scientific reports

OPEN

Enhancing parathyroid preservation in papillary thyroid carcinoma surgery using nano-carbon suspension

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This study evaluates the clinical significance of nano-carbon suspension in total thyroidectomy with cervical lymph node dissection for papillary thyroid carcinoma (PTC). The objective of this study was to assess the efficacy of nano-carbon suspension in enhancing parathyroid gland preservation, reducing postoperative complications, and improving surgical precision. A retrospective analysis on 219 PTC patients who underwent total thyroidectomy with cervical lymph node dissection between March 2014 and March 2018 was conducted. Patients were divided into two groups: an experimental group ($n = 107$) that received nano-carbon suspension and a control group ($n = 112$) that did not. Comparative analyses included demographics, surgical parameters, postoperative calcium and parathyroid hormone (PTH) levels, the number of dissected lymph nodes, and the incidence of complications. Baseline characteristics, including age, sex, and BMI, showed no statistically significant differences between the experimental and control groups. Postoperative calcium levels were significantly more stable in the experimental group, with median levels of 2.22 mmol/L on day 1 versus 2.06 mmol/L in the control group ($P < 0.001$), and 2.29 mmol/L at week 1 versus 2.22 mmol/L ($P < 0.001$). PTH levels were higher in the experimental group (35 pg/mL on day 1 versus 28 pg/mL, $P < 0.001$; 37 pg/mL at week 1 versus 30 pg/mL, $P < 0.001$). The experimental group had a greater median number of dissected lymph nodes (median 11.00 versus 7.00, $P < 0.001$) and a lower pathological parathyroid gland count (6.5% versus 23.2%, $P < 0.001$). Postoperative numbness and twitching were significantly reduced (4.7% versus 16.1%, $P = 0.006$), and the recurrence rate at 12 months was lower (4.7% versus 12.5%, $P = 0.040$). The use of Nano-carbon suspension in thyroidectomy and cervical lymph node dissection for PTC enhances parathyroid gland preservation, improves surgical precision, and reduces specific postoperative complications, supporting its standard adoption in thyroid cancer surgeries to optimize patient outcomes.

Keywords Papillary thyroid carcinoma, Nano-carbon suspension, Parathyroid gland preservation, Hypocalcemia, Parathyroid hormone, Postoperative complications

Papillary thyroid carcinoma (PTC) is the most common type of thyroid cancer, with its incidence steadily increasing worldwide[1]. Recent epidemiological data indicate that PTC accounts for approximately 85% of all thyroid cancer cases, and it is associated with a high rate of lymph node metastasis, which is observed in up to 50% of patients at the time of initial diagnosis[2]. This significant metastatic potential necessitates an aggressive surgical approach, often involving comprehensive lymph node dissection, to optimize oncological outcomes, such as higher survival rates and reduced recurrence[3].

The standard treatment for PTC commonly involves total thyroidectomy combined with cervical lymph node dissection[4]. Accurate identification and preservation of the parathyroid glands are crucial during surgery to prevent complications, including hypocalcemia and recurrent laryngeal nerve injury[5]. These complications can

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Variable	Total ($n=219$)	Control group ($n=112$)	Experimental group ($n=107$)	P value
Sex, n (%)				0.942
Female	191 (87)	97 (87)	94 (88)	
Male	28 (13)	15 (13)	13 (12)	
Age (years)	42.0 (39.0–47.0)	42.5 (40.0–4.07)	41.0 (37.5–46.0)	0.101
BMI (kg/m^2)	21 (20–23)	22 (20–23)	21 (20–23)	0.481
Surgery duration (min)	92.0 (86.0–98.5)	91.0 (85.0–96.0)	95.0 (87.0–99.0)	0.141
Blood loss (ml)	30.0 (20.0–4.00)	30.0 (20.0–46.3)	32.0 (20.0–35.0)	0.306

Table 1. Baseline characteristics of control and experimental groups [Median (Q1-Q3)]. Q1 and Q3: represent the first quartile (25th percentile) and third quartile (75th percentile), respectively; BMI: body mass index.

Variable	Total ($n=219$)	Control group ($n=112$)	Experimental group ($n=107$)	P value
Ca_0 (mmol/L)	2.33 (2.30–2.36)	2.31 (2.25–2.35)	2.34 (2.30–2.36)	0.268
Ca_1 (mmol/L)	2.19 (2.01–2.22)	2.06 (1.99–2.20)	2.22 (2.15–2.30)	< 0.001
Ca_2 (mmol/L)	2.25 (2.21–2.33)	2.22 (2.13–2.30)	2.29 (2.23–2.38)	< 0.001
PTH_0 (pg/mL)	41 (39–44)	41.5 (39–44)	41 (38–45)	0.754
PTH_1 (pg/mL)	32 (27–37)	28 (25–34)	35 (30–39.5)	< 0.001
PTH_2 (pg/mL)	34 (30–39.5)	30 (27–37)	37 (33–40)	< 0.001

Table 2. Calcium and parathyroid hormone levels at different time points in both study groups [Median (Q1-Q3)]. Q1 and Q3: represent the first quartile (25th percentile) and third quartile (75th percentile), respectively; Ca_0: preoperative calcium levels; Ca_1: calcium levels one day postsurgery; Ca_2: calcium levels one week postsurgery; PTH_0: preoperative parathyroid hormone (PTH) levels; PTH_1: PTH levels one day postsurgery; PTH_2: PTH levels one week postsurgery.

affect patients' quality of life and increase healthcare costs due to extended recovery periods and the need for additional treatments[6].

