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Interlacing and Unweaving the Brachial Plexus: A Visual Demonstration Highlighting Form and Function

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Abstract

What happens when an individual spinal nerve is damaged or severed? The loss of function upon nerve damage is a straightforward concept to understand. But what if that spinal nerve contributes to the brachial plexus? The brachial plexus can be an intimidating structure for students, but this structure is also rich in regional anatomy connotations with physical redistribution related to its function. Thus, teaching the parts of the brachial plexus and how it gives rise to its five main terminal nerves innervating different regions of the upper limb has great utility in undergraduate human anatomy education taught with a regional approach. Low-fidelity models, while being limited in their comprehensive utility, are effective tools to help convey essential concepts in the form and function of select structures. Presented here is a demonstration which uses strings and shoelaces to be braided in class to engage students, trigger responses to posed questions, and convey the importance of spinal nerve redistribution within a nervous plexus. After performing this short activity, students voluntarily responded to a questionnaire and provided qualitative one-word descriptions or short reflection statements for assessment. Overall, this activity was highlighted as "visual", "helpful", and that they "understand" the brachial plexus structure with positive agreement in recognizing the importance of redistributing spinal nerves within the brachial plexus—to prevent full paralysis of a given limb region upon individual spinal nerve damage. https://doi.org/10.21692/haps.2024.017

Key words: undergraduate education, anatomy models, active learning, brachial plexus, low-fidelity models

Introduction

Low-fidelity models have been part of human anatomy instruction for centuries (or possibly millennia), dating well back to periods when gross dissection was highly limited and wax, wooden, or plastic models became important for training in various health professions (Marković & Marković-Živković, 2010). Low-fidelity models in use today have been successfully implemented to convey anatomical development or the final structure of several complex anatomical features using an incredible variety of materials and methods, including crocheted embryonic germ layers (McConnell & Mooney, 2021), aprons for highlighting mesentery position (Chan, 2010; Noël, 2013) or abdominal organ peritoneal placement (Chan, 2010), cut boxes with strings simulating the inguinal canal (Hindmarch et al., 2020), hair bands and gloves to map tendons and muscles along the digits (Cloud et al., 2010; Lisk et al., 2015), and clay used in anything from cross-sections to heart vasculature (Oh et al., 2009). Low-fidelity models can still be highly complex and involve large scale modeling like equine anatomy reconstruction (Bietzk et al., 2019; Leandro et al., 2019), highly personalized, as with body painting (McMenamin, 2008; Cookson et al., 2018), or highly intricate, as in pipe cleaner tying approaches used to model the brachial plexus (Lefroy et al., 2011; Yu & Husmann, 2021).

While some points have been raised regarding the use of only high-fidelity models (Nayak & Soumya, 2020), several studies have supported the use of adding low-fidelity instruction to aid programs already providing multiple resources as a means to supplement learning and incorporate active learning strategies with observable

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benefit (Chan & Cheng, 2011, 2020; Chytas et al., 2022; Collins, 2008; Sugand et al., 2010). Furthermore, the greater the variety of teaching strategies and tools utilized beyond lecturing alone, from model demonstration to dissection, the greater the enhancement of overall student engagement and learning (Collins, 2008; Sugand et al., 2010). This article describes a demonstrative activity for the brachial plexus intended for an undergraduate class; the materials and time allotment are minimal as the students also require review of high-fidelity models for later examination.

The textbook used for undergraduate instruction at the University of Wisconsin–Stevens Point, refers to the brachial plexus as the "anatomy student's nightmare" (Marieb et al., 2016, p. 447). Explaining the spinal nerve contributions, overall position, and function of the brachial plexus with its five main terminal branches can be challenging. These structures were reviewed in the laboratory using high-fidelity models (i.e., SOMSO® models BS3, BS31, or NS15) in addition to reading assignments provided to students in the aforementioned textbook. Additional use of a low-fidelity model with an active learning demonstration augmented this instruction by highlighting a critical component otherwise often missed – that redistribution of spinal nerves prevents full paralysis of a given limb region when an individual spinal nerve becomes damaged.

