scientific reports

OPEN

Ultrasound and high frequency equipment efficacy for abdominal obesity reduction in women

Yeo Ju Sohn & Hyejin Chun

The global and Korean obesity rates are increasing, leading to heightened risks of cardiovascular diseases. Abdominal obesity, in particular, is strongly associated with cardiovascular risks and metabolic syndrome. Although surgical options are available, non-invasive body contouring devices offer lower-risk alternatives. However, evidence regarding their effectiveness in managing abdominal obesity in Koreans is limited. This study evaluates the impact of these techniques on reducing abdominal circumference and subcutaneous fat volume, emphasizing both absolute and relative changes. This retrospective pilot study analyzed data from 9 women participants aged ≥ 18 years treated at Ewha Womans University Seoul Hospital's Well Aging Center in 2023. Participants underwent ultrasound-based body contouring and radiofrequency-based skin tightening. Pre- and post-treatment measurements included waist circumference and abdominal fat areas assessed via CT scans. Statistical analyses were conducted using Wilcoxon signed-rank tests. The treatments significantly reduced waist circumference (absolute: -3.82 cm; relative: -4.35%, $p < 0.01$), maximum waist circumference (absolute: -3.91 cm; relative: -4.14%, $p < 0.01$), superficial fat area (absolute: -18.90 cm²; relative: -7.19%, $p < 0.01$), and total fat area (absolute: -20.38 cm²; relative: -5.67%, $p < 0.01$). These consistent reductions in both absolute and relative terms underscore the robustness of the treatment effects on superficial fat layers. However, visceral fat area did not show statistically significant changes (absolute: -1.48 cm²; relative: -1.46%, $p > 0.05$). Ultrasound-based body contouring and radiofrequency-based skin tightening are effective non-invasive methods for reducing abdominal circumference and subcutaneous fat volume in Korean women with abdominal obesity, as evidenced by significant absolute and relative improvements. Future research should focus on optimizing treatment protocols, conducting comparative studies with other methods, and evaluating long-term outcomes to establish their clinical utility further.

Keywords Abdominal obesity, Subcutaneous fat, Ultrasound-based body contouring, Radiofrequency-based skin tightening, Waist circumference reduction

Obesity, characterized by excessive accumulation of body fat and associated metabolic abnormalities, is linked to a higher prevalence of chronic conditions such as diabetes mellitus, hypertension, dyslipidemia, obstructive sleep apnea, cardiovascular diseases, and certain cancers, resulting in elevated mortality rates[1,2]. In one previous study, it has been observed that globally, the proportion of adults with a body mass index (BMI) of 25 kg/m² or higher increased from 28.8 to 36.9% for men and from 29.8 to 38.0% for women between 1980 and 2013[3]. This indicates a significant rise in the global obesity prevalence. Such findings underscore the seriousness of the obesity issue over time and highlight the increasing trend, further emphasizing the need for further researches in this area. The prevalence of obesity among adults in Korea is 36.3% as of 2019, with a consistent upward trend over the past decade[4].

Abdominal obesity, defined by excessive fat accumulation in the abdominal region, particularly correlates with increased risk of cardiovascular diseases[5]. Assessment of abdominal obesity typically involves measuring waist circumference, with criteria defining abdominal obesity as waist circumferences ≥ 90 cm for men and ≥ 85 cm for women in Korean populations[6]. Imaging techniques like computed tomography (CT) can accurately assess visceral fat accumulation, a key predictor of metabolic syndrome[7]. Abdominal obesity contributes to insulin resistance, impaired fasting glucose, dyslipidemia, and hypertension, underscoring its significance as a precursor to metabolic syndrome[8,9]. Therefore, body shape correction, especially through the management of abdominal obesity, can be considered an important medical practice. Surgical interventions for body contouring,

Department of Family Medicine, Ewha Womans University Seoul Hospital, Ewha Womans University College of Medicine, Seoul, Korea. ✉email: fmewha@naver.com

while effective, may entail complications such as pain, swelling, scarring, and infection. Consequently, non-invasive body contouring devices have gained popularity for their ability to address aesthetic concerns without surgical risks[10]. However, evidence supporting the combined use of ultrasound-based body contouring and radiofrequency-based skin tightening techniques for abdominal obesity management in Koreans remains limited.