Recent advancements in surgical techniques have introduced nano-carbon suspension as a promising tool to enhance the visibility of the parathyroid glands and surrounding lymphatic structures during surgery[7]. Nano-carbon particles, owing to their small size and high affinity for lymphatic tissues, provide enhanced visual contrast for surgerys, thereby reducing the risk of inadvertent damage to the parathyroid glands[8]. Early studies suggest that the use of nano-carbon can significantly reduce the incidence of hypocalcemia and improve the precision of lymph node dissection[9,10].

However, comprehensive data on the long-term benefits and potential risks of nano-carbon in thyroid surgery remain limited. Furthermore, existing studies show inconsistencies in evaluating its impact on key surgical outcomes, including the number of lymph nodes dissected, recurrence rates, and postoperative complications. These inconsistencies underscore the need for more extensive, standardized research to fully understand the clinical implications of nano-carbon in thyroid surgery.

To address these gaps, this retrospective study examines the impact of nano-carbon suspension in patients undergoing total thyroidectomy with cervical lymph node dissection for PTC. By comparing outcomes, such as lymph node count, recurrence rates, surgical duration, blood loss, parathyroid function, and postoperative complications, between patients with and without nano-carbon suspension, this study aims to offer insights that can guide future clinical practices.

Results

Data normality

Data normality was assessed utilizing the Shapiro-Wilk test. P-values for all variables in both study groups were less than 0.05, indicating a non-normal distribution. Consequently, nonparametric tests were used for subsequent analyses.

Baseline characteristics

Table 1 presents the baseline characteristics of the control group ($n=112$) and the experimental group ($n=107$). Statistical analysis was performed using the CBCgrps package in R[11]. There were no significant differences between the groups in terms of age ($P=0.101$), sex ($P=0.942$), BMI ($P=0.481$), duration of surgery ($P=0.141$), or intraoperative blood loss ($P=0.306$).

Calcium and PTH levels

Table 2 presents the calcium and PTH levels at preoperative, postoperative day 1, and postoperative week 1 for both groups. Compared to the control group, the experimental group had significantly higher calcium levels on

Parameter	Coefficient	95% CI	SE	Z value	*P* value
Intercept	2.031	1.735–2.327	0.151	13.457	< 0.001
Time [T.Post-Op Week 1]	0.169	0.130–0.209	0.020	8.439	< 0.001
Time [T.Pre-Op]	0.300	0.260–0.339	0.020	14.930	< 0.001
Group	0.177	− 0.242–0.595	0.213	0.828	0.409
Group: Time [T.Post-Op Week 1]	− 0.090	− 0.147 to − 0.034	0.029	− 3.150	0.002
Group: Time [T.Pre-Op]	− 0.171	− 0.227 to − 0.115	0.029	− 5.950	< 0.001
Group Var	0.023				

Table 3. Results of the mixed-effects model for calcium levels. CI: confidence interval; SE: standard error; intercept: baseline calcium level when all predictors are at their reference levels; time [T.Post-Op week 1]: effect of postoperative week 1 on calcium levels; time [T.Pre-Op]: effect of preoperative time on calcium levels; Group: effect of the group on calcium levels; Group [T.Post-Op week 1]: interaction effect of group and postoperative week 1 on calcium levels; T.Pre-Op: effect of the preoperative period on calcium levels; Group Var: variance attributed to the grouping factor.

