mismatches: Kidney. HLA-DR Mismatches. All-cause graft failure.

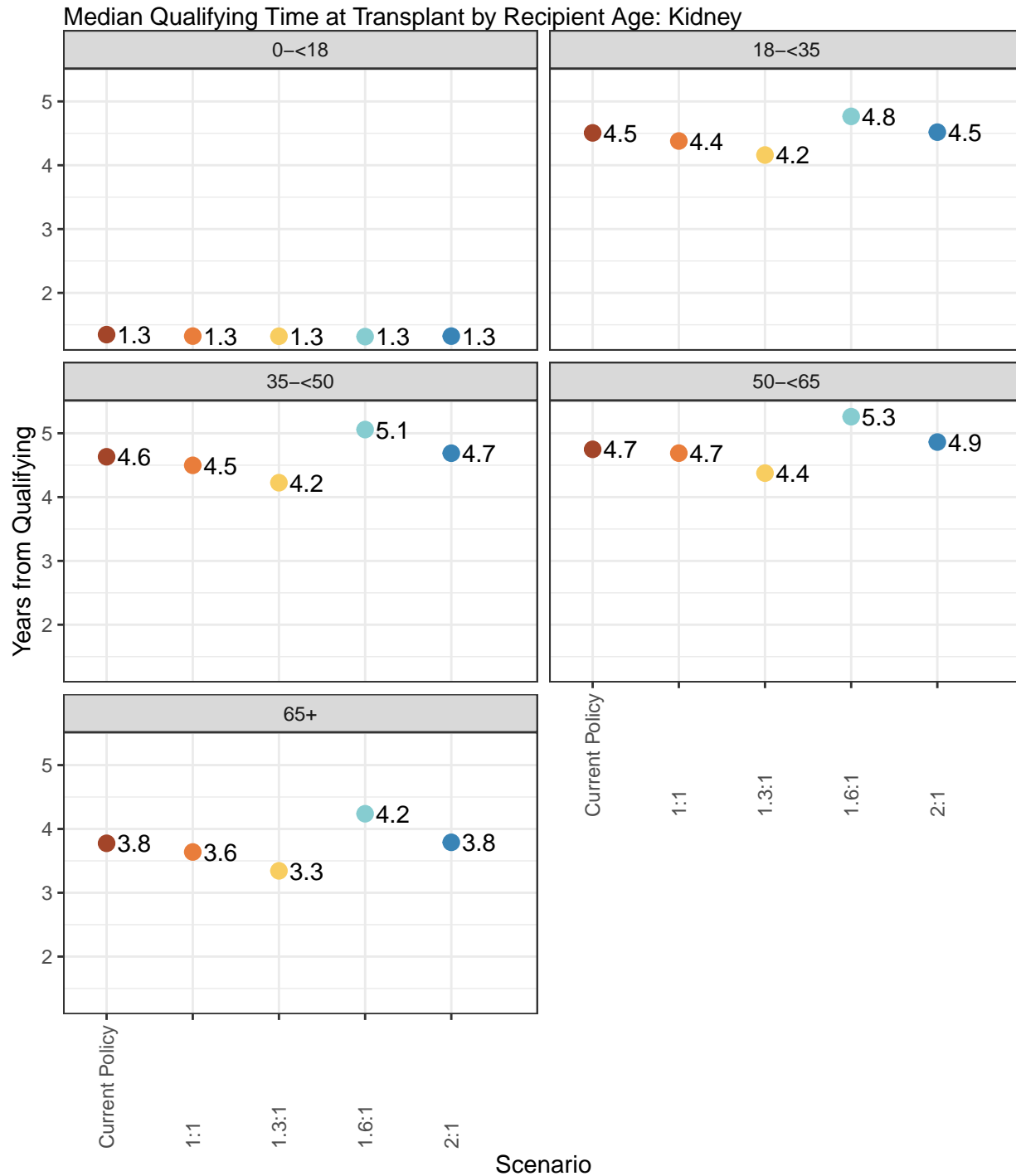


Figure 55: Median Qualifying Time at Transplant by Recipient Age: Kidney. Median time in years from qualifying date to transplant among those who underwent transplant.

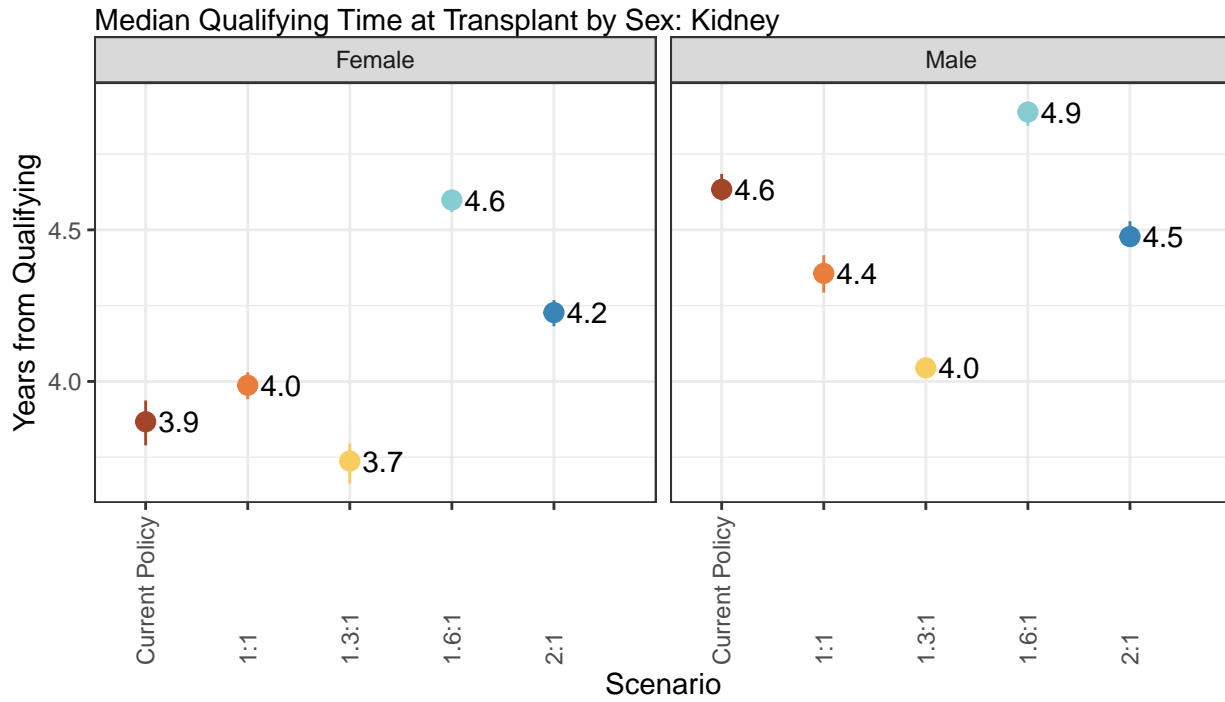


Figure 56: Median Qualifying Time at Transplant by Sex: Kidney. Median time in years from qualifying date to transplant among those who underwent transplant.

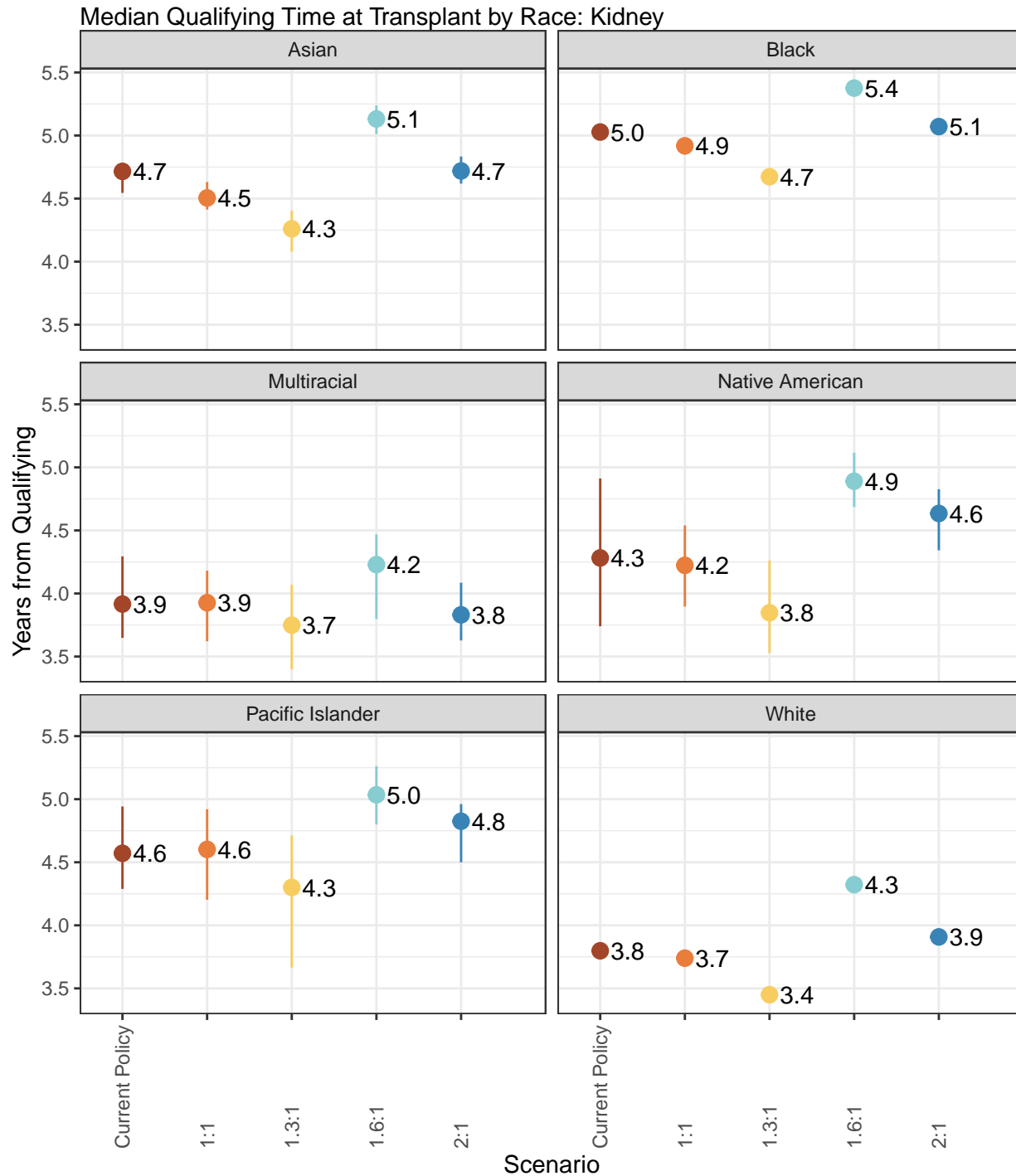


Figure 57: Median Qualifying Time at Transplant by Race: Kidney. Median time in years from qualifying date to transplant among those who underwent transplant.

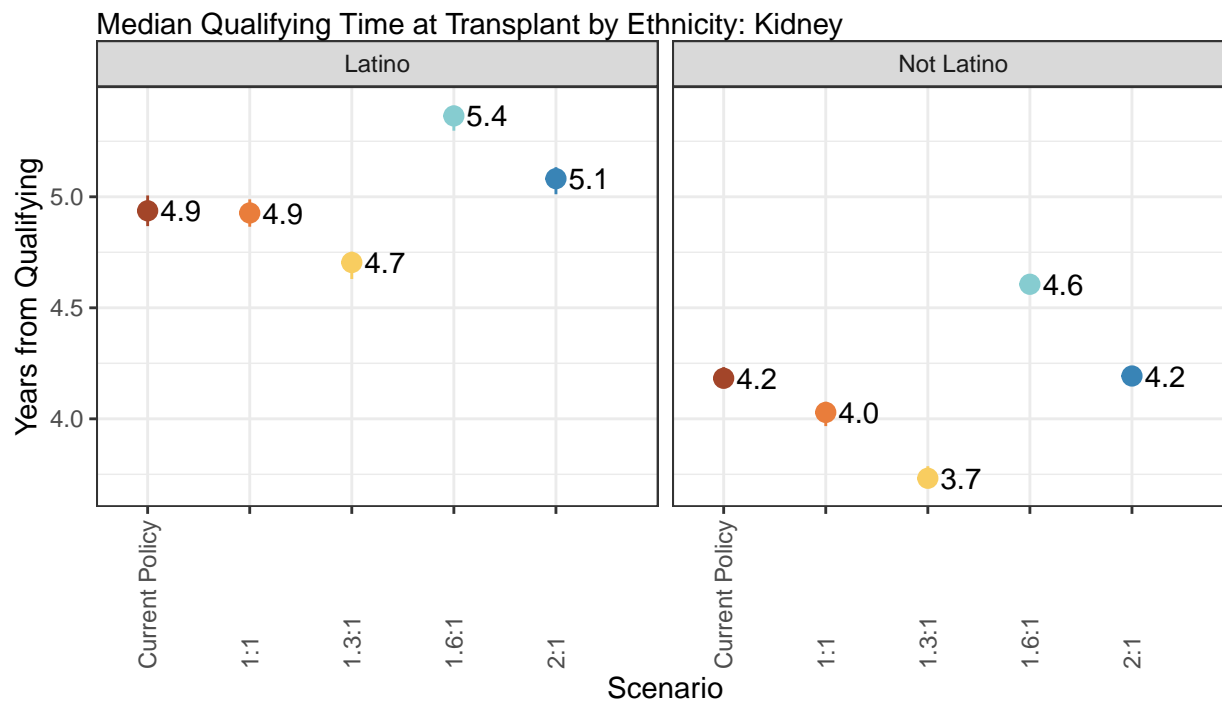


Figure 58: Median Qualifying Time at Transplant by Ethnicity: Kidney. Median time in years from qualifying date to transplant among those who underwent transplant.

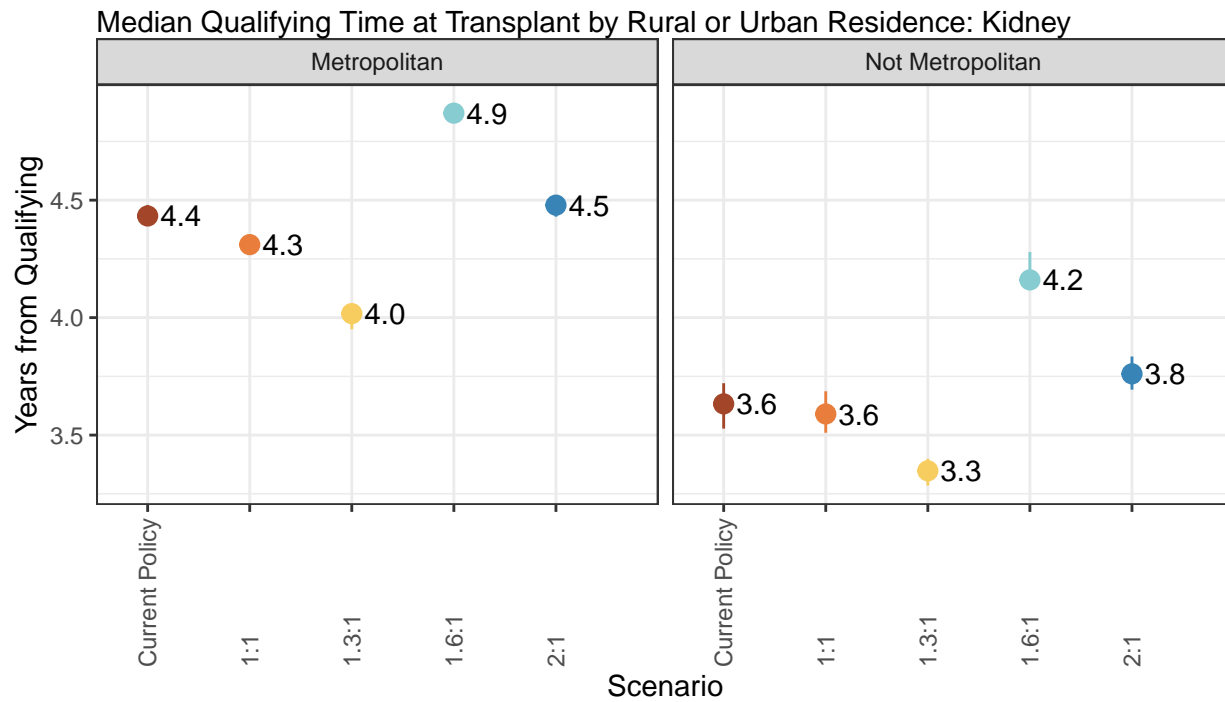


Figure 59: Median Qualifying Time at Transplant by Rural or Urban Residence: Kidney. Median time in years from qualifying date to transplant among those who underwent transplant.

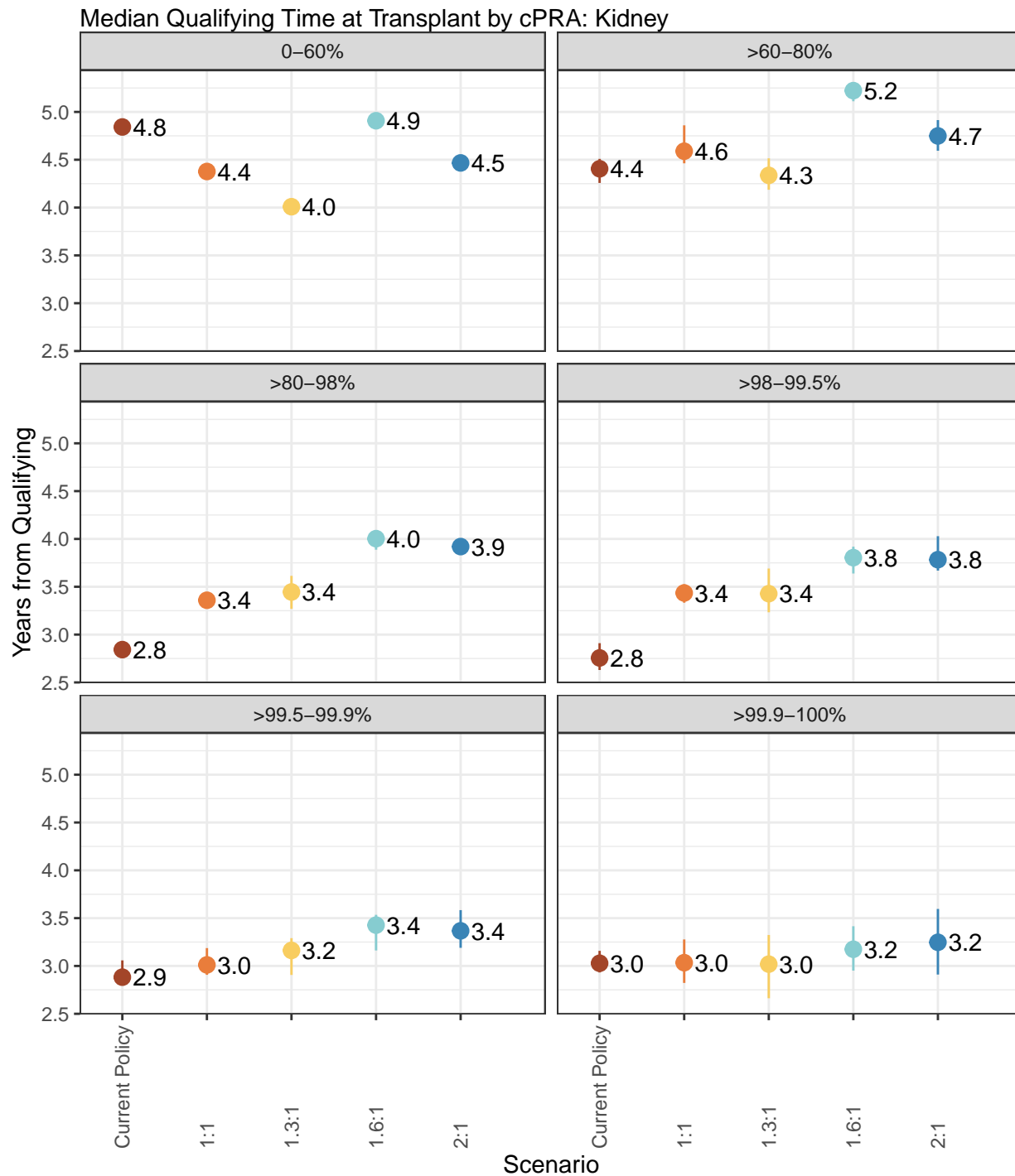


Figure 60: Median Qualifying Time at Transplant by cPRA: Kidney. Median time in years from qualifying date to transplant among those who underwent transplant.