All spinal nerves were assembled using a set of shoelaces and corrugated ribbons taped onto the front board in the classroom; anterior and posterior divisions were delineated per nerve by making dark and light sets per spinal nerve. These nerves were then braided together into the different trunks, cords, and five main terminal nerve branches: the axillary, radial, musculocutaneous, median, and ulnar nerves. Using this string-based model over the past ten years has consistently led to in-class engagement with the correct answers when posing questions about what happens if individual spinal nerves are severed or damaged. Similar models have been frequently made by others using pipe cleaners (Lefroy et al., 2011; Yu & Husmann, 2021), which do have great utility in conveying how spinal nerves are distributed within the brachial plexus. However, there is a key to this demonstration, in both form and function, using a string-based analogy and model that pipe cleaner-based models lack – a quick visualization of spinal nerve damage.

At the end of assembling the five main terminal nerves arising from the brachial plexus, select spinal nerves were "severed." While some terminal nerve branches were impacted more than others, there was a lack of total loss for any one of these five nerves. Thus, this string-based modeling activity not only conveys the structural features of the brachial plexus, but also provides a visual analogy for one of its most important functions: prevention of full paralysis to the different regions of the upper limb (or other areas innervated by a plexus), even if there is spinal nerve damage. At this stage, a greater discussion of common forms of nerve damage can take place.

Pathologies commonly involving individual cervical spinal nerves include impingement due to inflammation or intervertebral foramen stenosis. The cervical vertebral column can present with age-related degenerative disc pathologies such as cervical spondylolisthesis with subsequent narrowing from disc height loss (Iyer & Kim, 2016). The vulnerability of cervical nerve roots can also be highlighted as they lack significant protection from the dura mater or epineurium, but that tractional injuries would likely involve multiple nerves (Rubin, 2020). Clavicular crushing or other traumatic injuries influencing overall plexus function should also be impressed upon students (Rubin, 2020), and this could provide an opportunity to remind students to evenly distribute one's back-pack weight or select roller bag options.

Learning Objectives of the Brachial Plexus Demonstration

- Recognize how spinal nerves are redistributed within a plexus.
- Distinguish between anterior and posterior divisions of spinal nerves, including the placement of cords along the axillary artery.
- Explain how nerve divisions segregate into different functional muscle compartments and innervate muscles of similar function.
- Evaluate the impact of individual spinal nerve damage versus plexus damage on limb function.
- Recall the specific spinal nerve distributions to the individual five terminal branches of the brachial plexus.

Aims of the Data Collected Post-Demonstration

- Assess if the demonstration provided an added benefit beyond other available resources.
- Assess if the demonstration promoted understanding of the brachial plexus structure and its five main terminal nerve branches.
- Evaluate if students understood the importance of spinal nerve redistribution within a plexus and how this structural rearrangement can prevent full paralysis to a given area upon individual spinal nerve damage.

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Materials and Methods

In addition to the information provided below, in the video shown above that can be accessed at this link (https://www.youtube.com/watch?v=rNZleeFkPs4), I describe important points to consider when reproducing this demonstration in class.

Briefly, gather the following materials, with assembly as shown in Figure 1A.