Thus, this study aims to evaluate the effectiveness of combining these techniques in reducing abdominal circumference and subcutaneous fat volume, thereby addressing abdominal obesity among Korean women.

Materials and methods

Data source and study subjects

This study retrospectively analyzed clinical data obtained during treatment processes that had already been completed at Ewha Womans University Seoul Hospital. The study included women aged 18 years or older who visited the Well Aging Center at Ewha Womans University Seoul Hospital between January 1, 2023, and December 31, 2023.

Inclusion criteria were as follows:

1. Patients who underwent ultrasound-based body contouring using the UltraSpeed™ handpiece (Alma Accent Prime™ platform) and radiofrequency-based skin tightening using the UniForm™ handpiece (Alma Accent Prime™ platform).
2. Patients whose waist circumference was measured both before and after the procedure.
3. Patients who underwent abdominal fat computed tomography (CT) scans to assess subcutaneous and visceral fat areas.

Exclusion criteria included individuals with incomplete data required for analysis or those who died during the study period.

The UltraSpeed™ handpiece utilizes non-focused ultrasound technology delivered through a large plate-type sonotrode that generates acoustic-guided vibration waves to disrupt subcutaneous adipose tissue, facilitating body contouring. The UniForm™ handpiece employs radiofrequency energy to improve skin elasticity and stimulate collagen remodeling by generating heat in the dermal layers.

To minimize risks to participants, no prospective data collection for research purposes was conducted. All information was fully de-identified by removing personal identifiers and replacing them with unique identification codes. As such, the risk to participants did not exceed minimal risk. A waiver of informed consent was approved by the Institutional Bioethics Committee of Ewha Womans University Seoul Hospital (IRB approval number: SEUMC 2024-03-029).

Ethical approval

All methods in this study were carried out in accordance with relevant guidelines and regulations. The study protocol was reviewed and approved by the Institutional Bioethics Committee of Ewha Womans University Seoul Hospital (IRB file number: SEUMC 2024-03-029). As this study involved retrospective analysis of de-identified clinical data, obtaining informed consent from participants was waived by the ethics committee.

Analytical approach and statistics

Continuous variables were expressed as mean ± standard deviation (SD) or median (interquartile range, IQR), as appropriate. Pre- and post-treatment measurements were compared using the non-parametric Wilcoxon signed-rank test to evaluate changes in waist circumference, maximum waist circumference, subcutaneous fat area, visceral fat area, and total fat area at the umbilicus level among subjects who received abdominal treatment. This statistical method was chosen due to the small sample size ($n = 9$) and the non-normal distribution of the data. Statistical analyses were conducted using IBM SPSS Statistics version 29.0.2.0 (IBM Co., Armonk, NY, USA). A two-sided p-value of less than 0.05 was considered statistically significant.

Additionally, no missing data were encountered in this study, and all analyses were conducted on complete datasets. The time interval (in days) between the ultrasound-based body contouring session and the radiofrequency-based skin tightening session was also recorded for each participant. This information is presented in Table 1 to provide a detailed understanding of the treatment timeline.

Results

In this study, a total of 9 women participants underwent combined ultrasound-based body contouring and radiofrequency-based skin tightening techniques. The results demonstrated significant changes in several key metrics of abdominal obesity (Table 1). Table 1 summarizes the detailed data for each subject, including waist circumference, fat area measurements before and after treatment, and the time interval (in days) between the ultrasound-based body contouring and radiofrequency-based skin tightening sessions.

