Using nerve transfer to restore hand and arm function after spinal cord injury - Dr. Ida Fox

Northern New Jersey Spinal Cord Injury System Lecture Series

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JOAN BANKS-SMITH: 00:08

[music] Welcome to Northern New Jersey Spinal Cord Injury Systems lecture series podcast. In this lecture, Dr. Ida Fox presented restoring upper extremity function in cervical spinal cord injury. Dr. Fox is a professor of surgery at Washington University School of Medicine in St. Louis, Missouri. This lecture focused on the current approaches to restoring hand and upper extremity function in people with cervical spinal cord injury. Dr. Fox reviewed the physiology of nerve transfer procedures, strategies for preoperative evaluation, and testing and discussion of choice. In addition, preoperative selection and surgical outcomes, challenges, including practice environment, priorities of rehabilitation, availability of therapy, and outcome space preferences were also discussed. For more information about Dr. Fox, educational objectives, and the summary, more information is in the program notes. This lecture was hosted by Kessler Foundation and the Northern New Jersey Spinal Cord Injury System, which is supported by a grant from the National Institute on Disability, Independent Living, and Rehabilitation Research. NIDILRR grant number, 90SIM0012. NIDILRR is a center within the Administration for Community Living, Department of Health, and Human Services.

IDA FOX: 01:39

Thank you, everybody. I'm delighted and honored to be here, and really appreciate the turnout. It's quite a room full of people, and I look forward to just sharing a little bit to get you interested in this area of our shared field. I do have some closures. It's grant funding. It's directly related to this. And then I do work at the VA as well. And the contents of this work do not represent the views of the US government. So you guys know this better than I do, but spinal cord injury is something that affects a number of people in the United States, and in particular, mid-cervical level spinal cord injuries are a high proportion of this population. At Washington University, many of my colleagues have performed nerve transfers for a variety of other injury patterns, including peripheral nerve and brachial plexus injuries. And we started adapting this [really?] technique or surgical technique or skill set to spinal cord injury about a decade ago. So I'd like to talk to you a little bit about the use of nerve transfers. I'm going to talk about upper extremity reconstruction in general, a little bit of history, physiology, and clinical care.

FOX: 03:01

So spinal cord injury, as you know, affects the spine. It is not peripheral nerve injury, and I think for me, as a hand surgeon, it was really a different concept and really interesting. So some of what I say is peripheral nerve related. Some of it is more relevant to your area of expertise. And please ask if you have questions because there are some differences, and the way I talk about things is often very different from how you talk about things. And I think it's important that we don't get confused in discussing this really interesting physiology that helps us understand workarounds that we can harness in the upper extremity and peripheral nervous system to address a central nervous system disease. So in spinal cord injury, in some cases, the lower motor neuron is intact. That is not true at the level of the spinal cord injury. And that's

really a critical piece of information that I ask you to remember as we go through this lecture.

FOX: 04:05 So again, if there are intact lower motor neurons or if I get to those lower motor neurons in time, I can rescue muscle that is affected and does not function because of the spinal cord injury. And this is different from the paradigm of nerve transfers and peripheral nerve and brachial plexus, where there is always a lower motor neuron injury. And those injury patterns are what we call time sensitive. In spinal cord injury, some patterns may be time sensitive, and sometimes they're not. And this time sensitivity is what makes me want to go around and talk to people because when I see people in the office and I tell them that they're not a candidate for surgery because they waited too long, it really can be a difficult conversation. Traditional tendon transfers are not time sensitive, so that is potentially always a treatment option if it meets the individual's needs and preferences. But nerve transfers as a treatment option may go away as time passes, and that's why I think it's so important to just get information out there.