- A multi-colored pack of shoelaces (with at least 5 different, preferably darker, colors)
- A multi-colored pack of corrugated/ribbed ribbons commonly used in gift wrapping (with at least 4 different lighter colors, preferably matched to the color combinations obtained in the pack of shoelaces)
- Clear tape, packing tape, scissors, ~8-10 small binder clips (15-20 mm)
- Markers and/or chalk (depending upon one's classroom set-up), and
- An undergraduate student audience (preferably in a lab setting) with volunteers willing to provide anonymous feedback to a questionnaire.
    - This demonstration was performed in front of two lab sections taught in the same term. A total of 34 students were retained through the topics involving upper limb regional anatomy when this demonstration was given. Both lab sections and the corresponding lecture were taught by the same instructor (the author).
    - The students who watched the demonstration and who were asked to provide anonymous feedback for the term in which data was collected included students majoring in: health sciences (56%), biochemistry or biology (26%), or other fields (3-6% for all other individual majors). Of these students, 24% had additionally self-identified as being on a pre-medicine, pre-physicians assistant, or pre-nursing professional track. Most students (41%) were seniors, while the remaining 59% of students were evenly split between juniors and sophomores based upon class standing at the start of the term. However, no specific ages or other demographics were collected. Given the anonymity involved, it is unknown what proportions of the students having declared different pre-professional tracks or majors provided feedback.
    - The institutional review board (IRB) assessed the experimental design. Student anonymity was maintained throughout the data collection process and all feedback was provided voluntarily without incentive (not even extra credit). Also, students were given the option to declare permission (or not) to have their feedback used for publication purposes; no student selected the option to have their feedback rescinded for publication purposes. Therefore, the IRB designated this study as exempt from a formal human subject research protocol.

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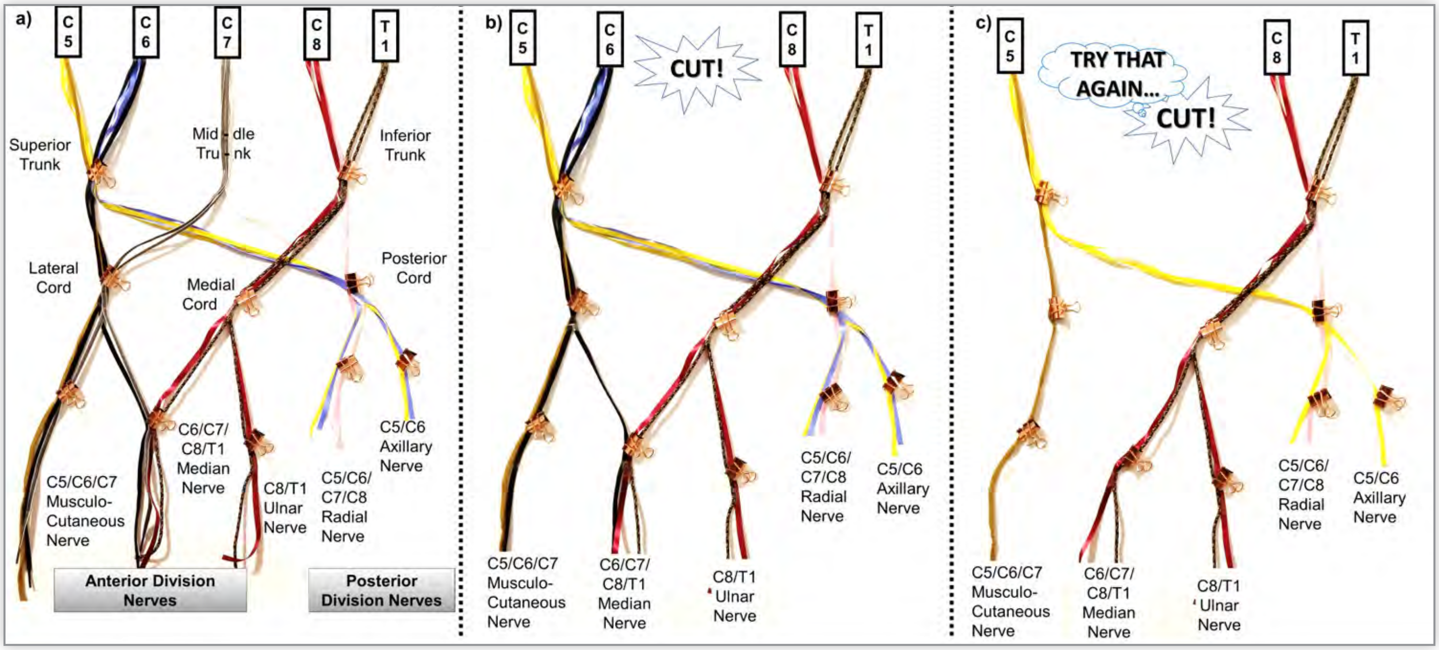