The mean reduction in waist circumference (ΔWC) was − 3.83 cm ($SD = 1.79$, $p < 0.01$). This consistent reduction across participants, ranging from − 1.00 cm to -6.50 cm, indicates a significant decrease in abdominal girth post-treatment. The average reduction in maximum waist circumference (ΔWC Max) was − 3.91 cm ($SD = 2.52$, $p < 0.01$). These reductions varied from − 1.00 cm to -7.70 cm, suggesting the treatment's efficacy in addressing not just the baseline but also the maximal abdominal expansion. The treatments resulted in a mean decrease of 18.90 cm² in the superficial fat area (SFA) ($SD = 13.70$, $p < 0.01$). This significant reduction highlights the ability of the combined techniques to effectively reduce superficial abdominal fat. Contrary to other measurements, the visceral fat area (VFA) did not exhibit a statistically significant change (mean ΔVFA = -1.48 cm², $SD = 10.63$, $p > 0.05$). This suggests that the procedures predominantly target superficial layers of

Subject #	Sex	TI	WC_1	WC_2	△WC	WC MAX_1	WC MAX_2	△WC_Max	SFA_1	SFA_2	△SFA	VFA_1	VFA_2	△VFA	TFA_1	TFA_2	△TFA
1.00	F	1 day	96.00	92.00	−4.00	105.00	97.30	−7.70	374.13	368.86	−5.27	181.18	167.50	−13.68	555.31	536.36	−18.95
2.00	F	26days	90.00	88.00	−2.00	94.00	93.00	−1.00	342.36	333.27	−9.09	195.14	198.64	3.50	537.50	531.91	−5.59
3.00	F	0 day	83.00	80.50	−2.50	95.50	89.00	−6.50	145.82	140.12	−5.70	47.06	51.22	4.16	192.88	191.34	−1.54
4.00	F	9 day	90.00	85.50	−4.50	92.00	91.00	−1.00	310.18	267.60	−42.58	113.62	125.29	11.67	423.80	392.89	−30.91
5.00	F	0 day	81.00	80.00	−1.00	88.00	86.00	−2.00	309.13	272.03	−37.10	127.46	119.02	−8.44	436.59	391.05	−45.54
6.00	F	0 day	80.00	73.50	−6.50	87.00	81.00	−6.00	148.56	133.01	−15.55	67.53	49.24	−18.29	216.09	182.25	−33.84
7.00	F	0 day	81.00	77.00	−4.00	88.00	83.00	−5.00	207.49	187.59	−19.90	91.43	85.15	−6.28	298.92	272.74	−26.18
8.00	F	1 day	99.00	93.00	−6.00	102.00	100.00	−2.00	398.14	372.40	−25.74	138.31	141.74	3.43	536.45	514.14	−22.31
9.00	F	0 day	92.00	88.00	−4.00	97.00	93.00	−4.00	205.50	196.32	−9.18	91.35	101.99	10.64	296.85	298.31	1.46

Table 1. Detailed subject data before and after intervention. *Subject#* Subject number, *TI* Time interval between ultrasound and radiofrequency treatments, *F* Female, *M* Male. WC_1 = waist circumference before treatment, WC_2 = waist circumference after treatment, △WC = WC_2 - WC_1, △WC %= (WC_2 - WC_1)/, WC_1 × 100. WC MAX_1 = maximum waist circumference before treatment, WC MAX_2 = maximum waist circumference after treatment, △WC_Max = WC MAX_2 - WC MAX_1. △WC_Max% = (WC MAX_2 - WC MAX_1)/WC MAX_1 × 100. SFA_1 = superficial fat area before treatment, SFA_2 = superficial fat area after treatment, △SFA = SFA_2 - SFA_1, △SFA %= (SFA_2 - SFA_1)/SFA_1 × 100. VFA_1 = visceral fat area before treatment, VFA_2 = visceral fat area after treatment, △VFA = VFA_2 - VFA_1, △VFA % = (VFA_2 - VFA_1)/VFA_1 × 100. TFA_1 = total fat area before treatment, TFA_2 = total fat area after treatment, △TFA = TFA_2 - TFA_1, △TFA % = (TFA_2 - TFA_1)/TFA_1 × 100.