FOX: 05:17 So as I said, nerve transfers are a technique. It's basically a surgical thing that I'll show you pictures of so you understand, but we take nerves. We swap them over to reroute things that are working, to get things that aren't working to work again. They are used in peripheral nerve patterns of injury and have really been popularized in the last three decades. In the setting of spinal cord injury, it's a little more of an unusual application of this technique. But similarly, it's increasing, and over just the last 10 years that I've been involved in this field, the literature has nearly quadrupled, again, showing great interest and I think also showing the power of using this tool in this field. This article epitomizes this. This was an article written by Natasha van Zyl, who is a hand surgeon in Australia and wrote this proof of concept paper that talked about the use of nerve transfers along with traditional tendon transfers. And I was really honored to write the commentary on that. And I think that's where a lot of interest is coming from.

FOX: 06:33 So I'll go through a little bit of the details of this work and try and give you an idea of what it means, how it's applicable so you know about it and can consider spreading the word if you feel that that's appropriate. So what we do is take a nerve that's working and swap it over to a nerve that isn't. The nerve transfer that my senior colleague, Susan McKinnon, originally was doing in patterns of lower plexus injury really came out of just learning about muscles and physiology and what's possible and knowing those things and being creative. And when we adapted this concept to spinal cord injury, it made us really think about innervation patterns, what's physiologically possible, what gets live axons to where we want them to be in time, and also what makes sense from a rehab perspective, what movements work together and are easy to learn and incorporate in daily life. So one of the transfers is using a branch to one of the three muscles that bends the elbow - that's brachialis - and taking it and putting it into part of the median nerve that goes to bend the thumb and fingers. And that was one of the first papers that came out of our institution on the subject. And this paper, again, by Dr. Susan McKinnon, was one of those just happenstance stories, and I'll share the story because I think it's a really interesting way to think about how we expand care in medicine and think about creativity.

FOX: 08:16

So she's done nerve transfers for years. She had a friend who was a plastic surgeon who had a friend from residency who is a trauma surgeon and had a spinal cord injury on his way driving into a trauma case. He was a gentleman in his 70s. He's agreed to let his name be shared, so I'll call him by name, Dr. Wachtell. He's now deceased. But he was brought by his plastic surgery friend to Dr. McKinnon's clinic, and she said, "I don't do spinal cord injury. I don't know anything about this field." And his friend said, "Oh, think of something you can do, something to help him gain hand function back." And she did, and that's sort of where it started at our institution. And I was able to go visit him at home in Arizona, I think, about five or six years after his nerve transfer. And it's really a subtle change, and I, at first, thought, "This is just not a game changer. He has mostly just tenodesis, but he has a little bit of resting tone that [upticked?] his function." But as somebody who is a clinician surgeon and really thoughtful person, he said, "The difference is that I can do things independently without just using tenodesis. I have this resting tone." And he really felt that there are secondary effects with being able to independently self-feed, being able to drink more independently and easily that he felt decreased his urinary tract infection risk and then his ability to exercise. So because his hands worked a little bit better, he could work out and maintain cardiovascular health. And I think it was pretty profound to think of that perception by one person who was a clinician and researcher about his own body and the changes that developed. And that's what set me on my way to further investigate our outcomes and sort of the secondary effects of this surgical technique.

FOX: 10:13

So I'll get back to pathogenesis. Again, all of you probably know more than I do about spinal cord injury, but I wanted to point out this one concept that the nerve transfer brings. So a nerve transfer-- I'm an upper extremity surgeon. I'm not a neurosurgeon. I do not go into the spinal cord. I simply bypass the spinal cord. So it's really a workaround. I'm out in the arm. I take a nerve that's working, that's under volitional control. And I swap it into a nerve that is not working, that's not under volitional control. And the reason it's not working can be multifactorial. So it can be because that lower motor neuron is within the zone of spinal cord injury, or it can be because that lower motor neuron is below the level of spinal cord injury and the brain simply can't talk to that nerve and muscle. When I do the transfer, I think what's really important and critical to understand is I cut a nerve. So I create a peripheral nerve injury to treat a central nervous system disorder. We know that peripheral nerves do regenerate, but they have to get to muscle in time. So that muscle, if it's denervated for more than a year or two, will become unresponsive, I call it. And we can't reinnervate it. So when I do these nerve transfers, I'm very careful to think about distance because that peripheral nerve regenerates at a millimeter a day or an inch a month. I also want to see if that lower motor neuron is within the zone of spinal cord injury, and that's where some of my research has been directed, and then as I get increased clinical acumen and see things like spasticity, I know those lower motor neurons are preserved. So I think it's just really interesting to focus on that physiology, understand it, and own it and understand the difference between manipulating the central nervous system, the peripheral nervous system, and the physiology that exists. And I'm happy to answer questions about that later.