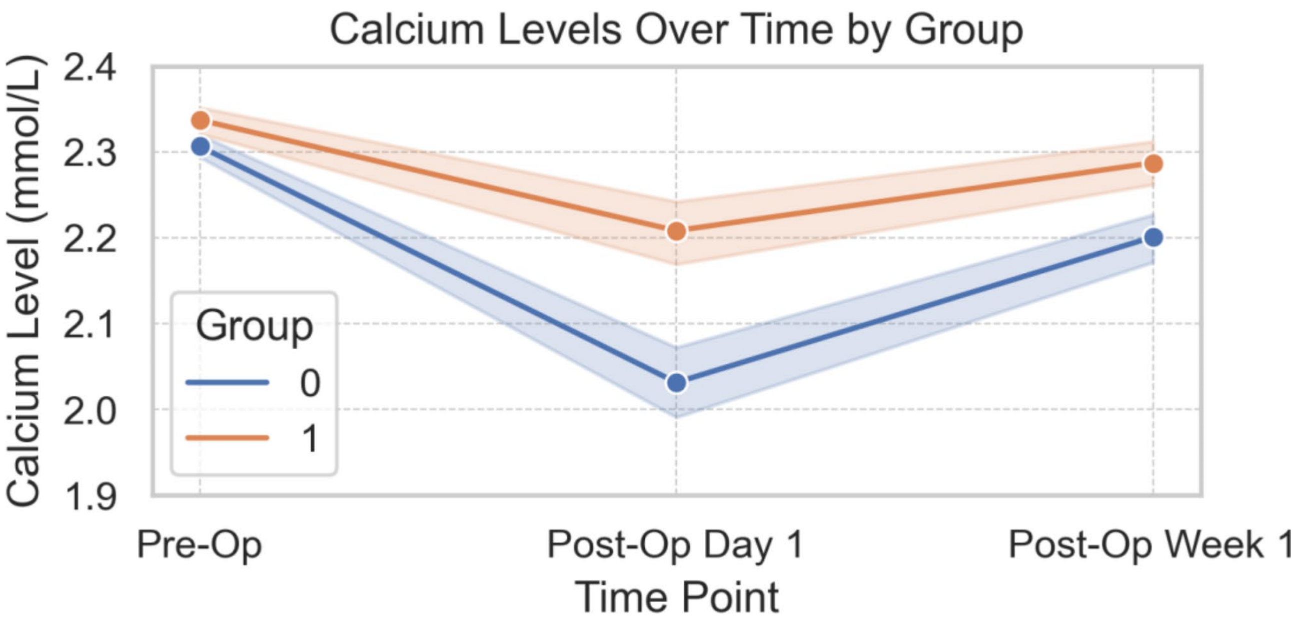

Fig. 1. Calcium levels over time by group. This figure illustrates changes in calcium levels at three time points: preoperation (pre-op), postoperation day 1 (post-op day 1), and postoperation week 1 (post-op week 1). The blue line represents the control group (Group 0), and the orange line represents the experimental group (Group 1). Shaded areas indicate the confidence intervals for the calcium level changes in both groups. Both groups exhibited a decrease in calcium levels on post-op day 1, followed by a subsequent increase by post-op week 1. The experimental group (orange line) shows a more stable calcium level postoperatively compared to the control group.

postoperative day 1 (2.22 mmol/L versus 2.06 mmol/L, $P < 0.001$) and postoperative week 1 (2.29 mmol/L versus 2.22 mmol/L, $P < 0.001$). Similarly, PTH levels were higher in the experimental group on postoperative day 1 (35 pg/mL versus 28 pg/mL, $P < 0.001$) and postoperative week 1 (37 pg/mL versus 30 pg/mL, $P < 0.001$), indicating greater postoperative stability.

The mixed-effects model analysis (Table 3) supports these findings, showing significant time effects on calcium levels at postoperative week 1 ($P < 0.001$) and postoperative day 1 ($P < 0.001$). Although the group variable was not significant ($P = 0.409$), its interaction with postoperative week 1 was significant ($P = 0.002$). The experimental group maintained higher calcium levels at postoperative week 1 (2.29 mmol/L versus 2.22 mmol/L, $P < 0.001$), suggesting that the intervention may reduce surgical trauma and improve parathyroid preservation (Fig. 1).

Similarly, the mixed-effects model for PTH levels (Table 4) showed significant changes over time at postoperative week 1 ($P = 0.013$) and postoperative day 1 ($P < 0.001$). The experimental group exhibited more stable PTH levels at postoperative week 1 (37 pg/mL versus 30 pg/mL, $P < 0.001$), indicating reduced surgical impact and improved parathyroid function preservation (Fig. 2).

Parameter	Coefficient	95% CI	SE	Z value	*P* value
Intercept	27.134	11.756–42.512	7.846	3.458	0.001
Time [T.Post-Op Week 1]	2.589	0.543–4.635	1.044	2.481	0.013
Time [T.Pre-Op]	14.250	12.204–16.296	1.044	13.652	< 0.001
Group	6.455	−15.295–28.205	11.097	0.582	0.561
Group: Time [T.Post-Op Week 1]	0.457	−2.469–3.384	1.493	0.306	0.759
Group: Time [T.Pre-Op]	−5.633	−8.560 to − 2.706	1.493	-3.772	< 0.001
Group Var	61.014				

Table 4. **R**esults of the mixed-effects model for parathyroid hormone (PTH) levels. CI: confidence interval; SE: standard error; intercept: baseline PTH level when all predictors are at their reference levels; time [T.Post-Op week 1]: effect of postoperative week 1 on PTH levels; time [T.Pre-Op]: effect of preoperative time on PTH levels; Group: effect of group on PTH levels; Group [T.Post-Op week 1]: interaction effect of group and postoperative week 1 on PTH levels; T.Pre-Op: effect of the preoperative period on PTH levels; Group Var: variance attributed to the grouping factor.