Figure 1. *(A) Assembled brachial plexus. (B) Removal of the C7 spinal nerve. (C) Severance of a second contributing spinal nerve (C6).*

Instructions, in Brief

Assemble the spinal nerves with dark and light color combinations (delineating anterior and posterior divisions, respectively) as shown in Figure 1A. Braid together the laces and strings to form the trunks, cords, and five main terminal nerve branches of the brachial plexus (Figure 1A). "Sever" a spinal nerve, like C7 (Figure 1B) and ask the class, "What just happened?". Carefully pull the corresponding lace/string bundle for that nerve out of the assemblage to reveal that all five terminal branches remain. Repeat as desired, as shown for C6 (Figure 1C). Take this opportunity to discuss differences between injury to individual spinal nerves, common forms of individual cervical spinal nerve injury (i.e., cervical radiculopathy including age-related cervical spondylolisthesis), and compare these injuries to damage of the brachial plexus as a whole and/or damage to the five main terminal branches after they have formed (Iyer & Kim, 2016; Rubin, 2020).

Assessment

Students were provided with a questionnaire (Appendix 1) to complete in a purely anonymous and voluntary manner (no incentives were provided for participation). Students whose responses indicated that they were both present for this demonstration, and that they consented to provide feedback for potential publication of results (100% of volunteers who identified as being present for this demonstration), were assessed further. Likert-scale responses to the questions are reported with averages and standard deviations using the data from 18 qualifying respondents. Short descriptive feedback and elaboration with additional comments were further assessed to assemble key terms in a word cloud (https://www.wordclouds.com/). Words or phrases appear in proportion to their occurrence in the assembled graphic (depending upon word length, letter height, and fit to the cloud-form graphic chosen). A comparable word cloud was generated by a colleague using the same software to confirm that similar results were obtained without the introduction of bias.

Additional qualitative data thematic analysis was conducted (Guest et al., 2012). Terms were tagged by theme, as shown in Figure 2, using both Dovetail 3.0 (https://dovetail.com/#recruit) and Taguette (Rampin and Rampin, 2021) qualitative thematic software platforms. Similar results with slight variation were obtained using the indicated coded tags; graphical information was generated using the Dovetail 3.0 platform, while tabular information was modified from Taguette platform output files.

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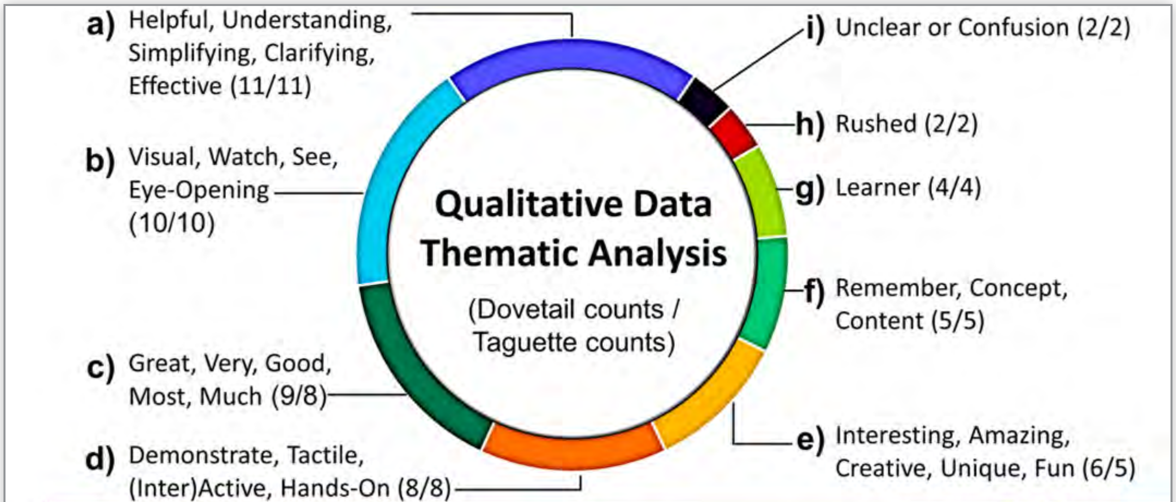