FOX: 12:12

You guys know the cervical root innervation. What you may not know is what's possible with certain musculotendinous units. So some musculotendinous units are great for tendon transfers, and some are not. So the supinator muscle is a flat, broad muscle. It has two tiny little nerve branches, which are really expendable because biceps is also a supinator. So I can take supinator nerve and swap it over. Supinator does not work to use in tendon transfers because it is that broad, flat muscle with almost no tendon. You can't make it weave into something and do something else, but it is something that is intact up here in mid-cervical level spinal cord injury and incredibly useful for nerve transfers. Similarly, brachialis is a muscle that has been described for tendon transfers, but it's not standard technique because it's a broad, flat insertion without a really good tendon to reach somewhere. You can make it work, but it's hard. It requires a lot of therapy and mobilization and non-weight bearing to make that not [pop apart?]. So there are some technical aspects that influence how we use different expendable things. And I think that's also something I've thought about as a surgeon that you guys might not be as aware of.

FOX: 13:33

This stuff you're much more aware of, knowing which level has which pattern, and then there are these different classification systems. I don't think either of them fit the nerve transfer field well. That's something we need to work on because this-- I call it the-- it's a terrible name, but it is a classification system developed for hand surgeons. And it doesn't take into account the nerve transfer field. So hopefully, we'll update that next year in November when we have the international tetraplegia meeting in Atlanta. You guys know about tenodesis. So for me as a hand surgeon, not having seen a lot of people with spinal cord injury, seen how workarounds occurred using gravity to get the elbow to extend using tenodesis to get the hand to do really amazing things was a learning process, and I think it's incredibly important to look at somebody who's using their hand really successfully and ask, "Well, what are you going to do with the surgery? Are you going to interrupt natural tenodesis? Are you going to make it worse, make it better? Is it worth it? What can we do to think about how we change the movement to either improve function and activities of daily living or not?" And that's, again, another area of interest.

FOX: 14:54

So there are these two different paradigms of injury patterns. It's really important to think about that time sensitivity as you're seeing people if they're considering this option. Ideally, I would say I'd like to see people within about three to six months of injury, evaluate over time, look for plateaus and spontaneous recovery, and consider electrodiagnostic testing because that will help me understand whether they have the option for nerve transfer at any time or whether they would lose that option so they can start thinking about what they would like to do. There are people in other practice settings who are going much more aggressively into early nerve transfer in Brazil and Australia. I think there's really a movement to do nerve transfers. Even, there's a neurosurgeon in Brazil who recommends nerve transfers within a month of surgery-- or sorry, a month of injury or one to three months or even less in some cases. And I think that's probably a little bit controversial and not something that will necessarily happen here in the US. And I talked a little bit about that muscle atrophy over time.

FOX: 16:09 So the traditional surgery in this setting has been tendon transfers. And there are a lot of good options but only if you have those expendable musculotendinous units that can be used for tendon transfers. And as you go sort of down the spinal cord, you notice you get more and more options. But if you're at that higher level, especially if there is only elbow flexion and wrist extension, there aren't as many options for tendon transfers. So to me, another thing about nerve transfers is it opens options for people with a slightly more cephalad pattern of injury who may not be candidates for tendon transfer surgery if, again, that's something that they want and would work out for them. There are other people who have preferences for nerve transfers. They don't want the downtime. They want to do this and not do that. And I think that's, again, all stuff that we need to think about and investigate over time.