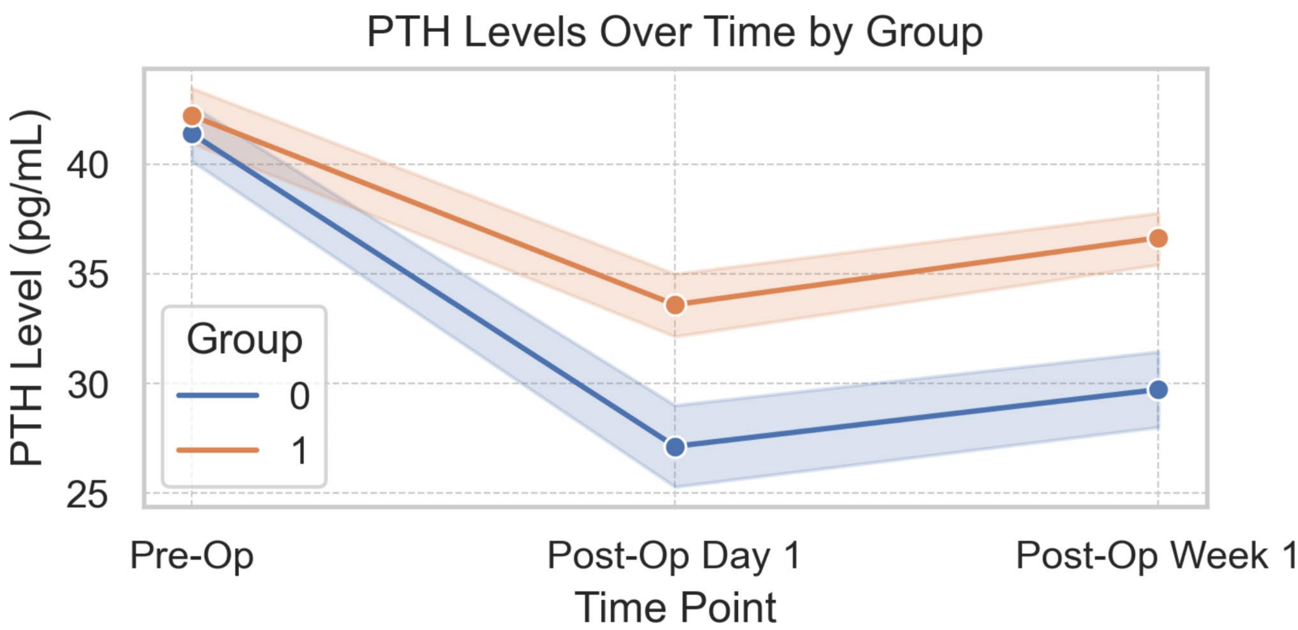

Fig. 2. Parathyroid hormone (PTH) levels over time by group. This figure illustrates changes in PTH levels at three time points: preoperation (pre-op), postoperation day 1 (post-op day 1), and postoperation week 1 (post-op week 1). The blue line represents the control group (group 0), and the orange line represents the experimental group (group 1). Shaded areas around the lines indicate the confidence intervals for PTH levels in each group. Both groups experienced a decrease in PTH levels on post-op day 1, followed by an increase by post-op week 1. Group 0 exhibited a more pronounced decline, while Group 1 maintains higher PTH levels throughout the postoperative period, indicating better preservation of parathyroid function in the experimental group.

Lymph node dissection

The number of lymph nodes dissected differed significantly between the experimental and control groups, as shown in Table 5. The experimental group, which utilized nano-carbon suspension, had a median of 11.00 lymph nodes dissected (Q1-Q3: 8.00-16.50), compared to 7.00 lymph nodes (Q1-Q3: 5.00-10.50) in the control group, indicating a statistically significant difference ($Z = -6.126$, $P < 0.001$). When analyzed by specific surgical techniques, the experimental group consistently showed higher median lymph node counts across all techniques: Technique 1: 9.00 versus 5.00 ($Z = -6.825$, $P < 0.001$); Technique 2: 15.00 versus 9.00 ($Z = -5.285$, $P < 0.001$); Technique 3: 29.50 versus 17.00 ($Z = -3.957$, $P < 0.001$). These findings suggest that the use of nano-carbon suspension facilitates a more thorough lymph node dissection.