Statistic	△WC	△WC_Max	△SFA	△VFA	△TFA
Mean	−3.83	−3.91	−18.90	−1.48	−20.38
Median	−4.00	−4.00	−15.55	3.43	−22.31
SD	1.79	2.52	13.70	10.63	15.87
Min	−6.50	−7.70	−42.58	−18.29	−45.54
Max	−1.00	−1.00	−5.27	11.67	1.46
p−value	< 0.005	< 0.005	< 0.005	0.73	< 0.01

Table 2. Summary statistics and p-values for body composition changes. P values were analyzed by using Wilcoxon signed rank test to evaluate changes. △WC = WC_2 - WC_1, WC_1 = waist circumference before treatment, WC_2 = waist circumference after treatment. △WC Max = WC MAX_2 - WC MAX_1, WC MAX_1 = maximum waist circumference before treatment, WC MAX_2 = maximum waist circumference after treatment. △SFA = SFA_2 - SFA_1, SFA_1 = superficial fat area before treatment, SFA_2 = superficial fat area after treatment. △VFA = VFA_2 - VFA_1, VFA_1 = visceral fat area before treatment, VFA_2 = visceral fat area after treatment. △TFA = TFA_2 - TFA_1, TFA_1 = total fat area before treatment, TFA_2 = total fat area after treatment. *SD* standard deviation, *Min* minimum, *Max* maximum.

Statistic	△WC%	△WC_Max%	△SFA%	△VFA%	△TFA%
Mean	−4.35	−4.14	−7.19	−1.45	−5.67
Median	−4.35	−4.12	−6.47	1.79	−4.16
SD	2.06	2.61	4.40	12.20	5.31
Min	−8.13	−7.33	−13.73	−27.08	−15.66
Max	−1.23	−1.06	−1.41	11.65	0.49
p−value	< 0.005	< 0.005	< 0.005	0.91	< 0.01

Table 3. Relative percentage changes and P-values for body composition. P values were analyzed by using Wilcoxon signed rank test to evaluate changes. △WC %= (WC_2 - WC_1)/, WC_1 × 100, △WC = WC_2 - WC_1, WC_1 = waist circumference before treatment, WC_2 = waist circumference after treatment. △WC Max = WC MAX_2 - WC MAX_1, WC MAX_1 = maximum waist circumference before treatment, WC MAX_2 = maximum waist circumference after treatment. △WC_Max% = (WC MAX_2 - WC MAX_1)/WC MAX_1 × 100. △SFA %= (SFA_2 - SFA_1)/SFA_1 × 100, △SFA = SFA_2 - SFA_1, SFA_1 = superficial fat area before treatment, SFA_2 = superficial fat area after treatment. △TFA % = (TFA_2 - TFA_1)/TFA_1 × 100, △TFA = TFA_2 - TFA_1, TFA_1 = total fat area before treatment, TFA_2 = total fat area after treatment. △VFA % = (VFA_2 - VFA_1)/VFA_1 × 100, △VFA = VFA_2 - VFA_1, VFA_1 = visceral fat area before treatment, VFA_2 = visceral fat area after treatment. *SD* standard deviation, *Min* minimum, *Max* = maximum.

fat rather than deeper visceral fat. The total fat area(TFA) showed a significant mean reduction of 20.38 cm^2 (SD = 15.87, $p < 0.01$), indicating an overall decrease in abdominal fat content post-treatment.

Table 2 provides a summary of these changes and their statistical significance. The data illustrates that while significant reductions were observed in most metrics, the lack of change in visceral fat underscores the need for additional research to understand the differential effects of the treatments on various fat compartments.