FOX: 17:07 So I'll focus a little bit on the options for nerve transfers. I think they're similar to the options for tendon transfers, and basically, we're trying to restore elbow extension, in some cases, trying to restore wrist extension, but I'll talk a little bit, especially this afternoon, about the limits on that. And then really, hand closing and opening, I think, it's a critical thing we can do. I really like using nerve transfers to restore elbow extension because I do not have access to the type of rehab facility you have here, and it's really hard to do the immobilization and send somebody home with a tendon transfer to restore elbow extension because of the positioning with the elbow extended and the need to kind of safely do transfers and protect that. It does work well in some practice settings, where there is more access to care and therapy. But that's not necessarily my setting. Whereas with the nerve transfer, I let people go home. They can bend their elbow. There's no splint, no cast, and no real immobilization. There is non-weight bearing. And that's what I'll say about nerve and tendon transfers, and I kind of get in trouble. The tendon transfers are really tried and true and do really work. So I would not necessarily say they rupture or stretch out over time although that can certainly happen. I think the big difference is in that first three months, where there's much more of a limit on activities of daily living if a tendon transfer is performed compared to a nerve transfer. Is that period worth it? A lot of people in a lot of studies have said yes. And I think that's very true of countries like Switzerland, where people get inpatient therapy after a tendon transfer. It is amazing. But here, at least in my practice setting, I'm usually sending people home with a splinter cast. They get a couple of visits of therapy and not the type of intensive rehab that really makes tendon transfers do well.

FOX: 19:06 Next, I was just going to touch on electrodiagnostic studies. There's a lot more that can go into the preoperative evaluation. I'll talk about that this afternoon. But some of my work has been focused on trying to see if there's anything that can predict that zone of lower motor neuron injury, and I talked to our neurologists at Washington University, who are super smart. And we kind of developed an algorithm and then have looked at that in predicting not just the intraoperative stimulation, which tells us if that lower motor neuron is intact, but now trying to look a little bit more at long-term outcomes and whether some of this can predict our outcomes. And what we find is nerve conduction studies do a really good job of providing quantitative data about the sort of health of the lower motor neuron. Surface electrical stimulation doesn't provide as much detail, I think, although that's something other people have

proposed. Ultrasound can provide some information about the muscle health below the spinal cord injury, and I'd certainly be interested in hearing the thoughts of all the people here and researchers about other testing that can be done.

FOX: 20:22 Once we have that information, we talk about different things. Obviously, we want to focus on overall health and suitability to undergo general anesthetics. Some of these surgeries can take several hours, and so I want to be sure that cardiopulmonary skin and other health is under good management before doing this really elective surgery. And then at least for me and the residents that I train, I think knowing about keeping people warm, avoiding complications with skin issues, and also recognizing and treating autonomic dysreflexia was important, and then finally, rehab. While I said that rehab can be easier after nerve transfers in some ways, getting a good outcome does take motor reeducation and time. And that's probably the biggest downside. So the nerve grows down the new path. The brain has to figure it out. The muscle has to strengthen from grade zero to grade whatever we get. And that really seems to take a long time, especially if the distance is long. Some of the transfers work really well and are really intuitive, but the transfer for hand closing can take a long time, and transfers in people who are further out from spinal cord injury seem to have more mixed results.

FOX: 21:44 This just shows sort of the co-contracture and what the therapy entails. So this is someone who had the supinator transfer to the posterior interosseous nerve to restore hand opening. You can see the therapist is resisting forearm supination on the video to your left, and there's that nice hand opening of the thumb and fingers primarily at the MP joints because we are restoring the extrinsic extensors. But I have noticed in some individuals, they get a little pull-through of their IP joints as well, and it really gives a pretty amazing hand opening. The hand closing is, again, a little bit of a challenge. It's a transfer that takes place further from the recipient muscle belly. And so there's a long path of regeneration, and it really does require a lot more therapy of elbow flexion and hand closing. I think it augments tenodesis, but I and the people who do the early nerve transfers have gotten measurable pinch and grip in some cases. We looked a little bit and did a retrospective review of some of our work and had some nerve specimens as part of the study. And so we were able to kind of prove that the recipient lower motor neuron in people with retained intact nerve conduction studies was intact and did successfully, as I said, get function back, and that was a really important, I think, study, and also, we've pushed the envelope.

