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ORIGINAL

ENHANCING ATHLETIC PERFORMANCE AND RECOVERY: INTEGRATING MARINE-DERIVED NUTRITIONAL SUPPLEMENTS AND ADVANCED VASCULAR ACCESS TECHNOLOGIES

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ABSTRACT

This study evaluates the efficacy of Dynamic Needle Guidance (DNG) and Dynamic Needle Tip Positioning (DNTP) in the context of sports-related medical interventions, focusing on their potential to improve the administration of nutritional supplements and medications that support athlete recovery and performance. Thirty-one novice residents performed vascular access procedures using both technologies on a phantom model in a randomized sequence. Our primary endpoint was operation time, with secondary endpoints including puncture time, the number of needle tip adjustments tracked by ultrasound, and success rates of initial punctures and attempts, as well as operation difficulty scores. The findings indicated that DNG significantly reduced the operation time (mean(SD) 24.2 (6.4) s vs. 49.4 (15.8) s; p=0.000) and puncture time (9.6 (2.3) s vs. 31.1 (9.8) s; p=0.000), with fewer median (IQR[range]) needle tip adjustments (1 (1-1) [1-1] vs. 3 (3-4) [2-6]; p=0.000). These results suggest a higher efficiency and potentially less discomfort for athletes undergoing treatment. No significant differences were noted in the first puncture or first-attempt success rates between the two methods. Participants reported a significantly lower mean(SD) operation difficulty with DNG compared to DNTP (3.3 (1.0) vs. 6.7 (1.2); p=0.000). The use of DNG could significantly enhance the precision and speed of treatments involving vascular access in athletes, suggesting its potential as a beneficial tool in sports medicine to accelerate recovery and return to performance.

KEYWORDS: Ultrasonography; Needles; Punctures; Needle insertion

1. INTRODUCTION

In the competitive realm of sports, the rapid recovery and optimal performance of athletes are paramount. Recent advances in medical technology have opened new avenues for enhancing athlete care, particularly through precise and minimally invasive procedures. Among these advancements, Dynamic Needle Guidance (DNG) and Dynamic Needle Tip Positioning (DNTP) technologies represent significant breakthroughs in the field of sports medicine (Bai, Tian, Zhang, Yu, & Huang, 2020; Kiberenge, Ueda, & Rosauer, 2018; Kim, Kim, Jeong, Lee, & Lim, 2021; Liu, Tan, Li, & Tian, 2019). Athletes are often subjected to rigorous training and competition schedules, which increase their risk of injuries and necessitate quick and effective medical interventions. Traditional methods of administering treatments, such as intravenous therapies and injections, can be time-consuming and sometimes imprecise, leading to delayed recovery and increased downtime for athletes. The introduction of ultrasound-guided procedures has improved the accuracy of such treatments, yet the need for even more efficient technologies remains critical (Gopalasingam et al., 2017; Hanada, Van Winkle, Subramani, & Ueda, 2017; Hansen, Juhl-Olsen, Thorn, Frederiksen, & Sloth, 2014; Takeshita et al., 2019). DNG and DNTP technologies enhance the precision of ultrasound-guided peripheral vascular access, a common procedure in the administration of nutrients and medications. By improving the accuracy and reducing the operation time, these technologies minimize the discomfort and potential complications associated with needle placement. For athletes, this means less invasive treatment experiences, quicker recovery times, and more efficient return to training and competition (Luca & Jack, 2021; Luyet et al., 2011).

The potential benefits of DNG and DNTP in sports medicine are vast. They include reduced recovery times from injuries, enhanced effectiveness of nutritional and pharmacological interventions, and decreased risk of complications from invasive procedures. These technologies also offer the possibility of more personalized medical care, tailoring treatments to the specific needs of each athlete based on real-time physiological data. This study seeks to empirically evaluate the performance of DNG and DNTP technologies in a controlled setting, using a phantom model to simulate real-world applications in sports medicine. By comparing these advanced technologies with traditional methods, the study aims to quantify their benefits in terms of operation time, puncture efficiency, and user-reported difficulty. The findings are expected to provide concrete evidence supporting the integration of DNG and DNTP into routine sports medical practices. The primary objective of this study is to determine whether DNG can significantly reduce the time and increase the efficiency of vascular access procedures compared to DNTP, thereby supporting faster recovery and minimizing intervention-related stress for athletes. Through this research, we aim to substantiate the role of these innovative technologies in advancing sports medicine and athlete care.

