

A Conversation with ... Alvin E. Roth PhD, Economist, Game Theorist, and Nobel Laureate Who Improved the Modern Residency Match

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Let's jump into our time machine. It's 1921. You and I both are third-year medical students at the somewhat-less-than-illustrious Eclectic

A note from the Editor-in-Chief: A few times each year, in place of my monthly editorial, I will introduce and interview a deep thinker on topics that matter to surgeons. In this editorial feature, called "A Conversation with ...", my goal is to speak with guests whom most readers may be unfamiliar. When possible, I will look outside our specialty, and even outside our profession, in the hopes of gaining new perspectives on familiar topics or themes. Interviews may be edited for length and clarity.

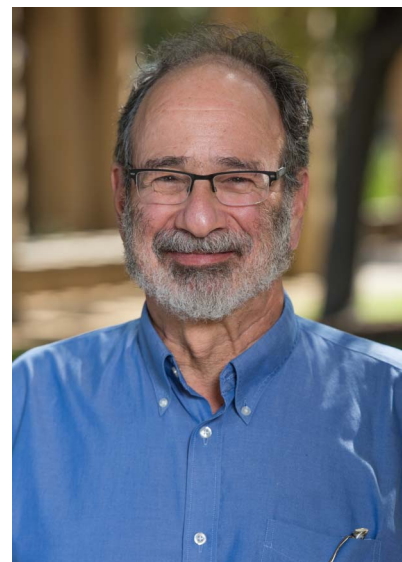
This month's guest is Nobel Laureate economist Alvin E. Roth PhD of Stanford University, whose discoveries in game theory and market design undergird today's residency match program, and whose work has made large systems fairer for students, patients, and many others. We welcome reader feedback on all of our columns and articles; please send your comments to eic@clinorthop.org.

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Medical College in Cleveland, OH, USA. But you're more industrious than I am, and you just received an offer to go to Cambridge, MA, USA for a residency—as a junior in medical school! Your mom must be proud. The year ends, and fourth year begins; more and more of our classmates get offers, but I'm still out in the cold. With time, the quality of the programs and the salaries offered decrease. But the offers—such as they are anymore—seem to share one trait: Take it or leave it, and do it quickly. My envelope finally comes: Do I take the job at the Lima Tuberculosis Hospital (some say it's haunted [10]), or wait to see if I get one from Columbus State (formerly the Ohio State Hospital for the Insane)? I'll take option 3 instead. I'm resetting the time machine.

It's 30 years later, 1951. Plenty of time for the greybeards to have figured out how best to put interns into hospitals, right? Nope, the process has only gotten worse. Although medical schools generally have converged on uniform dates to make offers, we aspiring residents still have to respond to offers on desperately short deadlines—12 hours is said to be too long [17]—and as before, we have to

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take or leave the opportunities we're offered without knowing whether others may come later. Hospitals are stressed, too; if a preferred candidate dallies and declines, they often don't have time to find an alternate. Time machine's out of batteries; I should have been born a year later.

Because finally, in 1952, a solution to the "stable marriage problem" [9] was put into play in the form of a rudimentary residency match. I'm glad you asked. The stable marriage problem is this: For n men and n women, create a system in which each person ranks all members of the opposite

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gender in order of preference, to create unions of men and women such that no two people of opposite gender would both rather have each other instead of their current partners. (In 1952, they did not work the stable marriage problem for same-gender unions).

Subsequently, economist Alvin E. Roth PhD demonstrated that the Match, as we now understand it, is both stable (defined as a situation in which no pairs could break up to form new matches that would make both the resident and the training program happier with the pairing [21]) and resistant to strategic manipulation by hospitals [18]. His subsequent work has continued to improve the Match, including evolving it to a condition that allows stable matches for couples as well as individuals—a happy result that earlier was believed perhaps to be impossible [15]. Dr. Roth won a Nobel Prize in 2012 for his work on this and other topics on market design and matching theory [22].