FOX: 23:18 So recipient nerves, you have to reinnervate a certain number of fibers. There's been work that shows you need 20% of fibers to get enough juice, I call it, but I think we're pushing that envelope, and we've had some big discrepancies in the donor brachialis to the recipient AIN, especially when we add FDS. And I've had some pretty good outcomes despite the donor being relatively, what I call, puny or small with a few fibers. And that's incredibly true of supinator to PIN. So you're asking supinator, which are these tiny little nerves, to go into all of the nerves to the thumb and finger extensors as well as abductor pollicis longus, and you get really fantastic function. So again, I think we have a lot to learn about that, and I'll just kind of gloss over that because we're running out of time. The reasons to do these transfers is because

improvements in hand function directly lead to improvements in function and independence. This was another study we did looking at the MSKI database.

FOX: 24:25

So in Europe, they have prospectively collected various outcomes, measures, [MSKI?] exam over time, skin measurements, and other information. And we did an analysis that looked at individuals who had bilateral motor C6 versus bilateral motor C7 and unilateral on various combinations and really found that function improves with greater gains in hand motion in particular. And this changes over time. So we also try to look at recovery over time. And we had quite a few numbers. So this is prospectively collected information. We had almost 300 people with data from 6 to 12 months post spinal cord injury and 450 limbs. And we found that spontaneous recovery really drops off between that 6- to 12-month time point. And that's when we really want to think about nerve transfers. And as I said, in individuals who have, say, C6 versus C7 versus C8, we really see that hand function or C8 motor level really improves [self-feeding?] urinary function, which you would think of, but also mobility and the ability to [transfer?] because [of?] the ability to reach out, grasp, and hold onto the side rail.

FOX: 25:57

And then in terms of spontaneous recovery, we then looked at limbs and, again, tried to divide sort of what we would consider meaningful recovery, so grade three or more or grade four or five on manual muscle testing. And what we found is that recovery occurs spontaneously in a high proportion of individuals who do not have wrist [extension 6 months?]. 30% get it back at 12 months. Elbow extension similarly has a fairly good proportion of spontaneous recovery. 20% of limbs without elbow extension get it back at 12 months. But when you go down to finger flexion, only 13% of individuals with no meaningful finger flexion at 6 months gain it at 12 months. And again, that's an area that we can intervene successfully with nerve transfers and I think putting this information out there and having individuals consider if they are a gambling person or they'd rather wait for spontaneous recovery. I think other things, when I talk to somebody who's considering all these options, is I'll say, "Listen. You have good options for tendon transfers. Waiting makes sense." Or I'll see somebody and say, "Hey, there aren't really any tendon transfer options. Let's get electrodiagnostic studies," and then I'll say, "Okay. Well, electrodiagnostic studies show that you have a nontime-sensitive pattern. You can take your time," or, "They do show you have a time sensitive pattern. And if you want to retain this as a treatment option, you might consider thinking about this early." So I think just getting that information out there and letting people make decisions is important. I'm not trying to force people to do surgery that they don't want to. I just want to provide the information so they don't lose the opportunity if they do want to, if that makes sense.

FOX: 27:49

And then again, just kind of reiterating the options with nerve transfer, I take a branch of the axillary nerve that goes to posterior deltoid. A lot of times, there are some redundancies. So sometimes when I go in, I'll see two branches, one that divides to go to middle and posterior deltoid. I can save one branch so people really do retain that donor site function and take the other branch and go into some triceps branches that aren't working and restore elbow extension. This is a surgery. I won't show you too many pictures. I know some of you are eating and you're not all surgeons, but I think it's really important to know what these nerves look like and the fact that we're

just swapping around these little pieces of, what I call, spaghetti like this, and there's not tension on it. So somebody can move their arm immediately. And it's very different from a tendon transfer.

