Optimal Vascular Access Choice for Patients on Hemodialysis

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Introduction

In 2010, 600,000 US adults had End-Stage Renal Disease (ESRD), 65% of which relied on Hemodialysis (HD), the most common form of dialysis, to remain alive [1]. To deliver HD, patients need to have a vascular access. The gold standard for delivering HD is via Arteriovenous Fistula (AVF) because of lower infection rates, higher blood flow rates (which translates to more effective dialysis), and a lower incidence of thrombosis [2]. These along with patient preferences lead to a higher quality of life for using AVF.

Nevertheless, due to AVF creation failure (around 60% of AVFs fail to mature), limited lifetime of a functional AVF (15% annual failure rate), and limited places to create an AVF (at most 4), patients may use an inferior access substitute called Central Venous Catheter (CVC). Furthermore, AVF is created via a surgery, which comes with its own risks and inconveniences. One would avoid this disutility if it cannot be compensated by better HD outcome (better survival and quality of life).

In this paper, we address the question of whether and when to perform AVF surgery on incident and established HD patients, with the aim to find individualized policies that maximize a patient's probability of survival and remaining quality adjusted life expectancy (QALE). Under certain data-driven assumptions and using a continuous-time dynamic programming model, we establish structural properties of the optimal policy for each objective

Problem Description

We consider a patient on HD with no functional AVF in place, and with at least one AVF chance remaining. The question we examine is whether and when to refer a patient for AVF creation, with an objective of maximizing the patient's total expected lifetime or QALE. We suppose the following assumptions, which are supported by the empirical data:

1. A patient's survival depends on the length of duration the patient has been on HD and the current mode of HD access (AVF or CVC), and is independent of the history of HD access.
2. A patient's residual lifetime on HD using CVC is stochastically smaller than the residual lifetime on AVF, at all ages.
3. The difference of hazard rates of lifetime on HD using CVC and AVF is decreasing in time.
4. A patient's residual lifetime on HD on AVF have the increasing failure rate property.
5. The maturation time and lifetime of AVFs are i.i.d. and age independent. The AVF creation success probability decreases in the number of previous maturation failures.
6. Patients experience a better quality of life dialyzing via an AVF than via a CVC.

We prove the following results:

1. Proposition 1: Under Assumptions 1-5, we prove a patient referred for AVF earlier than another patient lives stochastically longer than that patient. This also means that the first patient has a longer expected lifetime.

2. Proposition 2: Under Assumptions 1-6, the optimal AVF referral policy to maximize a patient's expected QALE is of a threshold type: for each age, if AVF creation disutility is less than a critical value, then it is optimal to refer the patient for AVF creation at the time of decision; otherwise, the optimal policy is to use CVC for the rest of the patient's life. This critical value is decreasing in total HD duration and in the number of previous maturation failures, but independent of remaining number of AVF chances.

Role of Kidney Transplant:

In an extension to the basic model, we also consider kidney transplant as a possible renal replacement therapy for the patient. We then show that the lifetime result holds under the extended model as well. For the QALE metric on the other hand, the result of the basic model (optimality of threshold policies) does not necessarily extend, even under a deterministic time until transplant. We show in an example that the optimal policy can be neither immediate surgery, nor to stay on CVC forever (i.e., until transplant or death). Although threshold policies may be suboptimal in general, we prove their optimality under additional assumptions.

Numerical Results

Figure 1 shows estimated on-HD failure rates for a typical 67 year old patient with CVC or AVF [3]. Note that the figure provides data-driven support for Assumptions 2-4. Figure 2 shows the optimal policy as a function of HD-duration, for patients starting HD at ages of 67 and 82, and for different values of AVF creation disutility. As the figure suggests, the area under which the optimal policy is to refer for AVF creation is larger for 67 year olds compared to 82 year old patients. This is because the critical value is lower for patients starting HD at higher ages, which itself is due to a smaller overall survival (for both CVC and AVF) for older patients.

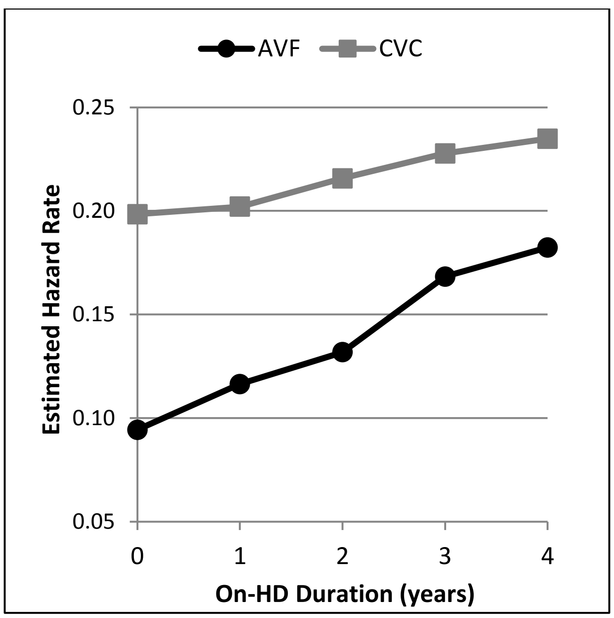

Figure 1: Estimated ON-HD Failure Rate

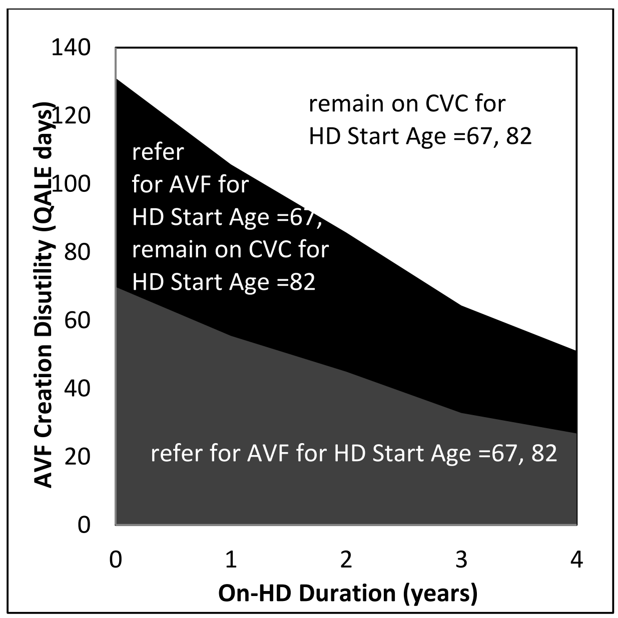

Figure 2: Critical AVF Creation Disutility

Conclusion

We investigated the question of whether and when to refer on-HD patient for AVF creation. We showed that later AVF creation referral stochastically reduces a patient's survival. Also, immediate referral maximizes the quality adjusted life expectancy, as long as AVF creation disutility is below a critical value; otherwise the optimal policy is to use CVC for the rest of the patient's life. We also found that the possibility of receiving a kidney transplant adds new complexities to the model and optimal policy structure.

References

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