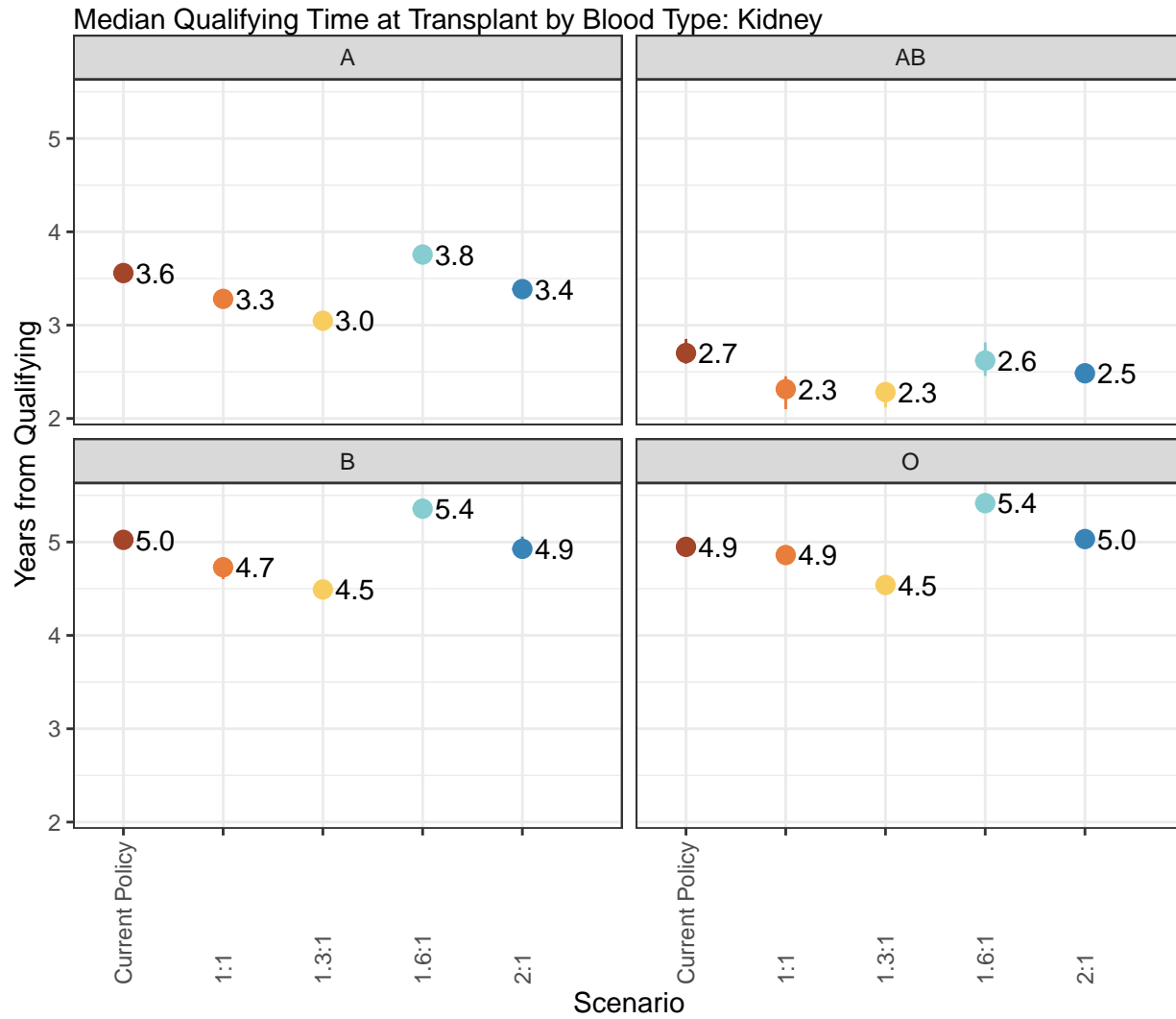


Figure 61: Median Qualifying Time at Transplant by Blood Type: Kidney. Median time in years from qualifying date to transplant among those who underwent transplant.

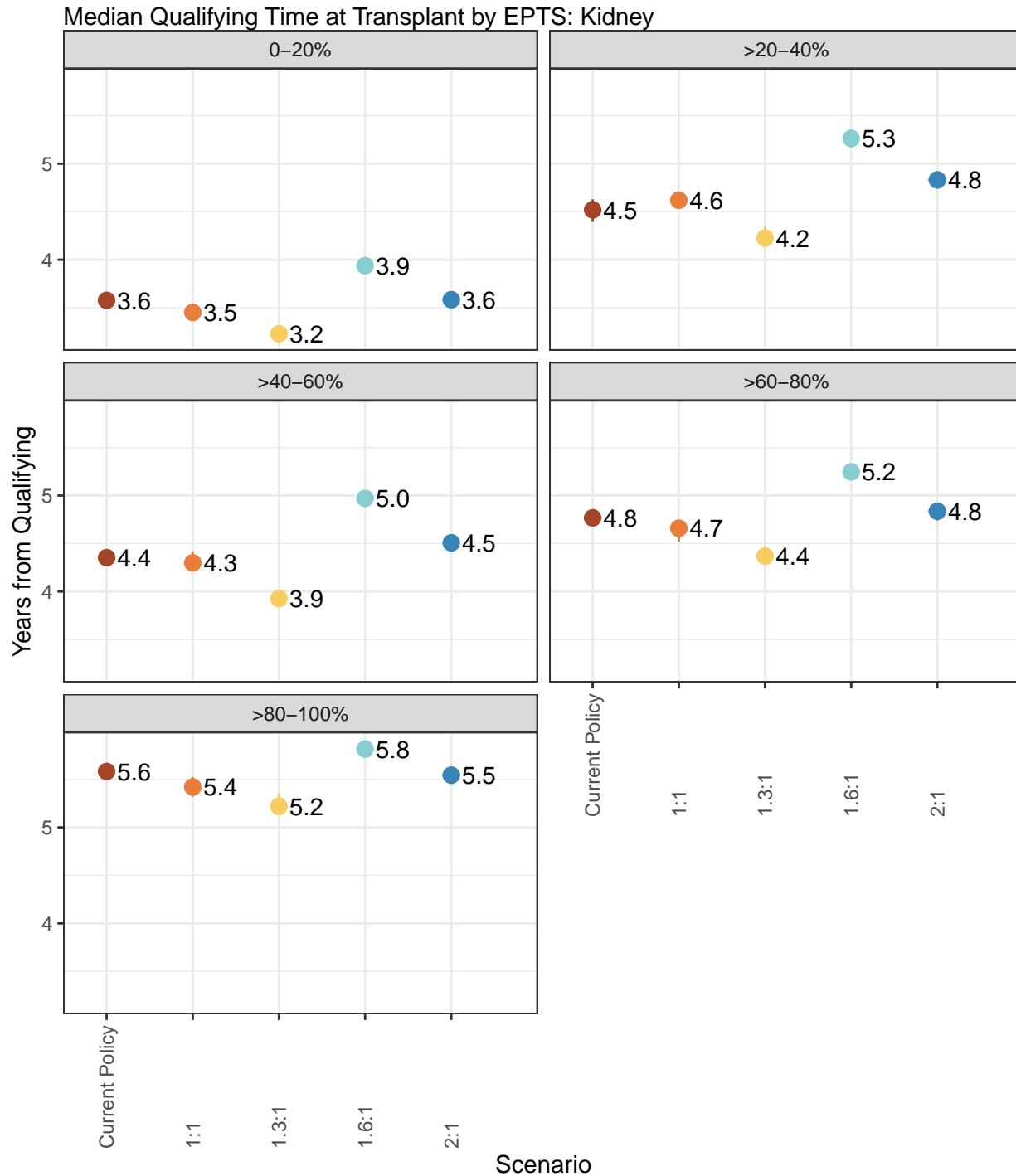


Figure 62: Median Qualifying Time at Transplant by EPTS: Kidney. Median time in years from qualifying date to transplant among those who underwent transplant.

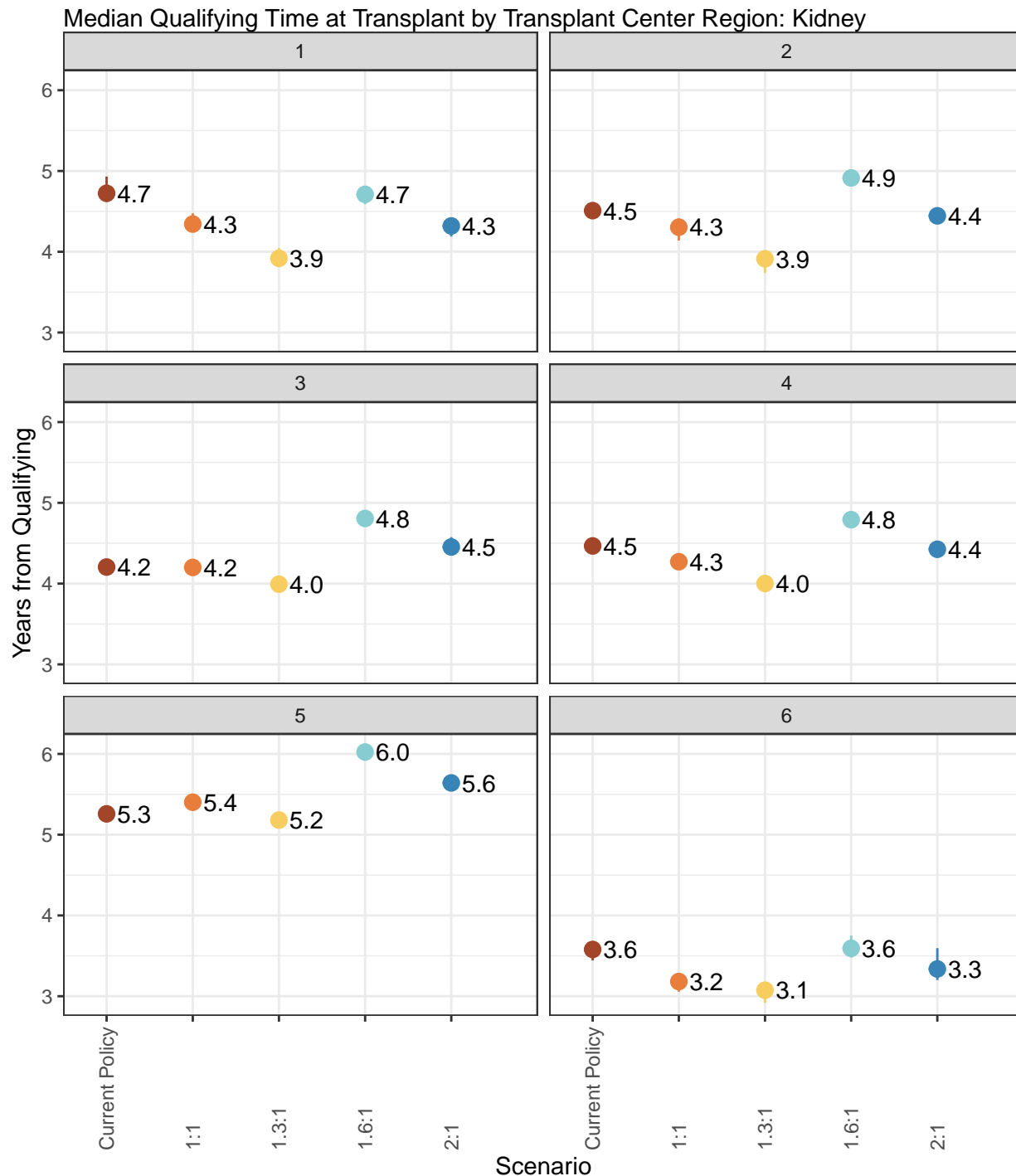


Figure 63: Median Qualifying Time at Transplant by Transplant Center Region: Kidney. Median time in years from qualifying date to transplant among those who underwent transplant.

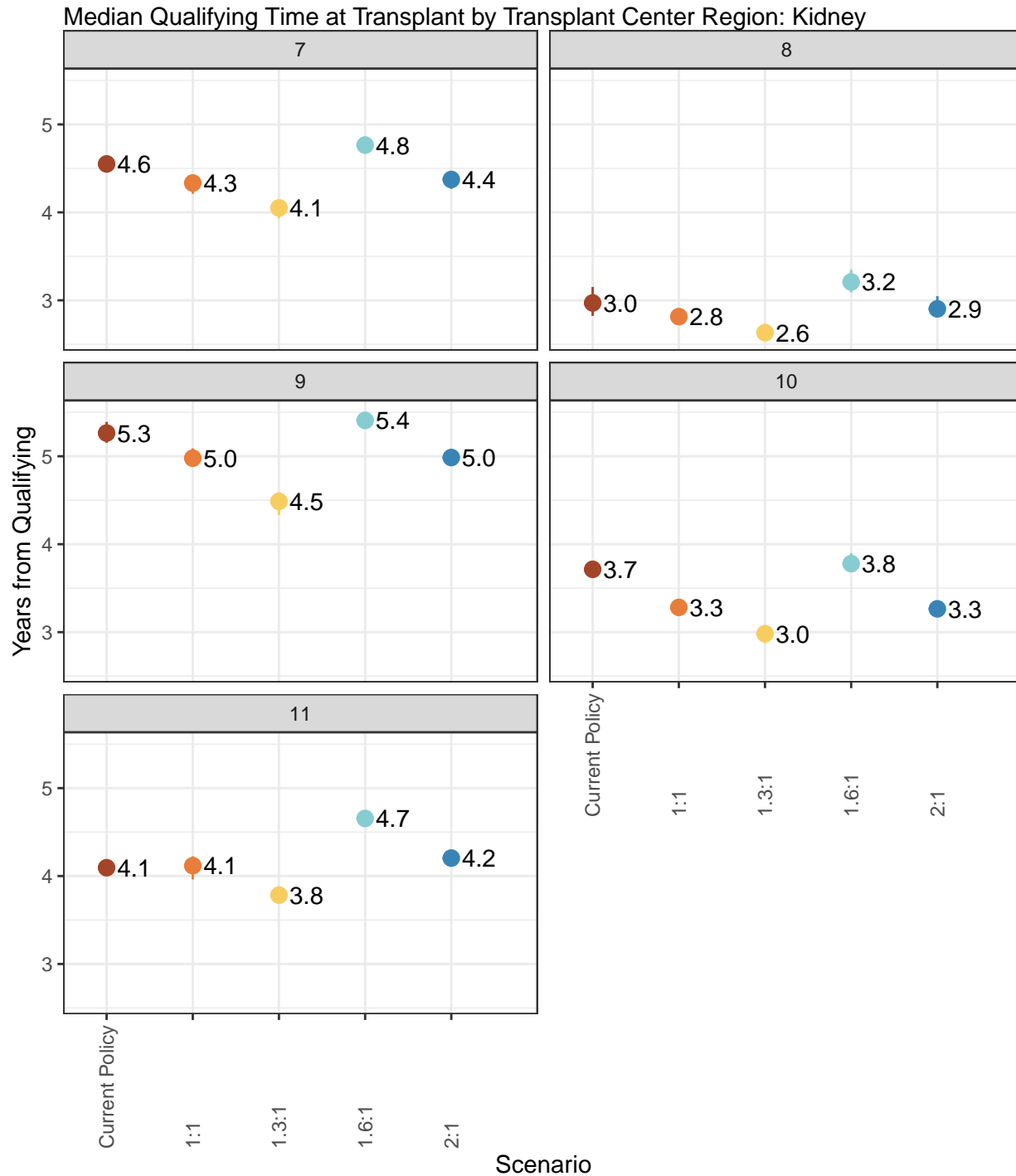


Figure 64: Median Qualifying Time at Transplant by Transplant Center Region: Kidney. Median time in years from qualifying date to transplant among those who underwent transplant.

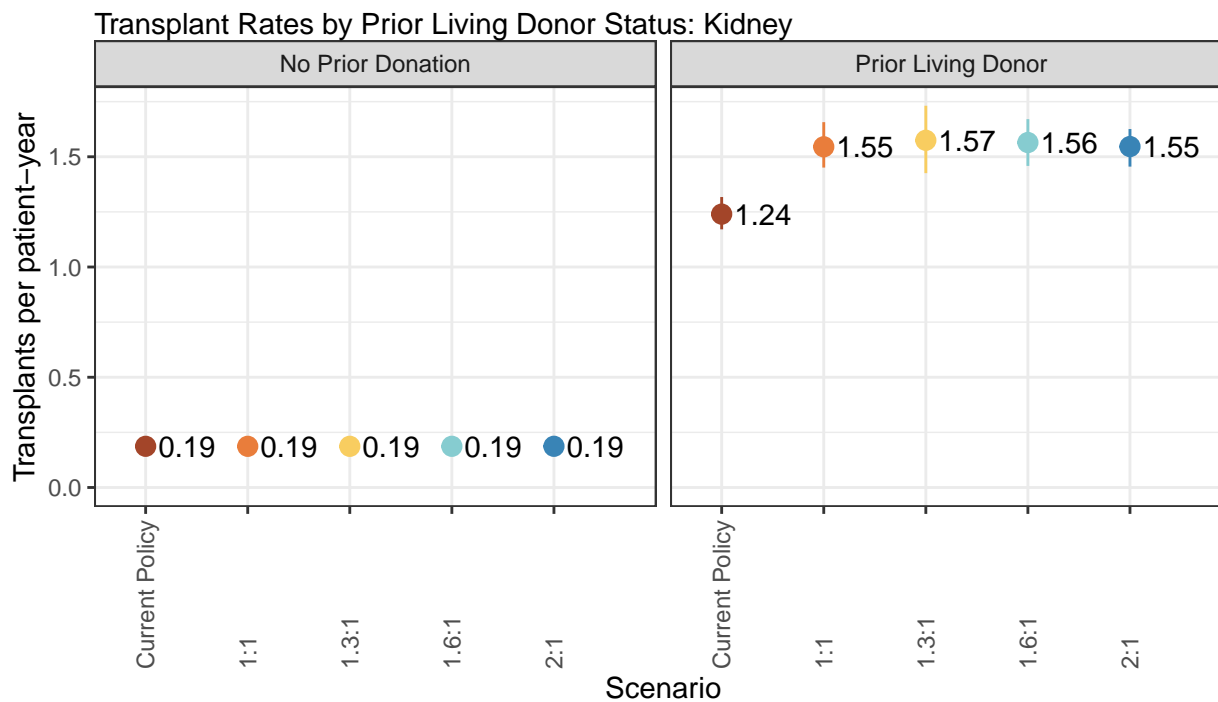


Figure 65: Transplant Rates by Prior Living Donor Status: Kidney. Person-time is calculated in days for all candidates from the start of their simulation period (simulation start or listing) to transplant, waitlist removal, or simulation end.

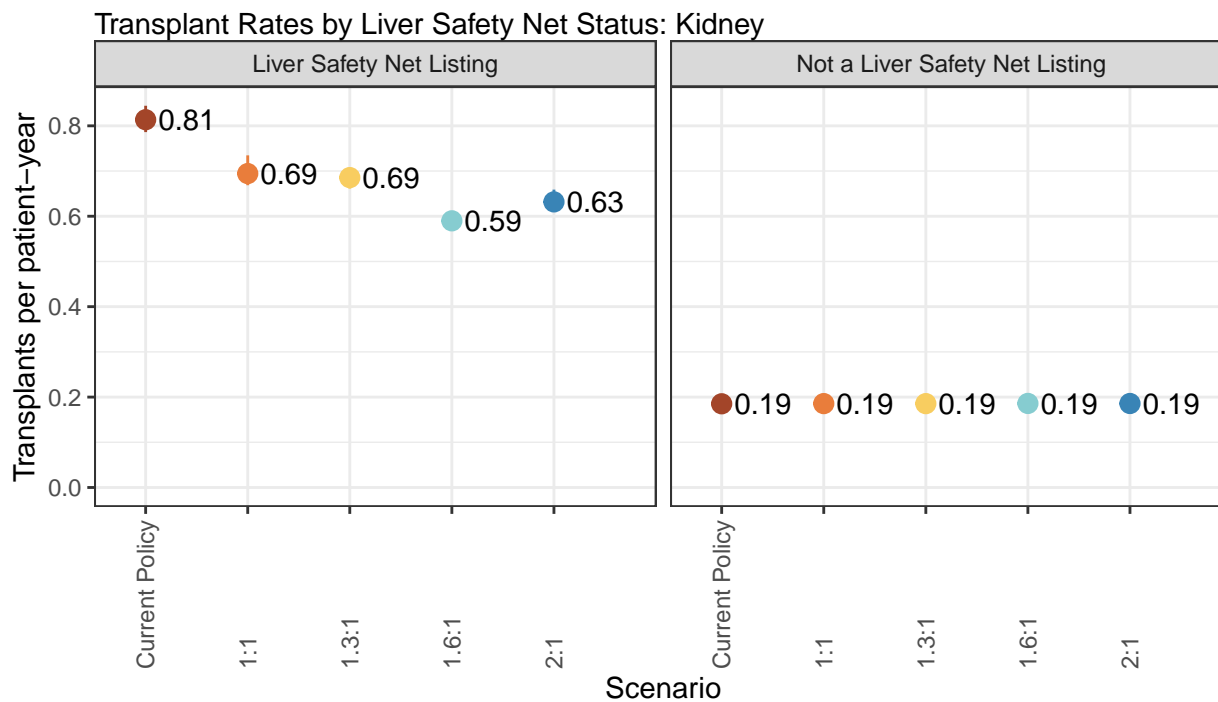


Figure 66: Transplant Rates by Liver Safety Net Status: Kidney. Person-time is calculated in days for all candidates from the start of their simulation period (simulation start or listing) to transplant, waitlist removal, or simulation end.

Pancreas and Kidney-Pancreas Additional

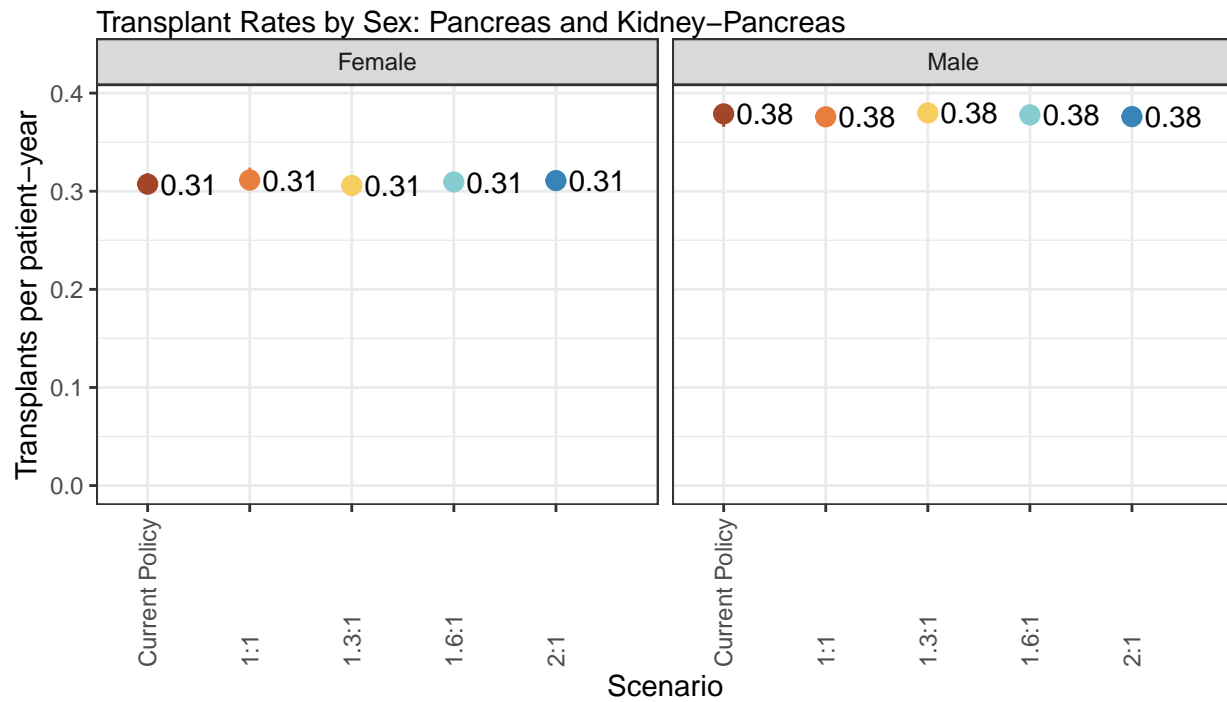


Figure 67: Transplant Rates by Sex: Pancreas and Kidney-Pancreas. Person-time is calculated in days for all candidates from the start of their simulation period (simulation start or listing) to transplant, waitlist removal, or simulation end.