Whether you love the Match or hate it (and does anyone really love it?), there is no question Dr. Roth's foundational discoveries have made life better for physicians. But his approaches to market design have transformed the world far beyond medical education. Dr. Roth's work on assigning students to sought-after high schools has reduced the number of families unhappy with the result some tenfold, improving the lives of nearly 30,000 teenagers each year. His work on the marketplace that is transplant surgery hasn't merely improved lives, it's saved them [7].

Needless to say, inequities remain—in the Match, across healthcare, and outside it. Finding value and improving fairness are goals that all readers of *Clinical Orthopaedics and Related Research*® share, and Dr. Roth's perspectives on them will change yours.

Come explore those perspectives—and other topics that matter to

orthopaedic surgeons—in the conversation that follows with Alvin E. Roth PhD, the Nobel Prize-winning economist whose work in game theory and market development underlies today's Match program and has improved care for patients around the world.

Seth S. Leopold MD: *Many readers will dispute the idea that the Match is resistant to strategic manipulation (“gaming the system”); why do you believe it is, and why do you think this perception persists?*

Alvin E. Roth PhD: That question requires a somewhat complicated answer. The Match is built around an idea of how to organize a simple labor market, and that idea had to be adapted to the complex structure of the modern medical labor force. A simple labor market would be one in which graduating medical students each seek a single position, positions are well described in advance, and applicants and residency programs can each rank-order all of their possible matches; that is, applicants can rank programs and programs can rank applicants. That simple market can be modeled mathematically, and it can be shown that a deferred acceptance algorithm with applicants proposing makes it a dominant strategy for all applicants to submit rank-order lists corresponding to their true preferences. (A dominant strategy is one in which regardless of what rank-order lists others submit, no applicant can do better than to rank residency programs in order of his or her true preferences. For instance, your chance of getting your second-choice program if your first choice rejects you is exactly the same as if you had listed your second choice first.)

That's a theoretical answer about a market that is quite a bit simpler than the modern market for residencies. The deferred acceptance algorithm for that simple market was studied by Gale and Shapley [8], for which Shapley shared the 2012 Nobel Prize in Economics. (I

had earlier shown that in a simple market, applicants can't profitably manipulate their rank-order lists [16].)

The actual modern market for residencies differs from that simple market in several ways. For one thing, not all applicants are seeking a single position. This can happen for several reasons, the most important of which is that couples can enter the Match looking for pairs of jobs; in 2020, for example, more than one thousand couples submitted rank-order lists consisting of pairs of jobs. There are also many more residency programs than an applicant can submit on a rank-order list, and many more applicants than programs can interview, so decisions have to be made beforehand that are more complicated than how to order the rank-order list. These complications may also add to confusion about the Match and about how the Match algorithm works.

Computational studies of the Match nevertheless confirm that once interviews are over and an applicant has decided what programs to apply to, it is perfectly safe to submit a rank-order list that corresponds to the applicant's true preferences [18]. To put it another way, there is no advantage to submitting a rank-order list that differs from an applicant's preferences (and there is a danger in submitting a different rank-order list, because the Match will use the submitted list to make matches, in order).

This fact doesn't seem to have yet penetrated to everyone who participates in the Match [13]. For this reason, all those who advise medical students entering the Match should increase their advising efforts around this point.

Note that the Match is only the final part of the transition to residency (or to fellowships). That transition starts with applications and interviews and

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includes various kinds of signals, like exam scores and transcripts and letters of reference. While the dominant-strategy property of the Match makes that part of the process strategically simple (that is, we can confidently advise students to submit rank-order lists in order of their true preferences), the other parts of the process (what rotations to take before applying, where to apply, how to conduct yourself at interviews) are not simple at all.

Dr. Leopold: *Adding variable salaries to the residency match has been proposed from time to time, but you've said that wages needn't play much of a role because residents generally care more about a program's prestige than about salary. You also noted that there generally are many more applicants than positions, and because of the relationship between residents' salaries and Medicare reimbursements, hospitals have little flexibility anyway [14]. How has this changed in the 15 or so years since then?*

Dr. Roth: I think it is still the case that the Match itself has at most a very small effect on the salaries of residents and fellows.