Relative percentage changes were calculated for waist circumference (ΔWC %), maximum waist circumference (ΔWC Max%), superficial fat area (ΔSFA %), visceral fat area (ΔVFA %), and total fat area (ΔTFA %) to provide a standardized metric for evaluating treatment effects across participants. These calculations were performed using the formula:

$$\Delta\% = \frac{Post\, treatment\, value - Pr\,e\, treatment\, value}{Pr\,e\, treatment\, value} \times 100$$

The relative percentage changes have been included in Table 3 to enhance the interpretability of the results. Relative percentage changes revealed a similar trend, with significant reductions observed in waist circumference (△WC%)(-4.35%, $p < 0.01$), maximum waist circumference (△WC_Max%)(-4.14%, $p < 0.01$), superficial fat area (△SFA%)(-7.19%, $p < 0.01$), and total fat area (△TFA%)(-5.67%, $p < 0.01$). Visceral fat area (△VFA%) (-1.46%) did not show significant changes ($p > 0.05$).

These findings highlight the efficacy of the applied techniques in targeting superficial fat, as corroborated by Table 3. The consistency between absolute and relative percentage reductions highlights the robustness of the treatment effects across different metrics and further supports the efficacy of these non-invasive methods in managing abdominal obesity among Korean women.

Discussion

This study investigated the effectiveness of combining ultrasound-based body contouring and radiofrequency-based skin tightening techniques on abdominal obesity in Korean women. These non-invasive procedures aimed to reduce abdominal circumference and subcutaneous fat volume. The results demonstrated statistically significant changes in waist circumference, maximum waist circumference, superficial fat area, and total fat area after the treatments. Visceral fat area did not show a statistically significant difference.

Patients often experience initial reductions in visceral fat during weight loss, while reductions in subcutaneous fat take longer, leading to frustration for some individuals. In this context, the findings of this study confirm that ultrasound-based body contouring and radiofrequency-based skin tightening techniques can be effective for reducing abdominal circumference and subcutaneous fat volume in female patients.

The thermal disruption of adipose tissue by ultrasound and radiofrequency technologies involves several mechanisms. Ultrasound induces mechanical vibrations that disrupt adipocyte membranes, leading to triglyceride release and subsequent cellular apoptosis or necrosis[11,12]. Radiofrequency generates heat through electromagnetic waves, which accelerates adipocyte metabolism via lipase-mediated triglyceride degradation and promotes apoptosis[13]. Additionally, both modalities improve local blood circulation by inducing vasodilation, enhancing oxygen supply, and stimulating fibroblast activity for collagen remodeling[14]. These combined effects contribute to reductions in subcutaneous fat volume and improvements in skin elasticity.

The relative percentage results align with these findings, as superficial fat was most affected by the interventions with a mean reduction of 7.19%. This supports the role of ultrasound-based body contouring and radiofrequency-based skin tightening techniques as valuable options for addressing localized fat deposits and improving body contour.

Various modalities exist for body contouring through weight loss or amelioration of abdominal obesity. According to Clinical Practice Guidelines for Obesity 2022 in Korea, lifestyle modifications, including diet and exercise, should be prioritized. Pharmacological interventions may follow when necessary[15]. For cases of severe obesity or obesity accompanied by complications, with a BMI of 35 kg/m2 or more, or a BMI of 30 kg/m2 or more with obesity-related comorbidities, who have failed to lose weight with non-surgical treatment, bariatric surgeries such as laparoscopic sleeve gastrectomy (LSG), laparoscopic Roux-en-Y gastric bypass (LRYGB), biliopancreatic diversion with duodenal switch (BPD/DS), and laparoscopic adjustable gastric banding (LAGB) are indicated[16–18]. Additionally, intragastric balloon placement can be contemplated[19,20]. However, physicians could consider non-surgical approaches as part of comprehensive body contouring strategies and also, patients seeking aesthetic improvements without invasive surgery may find these procedures appealing. Among the techniques available, liposuction aims to reduce localized adipose tissue. The findings of this study suggest that ultrasound-based body contouring and radiofrequency-based skin tightening techniques are noninvasive and could be beneficial for female patients with abdominal obesity.