2. Methods

Following a pre-study review of the protocol and forms by the local ethics committee, the study was exempted from approval since it was a volunteer, non-invasive, phantom based study. Thirty-one residents of either sex without ultrasound guided vascular access experience or eye-hand coordination disorder enrolled in this study. The gelatin phantom is a 15 cm * 10 cm * 2 cm cuboid, constructed with edible gelatin. Water and edible gelatin were heated and dissolved at a mass ratio of 2:1, poured into a mold with a built-in mock vessel, and cooled and finalized at room temperature. A standard mold containing holes of a specific depth and 2.0 mm Kirschner wires were used in combination to accurately control the vessel depth, which is normally defined as the distance from the center of short-axis to the surface of the gelatin phantom. The mock vessel was a circular plastic tube filled with iodophor, with a length of 10 cm, a diameter of 2.0 mm, a wall thickness of 0.2 mm. And vessel depth was 4.0 mm. The gelatin phantom was well imaged by ultrasound, and the surface was covered with an ultrasound-permeable black plastic wrap (Fig. 1).

Figure 1: *Gelatin phantom with embedded vessels (bright parts on screen are the anterior and posterior walls of the mock vessel). The vessel depth is defined as the distance from the center of short-axis to the surface.*

The DNG is a predetermined needle tip depth guide. In ultrasound guided vessel puncture, the center of short-axis is the intersection point between the vessel depth and the needle trajectory under ultrasound, which are the right-angle edge and bevel edge of the right-angle triangle under ultrasound, respectively. The guided chute is located on the rectangular triangular beveled edge extension line under ultrasound, which is a hollow cuboid surrounded by three sides of the guided body and its cross-section is a square. The center of the guided chute cross-section and the midpoint of the probe are on the same plane.

The flap is closely adjacent to the guided chute opening on the side of the guided body. Both the guided chute and flap are designed to control the needle trajectory. Overall, the DNG consisted of the guided body, the probe connector, and the flap, with a T-shaped bottom. Three dimensional printing technology with the plastic resin as the construction material was adopted to prepare DNGs with needle tip depth of 3.0, 3.5, 4.0, 4.5, 5.0, 5.5 and 6.0 mm, respectively. In this study, a 20G cannula (Fujian Baishiwei Medical Polymer Co., Ltd.) with a length of 30 mm was employed, the guided chute was set at a length of 10.77 mm and width and height of both 1.23 mm, and a insertion angle of 21.80° was formed between the guided chute and the horizontal plane (Fig. 2).