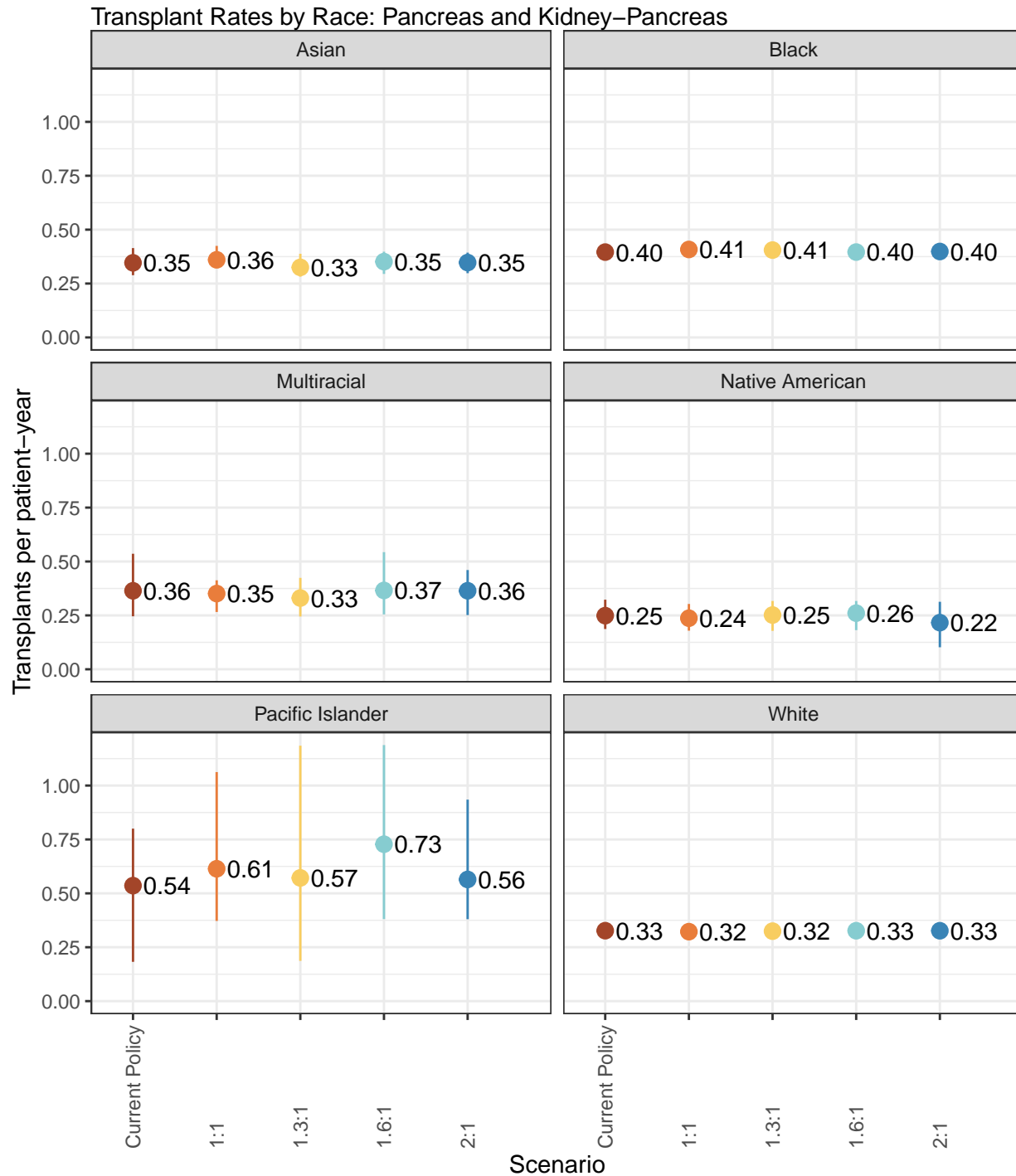


Figure 68: Transplant Rates by Race: Pancreas and Kidney-Pancreas. Person-time is calculated in days for all candidates from the start of their simulation period (simulation start or listing) to transplant, waitlist removal, or simulation end.

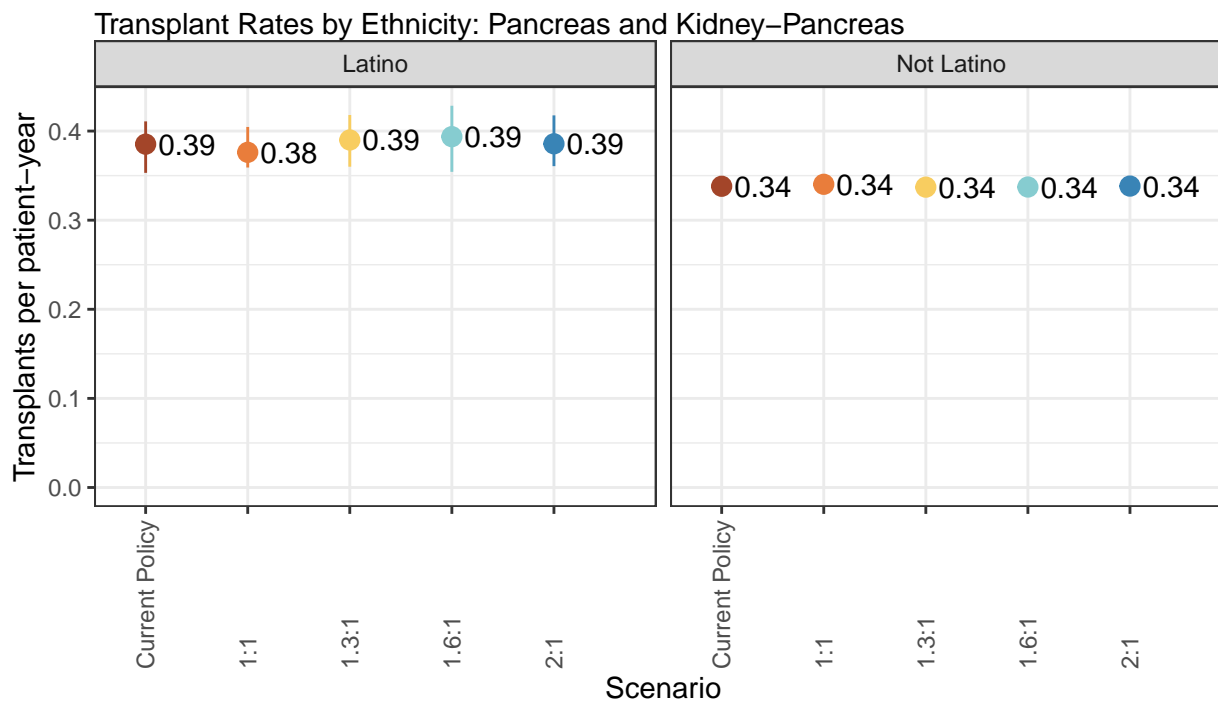


Figure 69: Transplant Rates by Ethnicity: Pancreas and Kidney-Pancreas. Person-time is calculated in days for all candidates from the start of their simulation period (simulation start or listing) to transplant, waitlist removal, or simulation end.

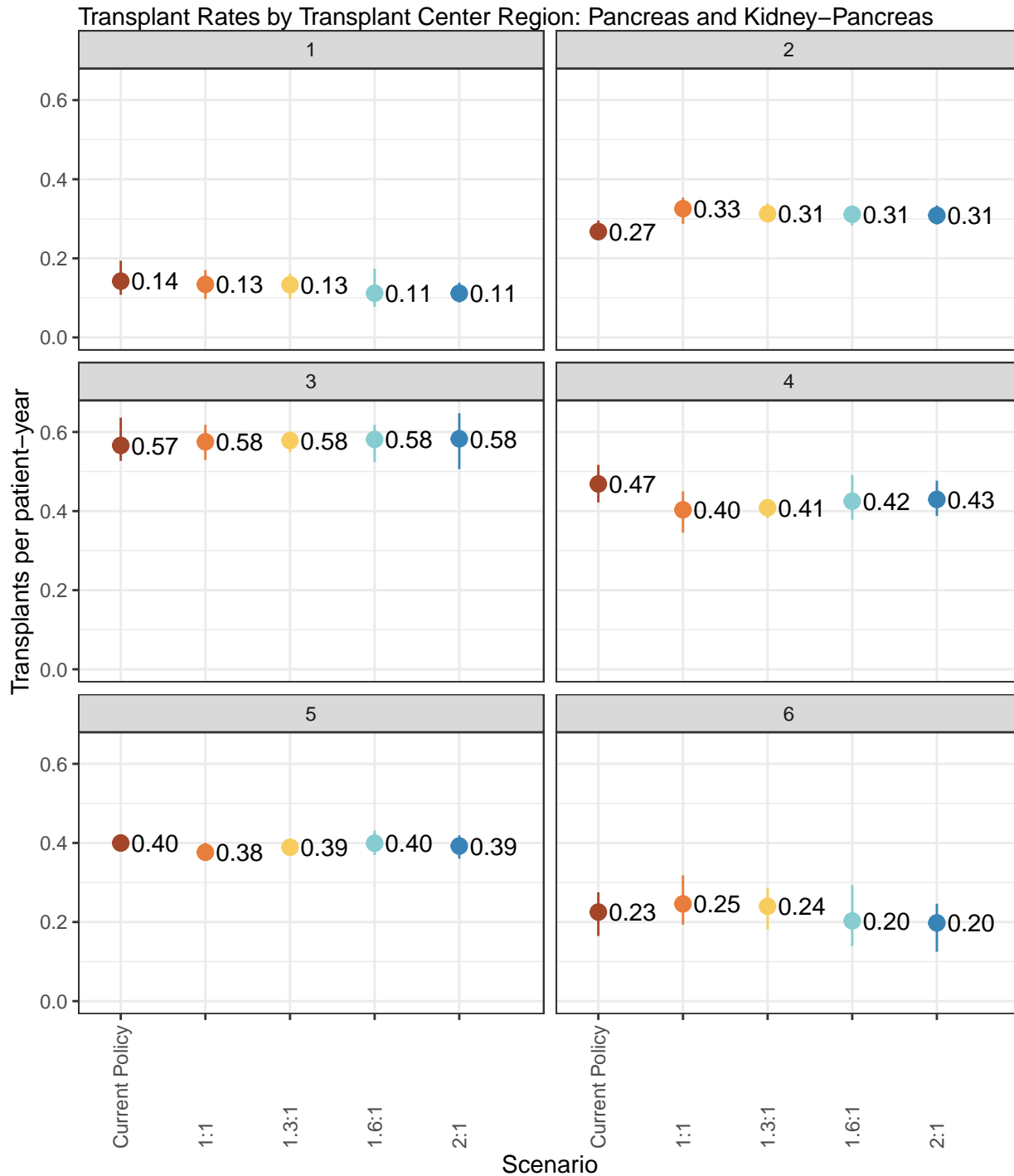


Figure 70: Transplant Rates by Transplant Center Region: Pancreas and Kidney-Pancreas. Person-time is calculated in days for all candidates from the start of their simulation period (simulation start or listing) to transplant, waitlist removal, or simulation end. OPTN regions numbers 1 to 6.

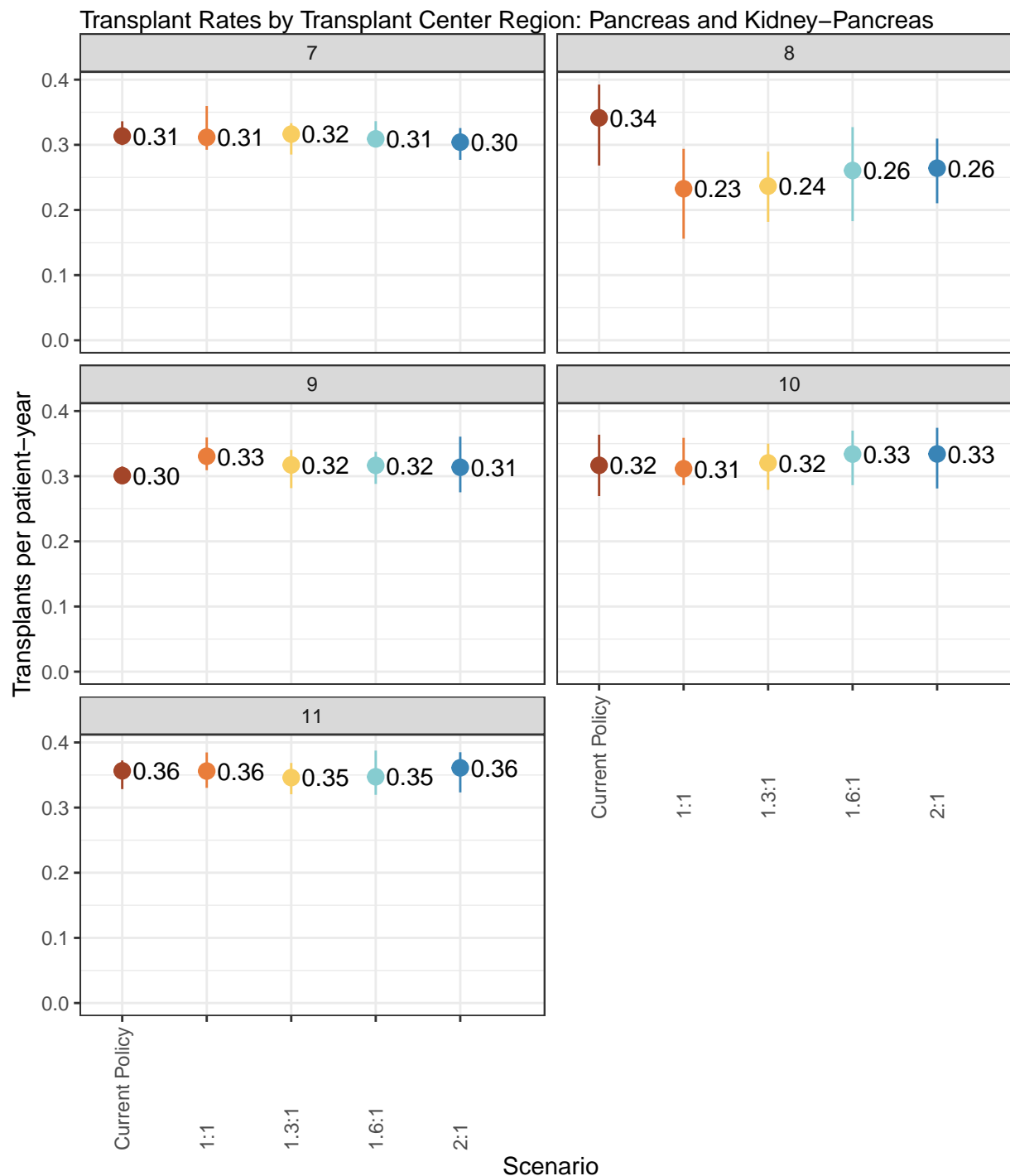


Figure 71: Transplant Rates by Transplant Center Region: Pancreas and Kidney-Pancreas. Person-time is calculated in days for all candidates from the start of their simulation period (simulation start or listing) to transplant, waitlist removal, or simulation end. OPTN regions numbers 7 to 11.

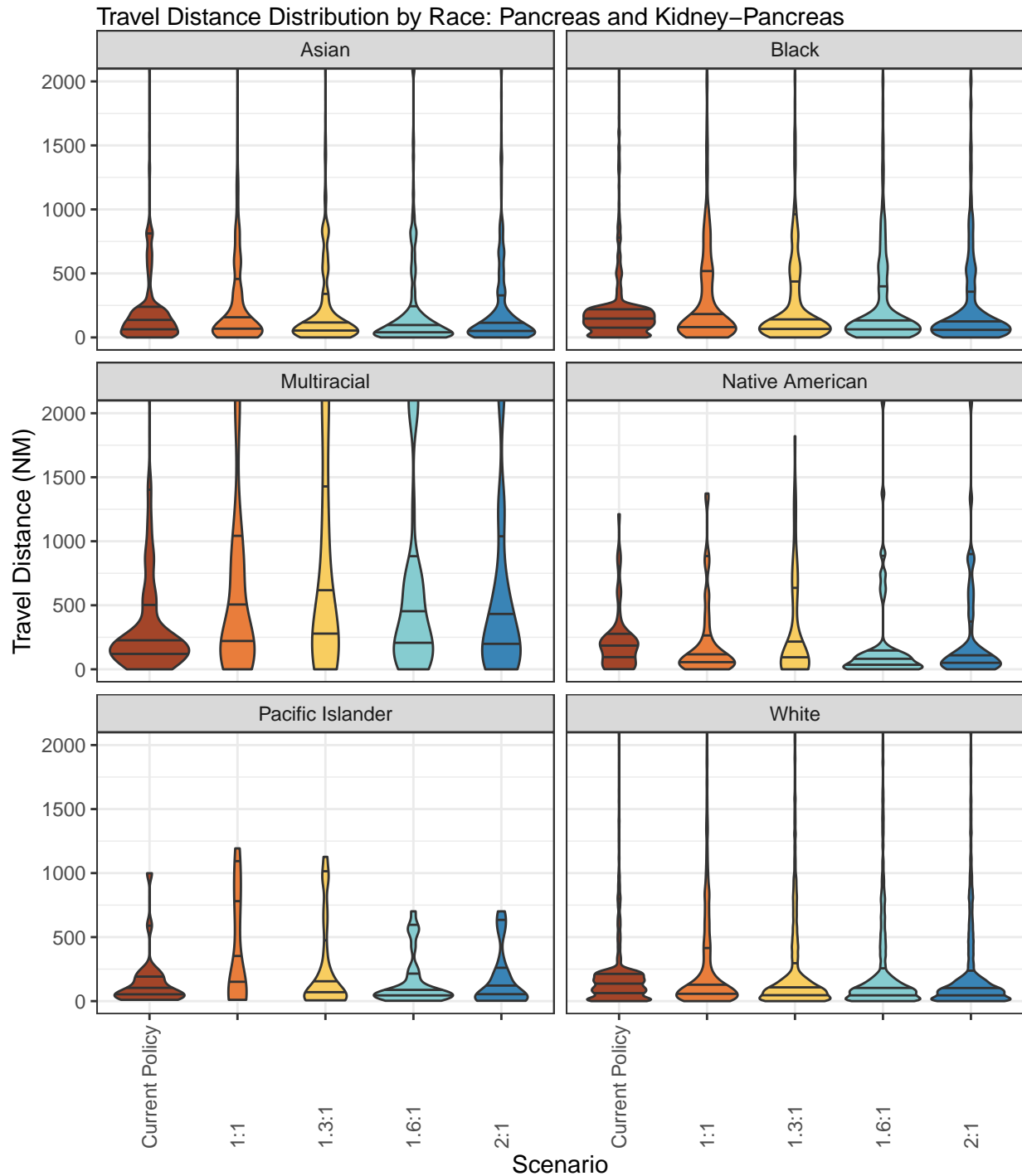


Figure 72: Travel Distance Distribution by Race: Pancreas and Kidney-Pancreas. Distribution of travel distance. Travel distance is between the donor hospital and the transplant center, in nautical miles.

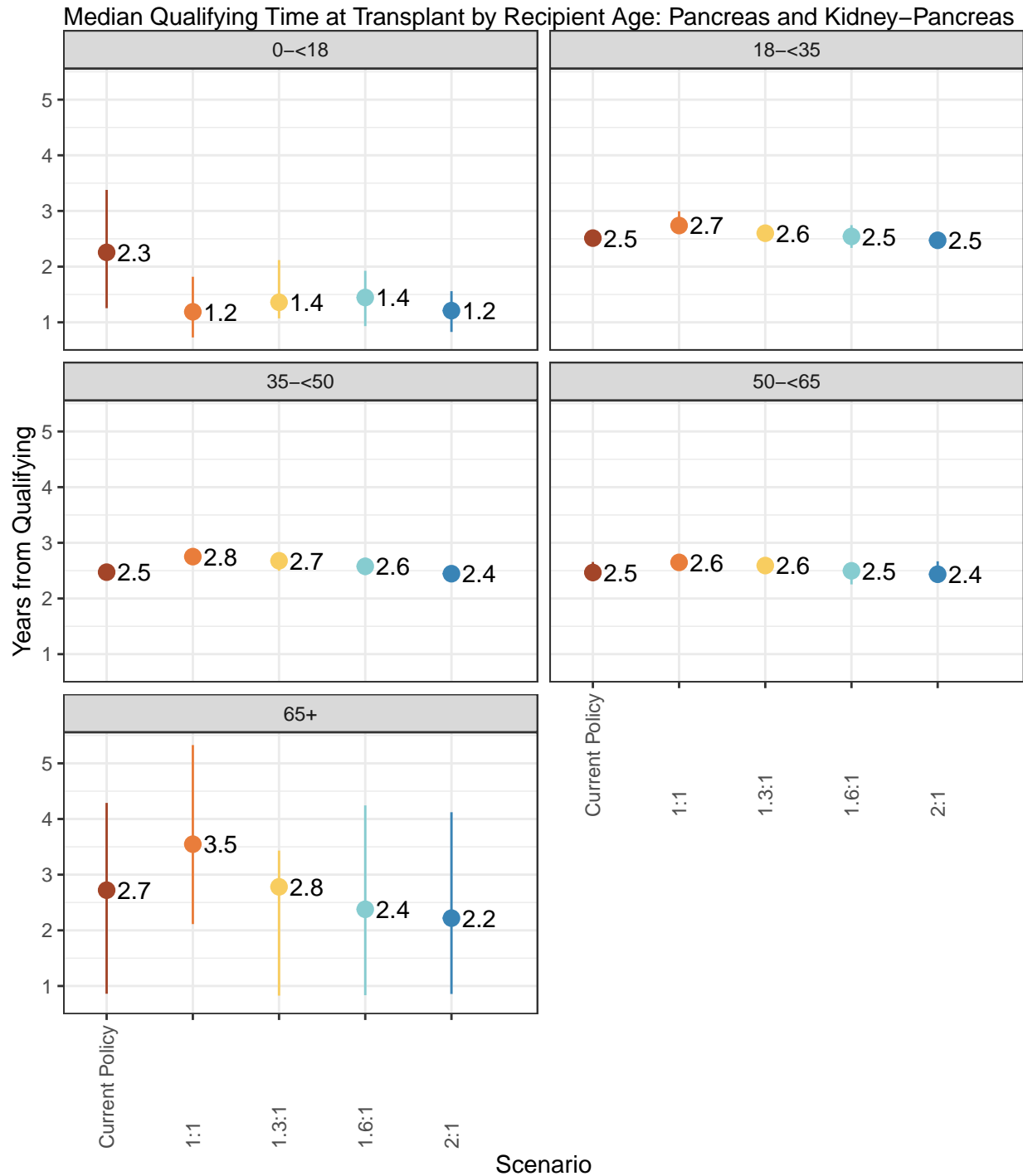


Figure 73: Median Qualifying Time at Transplant by Recipient Age: Pancreas and Kidney-Pancreas. Median time in years from qualifying date to transplant among those who underwent transplant.