Postoperative complications

The incidence of postoperative complications, summarized in Table 6, revealed that the experimental group had a significantly lower rate of numbness and twitching (4.7% versus 16.1%, $P = 0.006$). Additionally, the pathological parathyroid gland count was significantly lower in the experimental group (6.5% versus 23.2%,

Technique	Group	Number	Nodes [Median (Q1-Q3)]	Mean ranks	Statistic	Wilcoxon	Z value	*P* value
Techniques (total)	Experiment	107	11.00 (8.00–16.50)	136.78	3127.00	9455.00	− 6.126	< 0.001
	Control	112	7.00 (5.00–10.50)	84.12				
Technique 1	Experiment	62	9.00 (8.00–11.00)	83.63	550.00	2441.00	− 6.825	< 0.001
	Control	61	5.00 (4.00–7.00)	40.02				
Technique 2	Experiment	31	15.00 (13.50–17.50)	45.95	125.50	720.50	− 5.285	< 0.001
	Control	34	9.00 (0.00–12.00)	21.19				
Technique 3	Experiment	14	29.50 (27.00–32.00)	23.11	19.50	172.50	− 3.957	< 0.001
	Control	17	17.00 (15.00–20.00)	10.15				

Table 5. Mann-Whitney U-test results for pathological lymph node counts post-surgery between the two study groups. Q1 and Q3: represent the first quartile (25th percentile) and third quartile (75th percentile), respectively; Technique 1: total thyroidectomy with unilateral level VI lymph node dissection; Technique 2: total thyroidectomy with bilateral level VI lymph node dissection; Technique 3: total thyroidectomy with bilateral level VI lymph node dissection and unilateral lateral neck lymph node dissection; number: the number of cases in each group; Mean Rank: the average rank of lymph nodes removed for each group; Wilcoxon: the wilcoxon rank-sum test statistic, representing the cumulative rank sum of the groups.

Complication	Status	Total cases (*n* = 219)	Control case (*n* = 112)	Experimental case (*n* = 107)	χ2	*P* value
Hoarseness	Yes	14 (6.4)	7 (6.2)	7 (6.5)	0.008	0.930
	No	205 (93.6)	105 (93.8)	100 (93.5)		
Numbness and twitching	Yes	23 (10.5)	18 (16.1)	5 (4.7)	7.564	0.006
	No	196 (89.5)	94 (83.9)	102 (95.3)		
Lymphatic leakage	Yes	15 (6.8)	7 (6.3)	8 (7.5)	0.129	0.719
	No	204 (93.2)	105 (93.7)	99 (92.5)		
Hematoma	Yes	5 (2.3)	3 (2.7)	2 (1.9)		1.000*
	No	214 (97.7)	109 (97.3)	105 (98.1)		
Coughing	Yes	7 (3.2)	4 (3.6)	3 (2.8)		1.000*
	No	212 (96.8)	108 (96.4)	104 (97.2)		
Pathological parathyroid gland count	Yes	33 (15.1)	26 (23.2)	7 (6.5)	11.885	< 0.001
	No	186 (84.9)	86 (76.8)	100 (93.5)		

Table 6. Comparison of complications between the two study groups [n (%)]. χ^2: Chi-square; *Fisher's exact test; n (%): number of cases and their respective percentages.

Duration	Recurrence	Control case (*n* = 112)	Experimental case (*n* = 107)	χ2	*P* value
One Month	Yes	2 (1.8)	1 (0.9)		1.000*
	No	110 (98.2)	106 (99.1)		
Six Months	Yes	7 (6.3)	3 (2.8)		0.334*
	No	105 (93.7)	104(97.2)		
Twelve Months	Yes	14 (12.5)	5 (4.7)	4.231	0.040
	No	98 (87.5)	102 (95.3)		

Table 7. Recurrence cases of thyroid cancer post-surgery at one month, six months, and twelve months [n (%)]. χ^2: Chi-square; *Fisher's exact test: applied at one month and six months due to the small sample size in these categories; n (%): number of cases and their percentages.

$P < 0.001$), indicating better parathyroid preservation with nano-carbon suspension use. No statistically significant differences were found between the groups for other complications, including hoarseness ($P = 0.930$), lymphatic leakage ($P = 0.719$), hematoma ($P = 1.000$), or coughing ($P = 1.000$).

Recurrence cases of thyroid cancer post-surgery

Recurrence rates of thyroid cancer after surgery were compared between the control and experimental groups at 1 month, 6 months, and 12 months (Table 7). The experimental group, which utilized nano-carbon suspension, demonstrated significantly fewer recurrences at 12 months than the control group ($\chi^2 = 4.231$, $P = 0.040$). No significant differences were observed at either 1 month or 6 months. These findings suggest that nano-carbon suspension use contributes to a reduced recurrence rate of thyroid cancer within a 12-month period in the experimental group.

Discussion

This study assessed the clinical significance of nano-carbon suspension in total thyroidectomy with cervical lymph node dissection for PTC patients. Our findings show that nano-carbon suspension significantly enhances the identification of parathyroid glands, thereby improving surgical precision and reducing postoperative numbness, twitching, and the misidentification of parathyroid glands as pathological lymph nodes.

Enhanced identification and preservation of parathyroid glands

Nano-carbon suspension's high affinity for lymphatic tissues provides distinct visual contrast, which is essential for preserving delicate parathyroid glands during neck dissections. This clear separation between parathyroid glands and surrounding tissues helps prevent inadvertent damage, significantly reducing postoperative complications such as numbness, twitching, and hypocalcemia[12–14]. These findings align with previous studies[15–17] reporting similar benefits of nano-carbon in other surgical settings.