Dr. Leopold: *You once commented in a Not the Last Word column in CORR[®] that the Match might be improved if a bit more room could be made for candidates to send "signals" to programs that indicate particular interest [5]; if you could make one change to the Match right now to make it fairer all around, what would that change be?*

Dr. Roth: I don't yet know enough about the whole pre-Match process of applications and interviews to answer that confidently. I'm hoping to gain access to data that will illuminate more clearly how applications lead to interviews, and how interviews interact with other kinds of information to influence what rank-order lists are submitted by applicants and programs.

Some of that process is surely in flux, between the pandemic causing interviews to be conducted remotely and the United States Medical Licensing Examination Step 1 going pass/fail. Signaling is a way to address miscoordination in interviewing (such as whether too many interviews are concentrating on too few candidates), but there are other ways the interview process might be broken that might better be addressed by other tweaks in how interviews are organized.

Dr. Leopold: *I believe the study you're proposing here would find a very attentive audience, both in medical schools and residency programs across the country, especially competitive ones like orthopaedic surgery. Based on other kinds of markets you've evaluated—I recognize I'm asking you to speculate—what do you think you might find here?*

Dr. Roth: Presently, in at least some specialties, many interviews are conducted for each residency and fellowship position. It could be that interviews play a critical role in allowing programs and applicants to assess each other, regardless of the other information they may have. But it could also be that at least some interviews are being conducted "defensively," because all the interviews that others are participating in make it hard for each program or applicant to predict how likely any interview will lead to a position being offered and accepted in the Match. So, it is possible that there is "too much" interviewing, in the sense that in perhaps predictable ways, some programs are interviewing some candidates they can virtually never hire, and some candidates they would never want to hire. Conversely, applicants are interviewing for some jobs they have hardly any chance of being offered, and some they sensibly think they won't need to take. Of course, some things can be

predictable even if they can't be predicted by individual applicants and programs with the information they now have available. It might therefore be possible to suggest institutional reforms that would help reduce the uncertainty in deciding which interviews to offer. That might also reduce the number (and costs) of interviews. (In just such a way, the Match helped solve the problem of uncertainty involved in offers and acceptances, back when offers were exploding.) And there's a possibility that fewer interviews could make everyone better off in terms of expectations, particularly if participants on both sides of the market will feel a reduced need to do so many interviews if everyone else reduces the number they do. But as you say, until we can look into this carefully, I'm just speculating.

Dr. Leopold: *In an era of increasing resource constraints, how might your discoveries help surgeons, practices, or healthcare systems to deliver greater value or to distribute care more fairly across populations?*

Dr. Roth: One thing we've learned from COVID-19 is that some of our supply chains are fragile, so that in emergencies, many things are suddenly in short supply. Another thing is that some of the market and organizational structures that work well for distributing goods and services in ordinary times don't work so well when scarce resources have to be allocated in emergency conditions. Of course, even in ordinary circumstances, allocating scarce resources is not so easy. But in ordinary, non-emergency times, nurses can move to where they are in short supply, and hospitals can purchase personal protective equipment and other supplies more or less as needed. Those systems and others broke down as the pandemic accelerated.

One lesson from market design is that it will help to build in emergency

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options for some of our regular procedures, to kick in when needed, as we do, for example, for the market for electricity [6].

Selling to the highest bidder isn't always acceptable in an emergency, and sometimes not in ordinary times, either. So, to be prepared for the next emergency's shortages, we might learn from some of the domains in which we presently allocate scarce goods without charging for them.

Assigning public school places to students is one of these. In a growing number of American cities, school choice has a good deal of similarity to the workings of the Match, in that a deferred acceptance algorithm is used [1-3].

Allocation of scarce goods without the use of money is at the center of the rapid growth of kidney exchange, which allows patients in need of a transplant, but whose intended donor—a person who loves them—is incompatible, to receive a compatible kidney transplant from another patient's donor [11, 12, 19, 20]. The algorithms that run kidney exchanges not only allow kidneys to be exchanged fairly and efficiently, but help to reduce the shortage of transplantable kidneys by facilitating donations and transplants that otherwise couldn't take place.