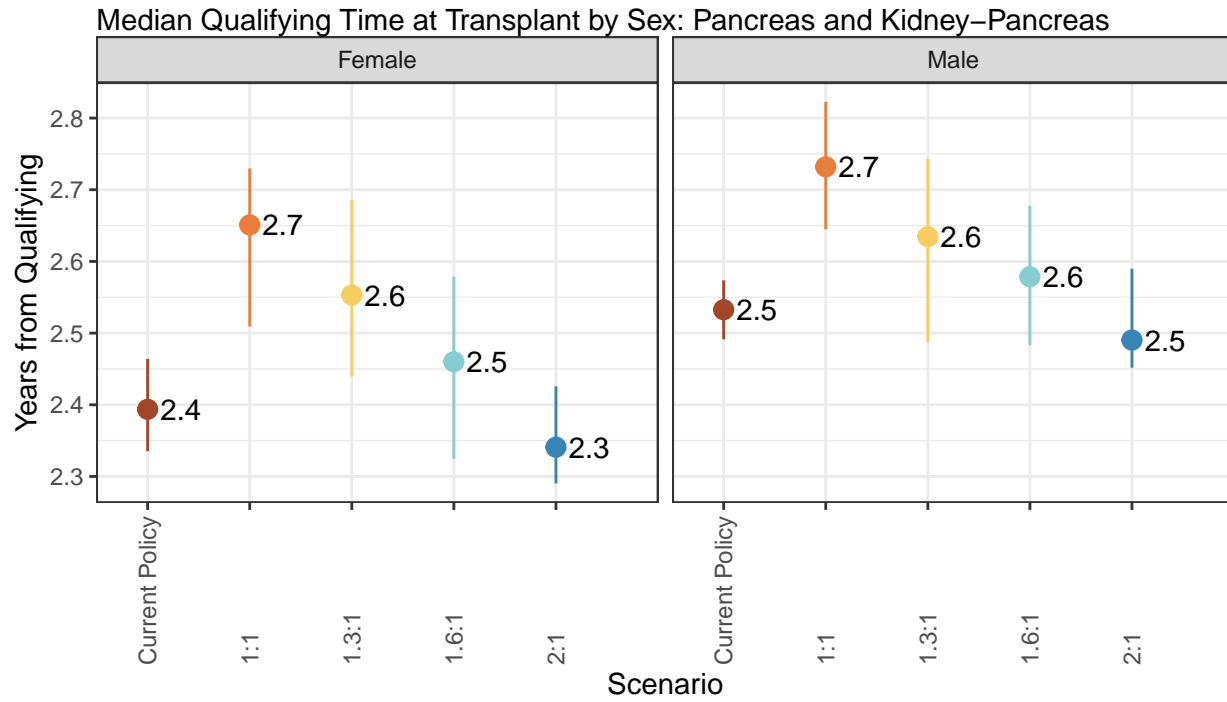


Figure 74: Median Qualifying Time at Transplant by Sex: Pancreas and Kidney-Pancreas. Median time in years from qualifying date to transplant among those who underwent transplant.

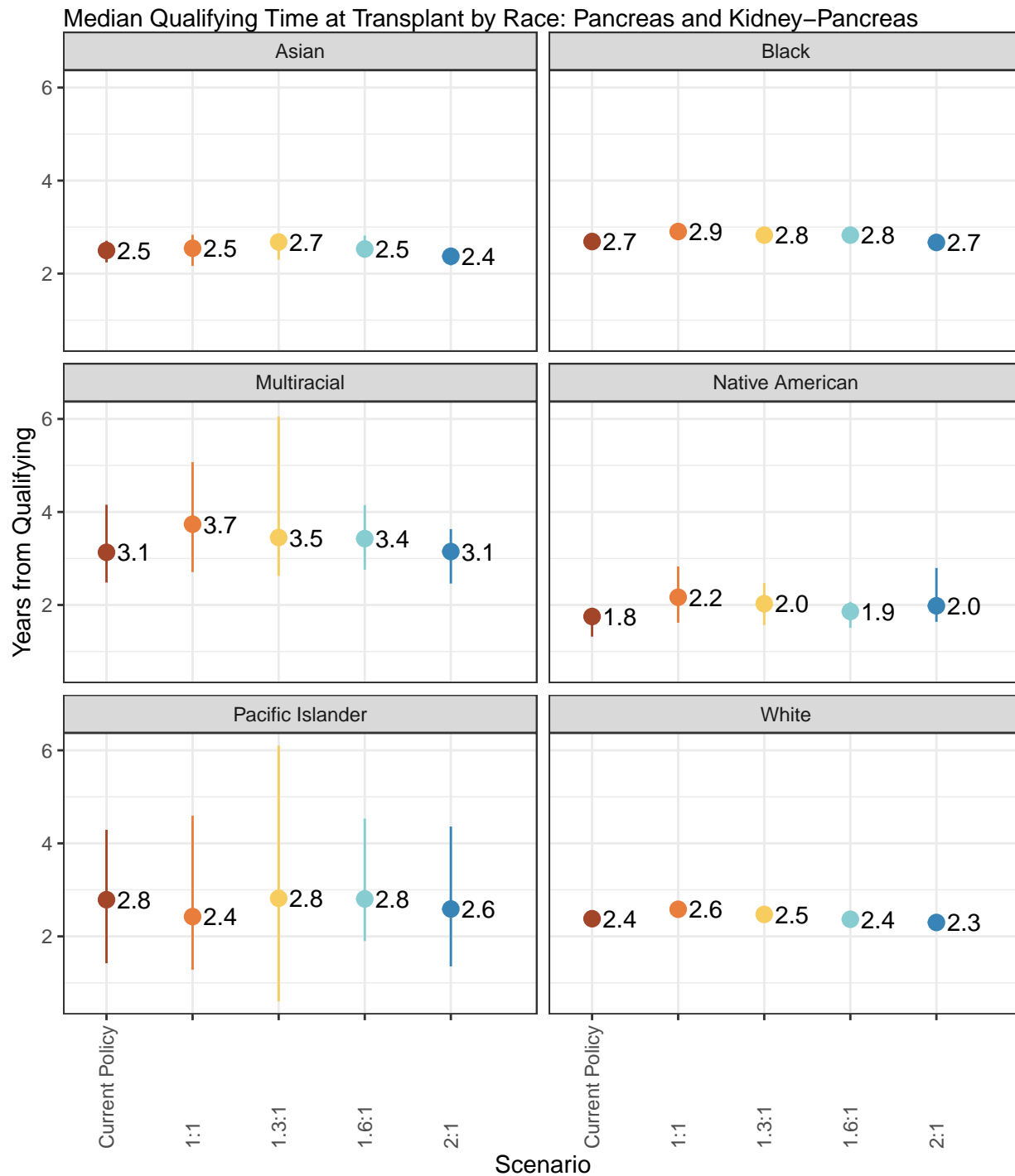


Figure 75: Median Qualifying Time at Transplant by Race: Pancreas and Kidney-Pancreas. Median time in years from qualifying date to transplant among those who underwent transplant.

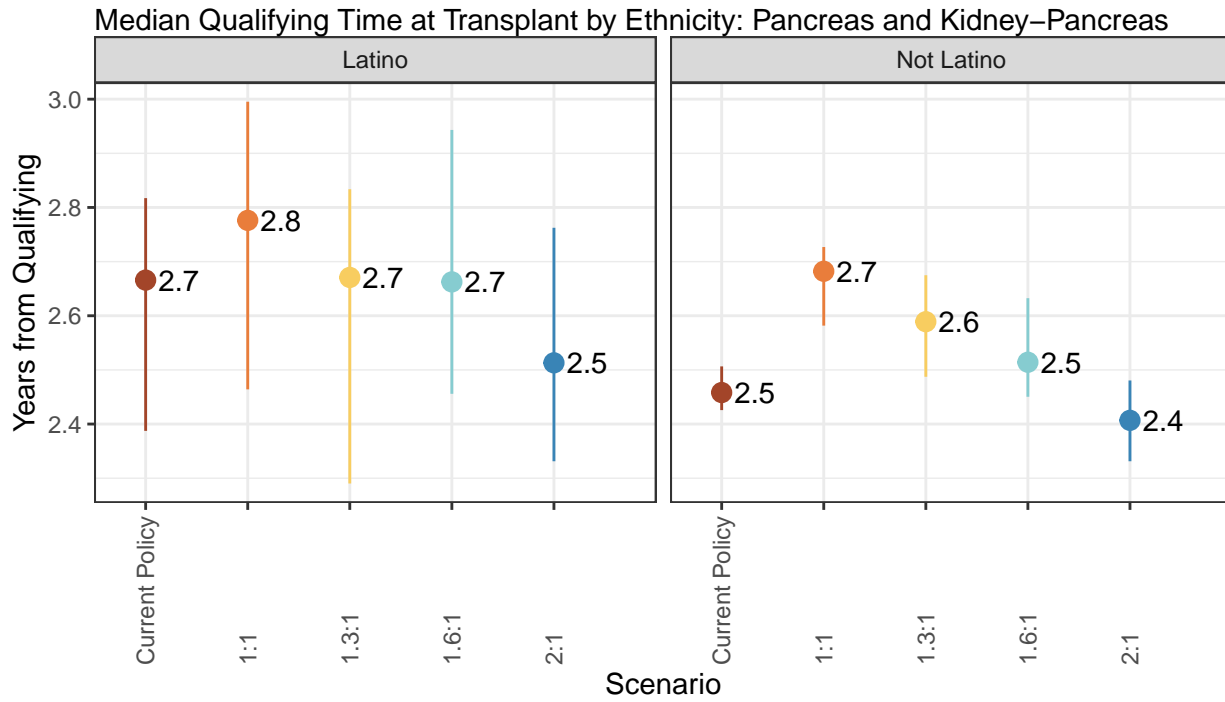


Figure 76: Median Qualifying Time at Transplant by Ethnicity: Pancreas and Kidney-Pancreas. Median time in years from qualifying date to transplant among those who underwent transplant.

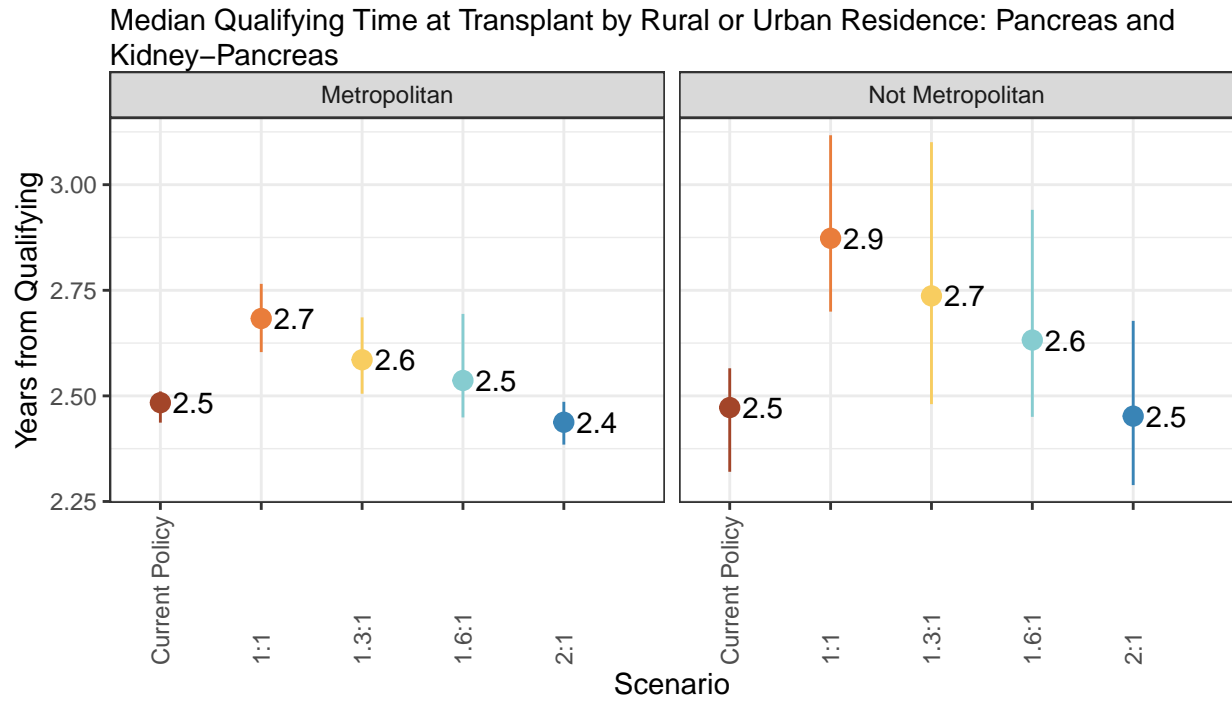


Figure 77: Median Qualifying Time at Transplant by Rural or Urban Residence: Pancreas and Kidney-Pancreas. Median time in years from qualifying date to transplant among those who underwent transplant.

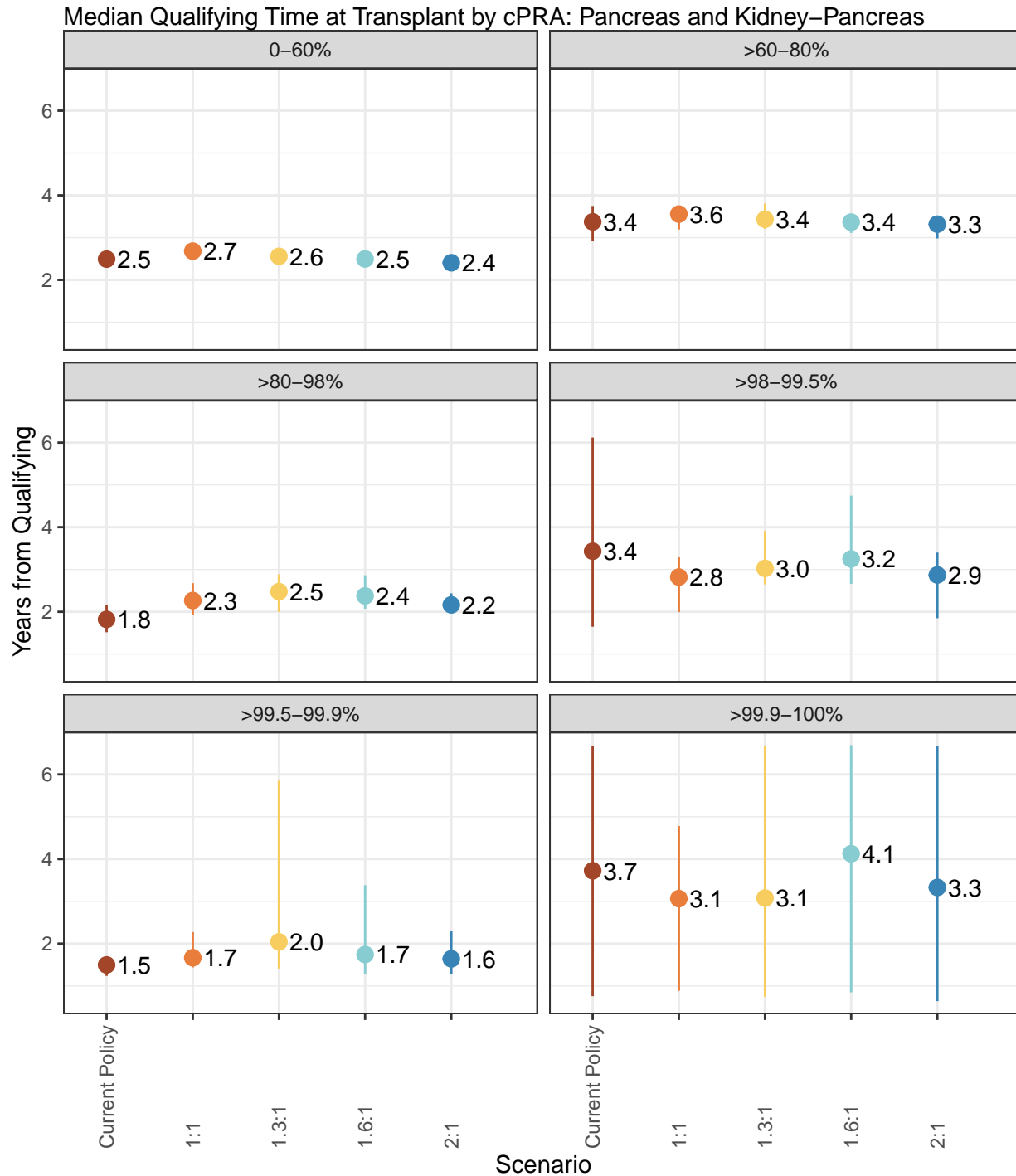


Figure 78: Median Qualifying Time at Transplant by cPRA: Pancreas and Kidney-Pancreas. Median time in years from qualifying date to transplant among those who underwent transplant.

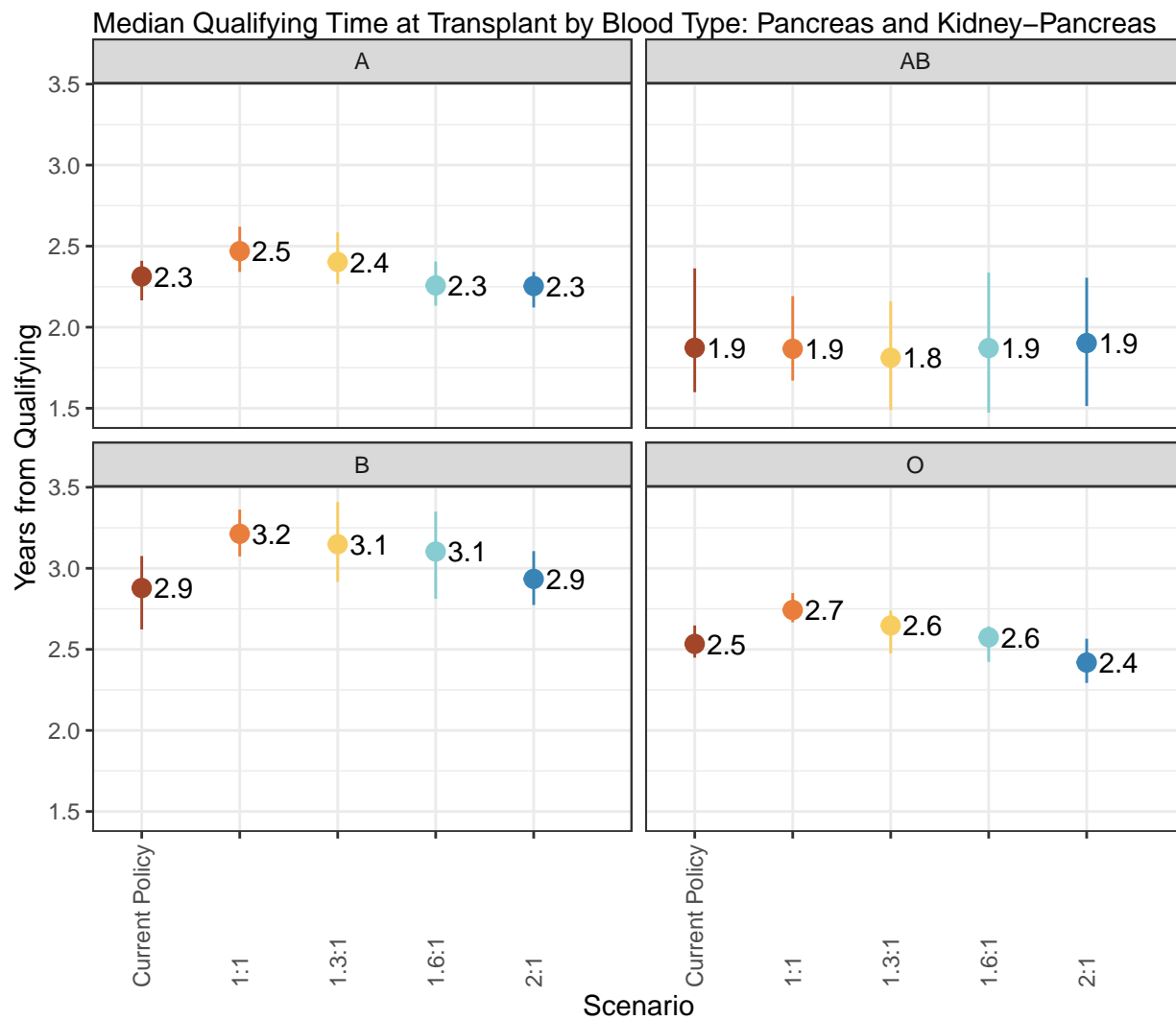


Figure 79: Median Qualifying Time at Transplant by Blood Type: Pancreas and Kidney-Pancreas. Median time in years from qualifying date to transplant among those who underwent transplant.