		Tagged Term(s)	Tag Category Description	Total Counts Dovetail	Total Counts Taguette
a)	Positive Feedback	Helpful, Understanding, Simplifying, Clarifying, Effective	Comments on how the activity was helpful, improved understanding, added clarity, effectiveness, and simplification of the brachial plexus	11	11
b)	Positive Feedback	Visual, Watch, See, Eye-Opening	Descriptions of visualization or seeing the activity	10	10
c)	Positive Feedback	Great, Very, Good, Most, Much	Positive descriptions about the activity or form of learning	9	8
d)	Positive Feedback	Demonstrate, Tactile, Hands-on, (Inter)Active	Recognizing the demonstration or activity with interactive learning connotation and/or tactile, hands-on component	8	8
e)	Positive Feedback	Interesting, Amazing, Creative, Unique, Fun	Descriptions highlighting enjoyment of the activity	6	5
f)	Positive Feedback	Remember, Concept, Content	Remembering or recognizing the importance or overall concept of the brachial plexus	5	5
g)	Positive Feedback	Learner	Describing their learning style or how they learned through this activity	4	4
h)	Negative	Rushed	Indication that the activity was negatively viewed given the time set to understand the topic	2	2
i)	Negative	Unclear or Confusion	A description of desiring additional context or further depth	2	2

Figure 2. *Tagging of student written responses according to the categories listed in the associated table. The frequency of these terms relative to total tag counts are shown in the ring graphic generated using Dovetail platform 3.0. Tabular information was generated with modification to incorporate results of both platforms using Taguette.*

Since both Dovetail 3.0 and Taguette still analyze data with user-defined codes, this data was also uploaded to the YesChatGPT40 platform for artificial intelligence analysis (https://www.yeschat.ai/blog-gpt4-free), allowing an overall thematic summary to be generated.

Results

A total of 18 students provided feedback on the brachial plexus demonstration (Figure 3). Their responses to the Likert-based questions indicated that they found the brachial plexus to be, in general, a complex anatomical structure (4.22 ± 0.79). Meanwhile, their feedback indicated that the demonstration helped them in their understanding of how a plexus can redistribute nerves to prevent full paralysis to a particular region (4.72 ± 0.56) and that this activity was more effective in teaching them about the brachial plexus than the corresponding reading in the textbook (4.76 ± 0.55). If the results of the first question are "inverted" (Figure 3, orange bar), then those results could serve as a baseline for a rough comparison to observed improvements in student understanding. Thus, if students strongly disagreed that the brachial plexus was *not* a complex anatomical structure (1.78±0.79), then clarity of the brachial plexus after the demonstration improved roughly 2.5-to-2.7-fold. Since the first question, however, was not originally asked in this manner, it remains unclear if this perceived relative improvement would be appropriately assessed using further statistical analysis.