Fair and efficient allocation of scarce resources is surely going to be on our minds as new vaccines begin to become available for COVID-19. Allocating places in clinical trials may have some of the same character. In each case, we'll have goods that are at least temporarily scarce, and must be

allocated fairly, while also being made less scarce as quickly as possible [4]

References

1. Abdulkadiroğlu A, Pathak AP, Roth AE. The New York City high school match. *Am Econ Rev*. 2005;95:364-367.
2. Abdulkadiroğlu A, Pathak AP, Roth AE, Sönmez T. The Boston public school match. *Am Econ Rev*. 2005;95:368-371.
3. Abdulkadiroğlu A, Pathak AP, Roth AE. Strategy-proofness versus efficiency in matching with indifferences: redesigning the NYC high school match. *Am Econ Rev*. 2009;99:1954-1978.
4. Ambuehl S, Ockenfels A, Roth AE. Payment in challenge studies from an economics perspective. *J Med Ethics*. 2020;46:831-832.
5. Bernstein J. Not the Last Word: Want to match in an orthopaedic surgery residency? Send a rose to the program director. *Clin Orthop Relat Res*. 2017;475:2845-2849.
6. Cramton P, Ockenfels A, Roth AE, Wilson RB. Borrow crisis tactics to get COVID-19 supplies to where they are needed. *Nature*. 2020;582:334-336.
7. Ferrante E. Economist finds best matches for students and schools. Available at: <https://www.livescience.com/8778-economist-finds-matches-students-schools.html>. Accessed September 25, 2020.
8. Gale D, Shapley LS. College admissions and the stability of marriage. *Am Mathematical Monthly*. 1962;69:9-15.
9. GeeksforGeeks. Stable marriage problem. Available at <https://www.geeksforgeeks.org/stable-marriage-problem/>. Accessed September 25, 2020.
10. North Ohio Paranormal Scientific Society. Lima TB Hospital; Lima, Ohio. Available at <http://www.nopss.com/lima-tb-hospital.html>. Accessed September 25, 2020.
11. Rees MA, Kopke JE, Pelletier RP, et al. A nonsimultaneous, extended, altruistic-donor chain. *N Engl J Med*. 2009;360:1096-1101.
12. Rees MA, Dunn TB, Kuhr CS, et al. Kidney exchange to overcome financial barriers to kidney transplantation. *Am J Transplant*. 2017;17:782-790.
13. Rees-Jones A, Skowronek S. An experimental investigation of preference misrepresentation in the residency match. *Proc Natl Acad Sci U S A*. 2018;115:11471-11476.
14. Robinson S. Tweaking the math to make happier medical marriages. Available at: <https://www.nytimes.com/2004/08/24/science/tweaking-the-math-to-make-happier-medical-marriages.html>. Accessed September 25, 2020.
15. Ronn E. NP-complete stable matching problems. *J Algorithms*. 1990;11:285-304.
16. Roth AE. The economics of matching: stability and incentives. *Mathematics of Operations Res*. 1982;7:617-628.
17. Roth AE. The origins, history, and design of the resident match. *JAMA*. 2003;289:909-912.
18. Roth AE, Peranson E. The redesign of the matching market for American physicians: some engineering aspects of economic design. *Am Econ Rev*. 1999;89:748-780.
19. Roth AE, Sönmez T, Ünver UM. Kidney exchange. *Quarterly J Econ*. 2004;119:457-488.
20. Roth AE, Marino IR, Ekwenna O, et al. Global kidney exchange should expand wisely. *Transpl Int*. 2020;33:985-988.
21. Royal Swedish Academy of Sciences. The prize in economic sciences 2012. Stable matching: theory, evidence, and practical design. Available at: <https://www.nobelprize.org/uploads/2018/06/popular-economicsciences2012.pdf>. Accessed September 25, 2020.
22. Rampell C. 2 from U.S. win Nobel in economics. Available at: <https://www.nytimes.com/2012/10/16/business/economy/alvin-roth-and-llloyd-shapley-win-nobel-in-economic-science.html>. Accessed November 30, 2020.