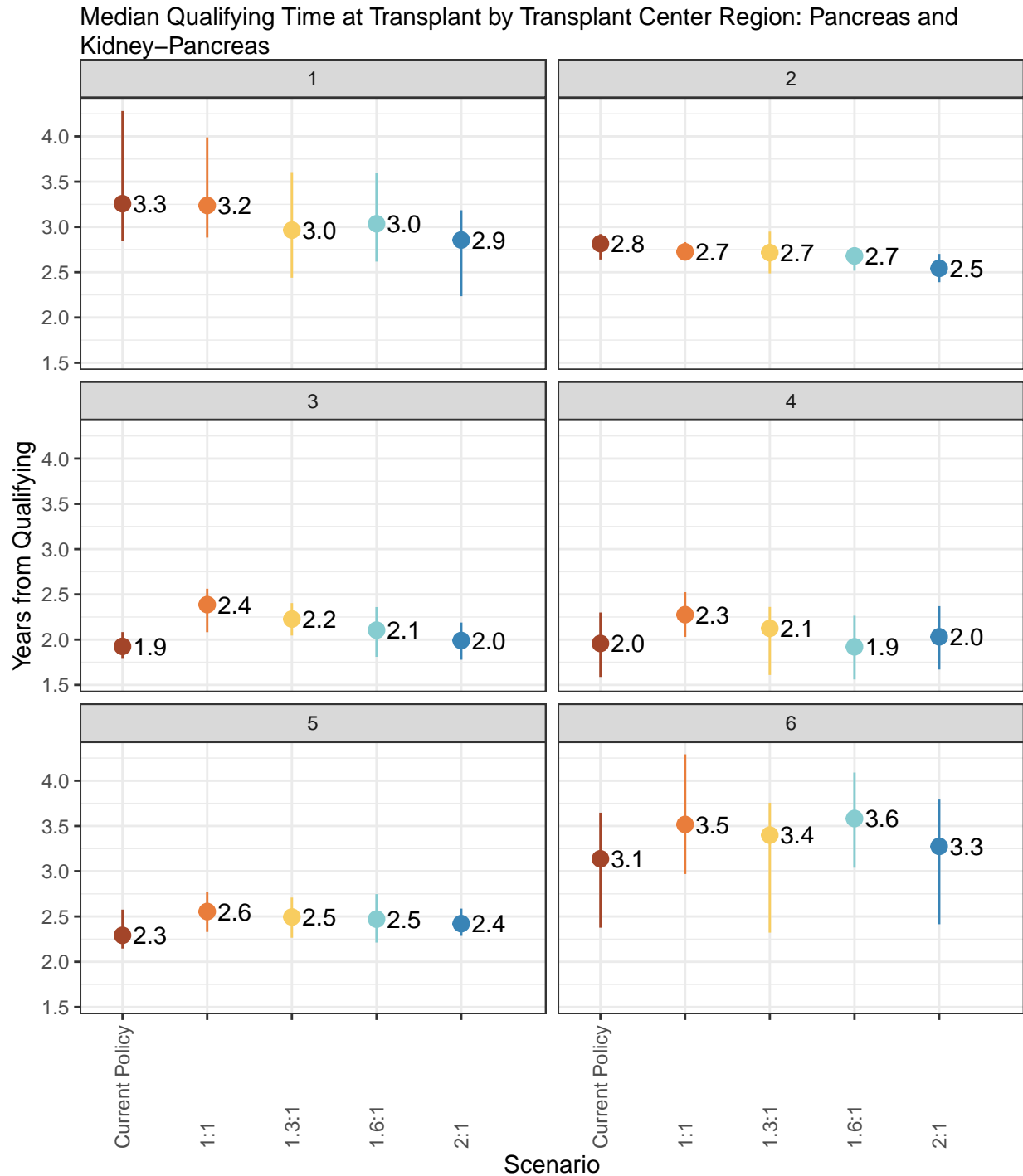


Figure 80: Median Qualifying Time at Transplant by Transplant Center Region: Pancreas and Kidney-Pancreas. Median time in years from qualifying date to transplant among those who underwent transplant.

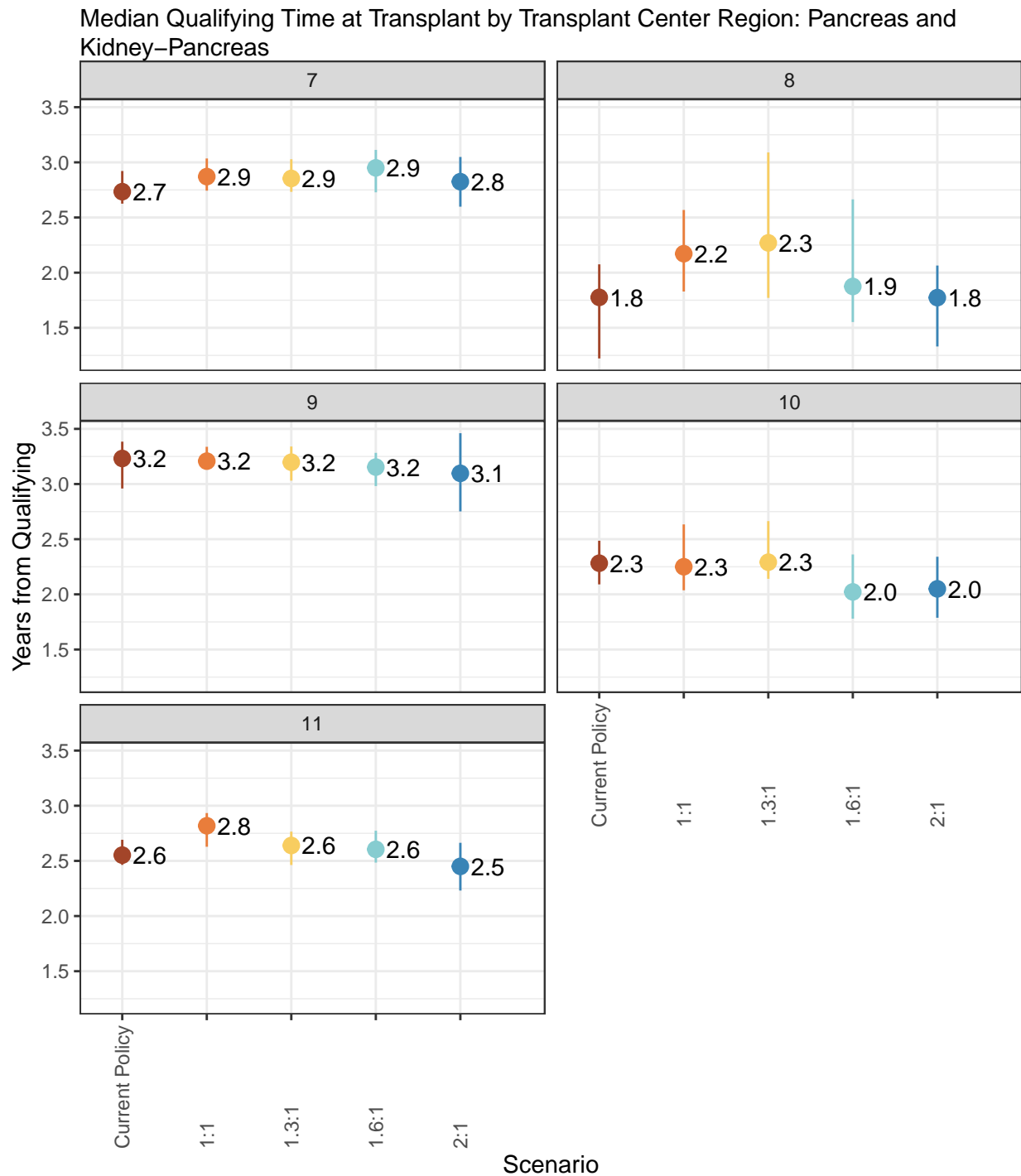


Figure 81: Median Qualifying Time at Transplant by Transplant Center Region: Pancreas and Kidney-Pancreas. Median time in years from qualifying date to transplant among those who underwent transplant.

Kidney-Pancreas: Transplant Rate

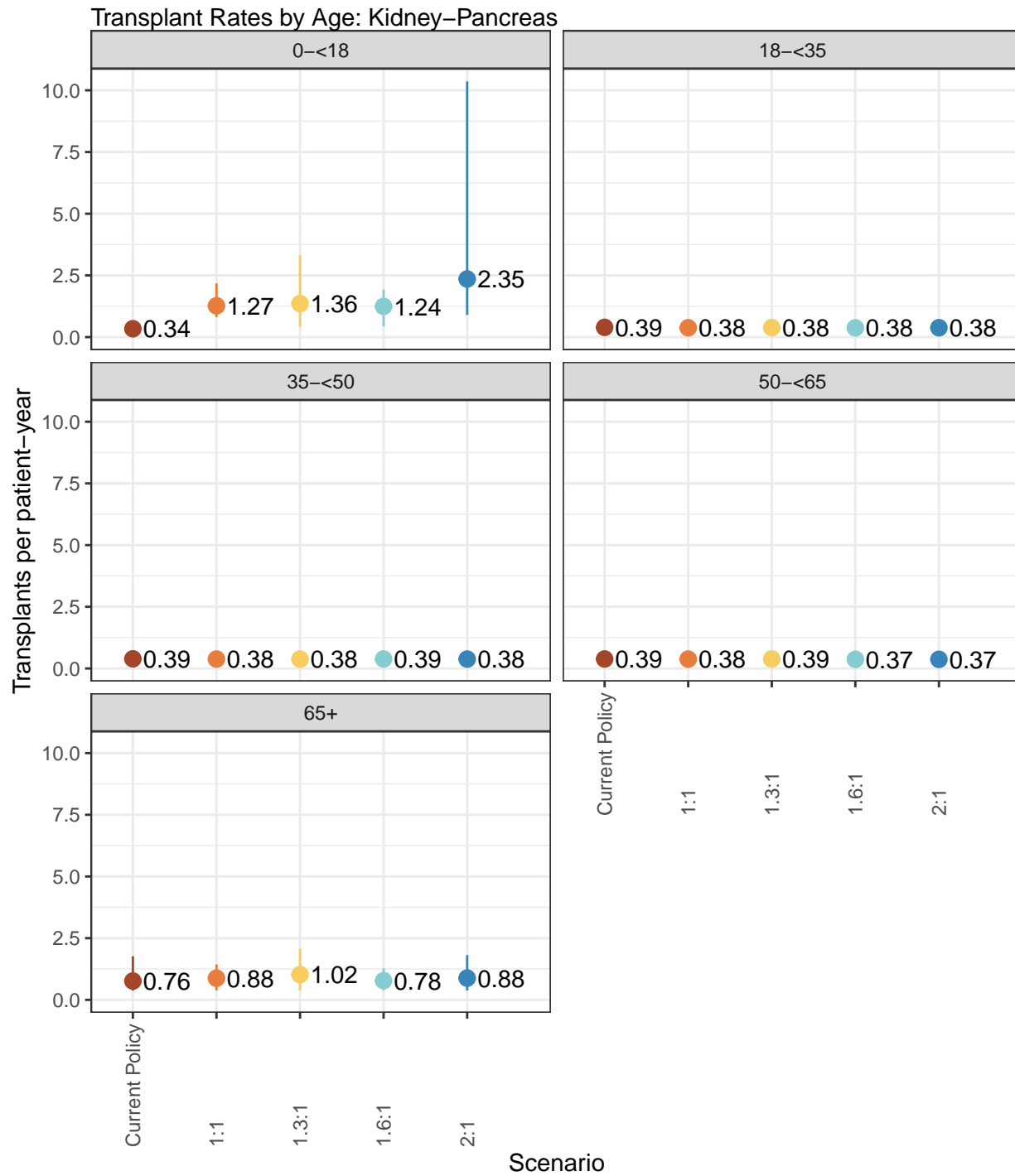


Figure 82: Transplant Rates by Age: Kidney-Pancreas. Age at listing. Person-time is calculated in days for all candidates from the start of their simulation period (simulation start or listing) to transplant, waitlist removal, or simulation end.

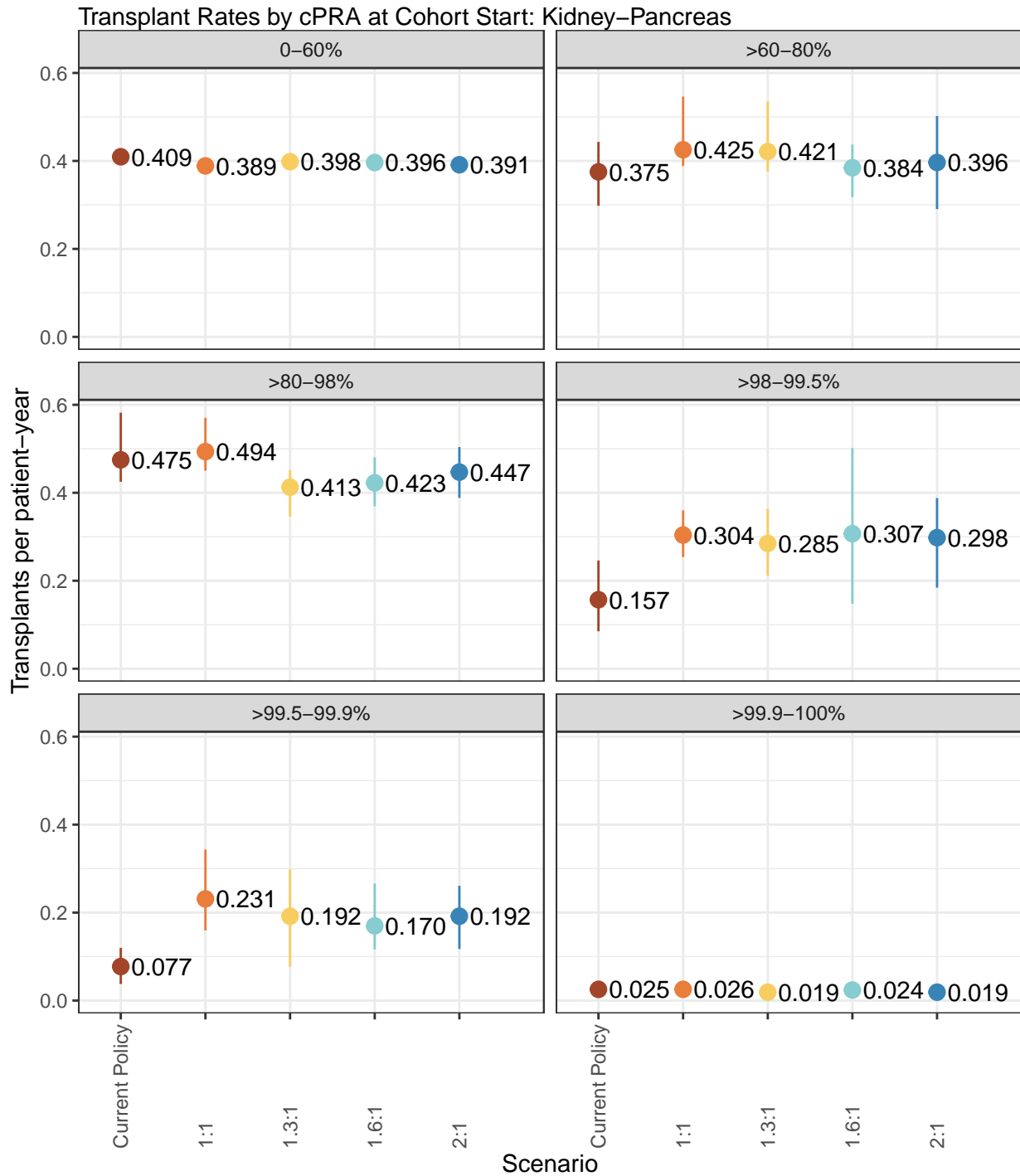


Figure 83: Transplant Rates by cPRA at Cohort Start: Kidney-Pancreas. cPRA at cohort start is the last value the candidate had prior to the simulation start or their value at listing. Person-time is calculated in days for all candidates from the start of their simulation period (simulation start or listing) to transplant, waitlist removal, or simulation end.

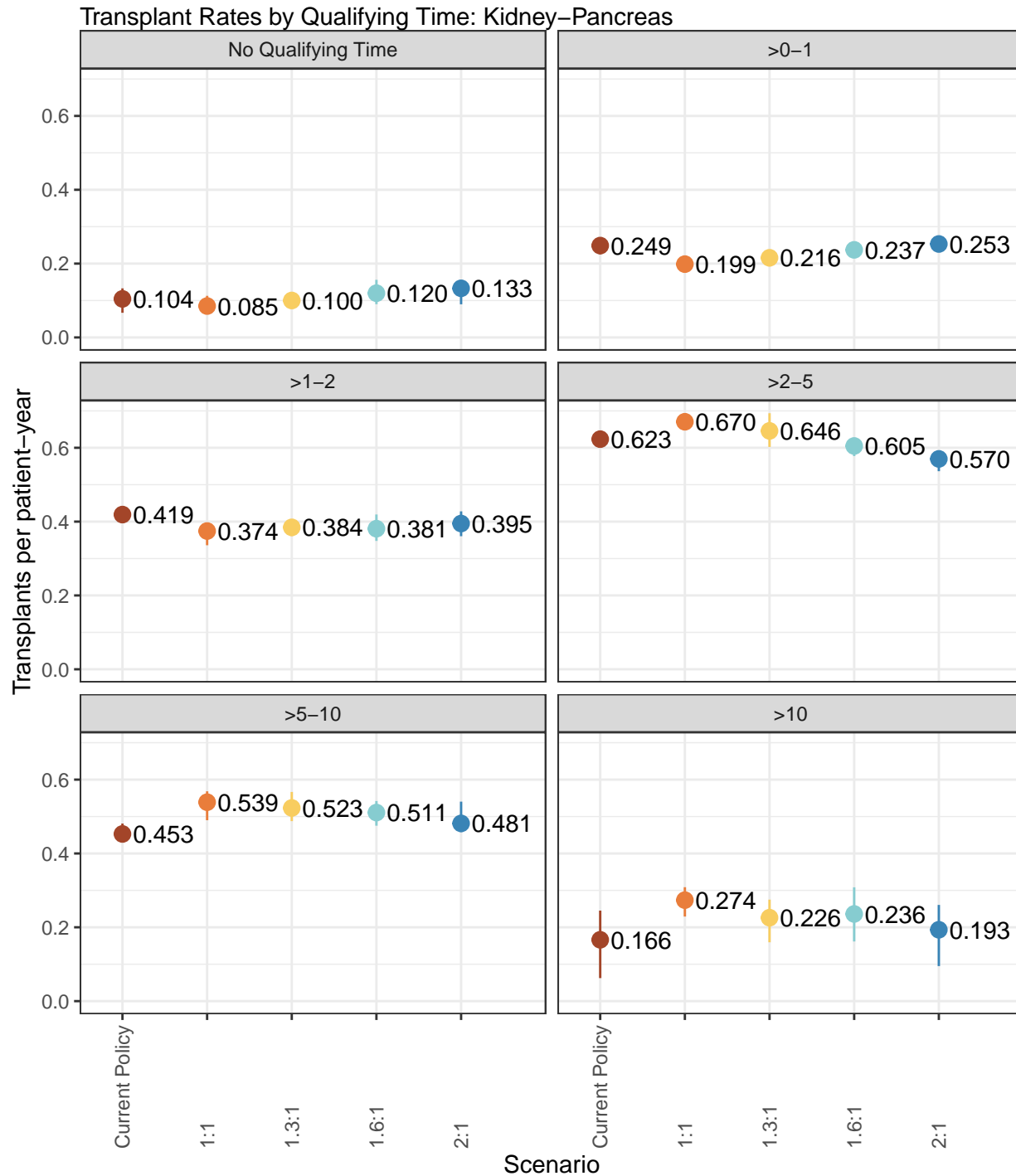


Figure 84: Transplant Rates by Qualifying Time: Kidney-Pancreas. Qualifying time is time in years from qualifying date to simulation start. Person-time is calculated in days for all candidates from the start of their simulation period (simulation start or listing) to transplant, waitlist removal, or simulation end.

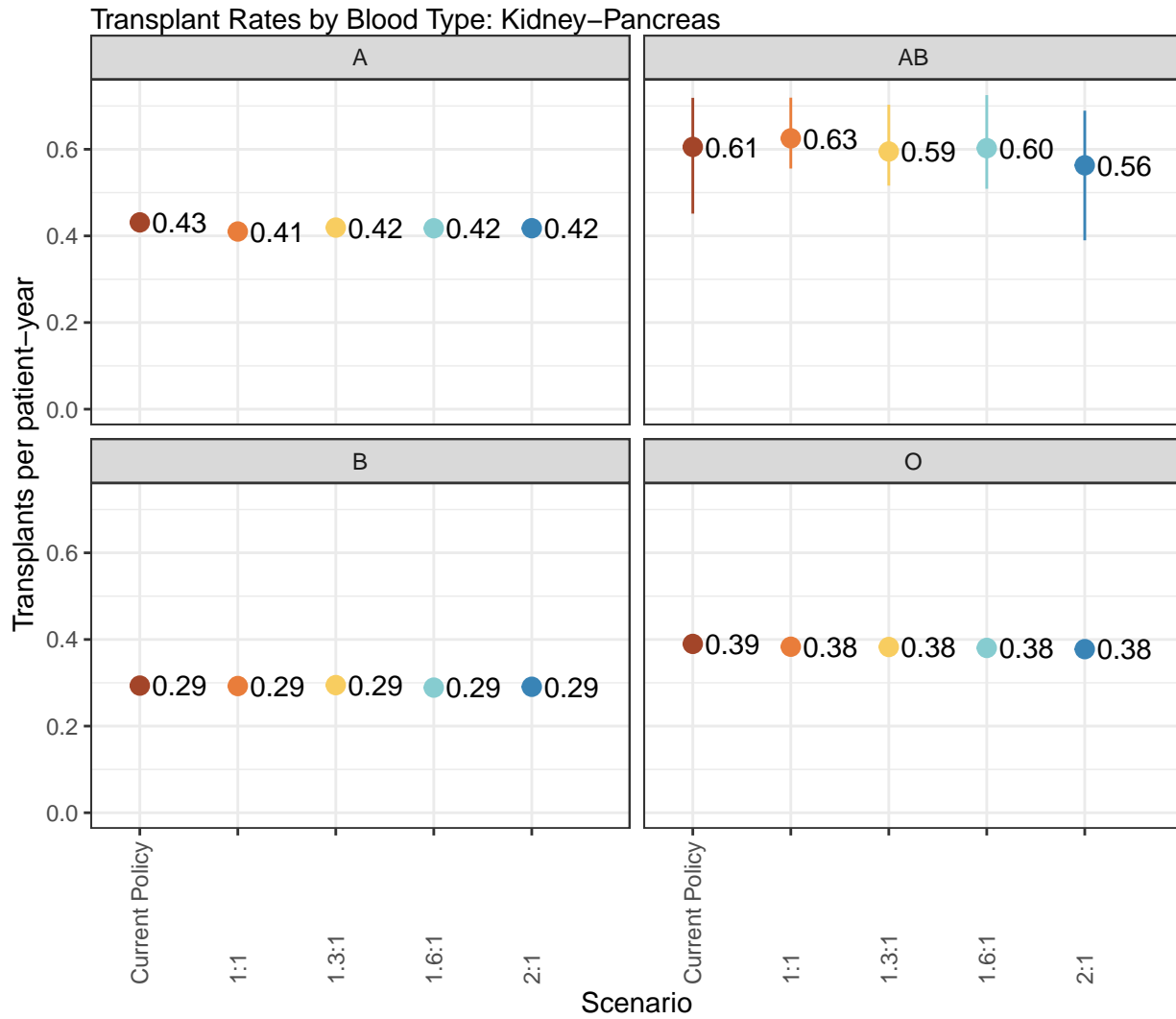


Figure 85: Transplant Rates by Blood Type: Kidney-Pancreas. Person-time is calculated in days for all candidates from the start of their simulation period (simulation start or listing) to transplant, waitlist removal, or simulation end.