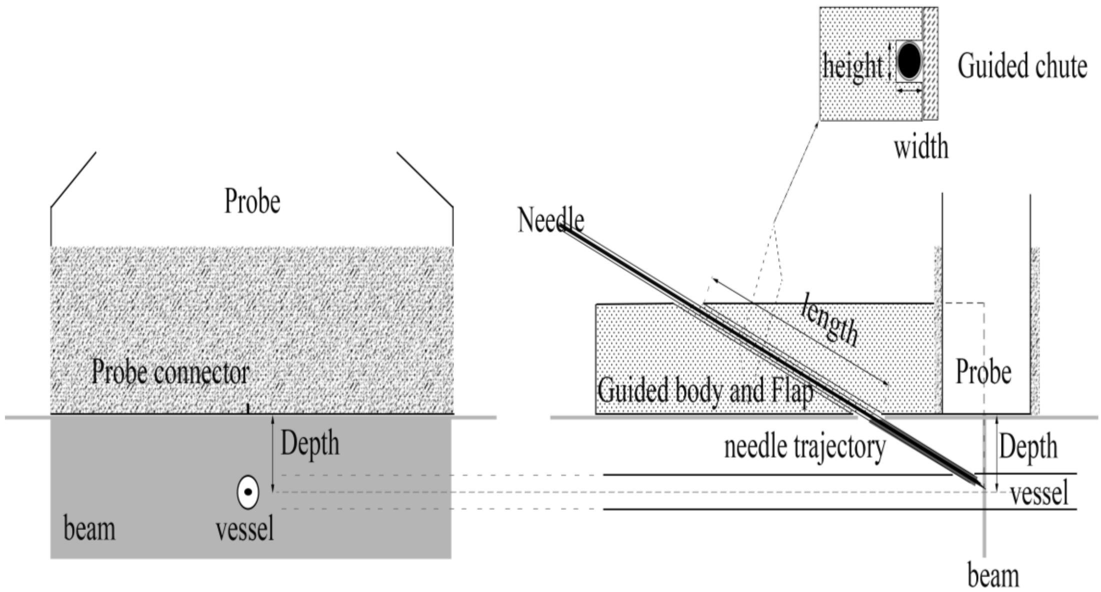

Figure 2: *Schematic illustration of DNG. Each DNG has a solely predetermined needle tip depth ranging from 3.0mm to 6.0mm with 0.5mm intervals. The DNG is selected for vessel puncture according to the vessel depth.*

The operation of DNG can be divided into three steps. The first step involves localization of the puncture point, whereas the second step involves vessel puncture (Fig. 3a-b). A straight portion of the target vessel was selected by ultrasound. And the diameter and vessel depth were measured in short-axis view. According to the depth of the vessel, DNG with a specific needle tip depth was selected to connect with the probe (L18-4, Konica Minolta, Inc., Hino-Shi, Tokyo, Japan). While the center of short-axis was placed within the screen midline by adjusting the probe, puncture point was localized (Fig. 3c-d). The needle with bevel up was inserted along the guided chute. When a hyperechoic dot was detected by ultrasound, needle insertion was stopped. (Fig. 3e-f) After that, cannulation was conducted.

With the right hand, the flap longitudinally was removed then the needle hub was held, and the needle was removed from the side of the guided chute with the left hand. The target vessel and hyperechoic dot were simultaneously shifted laterally on screen. Afterward, the insertion angle was decreased to about 15° and the needle was pushed forward for 2 to 3 mm. The hyperechoic dot moved toward the anterior wall of the vessel, and the area of hyperechoic dot increased on screen. Finally, the cannula was pushed into the mock vessel with left hand.