Pathological parathyroid gland count

We also observed a significant reduction in the pathological parathyroid gland count in the experimental group (6.5%) compared to the control group (23.2%) ($P<0.001$), indicating the effectiveness of nano-carbon suspension in preserving parathyroid glands. This reduction implies fewer inadvertent resections, which is crucial for minimizing the risk of hypoparathyroidism and associated complications[18,19].

Calcium and PTH levels

Mixed-effects models demonstrated that the experimental group maintained significantly more stable calcium and PTH levels postoperatively. These changes suggest improved homeostasis and a reduced risk of hypoparathyroidism[15]. The findings indicate that nano-carbon suspension may enhance postoperative calcium regulation, thereby reducing the likelihood of transient or permanent hypoparathyroidism. The observed stability in calcium and PTH levels in the experimental group is likely due to the more effective preservation of parathyroid tissue, which enhances surgical precision and further mitigates the risk of hypoparathyroidism[20,21].

Impact on complications and recurrence

The study found no increase in intraoperative or postoperative complications with nano-carbon suspension. The rates of symptoms such as hoarseness, coughing, hematoma, and lymphatic leakage were similar in both groups, indicating no additional risks[22]. However, the experimental group had significantly reduced incidences of numbness and twitching, along with a lower rate of parathyroid gland misidentification. Additionally, the lower postoperative lymph node recurrence rate in the experimental group suggests that nano-carbon suspension may enhance surgical precision and improve oncological outcomes without compromising oncological efficacy[23–25].

Comparison of alternative parathyroid preservation techniques

Various parathyroid preservation techniques are available, including methylene blue staining, nano-carbon negative contrast, fluorescent tracers, and near-infrared autofluorescence imaging (NIRAF). However, each technique has its limitations: methylene blue can impair the surgical field and cause neurotoxic reactions, while fluorescent tracers and NIRAF are costly and less widely available. Nano-carbon negative contrast stands out as the most widely used and advanced technique, providing rapid tracing and effective lymphatic targeting. It is particularly beneficial for total thyroidectomy, thyroid cancer with cervical lymph node metastasis, and reoperative thyroid surgeries.

Limitations and future directions

While this study provides strong evidence supporting the use of nano-carbon suspension, several limitations should be acknowledged. The single-center setting may limit the generalizability of the results, and the absence of randomization in patient selection could introduce bias, potentially affecting the reliability of causal conclusions. Future research should include a prospective, multicenter study with randomized patient allocation to better control for bias.The extended duration of the study may have influenced the results due to advancements in surgical techniques and equipment over time, which may have impacted outcomes such as lymph node dissection and parathyroid gland preservation. This variation represents a possible source of bias to be considered when interpreting the results.

The lack of long-term follow-up data is another limitation, hindering a comprehensive assessment of the sustained benefits of nano-carbon suspension on parathyroid function and cancer recurrence. Future studies should include long-term follow-up data on recurrence rates and parathyroid function to provide a more comprehensive evaluation of the efficacy and safety of nano-carbon suspension in thyroid surgeries. Furthermore, the study did not account for potential confounders, such as lymph node involvement, tumor size, and comorbidities, which may have influenced the results. Incorporating these variables in future research would allow for a more comprehensive analysis of the impact of nano-carbon suspension in thyroid surgery. Finally, exploring the molecular mechanisms behind nano-carbon's selective affinity for lymphatic tissues could offer valuable insights, potentially leading to the development of more targeted and effective applications in thyroid surgery.

Conclusion

Nano-carbon suspension significantly enhances the identification and preservation of parathyroid glands during total thyroidectomy with cervical lymph node dissection for PTC. This advancement improves surgical precision and reduces complications including numbness and twitching. Nano-carbon suspension is particularly beneficial in total thyroidectomy, cases of thyroid cancer with cervical lymph node metastasis, and reoperative surgeries. It shows promise as a standard practice in thyroid cancer surgeries, optimizing patient outcomes, particularly in complex cases.

Methods and materials

Study design and patients

This retrospective study analyzed 219 patients with papillary thyroid carcinoma (PTC) who underwent total thyroidectomy with cervical lymph node dissection at the Ningde Municipal Hospital affiliated with Fujian Medical University between March 2014 and March 2018. The inclusion criteria were: (1) preoperative imaging and/or fine-needle aspiration biopsy confirming PTC with lymph node metastasis; (2) initial thyroid surgery involving total thyroidectomy with lymph node dissection; (3) absence of other conditions affecting blood calcium and parathyroid hormone (PTH) levels. The exclusion criteria were: (1) history of thyroid or other neck surgeries; (2) inability to comply with long-term follow-up.