In comparison to prior studies using radiofrequency and/or ultrasound device, our research demonstrates similar trends in waist circumference reduction[21–23]. Furthermore, this study holds a distinct advantage as it employs fat CT scans to assess abdominal fat area, allowing for precise pre- and post-treatment comparisons. Our findings that visceral fat (with an average reduction of only 1.48 cm^2 or 1.46%) was not significantly affected while superficial fat showed significant reduction (18.90 cm^2 or 7.19% decrease) provide important insights into the selective targeting of these technologies. This methodological approach enhances the reliability and accuracy of our findings, marking a significant strength of this pilot investigation.

This study has several limitations that should be addressed. Firstly, the small sample size(9 female participants) and pilot nature of the study necessitate further research with larger, more diverse populations. Randomized controlled trials (RCTs) could provide higher levels of evidence. Secondly, the follow-up period in this study was relatively short, limiting the evaluation of long-term effects and safety. Therefore, long-term follow-up studies are essential to assess sustained efficacy and potential adverse effects. Thirdly, this study was conducted at a single center with participants exclusively from Korea, which may limit the generalizability of the findings to other populations. Cultural, demographic, and physiological differences could influence the outcomes of similar interventions in broader or more heterogeneous populations. Future studies should aim to include multi-center designs and diverse participant groups to enhance external validity. This version integrates the additional limitation regarding the single-center design and Korean participants while maintaining a professional and academic tone. It also emphasizes the need for future research to address these limitations.

From a technical standpoint, the variability in ultrasound and radiofrequency equipment should be considered, as different devices and protocols may produce varying results. Further research is needed to optimize treatment protocols, including the frequency, intensity, and duration of treatment, to determine the most effective combination.

Comparative studies are also crucial. Evaluating ultrasound and radiofrequency treatments against other non-invasive body contouring methods, such as cryolipolysis and laser lipolysis, will help to assess their relative efficacy. Additionally, comparing these non-surgical methods with surgical options like liposuction and body lifts can elucidate the advantages and limitations of non-invasive approaches.

Patient satisfaction and quality of life assessments are important components that should be included in future studies. Understanding the psychological impact of non-invasive body contouring on patient satisfaction, self-esteem, and mental health is crucial. Moreover, conducting a cost-effectiveness analysis will provide insight into the economic benefits of these treatments from a healthcare perspective.

Other physiological effects should also be explored. Further research should evaluate the impact of non-invasive body contouring methods on metabolic health, including changes in insulin sensitivity and lipid profiles. Investigating the effects of ultrasound and radiofrequency treatments on inflammation and fibrosis within adipose tissue is also important to understand the long-term physiological implications.

Nevertheless, this pilot study provides a foundation for future clinical trials. Researchers should explore larger sample sizes, extend follow-up periods, and include additional outcome measures in subsequent studies. Comparative studies with other body contouring methods will also be valuable in informing clinical practice and determining the relative efficacy and benefits of these non-invasive procedures.

Conclusion

In conclusion, ultrasound-based body contouring and radiofrequency-based skin tightening techniques can be effective for reducing abdominal circumference and subcutaneous fat volume in Korean women, with our data showing significant reductions in waist circumference (3.83 cm or 4.35%) and superficial fat area (18.90 cm^2 or 7.19%). The finding that visceral fat was not significantly reduced (1.48 cm^2 or 1.46%) suggests these techniques primarily target subcutaneous rather than visceral fat deposits. However, these initial results highlight the need for more rigorous studies with larger sample sizes, diverse populations, and longer follow-up periods to establish clinical efficacy and safety. Future research should focus on optimizing treatment protocols, conducting comparative studies with other body contouring methods, and assessing the long-term physiological and psychological impacts of these non-invasive procedures.

Data availability

The authors confirm that the data supporting the findings of this study are available within the article.