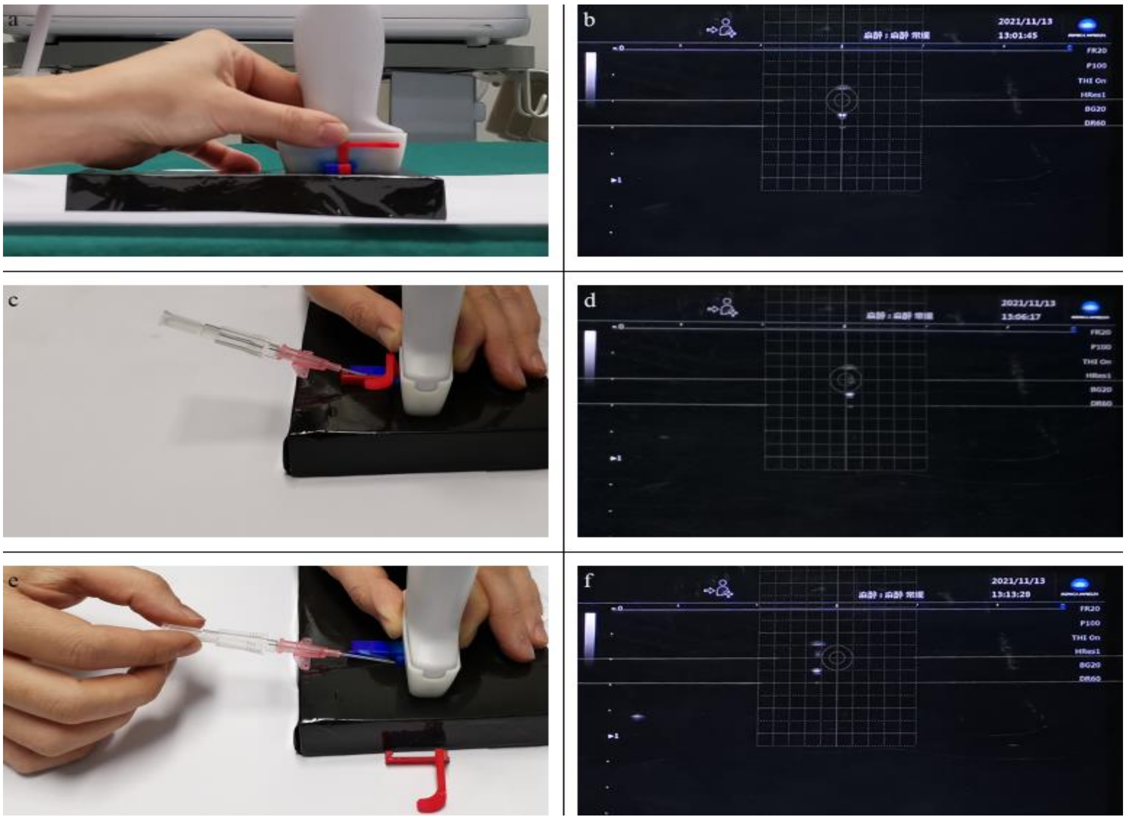

Figure 3 *The operation of DNG. (a and b) DNG with a specific needle tip depth was selected to connect with the probe, and the center of short-axis was positioned within the midline on the screen. (c and d) The needle was inserted along the guided chute until the hyperechoic dot appeared in the vessel. (e and f) Taking out the needle from DNG, and inserting the cannula into the vessel lumen.*

The operation of DNTP refers to a study reported by Clemmesen et al. (Clemmesen, Knudsen, Sloth, & Bendtsen, 2012) (Fig. 4a). Firstly, a straight portion of the target vessel was selected by ultrasound. Needle was inserted with an angle of 30° approximately through the SAX-OOP approach. The puncture point was localized at the middle mark of probe (Fig. 4b-d). After the hyperechoic dot of needle tip appeared between the target vessel and the phantom surface under ultrasound, the needle tip was first kept still and the probe was moved along the direction of the needle tip in the long-axis of target vessel for about 1 mm until the needle tip was invisible, then the probe was kept still, and the needle was moved for about 1 mm until hyperechoic dot appeared again.

During the process of vessel puncture, needle tip position was tracked by moving the needle and probe alternatively with two hands, and fine-adjusts on insertion direction were conducted according to the relative position of the needle tip and the target vessel, to assist the needle tip to accurately enter the target vessel (Fig. 4e). After vessel puncture, the insertion angle was reduced to about 15°. Needle tip position was then tracked twice before cannulation to ensure that the catheter tip was inside the vessel. Residents used both methods to perform puncture and cannulation successfully. The order of subjects was randomly selected, with odd numbers first using the DNG and even numbers first using the DNTP. The depth of the probe was set at 2.0cm. A circle and a Cartesian coordinate were superimposed on the screen to assist with the display of mock vessel wall and the center of short-axis. Before the operation, residents successively received training on ultrasonic theories and operation drills of vascular puncture and cannulation with the two methods for at least 30 minutes. Training on ultrasonic theoretical knowledge included ultrasonic operation principle, identification of the vessel in long-axis view and short-axis view, measurement of vessel diameter and vessel depth in short-axis view, manipulation of probe by the left hand, needle holding and insertion by the right hand, operation points of the DNG and the DNTP. During the operation drill, a gelatin phantom was used with built-in mock vessel diameter of 2.0 mm and depth of 5.0 mm. Before the formal study, residents were required to successfully puncture and cannulation three times under surveillance using DNG and DNTP, respectively. Resident was not allowed to operate until passing the operation drill and could not watch other subjects' operations before formal operation.