Kidney-Pancreas: Distance Traveled for Transplanted Organs

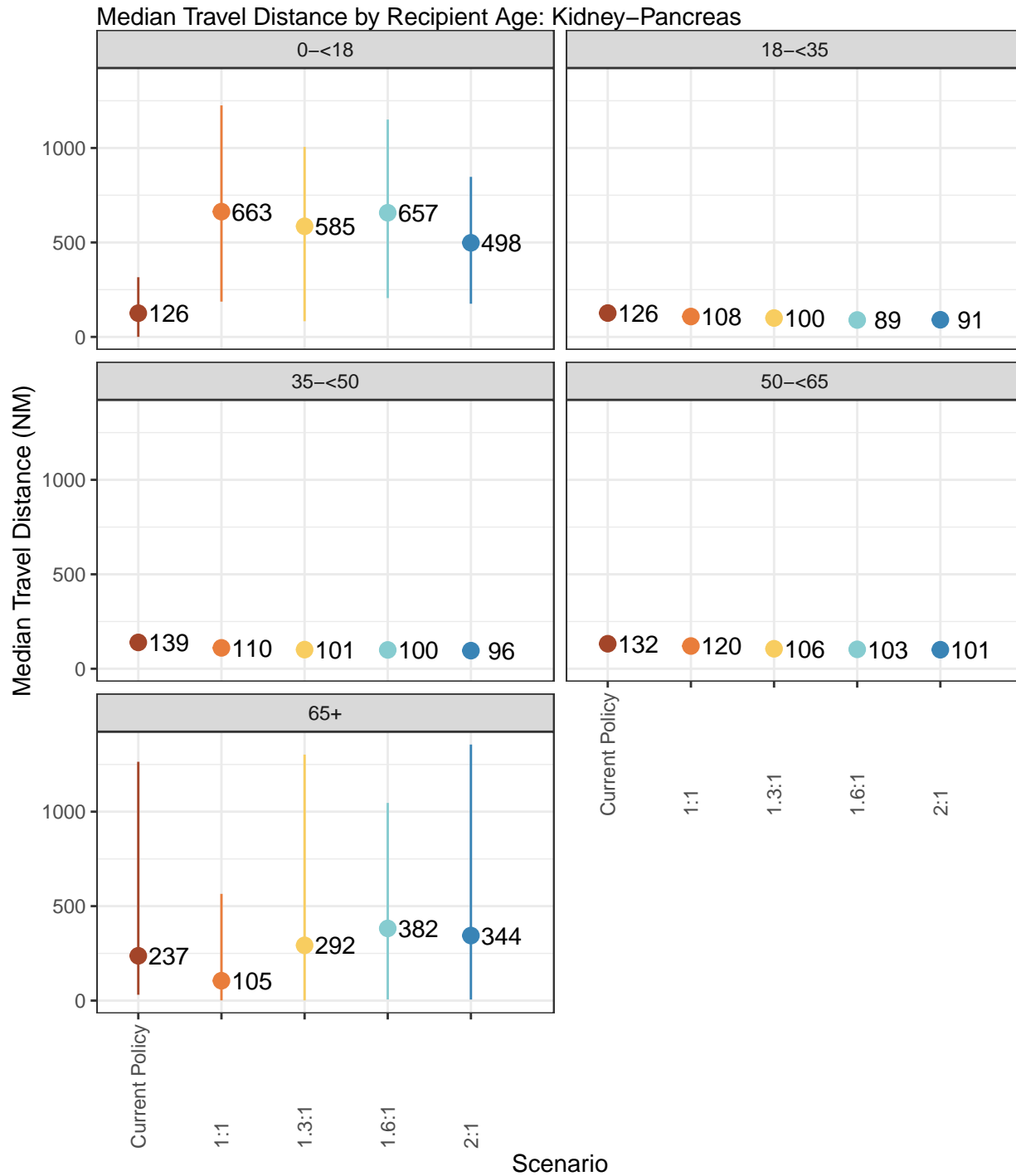


Figure 86: Median Travel Distance by Recipient Age: Kidney-Pancreas. Travel distance is between the donor hospital and the transplant center, in nautical miles.

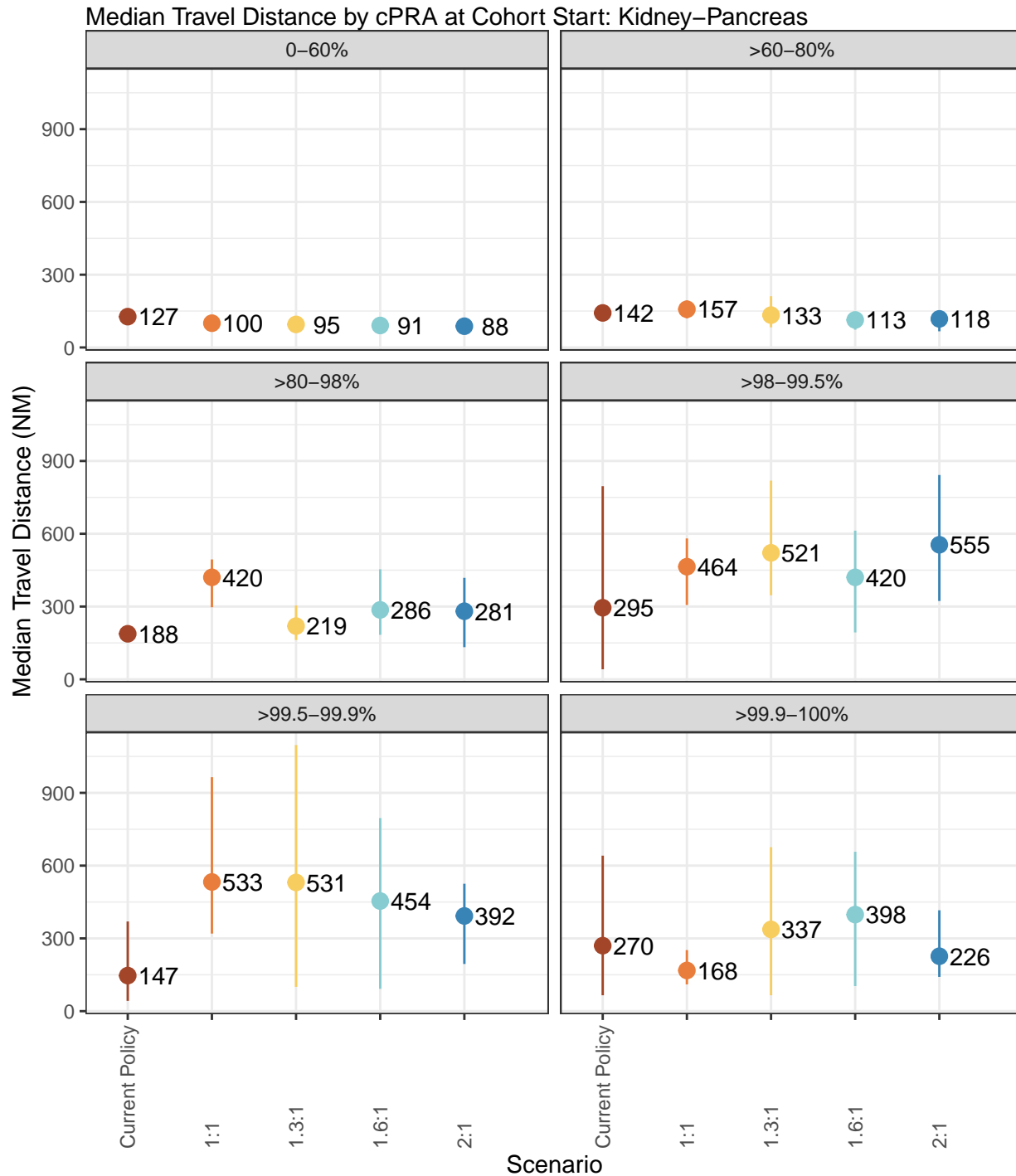


Figure 87: Median Travel Distance by cPRA at Cohort Start: Kidney-Pancreas. Travel distance is between the donor hospital and the transplant center, in nautical miles.

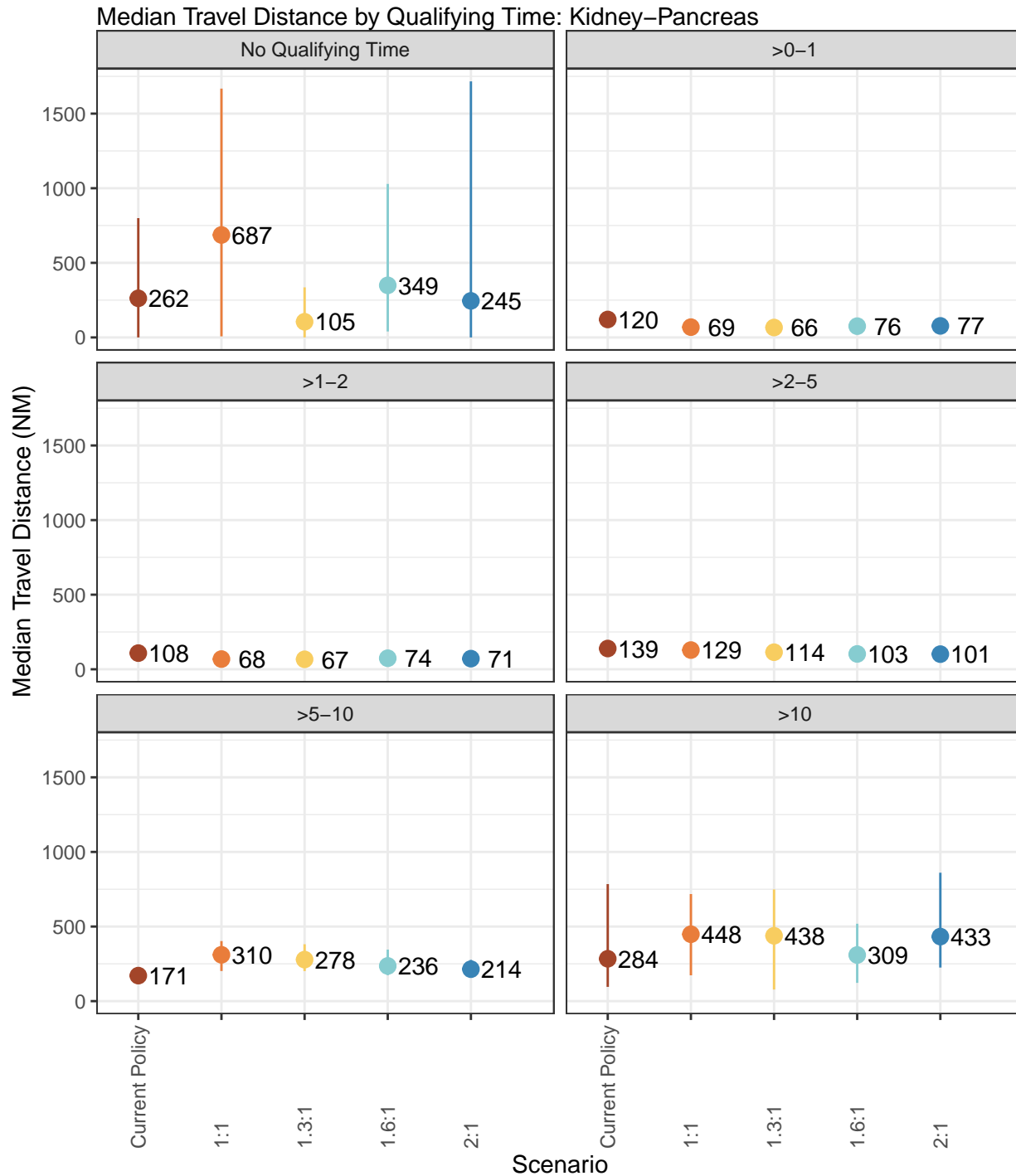


Figure 88: Median Travel Distance by Qualifying Time: Kidney-Pancreas. Qualifying time is time in years from qualifying date to transplant among those who underwent transplant. Travel distance is between the donor hospital and the transplant center, in nautical miles.

Kidney-Pancreas Additional

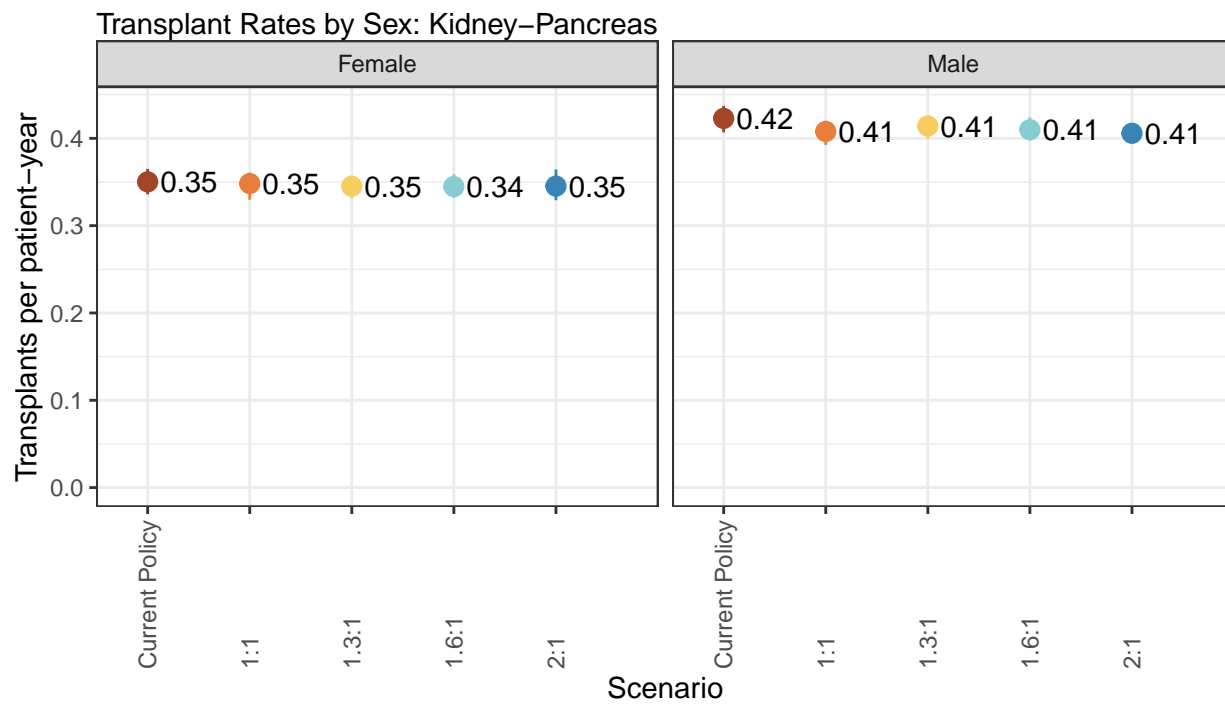


Figure 89: Transplant Rates by Sex: Kidney-Pancreas. Person-time is calculated in days for all candidates from the start of their simulation period (simulation start or listing) to transplant, waitlist removal, or simulation end.

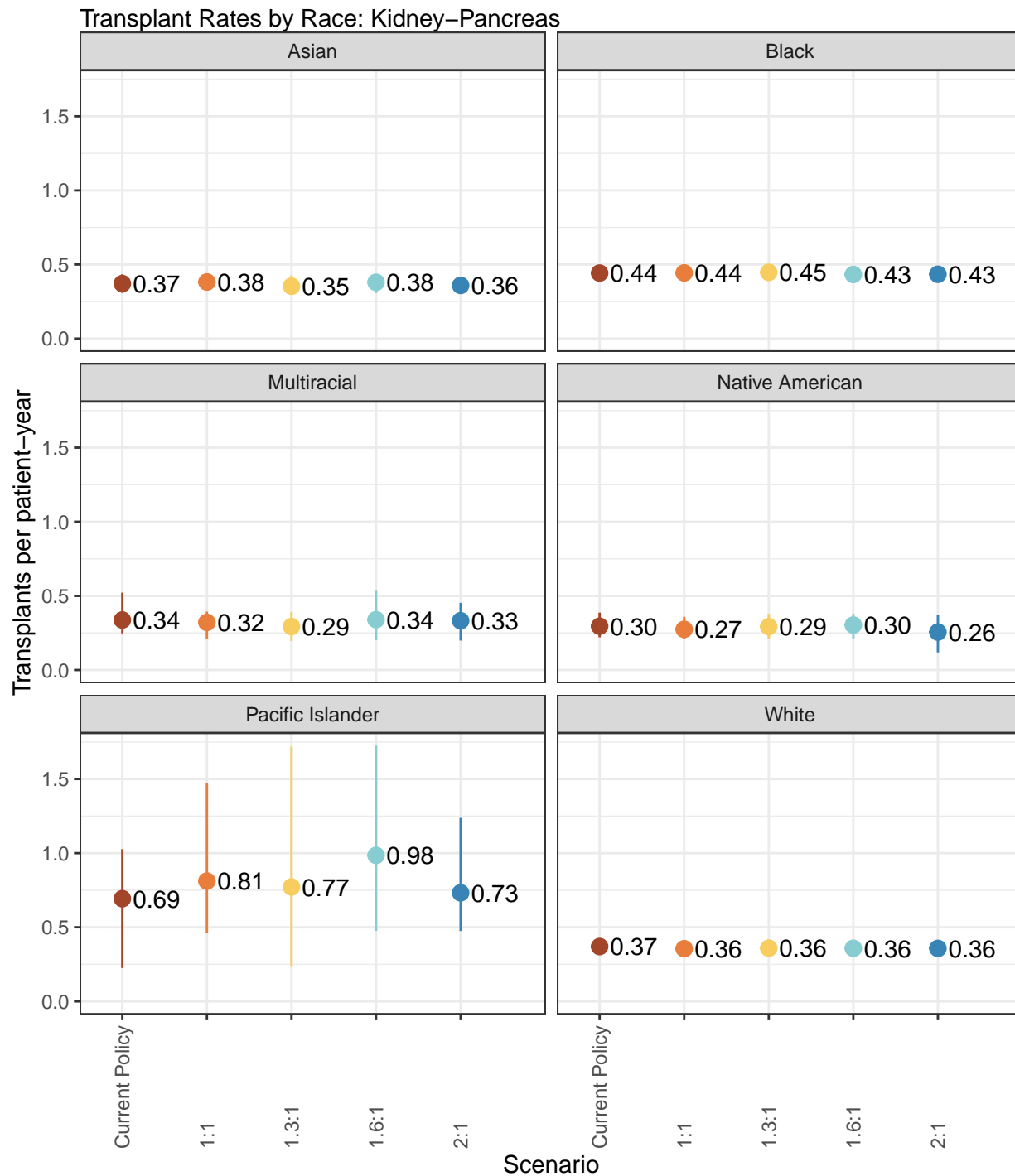


Figure 90: Transplant Rates by Race: Kidney-Pancreas. Person-time is calculated in days for all candidates from the start of their simulation period (simulation start or listing) to transplant, waitlist removal, or simulation end.

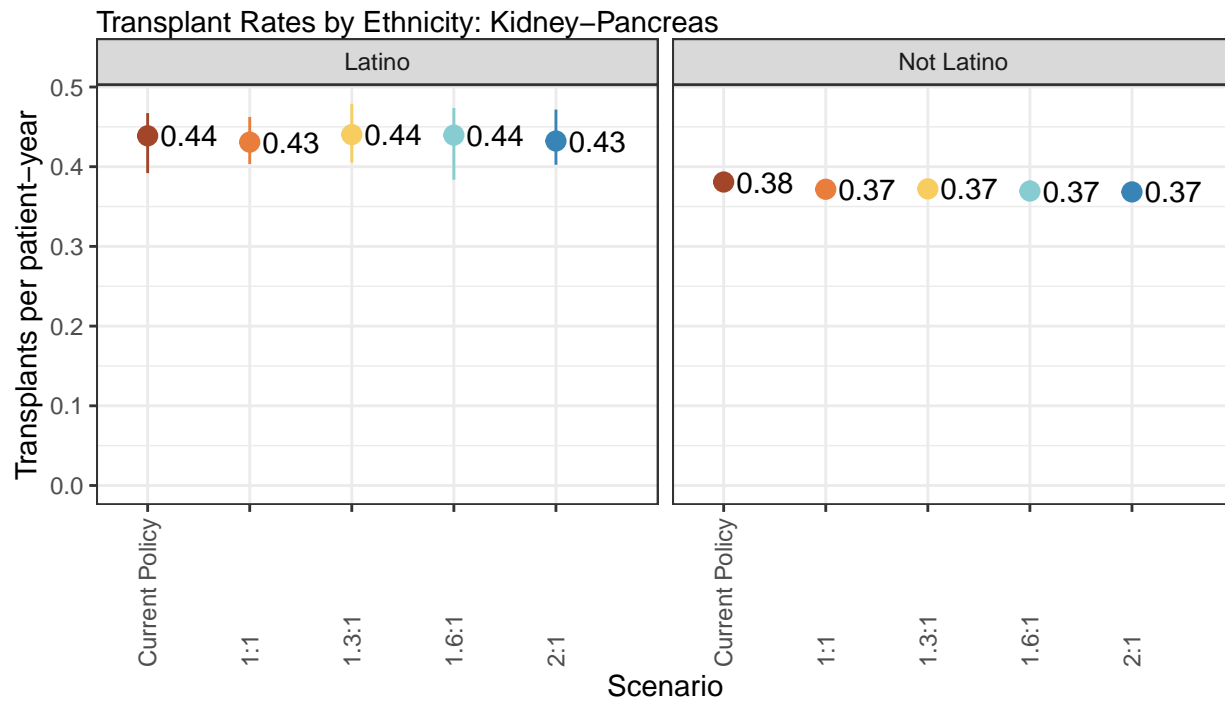


Figure 91: Transplant Rates by Ethnicity: Kidney-Pancreas. Person-time is calculated in days for all candidates from the start of their simulation period (simulation start or listing) to transplant, waitlist removal, or simulation end.