FOX: 28:42 And then these just show some of the results. It does take a really long time. But this is an individual who is over two years out, and he was able to successfully get elbow extension. It's anti-gravity. It is not strong, but I have had other individuals, especially people that I've intervened on early, who get much stronger function. This is that supinator to posterior interosseous nerve. I showed you an example of that. Again, it's two very small nerve branches to a muscle that I can't use successfully for much else and is often intact and working in people with C5 and 6-level injury. And so I swap that over to get hand opening. And that transfer is pretty intuitive to learn and pretty effective, almost too much. So the therapists I work for worries that were helping people with too much hand opening, and they have trouble with hand closing, which we have seen in a couple of cases. But you can see that pretty amazing hand opening even with the wrist held in neutral, so it's not tenodesis, but it is that new function.

FOX: 29:52 And then finally, that transfer for hand closing, I'm doing it way up high. It's going to the muscles in the forearm. So there's a long way to get to the target for regeneration. I go in. I find branches to the brachialis nerve, which bends the elbow, and then I pick up part of the median nerve and specifically go into fascicles that aren't working. And I think it's really important to note that if pronator teres is working or FCR for wrist flexion is working, I can know that in my pre-op exam, know they're under volitional control, and actually separate that nerve, pick out the branches, and find what I want to go into. It's a little bit harder to see the difference with the sensory fascicles, and I have had some individuals get numbness, tingling, and burning pain. It usually settles down over time. And then this is just the intraoperative stimulation showing that the lower motor neuron in this individual is intact. I'm tapping on it with a handheld electrical stimulator. It's not under volitional control, but that nerve-to-muscle connection is working. There's neurotransmitters there, so I can stimulate. In 72 hours, the neurotransmitters are gone, but my new nerve branch is kind of percolating along that new path, growing down at an inch a month and will hopefully get us function back in time. And again, these are done under absolutely no tension. I've had some problems with seroma, so I tell people to take it easy and not work out or use a manual wheelchair if they use their arms to pull up. But they don't need a splint or a cast. And it's a huge difference.

FOX: 31:26 And then this just shows some preoperative, and you can see it's pretty stiff. There's not a lot of motion. This guy, I actually didn't see for several years, and this was his outcome, which I thought was terrible. He was 12 years post-SCI when I did his surgery, didn't really use that right hand for very much because his left hand was so functional. He started to get some motion at one and a half years out, and then I ran into him in the elevator bank at four years post-op, and he had really gained quite a bit of function with his right hand. And so without using tenodesis on the right side, he could come down, bend the thumb, bend the fingers. He did not have the hand-opening procedure because I wasn't doing that at that time. We went back and tested him, and he wasn't a candidate for late hand-opening surgery. And then this just

shows the other individual who had both nerve transfers, hand opening and then closing, a little bit of augmented tenodesis, and then just kind of showing some activities of daily living or being able to open the medicine jar. Yes, sir, rubber bands. No, it's not strong. It's not like a tendon transfer, but it's something more than he had had previously and was able to do independently.

FOX: 32:51

So that sort of talks about nerve transfers. Tendon transfers are tried and true. I'm not going to go into that a lot, but you can see that this is a little bit of a different surgery. It's a bit fussy. There's a lot of little parts. There's a lot of splinting that is required after surgery to keep that and protect it. But you can get pretty amazing function with those strong function, strong pinch, and grip. And I won't go into that. And then as I said, I think the downstream effects are incredibly important and really require a long-term view. We're working on our outcomes measures. I know that's a field that's really tough across all sorts of disciplines within this and other fields, but I think looking at [inaudible] perceptions of what happens, gains in motion, gains in independent ability to use the hand for activities of daily living, and all of those things are really important. And then just comparing nerve and tendon transfers is sort of a work that's ongoing, that I'm doing with my team. Figuring out the clinical algorithm and improving function and restoring the ability to do things that people weren't able to do prior to surgery, I think, is our goal. Thank you. [applause]

BANKS-SMITH: 34:26

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