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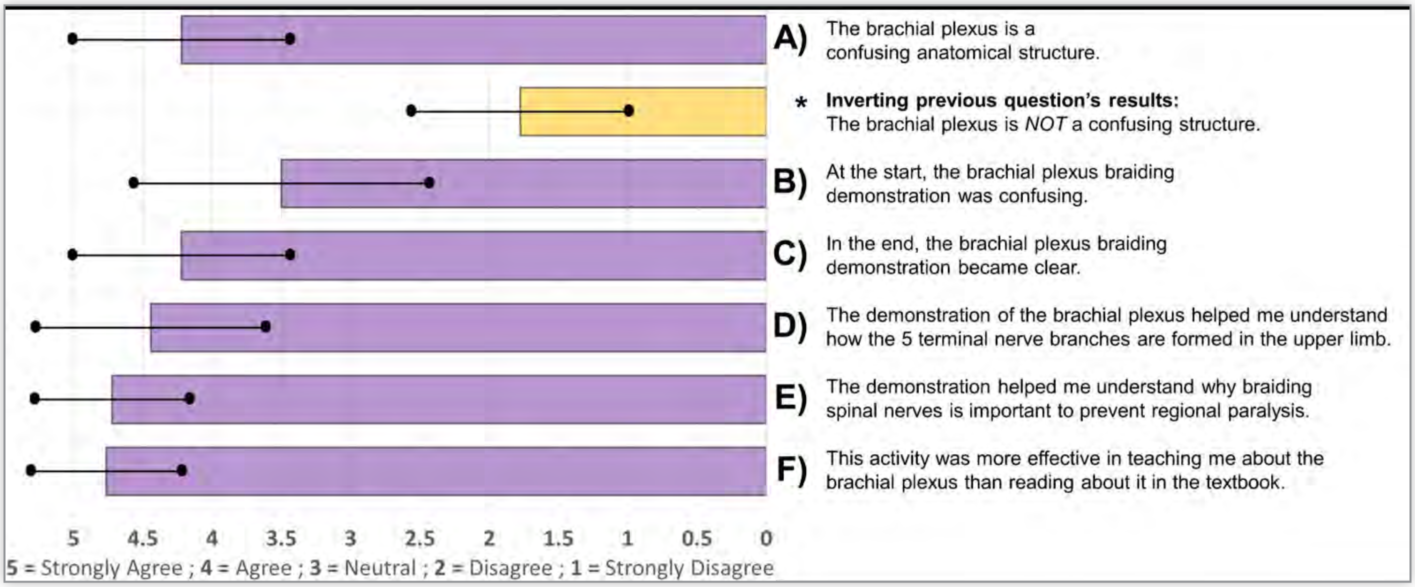

Figure 3. *Students were requested to provide responses to the indicated questions on a purely voluntary basis. Their answers were tabulated using the indicated Likert scale under strict anonymity. Average scores (± SD) on Likert-based questions from 18 participants (purple bars). The results of students' impression of the brachial plexus were inverted for comparison (orange bar) to assess shifts in clarity after the demonstration.*

One-word descriptive responses and short additional comments were assessed for key words and phrases as a word cloud (Figure 4A. Altogether, 33 words or short phrases with descriptive assessment were collated to 22 words. The most frequently occurring terms were "visual" (used 7 times), "helpful" (used 4 times), "understand", and "great" (each used twice). All remaining words appeared once in the provided feedback. Of the terms provided, only "rushed" (used 1 time, and described as "more time" being requested) was considered negative feedback. To eliminate assessment bias, the written results of these questionnaires were independently assessed by a colleague and a second, fairly similar word cloud was obtained (Figure 4B).

Figure 4. *(A) Word cloud generated in which words sizes are proportional to their occurrence in student feedback. (B). A separate word cloud was generated by a colleague to verify that similar results were obtained using scanned copies of the anonymized questionnaires.*

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Overall, of the highlighted tags using Dovetail and Taguette platforms, there were 53 and 51 positive feedback tags, respectively, and only 4 negative feedback attributes for either platform (Figure 2). The largest category tagged involved descriptions of being either helpful, (improving) understanding, and simplifying/clarifying the brachial plexus. Differences in the exact totals are attributed to how terms/codes could be highlighted using each interface. Codes were still formally defined by the researcher.

To evaluate themes coded using artificial intelligence and further reduce potential bias, all text from the questionnaire results was uploaded onto the YesGPT40 platform. The summary generated was consistent with the associated tags, including both summarized positive feedback, some suggestions for improvement, and included an overall summary of the merits of this activity (Figure 5).