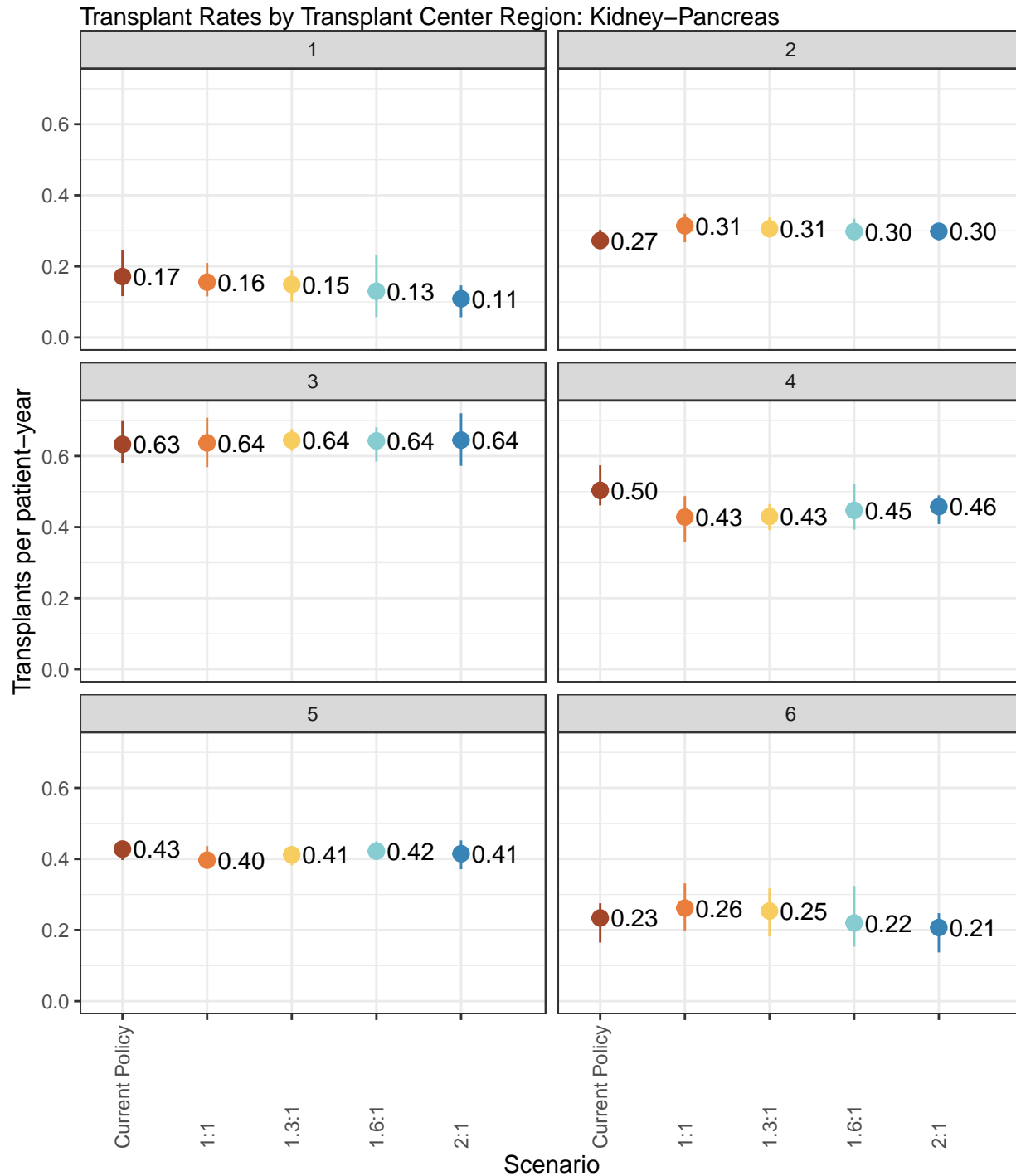


Figure 92: Transplant Rates by Transplant Center Region: Kidney-Pancreas. Person-time is calculated in days for all candidates from the start of their simulation period (simulation start or listing) to transplant, waitlist removal, or simulation end. OPTN regions numbers 1 to 6.

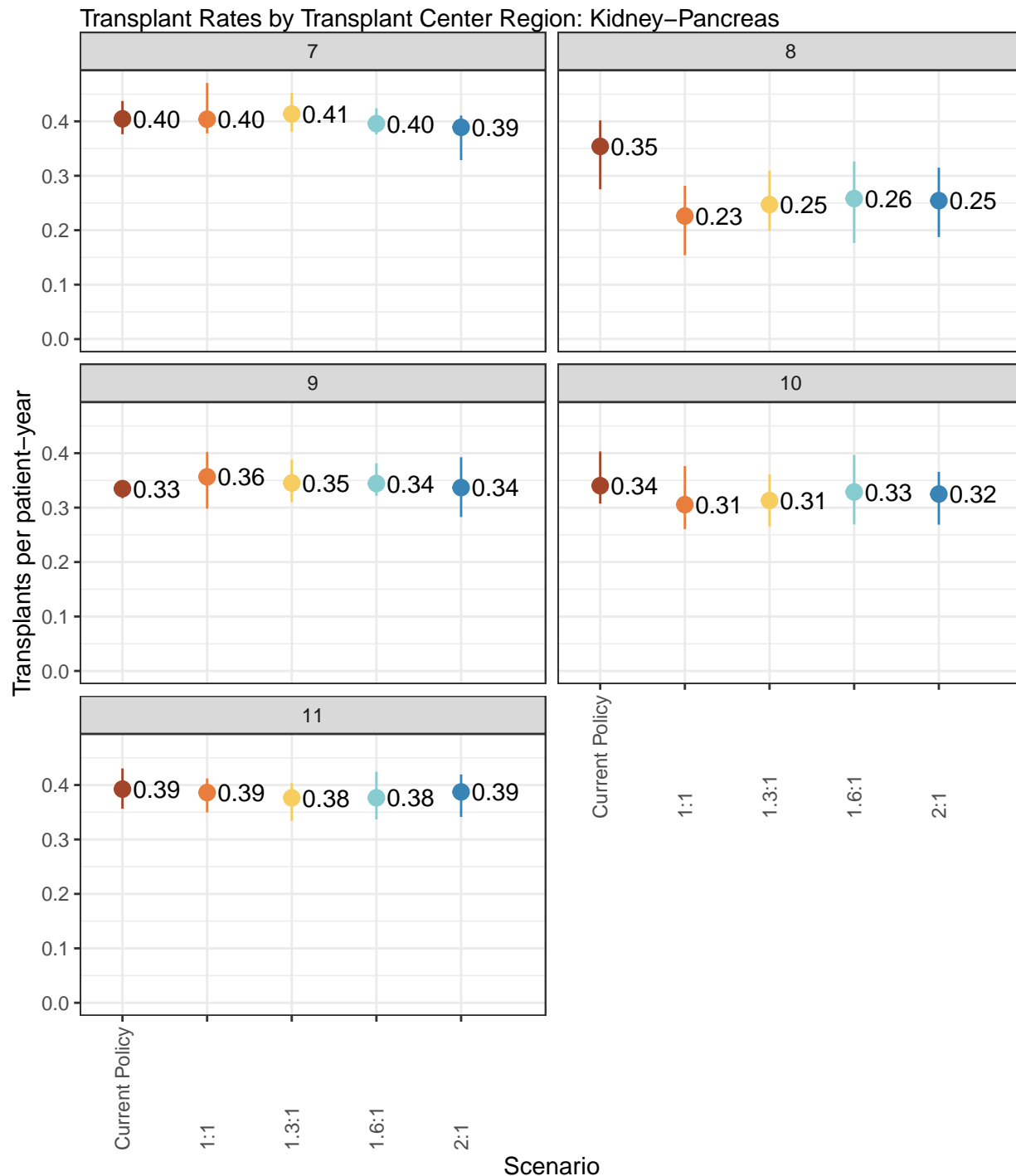


Figure 93: Transplant Rates by Transplant Center Region: Kidney-Pancreas. Person-time is calculated in days for all candidates from the start of their simulation period (simulation start or listing) to transplant, waitlist removal, or simulation end. OPTN regions numbers 7 to 11.

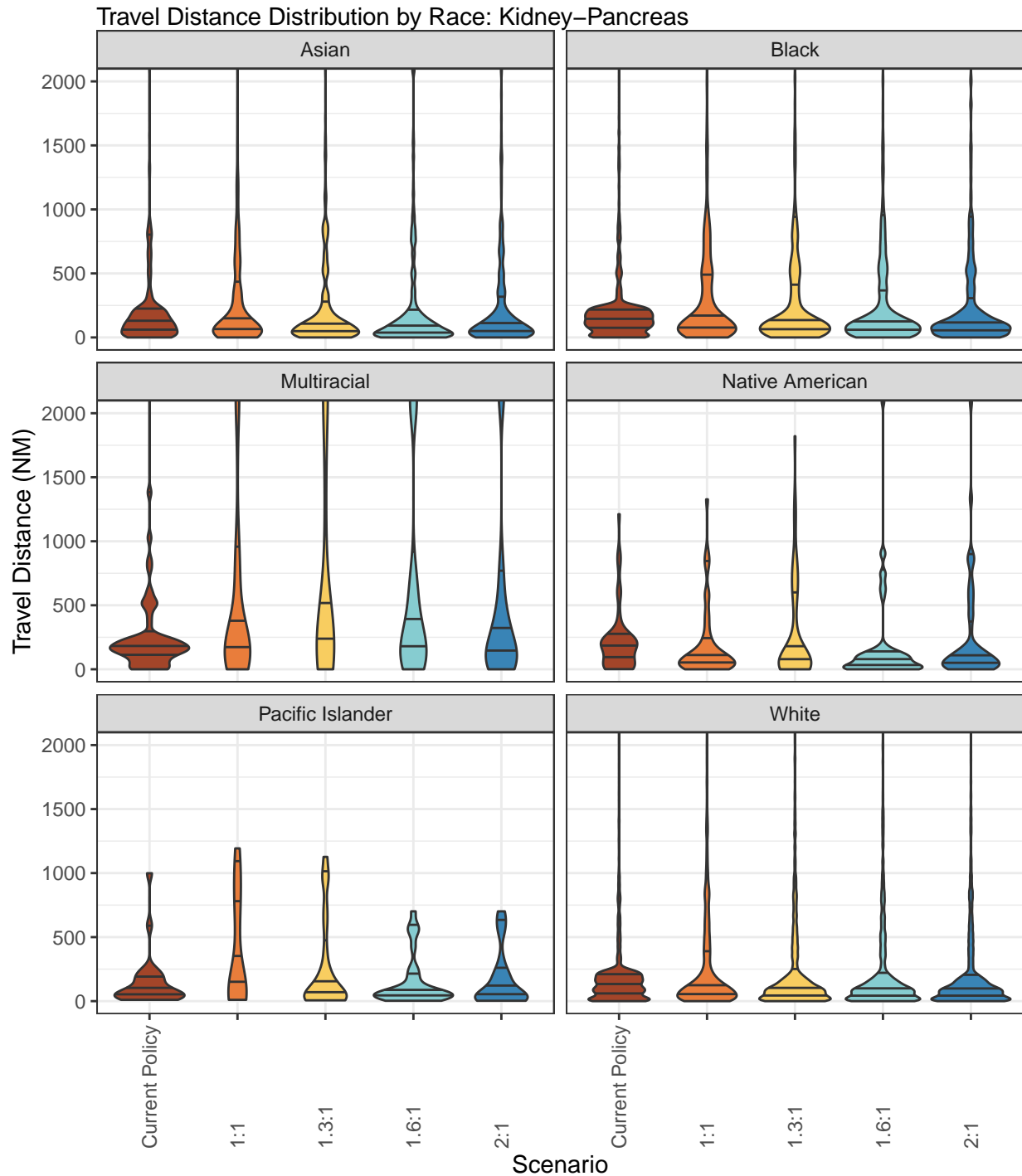


Figure 94: Travel Distance Distribution by Race: Kidney-Pancreas. Distribution of travel distance. Travel distance is between the donor hospital and the transplant center, in nautical miles.

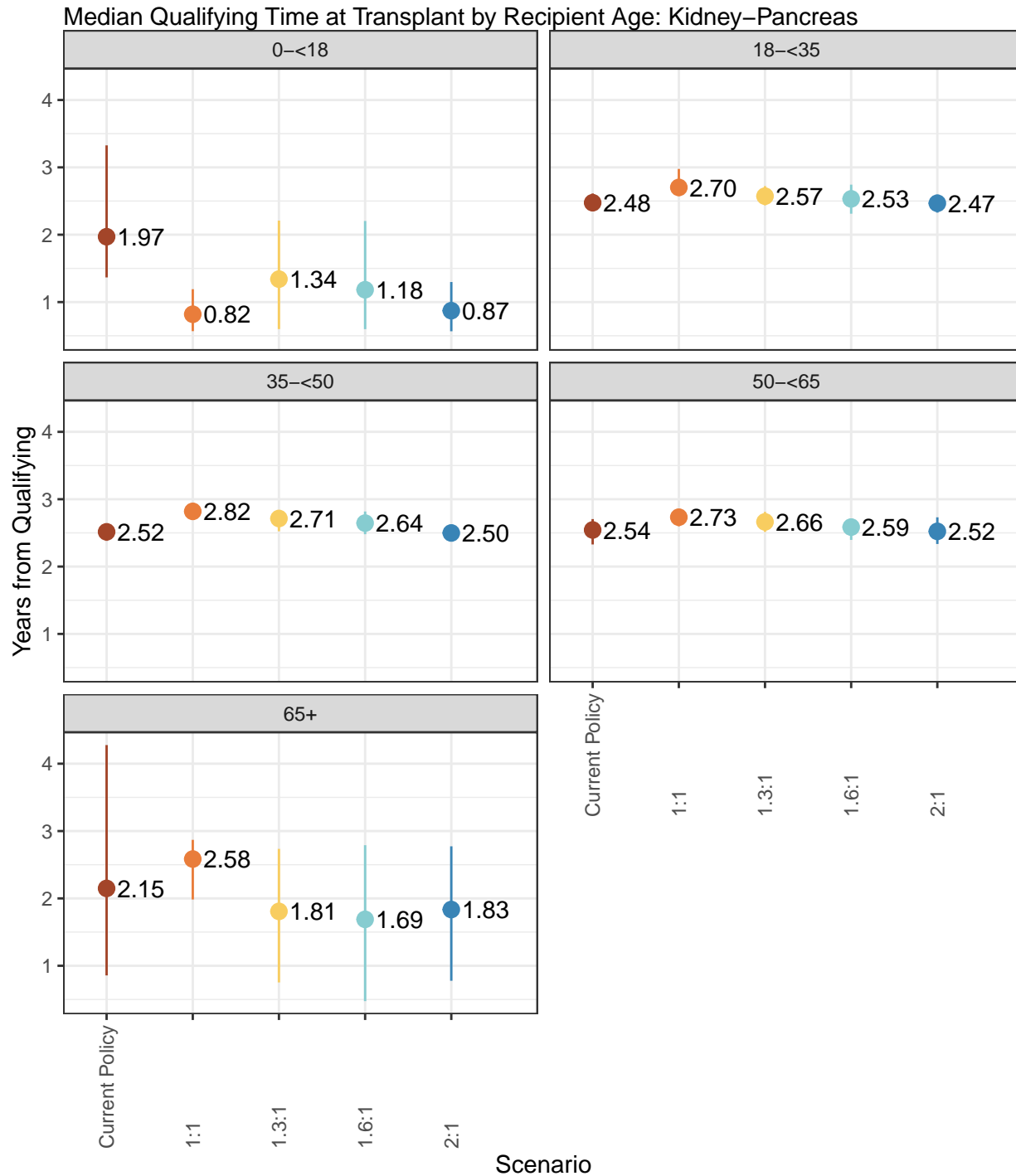


Figure 95: Median Qualifying Time at Transplant by Recipient Age: Kidney-Pancreas. Median time in years from qualifying date to transplant among those who underwent transplant.

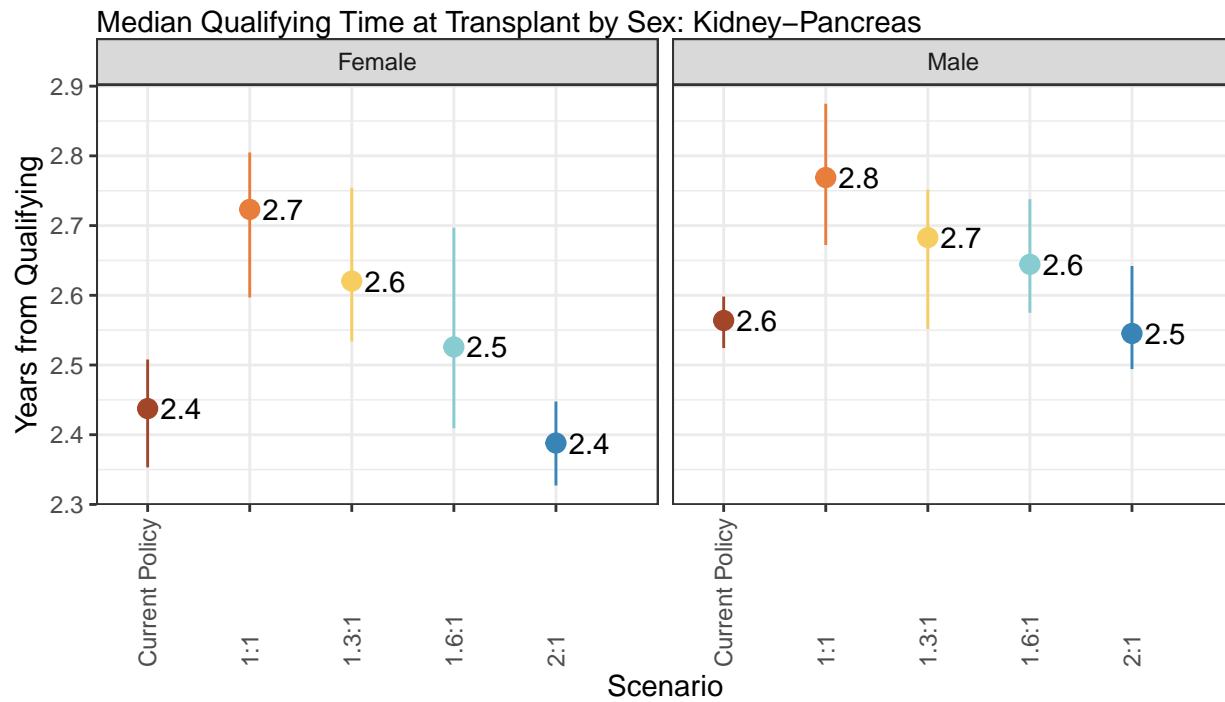


Figure 96: Median Qualifying Time at Transplant by Sex: Kidney-Pancreas. Median time in years from qualifying date to transplant among those who underwent transplant.

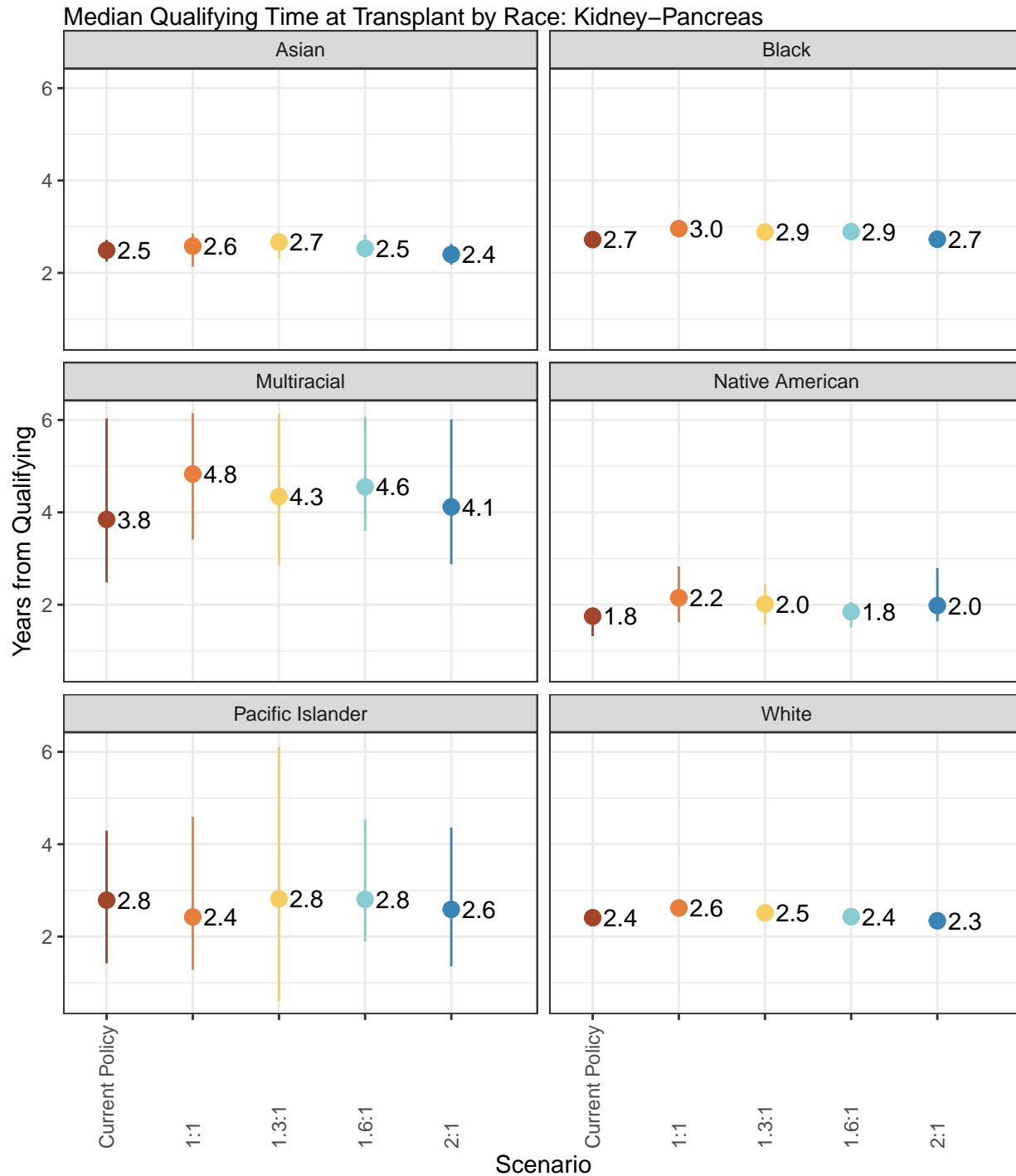


Figure 97: Median Qualifying Time at Transplant by Race: Kidney–Pancreas. Median time in years from qualifying date to transplant among those who underwent transplant.