Patients were divided into two groups: the control group ($n = 112$) comprised patients who did not receive nano-carbon suspension between March 2014 and February 2016; the experimental group ($n = 107$) comprised patients who received nano-carbon suspension as a marker during surgery between March 2016 and March 2018. There was no randomization in the selection of patients for the experimental or control groups, since this was a retrospective study. All surgeries were performed by the same, consistent surgical team.

This study was approved by the Medical Ethics Committee of Ningde Municipal Hospital, Ningde Normal University (Approval No.: NSYKYLL-2024-61), and informed consent was obtained from all subjects and/or their legal guardians. All procedures were performed in accordance with the relevant guidelines and regulations.

Nano-carbon suspension technique

Nano-carbon is a third-generation lymphatic tracer, primarily composed of carbon, polyvinylpyrrolidone, and saline. It rapidly enters capillary lymphatic vessels, providing consistent staining that enhances visibility during surgery without obstructing the field, thereby improving surgical precision.

Surgical procedure

Under general anesthesia, an incision was made along the anterior cervical line, exposing the thyroid gland and its false capsule while preserving their integrity. Based on the disease extent and preoperative assessment, patients underwent one of three surgical techniques:

Technique 1: Total thyroidectomy with unilateral central compartment (Level VI) lymph node dissection.

Technique 2: Total thyroidectomy with bilateral central compartment (Level VI) lymph node dissection.

Technique 3: Total thyroidectomy with bilateral central compartment (Level VI) lymph node dissection and unilateral lateral neck lymph node dissection.

In the experimental group, nano-carbon suspension (Canaline, Chongqing Laimei Pharmaceutical Co., Ltd., H20041829, 1 mL: 50 mg) was injected into each thyroid lobe at two points (approximately 0.1 mL per point), ensuring to avoid intravascular administration. After 3–5 minutes, the thyroid and surrounding lymph nodes were black-stained (Fig. 3).

Using an ultrasonic scalpel, the thyroid was explored, and the affected lobe was excised according to the indicated technique. Upon confirmation of PTC through intraoperative frozen section pathology, lymph node dissection was performed based on the selected surgical technique. For patients with confirmed lateral neck lymph node metastasis (Technique 3), comprehensive lateral neck lymph node dissection was added. The control group underwent similar surgical procedures but without nano-carbon suspension.

Postoperative care included the standardized administration of intravenous calcium gluconate (10 mL, twice daily) and calcitriol capsules (0.5 µg daily) for suspected parathyroid injury or hypocalcemia. These interventions were implemented to reduce their effect on serum calcium levels in the postoperative period.

Observational parameters

The study compared the two groups in terms of age, sex, body mass index (BMI), surgical technique, surgery duration, and intraoperative blood loss. Blood calcium and PTH levels were measured preoperatively, postoperative day 1, and postoperative week 1. Blood calcium was analyzed using an automated analyzer (Beckman Coulter AU5800) with a reference range of 2.15–2.50 mmol/L. PTH was determined using a chemiluminescent immunoassay (Roche Elecsys PTH assay) with a reference range of 15–65 pg/mL.

The average number of lymph nodes retrieved (categorized as unilateral Level VI, bilateral Level VI, and unilateral lateral neck) and the number of parathyroid glands identified were calculated. Postoperative symptoms, including facial, lip, or extremity paresthesia; numbness, tetany, twitching; hoarseness, coughing, hematoma, and lymphatic leakage, were evaluated.

Accurate interpretation of results requires clear reference values and reliable methods for calcium and PTH measurements. Automated analyzers and chemiluminescent immunoassays offer consistent, reproducible results, essential for evaluating the impact of nano-carbon suspension on postoperative calcium and PTH levels.

Postoperative follow-up involved ultrasound examinations of the thyroid and cervical lymph nodes at 1, 6, and 12 months. Fine-needle aspiration biopsy was conducted if lymph node recurrence was suspected.