Received: 17 December 2024; Accepted: 18 April 2025
Published online: 20 May 2025

References

1. Anis, A. H. et al. Obesity and overweight in Canada: an updated cost-of-illness study. *Obes. Rev.* **11**, 31–40. https://doi.org/10.1111/j.1467-789X.2009.00579.x (2010).
2. Kannel, W. B., 1,2, Adrienne Cupples, L.1,2, Ramaswami, R.1,2, Stokes III, J.1,2, Kreger, B.E.1,2, Higgins, M. Regional obesity and risk of cardiovascular disease; the Framingham study. https://doi.org/10.1016/0895-4356(91)90265-B
3. Ng, M. et al. Global, regional, and National prevalence of overweight and obesity in children and adults during 1980–2013: a systematic analysis for the global burden of disease study 2013. *Lancet* **384**, 766–781. https://doi.org/10.1016/S0140-6736(14)60460-8 (2014).
4. Yang, Y. S. et al. Obesity fact sheet in Korea, 2021: trends in obesity prevalence and obesity-Related comorbidity incidence stratified by age from 2009 to 2019. *J. Obes. Metab. Syndr.* **31**, 169–177. https://doi.org/10.7570/jomes22024 (2022).
5. Coutinho, T. et al. Combining body mass index with measures of central obesity in the assessment of mortality in subjects with coronary disease. *J. Am. Coll. Cardiol.* **61**, 553–560. https://doi.org/10.1016/j.jacc.2012.10.035 (2013).
6. Yoon, Y. S. & Oh, S. W. Optimal waist circumference cutoff values for the diagnosis of abdominal obesity in Korean adults. *Endocrinol. Metab.* **29**, 418. https://doi.org/10.3803/EnM.2014.29.4.418 (2014).
7. Shuster, A., Patlas, M., Pinthus, J. H. & Mourtzakis, M. The clinical importance of visceral adiposity: a critical review of methods for visceral adipose tissue analysis. *Br. J. Radiol.* **85**, 1–10. https://doi.org/10.1259/bjr/38447238 (2012).
8. Taverne, F., Richard, C., Couture, P. & Lamarche, B. Abdominal obesity, insulin resistance, metabolic syndrome and cholesterol homeostasis. *PharmaNutrition* **1**, 130–136. https://doi.org/10.1016/j.phanu.2013.07.003 (2013).
9. Kumar, B. et al. An important predictor of metabolic syndrome. *Scr. Med. (Brno).* **54**, 81–85. https://doi.org/10.5937/scriptamed54-40389 (2023).
10. Alizadeh, Z. et al. Non-invasive body contouring technologies: an updated narrative review. *Aesthetic Plast. Surg.* **48**, 659–679. https://doi.org/10.1007/s00266-023-03647-x (2024).
11. Bani, D., Li, A. Q., Freschi, G. & Russo, G. L. Histological and ultrastructural effects of Ultrasound-induced cavitation on human skin adipose tissue. *Plast. Reconstr. Surg. Glob Open.* **1**, e41. https://doi.org/10.1097/GOX.0b013e3182a7f222 (2013).
12. Silva, D. E ects of ultracavitation and radiofrequency on abdominal adiposity. **15**. (2022).
13. Duncan, D. I., Kim, T. H. M. & Temaat, R. A prospective study analyzing the application of radiofrequency energy and high-voltage, ultrashort pulse duration electrical fields on the quantitative reduction of adipose tissue. *J. Cosmet. Laser Ther.* **18**, 257–267. https://doi.org/10.3109/14764172.2016.1157368 (2016).
14. Yang, Q. et al. Low-Intensity Ultrasound-Induced Anti-inflammatory effects are mediated by several new mechanisms including gene induction, immunosuppressor cell promotion, and enhancement of exosome biogenesis and Docking. *Front. Physiol.* **8**, 818. https://doi.org/10.3389/fphys.2017.00818 (2017).
15. Kim, K-K. et al. Evaluation and treatment of obesity and its comorbidities: 2022 update of clinical practice guidelines for obesity by the Korean society for the study of obesity. *J. Obes. Metab. Syndr.* **32**, 1–24. https://doi.org/10.7570/jomes23016 (2023).
16. Homan, J. et al. Secondary surgery after sleeve gastrectomy: Roux-en-Y gastric bypass or biliopancreatic diversion with duodenal switch. *Surg. Obes. Relat. Dis.* **11**, 771–777. https://doi.org/10.1016/j.soard.2014.09.029 (2015).
17. Baptista, V. & Wassef, W. Bariatric procedures: an update on techniques, outcomes and complications. *Curr. Opin. Gastroenterol.* **29**. https://journals.lww.com/co-gastroenterology/fulltext/2013/11000/bariatric_procedures__an_update_on_techniques,.17.aspx (2013).
18. Lee, W. & Almalki, O. Recent advancements in bariatric/metabolic surgery. *Ann. Gastroenterol. Surg.* **1**, 171–179. https://doi.org/10.1002/ags3.12030 (2017).
19. Bazerbachi, F. et al. Intragastric balloon placement induces significant metabolic and histologic improvement in patients with nonalcoholic steatohepatitis. *Clin. Gastroenterol. Hepatol.* **19**, 146–154e4. https://doi.org/10.1016/j.cgh.2020.04.068 (2021).
20. Gleysteen, J. J. A history of intragastric balloons. *Surg. Obes. Relat. Dis.* **12**, 430–435. https://doi.org/10.1016/j.soard.2015.10.074 (2016).
21. Kapoor, R., Shome, D. & Ranjan, A. Use of a novel combined radiofrequency and ultrasound device for lipolysis, skin tightening and cellulite treatment. *J. Cosmet. Laser Ther.* **19**, 266–274. https://doi.org/10.1080/14764172.2017.1303169 (2017).
22. Toledano, O., Tsurgil, S., Topaz, O. & Lepselter, J. Guided acoustic waves technology for selective non-invasive lipolysis and circumference reduction– a preliminary report.
23. Fritz, K. & Salavastru, C. Long-term follow-up on patients treated for abdominal fat using a selective contactless radiofrequency device. *J. Cosmet. Dermatol.* **16**, 471–475. https://doi.org/10.1111/jocd.12429 (2017).