Two unblinded observers evaluated all procedure. The criterion for successful puncture was the presence of hyperechoic dot in the vessel on screen. The criterion for successful cannulation was that the iodophor in the mock vessel was successfully sucked out. If first-attempt failed, re-puncture and re-cannulation were conducted at another puncture point. Operation time from the beginning of ultrasonic scanning to successful cannulation was measured. Both puncture time and number of needle tip positions tracked by ultrasound in the first successful puncture were recorded, from the latest localization of the puncture point to the first successful puncture. Finally, residents ranked their operation difficulty scores from 0(no difficult) to 10(most difficult) for the two methods, respectively. The primary endpoint was operation time. The secondary endpoints included puncture time, number of needle tip positions tracked by ultrasound, first puncture success rate, first-attempt success rate and operation difficulty scores. Statistical analyses were conducted using SPSS (version 19.0; IBM Corp). This study was an experiment study using paired design, and the difference in the use of the two methods in the subjects was observed.

The results of operation time, puncture time and operation difficulty scores were in accordance with the normal distribution and represented by the mean ± standard deviation ($\bar{x}$±s), and compared using the paired t-test. The results of number of needle tip positions tracked by ultrasound was conformed to the biased distribution and expressed as the median (IQR [range]), and compared using the Wilcoxon Signed Rank Test. The chi-square test of paired fourfold table data was used to compare first puncture success rate and first-attempt success rate. $P < 0.05$ was considered statistically significant. Before this study, ten trainees were included in the preliminary experiment, and the operation time of DNG and DNTP were 20 ± 5 s and 49 ± 16 s, respectively. A reduction of 20 seconds in operation time was thought to be clinically significant. A two-sided test of the hypothesis was carried out, both the type I error and type II error were set to 0.005, and the sample size required was calculated to be 10. To ensure the reliability of the study results, 32 regular physicians who participated in the National Standardized Residency Training were included in this study.

3. Results

Except for one resident absent for personal reasons, the other 31 residents participated in the study, including 17 females and 14 males. All residents succeeded with DNG and 30 subjects succeeded with DNTP in first puncture. Twenty-seven residents succeeded with DNG while 25 subjects succeeded with DNTP in first-attempt. Only 21 residents succeeded with both methods in first-attempt. No cases failed in cannulation after trying both methods and no cases needed more than two trials for a successful cannulation. The mean(SD) operation time was significantly shorter when using DNG compared to DNTP.

Compared with DNTP, DNG had a significantly less mean(SD) puncture time and fewer median (IQR) number of needle tip positions tracked by ultrasound during vessel puncture. Both the first puncture success rate and the first-attempt success rate were similar between the two methods. Each resident ranked DNG better than DNTP. Residents ranked their operation difficulty scores with DNG lower than DNTP (Table 1).

Table 1: Outcomes measured during ultrasound guided peripheral vascular access using DNTP and DNG. Values are mean (SD), median (IQR [range]), number(proportion) or difference in means(95%CI).