Discussion

Altogether the results of the questionnaire indicate student appreciation of this low-fidelity model and in-class activity. Responses indicate that the demonstration was helpful in understanding both the anatomical form of the brachial plexus as well as its function to prevent full paralysis to a particular region of the upper limb. Routes of "severing" or otherwise damaging a spinal nerve, while not formally evaluated in this questionnaire, have repeatedly triggered recognition of plexus function during and after the demonstration. Students will often recognize or even volunteer responses in class regarding the problem-solving aspect of this activity, namely a request of what would happen should one or two spinal nerves become damaged.

Written Feedback Thematic Analysis using Artificial Intelligence

- All written text from evaluated questionnaires were loaded into the YesChatGPT40 platform.
- The summary output in its raw form is indicated below.

YesChatGPT4o

It seems like you've provided a series of reflections or feedback, possibly on a learning activity or demonstration related to the brachial plexus. Here's a summary of the key points and themes:

Positive Feedback:

- **Effective for Visual Learners:** Multiple mentions of how the demonstration was clarifying, helpful, and allowed concepts to "click" for visual learners.
- **Interactive and Engaging:** Described as fun, creative, and interactive, making the learning experience unique and memorable.
- **Tactile Learning Benefits:** Highlighted as effective for tactile learners, emphasizing the value of hands-on activities.

Suggestions for Improvement:

- **More Detail on Nerves:** Some feedback suggests a need for more time or focus on the nerves, especially their arrangement and connection.
- **Pacing:** Noted that the session felt rushed, particularly toward the end, which may have impacted comprehension.

Overall Impact:

- The activity was described as eye-opening, simplifying, and a great way to visualize and understand the brachial plexus's structure and function.

Figure 5. *The raw, written feedback data from the questionnaires was uploaded to an artificial intelligence platform to assess a non-user generated thematic analysis (YesChatGPT40). The positive feedback, suggestions for improvement, and overall impact are consistent with the results of other qualitative analyses.*

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While this demonstration is less robust than the pipe cleaner-based demonstrations described by Lefroy et al. (2011) or Yu & Hussmann (2021), it does provide an in-class critical thinking framework with minimal class-time use (usually under 15 minutes) as well as inexpensive materials which can be reused for multiple future demonstrations. This approach, while not intended to be a replacement altogether of the high-fidelity models subsequently studied in the human anatomy laboratory, is an inexpensive way to highlight a complex anatomical structure in both its form and function while also driving home the key features of the terminal nerves and the importance of braiding/redistributing spinal nerves when they develop. This demonstration further sets up the class to recall these concepts in later units, discussing the importance of the phrenic nerve arising off of the cervical plexus, as well as in upper-level courses involving cadaveric dissection (not formally evaluated at present).

Limitations of the Study

This demonstration is intended for an upper-level, undergraduate human anatomy course taught in a regional manner. It is likely too advanced for a systems-based, introductory-level undergraduate human anatomy course, which would likely neither discuss brachial plexus components like the roots, trunks, or cords, nor discuss the regional positioning relative to the axillary artery. This demonstration has some limited utility for an advanced undergraduate human anatomy course involving gross dissection, as the median nerve of the model closely resembles the formation of the median nerve anteriorly along the axillary artery with medial and lateral cord contributions. However, this activity concurrent with dissection labs was not assessed in the more advanced undergraduate or graduate courses also provided at UWSP.

It should also be noted that this demonstration does not incorporate more intricate detailing of the brachial plexus, as its intent is to highlight the "what-if" scenario of severing (or otherwise damaging) an individual cervical spinal nerve. Namely, it does not incorporate possible communication of the C7 spinal nerve to the ulnar nerve, it does not include branches arising from roots or trunks (i.e., the long thoracic nerve or the suprascapular nerve), it does not readily provide for additional spinal nerve contributions which are variably reported (i.e., the C5 spinal nerve may also contribute to the median nerve depending upon the individual assessed in dissection), nor does it provide the three-dimensional relationships the way that other models might (Lefroy et al., 2011; Yu & Husmann, 2021).