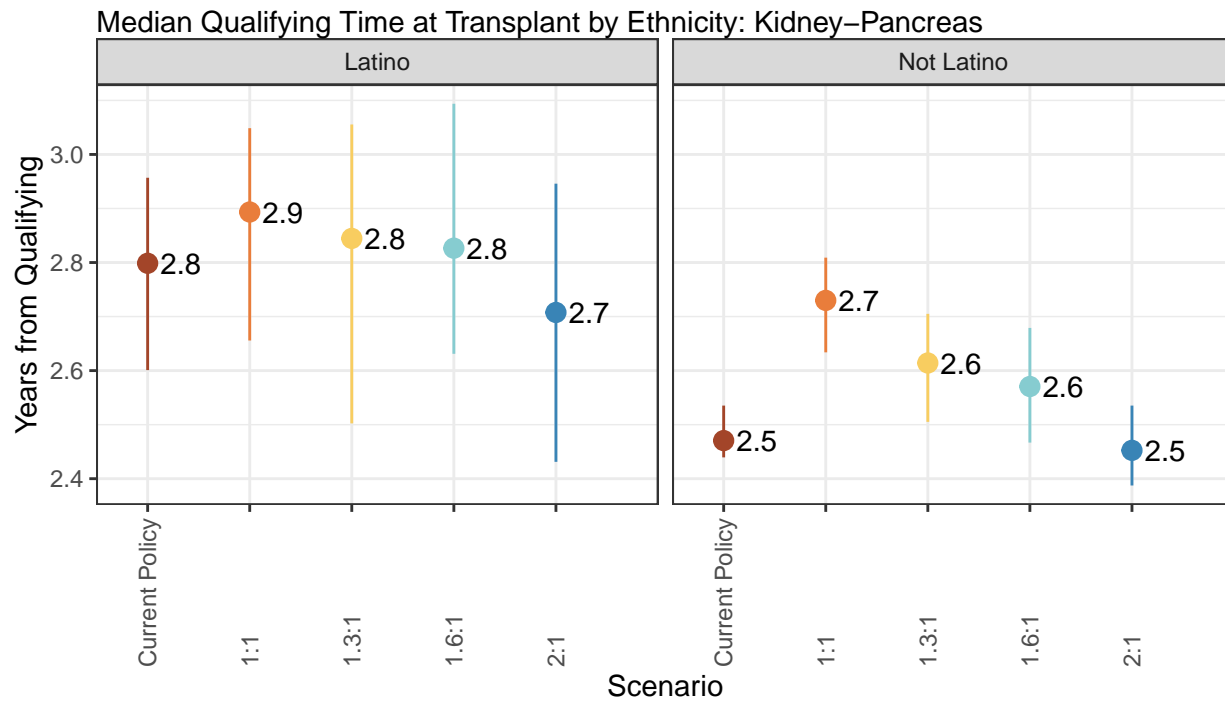


Figure 98: Median Qualifying Time at Transplant by Ethnicity: Kidney-Pancreas. Median time in years from qualifying date to transplant among those who underwent transplant.

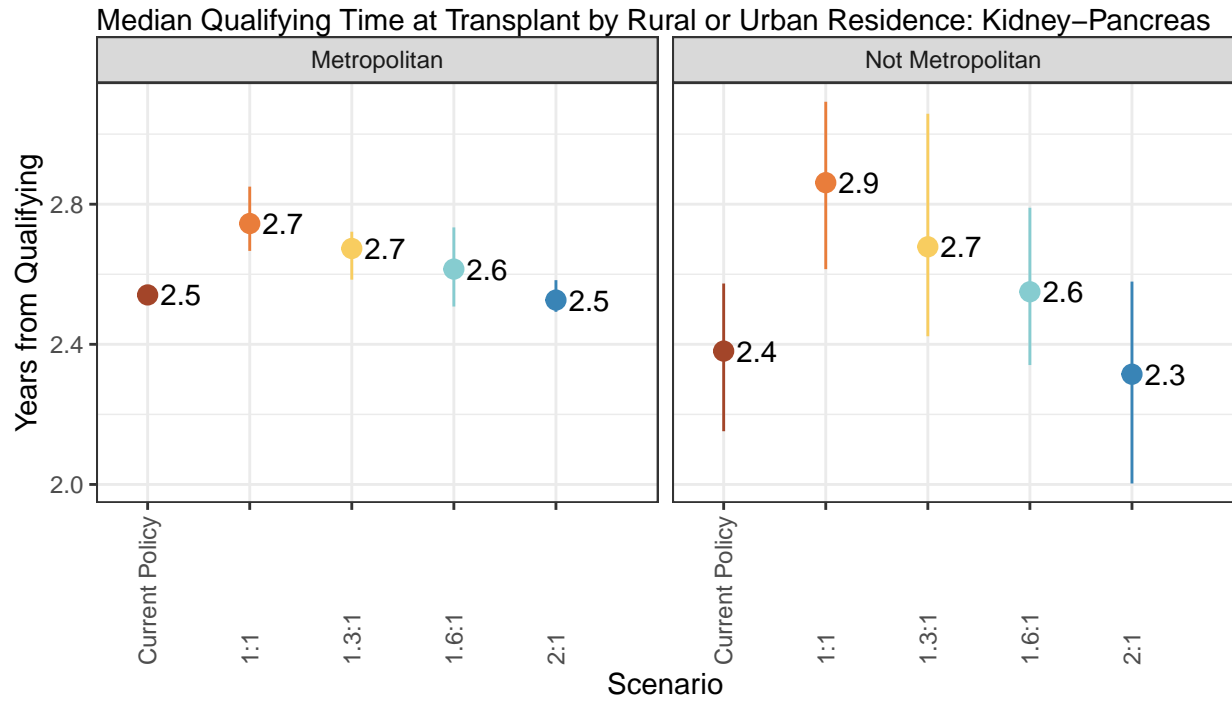


Figure 99: Median Qualifying Time at Transplant by Rural or Urban Residence: Kidney-Pancreas. Median time in years from qualifying date to transplant among those who underwent transplant.

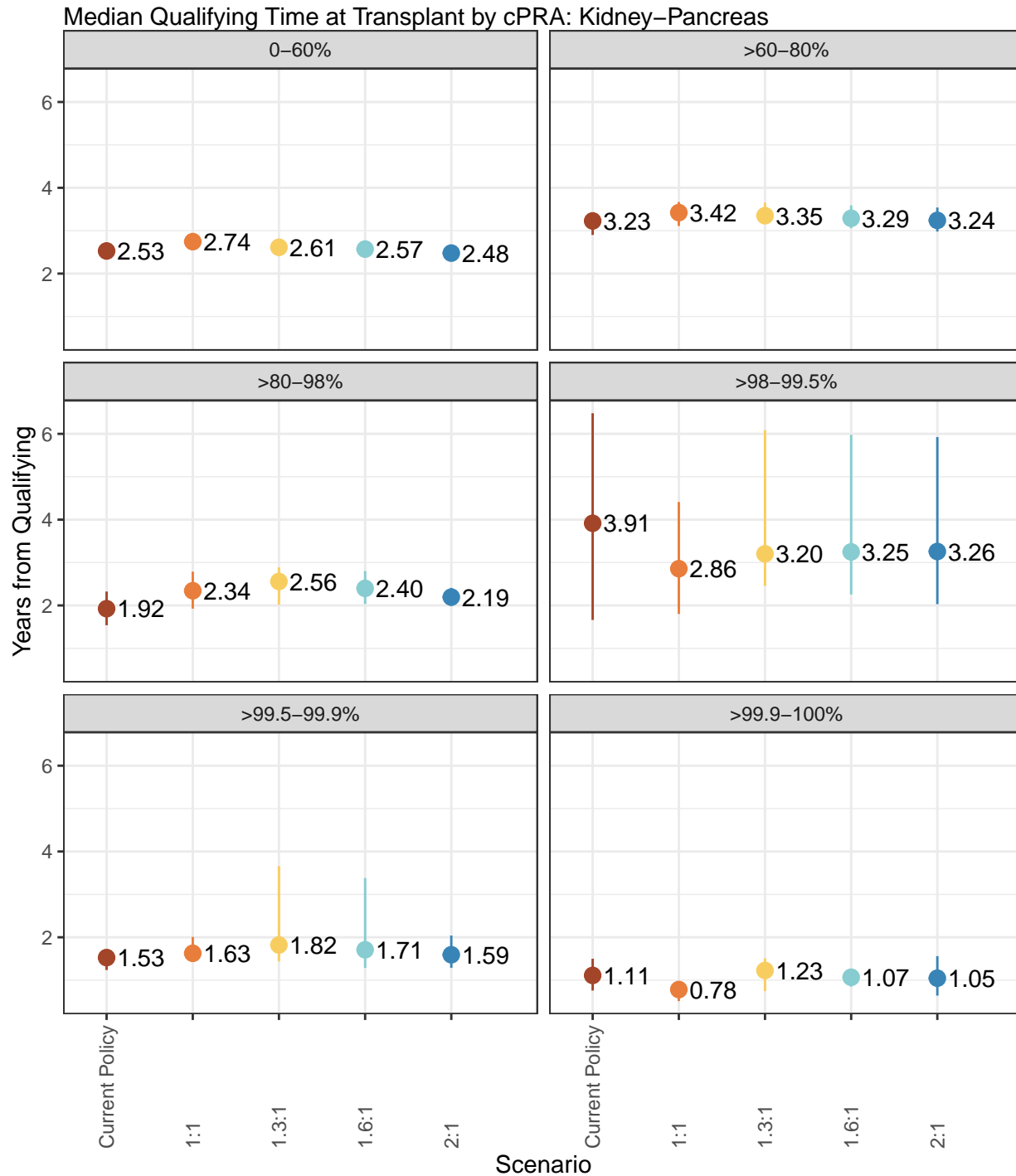


Figure 100: Median Qualifying Time at Transplant by cPRA: Kidney-Pancreas. Median time in years from qualifying date to transplant among those who underwent transplant.

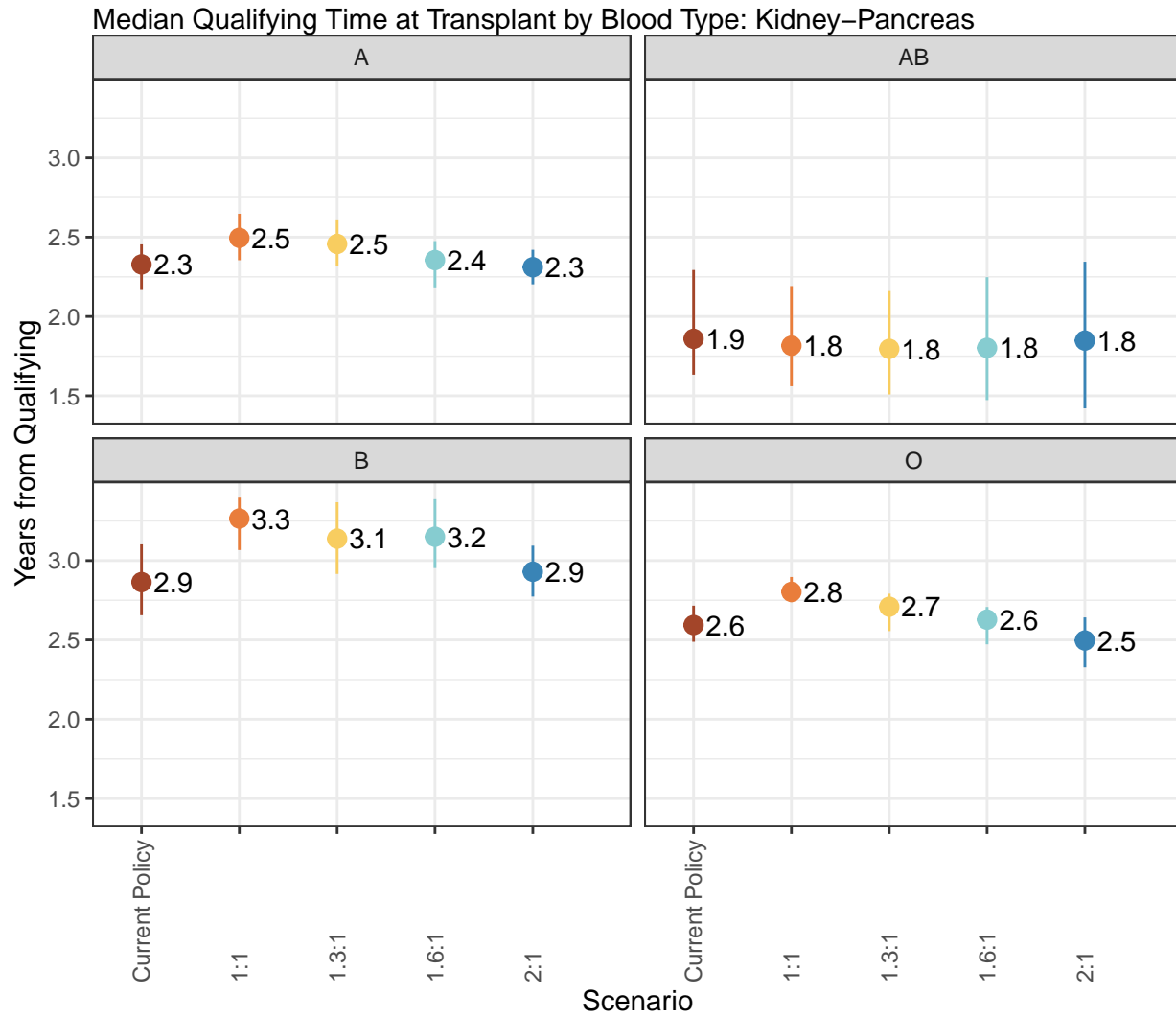


Figure 101: Median Qualifying Time at Transplant by Blood Type: Kidney-Pancreas. Median time in years from qualifying date to transplant among those who underwent transplant.

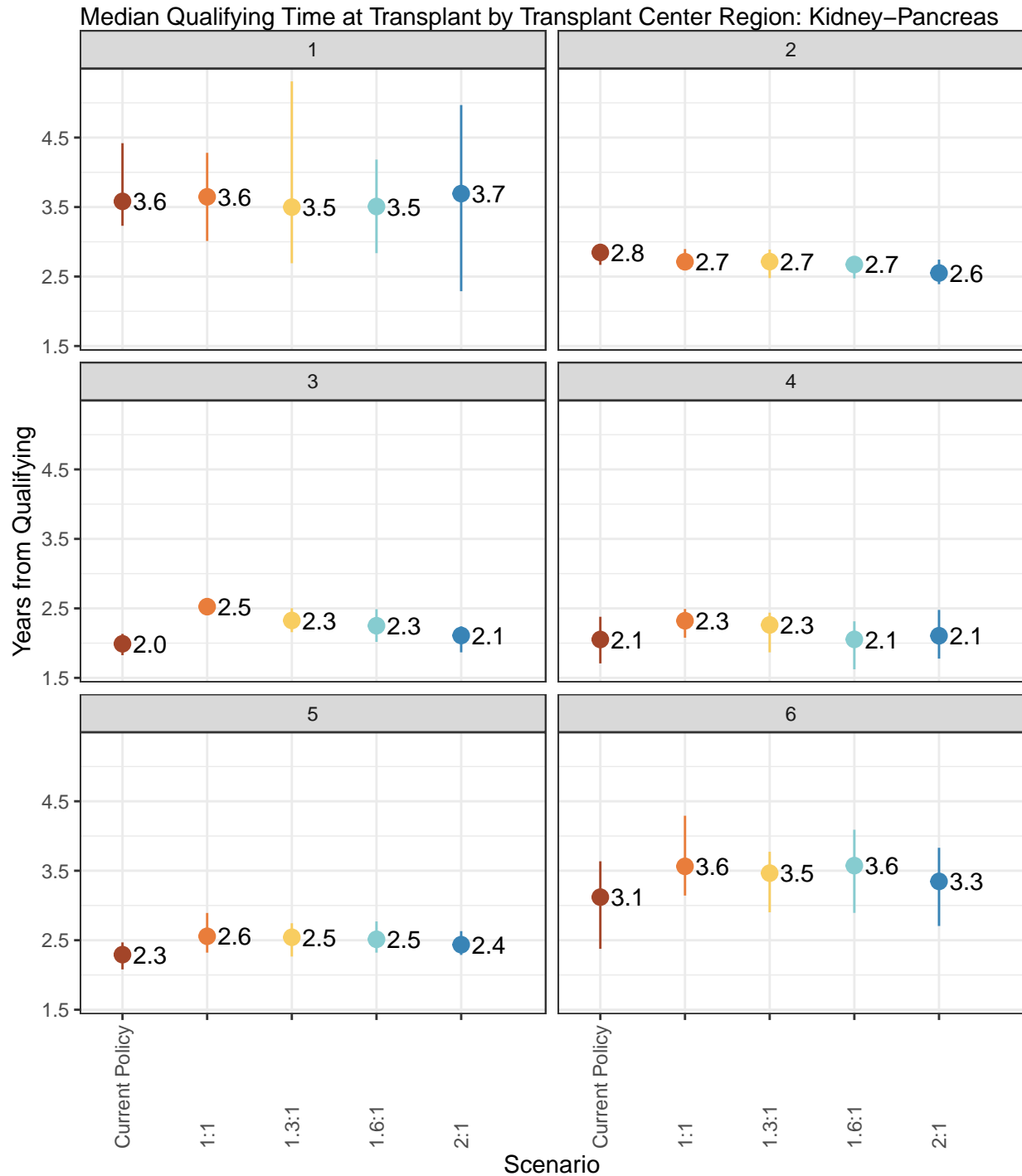


Figure 102: Median Qualifying Time at Transplant by Transplant Center Region: Kidney-Pancreas. Median time in years from qualifying date to transplant among those who underwent transplant.

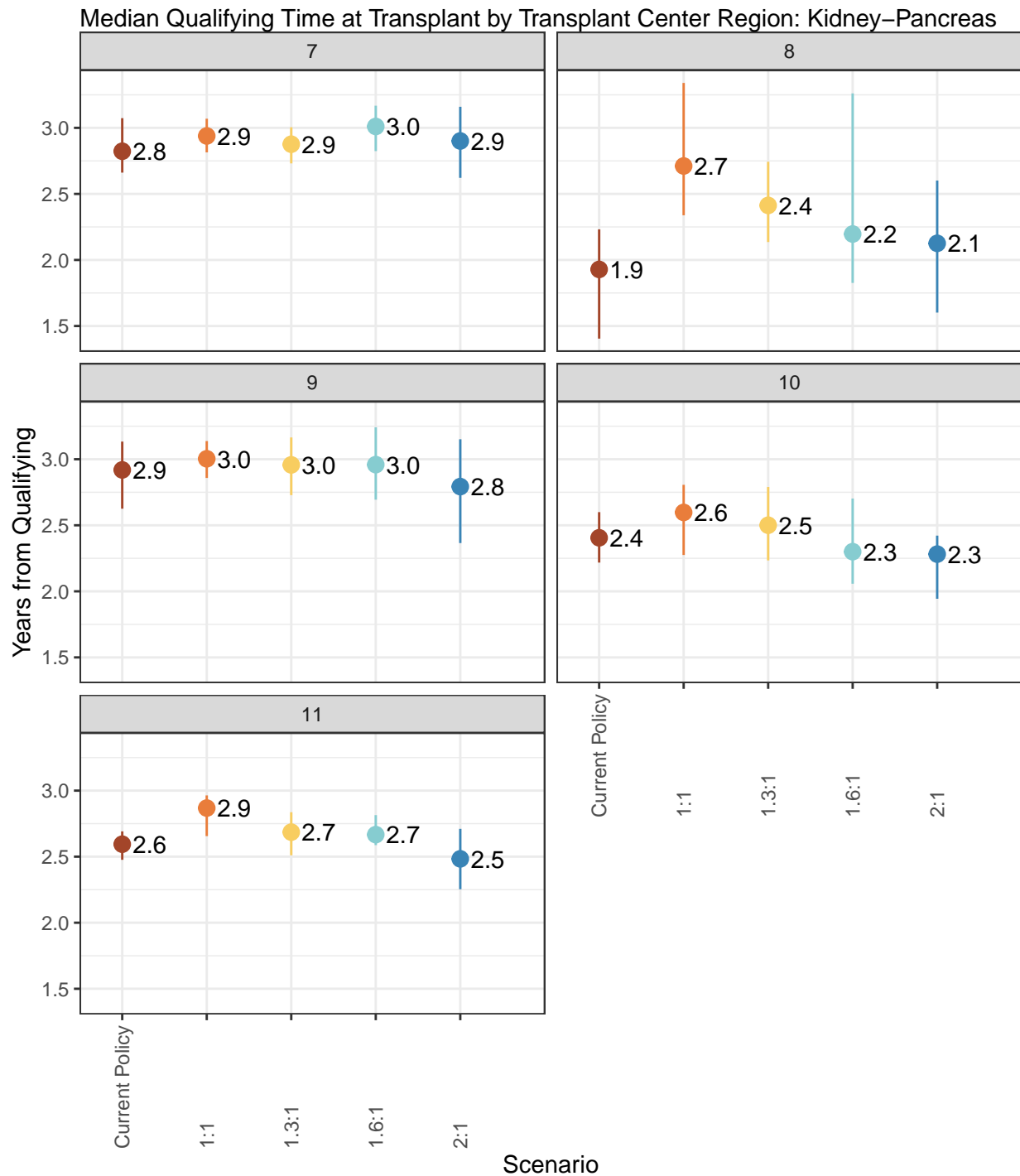


Figure 103: Median Qualifying Time at Transplant by Transplant Center Region: Kidney-Pancreas. Median time in years from qualifying date to transplant among those who underwent transplant.