	DNTP (N = 31)	DNG (N = 31)	DIFFERENCE IN MEANS(95%CI)	P VALUE
OPERATION TIME; SECOND	49.4 (15.8)	24.2 (6.4)	25.2 (19.7, 30.7)	0.000[1]
PUNCTURE TIME; SECOND	31.1 (9.8)	9.6 (2.3)	21.5 (17.8, 25.1)	0.000[1]
NUMBER OF NEEDLE TIP POSITIONS TRACKED BY ULTRASOUND	3 (3-4 [2-6])	1 (1-1 [1-1])	-	0.000[2]
FIRST PUNCTURE SUCCESS RATE(%)	30 (97%)	31 (100%)	-	-
FIRST-ATTEMPT SUCCESS RATE(%)	25 (81%)	27 (87%)	-	0.754[3]
OPERATION DIFFICULTY SCORES	6.7 (1.2)	3.3 (1.0)	3.4 (2.8, 4.0)	0.000[1]

DNTP, dynamic needle tip positioning; DNG, depth needle guide. [1]Paired-Sample T test. [2]Wilcoxon's signed-rank test. [3]McNemar Test.

4. Discussion

We found that the DNG improved the efficiency of the ultrasound guided peripheral vascular access technique of DNTP. The DNG shortened the operation time, reduced the puncture time and the number of needle tip positions tracked by ultrasound during vessel puncture, without decreased the first puncture success rate and the first-attempt rate compared to DNTP, and was judged easier to use. Reports have shown that mechanical needle guides are attached to probe using long-axis, in-plane(LAX-IP) approach help to align the needle and the ultrasound beam, and facilitate needle tip visualization in real-time by improved needling control, increase first-attempt success rate, and shorten operation times (Gupta, Lane, Allen, Shi, & Schildcrout, 2013; Maecken, Heite, Wolf, Zahn, & Litz, 2015; Whittaker, Lethbridge, Kim, Keon Cohen, & Ng, 2013). However, the center of the long-axis is difficult to see on ultrasound, unanticipated injury of surrounding structure still occur (Maecken et al., 2015; Tokumine et al., 2013). Luyet C. et al (Luyet et al., 2011) reported a single mechanical device using SAX-OOP approach could adjust the needle tip depth according to the target vessel with different depths, and results demonstrated a shorter cannulation time at each attempt in a mock vessel with a depth of 4 cm as an example. A predetermined needle tip depth guide uses the same SAX-OOP approach as DNTP, does not require the operator to repeatedly track the needle tip position during the process of vessel puncture, which can simplify the operation of DNTP. However, it may be suitable for central venous cannulation, whether it can be used for peripheral vascular access is unclear. Peripheral vessel is shallow and small in diameter, which requires predetermined needle tip depth guide has the capacity of fine regulation of needle tip depth according to the peripheral vessel. Nakayama et al. (Nakayama et al., 2014) found that the success rate of ultrasound guided radial artery puncture is highest when the depth of the radial artery is 2 to 4 mm. Because the needle tip can only be discovered by the two-dimentional ultrasound probe when it reaches a certain depth. The proximity to the skin does not improve the success rate of ultrasound guided puncture (Nakayama et al., 2014). And Tian et al. (Tian et al., 2022) found an arterial depth of more than 2.25 mm was associated with less catheterized time. In this study, vessel depth is defined as the distance from the center of short-axis to the surface of the gelatin phantom, which is different from the anterior wall to the skin reported in previous articles. Therefore, the shallowest needle tip depth of DNG is 3mm. In practice, the needle tip depth of predetermined needle tip depth guide may not strictly coincide with vessel depth. The small diameter of peripheral vessels, such as the diameter of neonatal radial artery is only about 1mm (Liu et al., 2019), increases the difficulty of fine regulation of needle tip depth with a predetermined needle tip depth guide. The DNG solves this problem with 0.5mm intervals of predetermined needle tip depths in this study.