While this demonstration highlights how multiple spinal nerves braided together contribute to multiple terminal nerve branches of the brachial plexus and prevent full paralysis to a region should one of the spinal nerves become damaged, it is far more frequent to observe injury to components past these brachial plexus roots (Iyer & Kim, 2016; Rubin, 2020). Discussing other forms of injury of terminal nerve branches (i.e., humeral fractures, cubital and/or carpal tunnel syndromes), impingement or traumatic impact associated with divisions and/or cords (i.e., compression injuries or advanced lung/breast neoplastic growth impinging upon the plexus), injuries involving multiple spinal nerves, (i.e., stretching/traction injuries), or specific trunk injuries (i.e., thoracic outlet syndrome) are warranted for comparison (Marieb et al., 2016; Rubin, 2020). Despite these limitations, the "severing" aspect of the demonstration still holds utility, provided these caveats are acknowledged along with specific examples of how individual spinal nerves could be damaged (i.e., age-related cervical radiculopathy from intervertebral disc compression, spondylolisthesis, and intervertebral foramina stenosis, as well as increased risk of lung cancer or breast cancer malignant growths regionally) (Iyer & Kim, 2016; Rubin, 2020).

Additionally, this demonstration, while used multiple times over the years, has only formally been assessed recently by one cohort in an assessment not correlated to post-demonstration performance in brachial plexus component recognition. Likewise, the discussions with students completing an advanced human anatomy section relating to this string-based demonstration are anecdotal at present, as it has not had the opportunity for uniform assessment since the hiatus taken during the pandemic between 2020 up to 2022. It will be useful to assess the utility of this demonstration if repeated for students who had previously seen it and those who did not previously see it (either due to transfer circumstances or to a prior class absence), and then see if there are noted differences in appreciation for how a brachial plexus is formed, as well as whether or not students can readily identify its contributing parts.

Conclusions

Altogether, the interlacing and subsequent unweaving of the brachial plexus using shoelaces and corrugated/ribbed ribbons demonstrates utility in teaching the brachial plexus components and their functions. This low cost, minimal time-requiring activity is a useful supplement to readings and high-fidelity models also employed in class. Additional evaluation is of interest to explore retention pre- and post-demonstration regarding terminal nerve's anterior/posterior division correlation, spinal nerve contribution, and other possible critical thinking scenarios involving severing of nerves. Assessment of this demonstration's utility at the level of gross dissection is also warranted.

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Appendix 1. Brachial Plexus Questionaire

You are not required to complete this questionnaire. Your answers to the following questions and your comments are entirely voluntary. If you choose to provide feedback regarding the brachial plexus demonstration, I will incorporate your responses into a teaching methods publication. Please provide feedback anonymously. Circle numbers or terms as needed and fill in comments if you have any.

1) Do you consent to provide feedback for the brachial plexus demonstration, which will be used in a teaching methods publication? YES / NO

2) Did you see the brachial plexus demonstration? YES / NO

3) Did you enjoy watching the brachial plexus demonstration? YES / NO

4) Please respond to the following statements using a scale of 1-5 (1= strongly disagree, 2 = disagree, 3 = neutral, 4 = agree, 5 = strongly agree):

   a) The brachial plexus is a confusing anatomical structure. 1 / 2 / 3 / 4 / 5

   b) At the start, the brachial plexus braiding demonstration was confusing. 1 / 2 / 3 / 4 / 5

   c) The demonstration of the brachial plexus helped me understand how the 5 terminal nerve branches are formed in the upper limb. 1 / 2 / 3 / 4 / 5

   d) The demonstration helped me understand why braiding spinal nerves is important to prevent regional paralysis. 1 / 2 / 3 / 4 / 5

   e) This activity was more effective in teaching me about the brachial plexus than reading about it in the textbook. 1 / 2 / 3 / 4 / 5

   f) In the end, the brachial plexus braiding demonstration became clear. 1 / 2 / 3 / 4 / 5

5) Please provide a word or phrase to describe the brachial plexus demonstration as a teaching tool.

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6) Please provide any additional comments you may have:

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