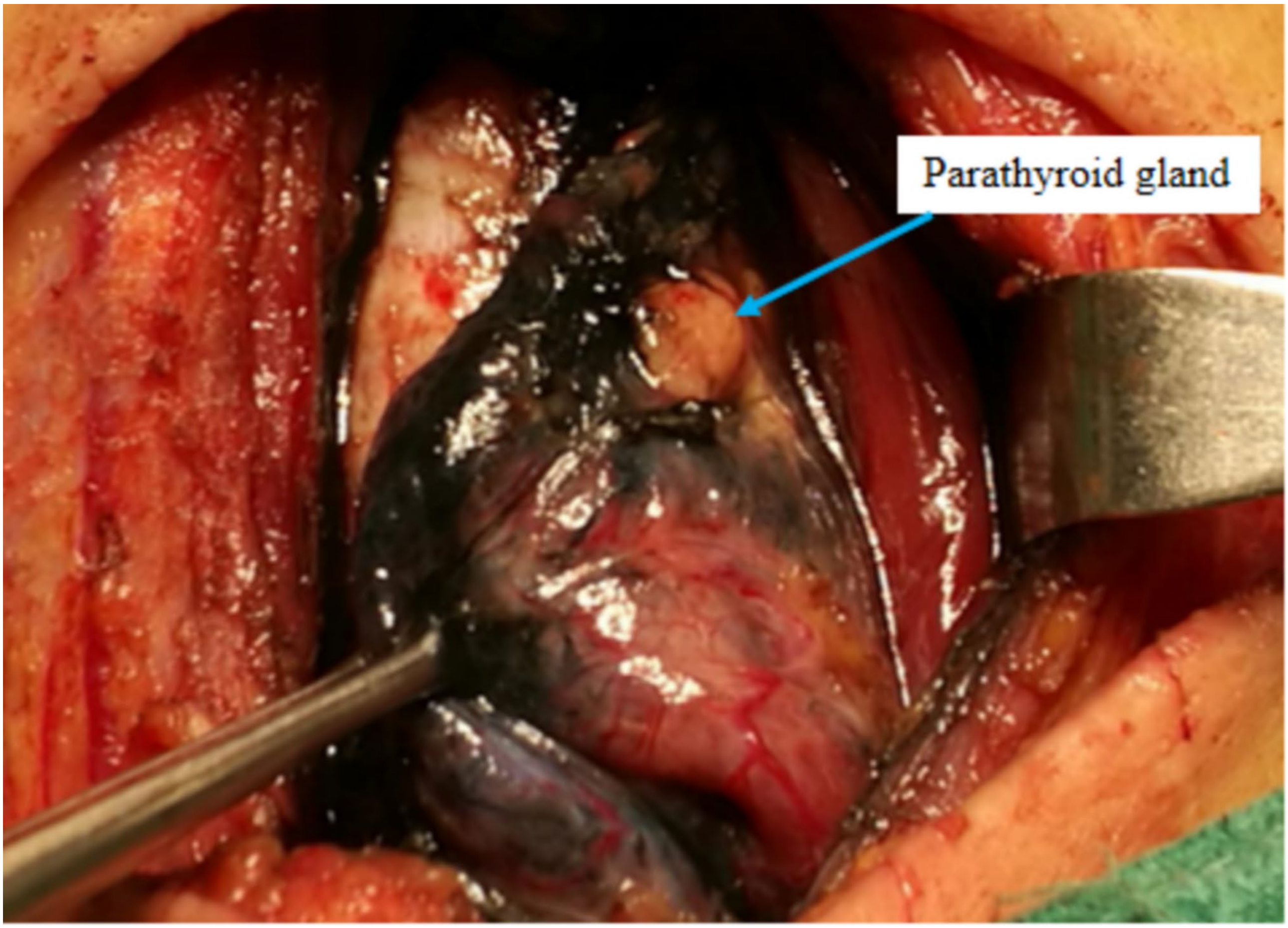

Fig. 3. Intraoperative contrast enhancement with nano-carbon suspension in thyroid surgery. This image shows the application of nano-carbon suspension during total thyroidectomy and cervical lymph node dissection for papillary thyroid carcinoma. Injecting nano-carbon into the thyroid gland and surrounding tissues enhances visual contrast, distinctly delineating the parathyroid glands from adjacent structures. The black staining facilitates the precise identification and preservation of the parathyroid glands, reducing the risk of inadvertent injury during surgery.

Statistical analysis

Statistical analysis was conducted using the Statistical Package for Social Sciences (SPSS) version 22.0 (IBM Corp., Armonk, NY, USA), the R package "CBCgrps"[11], and Python 3.7. The Shapiro–Wilk test was used to assess the normal distribution of variables. Non-normally distributed data were presented as medians and interquartile ranges (IQRs). Categorical data were analyzed using the chi-square test or Fisher's exact test. Continuous variables were compared between groups using the Mann–Whitney U-test. A mixed-effects model was applied to analyze calcium and PTH levels over time, accounting for the study's repeated-measures design.

Data availability

The datasets used and/or analyzed during the current study are available from the corresponding author upon reasonable request.

Received: 7 July 2024; Accepted: 10 October 2024
Published online: 21 October 2024

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Author contributions

D-X. L. Conceptualized and designed the study, performed the surgeries, and contributed to manuscript drafting and critical revision. X-B. Z. Assisted with the surgeries, managed patient follow-up, and contributed to the acquisition of clinical data. Y. L. Supervised the overall study, helped with data interpretation, and provided critical revisions of the manuscript for important intellectual content. W-D. L. and G-J. C. Reviewed the literature, ensured ethical compliance, and assisted in manuscript preparation. Y. Z. Provided technical support for the use of nano-carbon suspension and helped with the visualization of parathyroid glands during surgeries. S-Y. Z. Conducted the data collection, statistical analysis, and interpretation of the results. Each author has participated sufficiently in the work to take public responsibility for appropriate portions of the content. All authors have read and agreed to the published version of the manuscript.

Declarations

Competing interests The authors declare no competing interests.

Additional information

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