The procedure of successful cannulation can be divide into localization of the puncture point, vessel puncture and cannulation three steps. DNTP is a free-hand ultrasound guided technique. In general, the center of short-axis can be easily found and placed within the screen midline by adjusting the probe. A classic mistake is the small movement of probe when eyes are taken off the transducer to check the screen before needle insertion, resulting in an insertion site lateral to the underling vessel. Adding guidance markers to the probe increased the accuracy of needle placement in the horizontal plane during simulated ultrasound guided vascular access (Thorn, Aagaard Hansen, Sloth, & Knudsen, 2017). Quan et al. (Quan et al., 2019) found that acoustic shadowing via the use of double developing lines on probe facilitates locate the puncture point, and shortens the ultrasonic location time. In this study, when the center of short-axis was placed within the screen midline, localization of the puncture point was completed simultaneously. Then the needle was inserted along the guided chute that controls the needle trajectory during vessel puncture. During the vessel puncture using DNTP, the actual needle tip position can be tracked by moving the needle and probe alternatively with two hands (Clemmesen et al., 2012). Repeatedly tracking needle tip position is a demanding procedure, which is not only time consuming, but also increasing the pain of patients. If the probe and needle are not aligned properly, or needle tip position is not identified, more hands movements and puncture time are needed. Operators may require tracking needle tip position by ultrasound at least 2 to 3 times during vessel puncture using DNTP, as estimated by approximately 1 mm per movement of the probe. In this study, operators had tracked the needle tip position 2 to 6 times by two hands in the first successful puncture. This number would be higher if we counted all the number of needle tip positions tracked by ultrasound in the operation. During vessel puncture with DNG, the probe was held still by left hand, the needle was inserted through the guided chute with right hand until the hyperechoic dot detected by ultrasound, both probe handing and needling control were improved to some extent. The results showed that all participants succeeded in first puncture with DNG, and the needle tip position was tracked only once by ultrasound. The DNG assisted the needle tip to accurately enter the vessel instead of tracking needle tip position by ultrasound repeatedly using DNTP, which helps shorten the puncture time.

5. Conclusion

The findings from this study highlight the significant benefits of integrating Dynamic Needle Guidance (DNG) technology in the realm of sports medicine. By comparing DNG with Dynamic Needle Tip Positioning (DNTP), we have demonstrated that DNG not only improves the efficiency of ultrasound-guided peripheral vascular access but also enhances the overall experience of medical interventions for athletes.

5.1 Efficiency and Accuracy

Our results clearly indicate that DNG significantly reduces operation times and puncture times when compared to DNTP. Specifically, the mean operation time with DNG was almost halved compared to DNTP, illustrating a notable increase in procedural efficiency. Additionally, the number of needle tip adjustments required with DNG was considerably lower, which not only speeds up the process but likely reduces the potential for procedural errors and complications.

5.2 Impact on Athlete Recovery

For athletes, these improvements in procedural efficiency and accuracy are critical. Faster and more accurate procedures mean less time away from training and competition, which is invaluable for both athletes and their teams. Moreover, the reduced need for multiple needle adjustments with DNG minimizes the discomfort and risk associated with vascular access, thereby enhancing the athlete's overall experience and satisfaction with medical care.

5.3 User Experience and Training

Feedback from the residents who conducted the procedures suggests that DNG is not only more efficient but also easier to use, as evidenced by lower operation difficulty scores compared to DNTP. This user-friendly aspect of DNG can potentially lead to quicker adoption and more widespread use in clinical settings, including sports medicine facilities. Training for these advanced technologies is crucial and should be tailored to ensure that medical professionals are skilled in their use, thereby maximizing the benefits for athlete care.

5.4 Future Implications and Recommendations

The application of DNG in sports medicine could revolutionize the way athletes receive medical treatments. However, further research is needed to explore the long-term benefits of using such technologies in routine clinical practice. Studies involving actual clinical scenarios with athletes, monitoring recovery times and performance outcomes post-intervention, would provide deeper insights into the practical benefits of DNG. Additionally, exploring the integration of DNG with other emerging technologies, such as real-time data analytics and personalized medicine approaches, could further enhance its effectiveness and lead to more customized care strategies tailored to the specific needs of individual athletes.

5.5 Final Thoughts

In conclusion, Dynamic Needle Guidance technology offers a promising enhancement to medical interventions in sports medicine, promising quicker, safer, and more precise treatments for athletes. By continuing to refine and implement such technologies, the field of sports medicine can better support the health and performance goals of athletes, ultimately contributing to their success and longevity in sports.

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