Author contributions

S.Y.J. wrote the manuscript, organized and summarized the overall data, created the tables, and performed revisions. C.H.J. collected the data, performed procedures on patients, and supervised the manuscript overall.

Declarations

Competing interests
The authors declare no competing interests.

Statement of human and animal rights, or ethical approval
This study is a study that retrospectively analyzes clinical data obtained during a treatment process that has already been completed. The risk to the subjects did not exceed the minimum risk, and no prospective information for research purposes was collected from the subjects, and personal identification was not used. Information was completely removed and only data with a separate identification code was used. Therefore, waiver of consent was approved by the Institutional Bioethics Committee of Ewha Womans University Seoul Hospital, and the IRB file number is SEUMC 2024-03-029.

Additional information
Correspondence and requests for materials should be addressed to H.C.

Reprints and permissions information is available at www.nature.com/reprints.

Publisher's note Springer Nature remains neutral with regard to jurisdictional claims in published maps and institutional affiliations.

Open Access This article is licensed under a Creative Commons Attribution-NonCommercial-NoDerivatives 4.0 International License, which permits any non-commercial use, sharing, distribution and reproduction in any medium or format, as long as you give appropriate credit to the original author(s) and the source, provide a link to the Creative Commons licence, and indicate if you modified the licensed material. You do not have permission under this licence to share adapted material derived from this article or parts of it. The images or other third party material in this article are included in the article's Creative Commons licence, unless indicated otherwise in a credit line to the material. If material is not included in the article's Creative Commons licence and your intended use is not permitted by statutory regulation or exceeds the permitted use, you will need to obtain permission directly from the copyright holder. To view a copy of this licence, visit http://creativecommons.org/licenses/by-nc-nd/4.0/.

© The Author(s) 2025