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Objective Volumetric Comparison of Room Air versus Carbon Dioxide for Colonic Distention at Screening CT Colonography

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Abstract

Purpose—To objectively compare colonic distention at CT colonography (CTC) achieved with manual room air versus automated low-pressure carbon dioxide using a novel automated volumetric quality assessment tool.

Methods—Volumetric analysis was retrospectively performed on CTC studies in 300 asymptomatic adults using an automated quality assessment tool (V3D Colon [beta version], Viatronix). Colonic distention was achieved with room air self-administered to tolerance via hand-held pump (mean number of pumps, 39 ± 32) in 150 individuals (mean age, 59 years; 98 men, 51 women) and via continuous low-pressure automated infusion of carbon dioxide in 150 individuals (mean age, 57 years; 89 men, 61 women). CTC studies in supine and prone position were assessed to determine total colonic volume (luminal gas and fluid). The colonic length along the automated centerline was also recorded to enable calculation of length-adjusted colonic volumes.

Results—The mean total colonic volume ($\pm$ SD) for individuals receiving room air and carbon dioxide distention was 1809 ± 514 mL and 2223 ± 686 mL, respectively ($p < 0.01$). The prone position was better distended in 78.7% (118/150) of cases using room air; whereas, the supine was better in 66.0% (99/150) of carbon dioxide cases ($p < 0.01$). Using a volume threshold of 2000 mL, 49 (32.7%) of room air cases and 92 (61.3%) of CO₂ cases were above this cut-off. The mean length-adjusted colonic volume (mL/cm) for the room air and carbon dioxide techniques was 9.9 ± 2.4 mL/cm and 11.6 ± 2.6 mL/cm ($p < 0.01$).

Conclusions—Using automated volumetry allowed quantitative analyses of colonic volumes and objectively confirmed that continuous low-pressure carbon dioxide provides greater overall colonic distention than the manual room air technique at CTC. The supine position demonstrated better distention with carbon dioxide, whereas the prone position was better distended with the room air technique.

Introduction

There are many factors and technical obstacles that have been addressed to help streamline and optimize performance of CT colonography (CTC). Issues that must be addressed include: bowel preparation, colonic distention, CT scanning technique, and the rendering software for analysis.^{1, 2} Suboptimal performance of any of these areas will degrade sensitivity and specificity for polyp detection at CTC.

Adequate (and preferably optimal) colonic distention is critical for effective lesion detection at CTC.³⁻⁸ Initially, room air manually delivered from a patient- or staff-controlled simple handheld pump was used to distend the colon. More recently, automated carbon dioxide (CO₂) delivery systems have become widely available. It has been shown that CO₂ has a superior safety profile (due to lower peak pressures) and produces less discomfort post-procedure (due to rapid reabsorption).⁷⁻¹⁰ CO₂ systems are also easier to use as they do not require any patient coaching and have a more clearly defined end point. Anecdotally, it has been generally accepted that CO₂ produces better and more consistent colonic distention than room air. Through subjective and somewhat crude semi-quantitative scoring systems, it has been suggested that CO₂ provides improved colonic distention compared with room air.^{7, 8}

To our knowledge, no truly objective volumetric quantitative analysis has been performed to compare colonic distention with manually-delivered room air and automatically-delivered CO₂. The advent of a novel quantitative volumetric analysis tool now allows for the quantitative evaluation of colonic intra-luminal gas and fluid volumes.¹¹ The purpose of this study was to employ this new QA tool to quantitatively measure and compare the differences in colonic distention between patient-controlled room air insufflation and automated CO₂ delivery techniques.

Methods and Materials

Study group

A retrospective multi-institutional cohort study was performed that was Health Insurance and Portability and Accountability Act compliant, and was IRB approved. The need for specific additional patient consent was waived. A total of 300 asymptomatic patients who underwent CTC screening were selected for volumetric analysis of the colon. The patients consisted of two groups of 150. In the first group (mean height, 162.6 cm.; mean weight, 84.3 Kg.; mean BMI 27.8; mean age, 59 years; 98 men, 51 women), colonic distention was achieved using room air via self-administered handheld pump. This asymptomatic room air cohort represents a random subset of the DoD CTC screening trial.¹² In the second group (mean height, 169.1 cm.; mean weight, 97.7 Kg.; mean BMI 30.8; mean age, 57 years; 89 men, 61 women), distention was achieved via low-pressure CO₂ delivery. This group represents a subset of asymptomatic individuals who underwent screening within the CTC program at our institution [blinded for review]. To provide a more gender-matched comparison, 50 consecutive women were excluded from this CO₂ cohort (originally 200 consecutive patients), resulting in the final 150 patient sample.

CTC Distention Technique

Bowel preparation for both patient cohorts consisted of a cathartic agent (sodium phosphate or magnesium citrate) followed by oral contrast tagging as previously described.¹¹ All CTC examinations were evaluated online by an experienced CT technologist for quality assurance, with additional input from the interpreting radiologist as needed.

Colonic distention was achieved in the room air (DoD) group through patient-controlled insufflation via a small flexible rectal catheter connected by tubing to a standard air bulb insufflator used for barium enema examination (Fig 1A). The CT technologist coached the patient on self-insufflation and provided assistance if needed. The room air technique began in the left lateral decubitus position followed by supine and prone positioning. The total number of handheld bulb pumps was recorded for both positions (total mean number of pumps, 39 ± 32).

For the CO₂ group, colonic distention was achieved using an automatic low-pressure CO₂ delivery device (PROTOCO₂L, Bracco Diagnostics) via flexible rectal catheter (Fig 1B). The subject was initially placed in the left lateral decubitus position and an initial volume of 1 to 1.5 L of CO₂ were instilled with the equilibrium pressure set at approximately 17-18 mm Hg. The patient was then moved to a right lateral decubitus position until approximately 2.5 L of total CO₂ was delivered. Equilibrium pressure was gradually increased to 25 mmHg during this process. The patient was then placed in the supine position until steady-state equilibrium was achieved. A scout view was then obtained during end-expiration, followed by supine CT image acquisition, assuming adequate distention. The patient was then placed in the prone position and repeat scanning was performed once equilibrium pressure was again achieved.

CTC Acquisition Protocol

CT image acquisition was obtained in the supine and prone positions using multi-detector CT scanners (GE Healthcare, Waukesha, WI). Scanning technique consisted of 1.25–2.5 mm collimation with a technique of 25 to 100 mAs (or with tube current modulation), 120 KV_p, and 1–2 mm reconstruction interval. Any decubitus series obtained after the standard supine and prone series were not included for analysis in this study.

Data Analysis

Volumetric data analysis of colonic distention for both the room air and CO₂ cohorts was performed using a novel software application (V3D Colon beta version, Viatronix). The efficacy of this novel software application has been validated by a previous study.¹¹ This software has also been internally validated with phantom studies performed by the manufacturer, demonstrating accuracy for volume assessment on the order of 98%. DICOM data sets were exported to a dedicated CTC workstation for volumetric analysis. The colon segmentation algorithm detects the gas-filled luminal cavity by initial thresholding, and then uses a growing technique to delineate all tagged fluid regions connected to the gas-filled lumen by probing for seed pixels greater than 200 HU along the gravitational direction with defined spatial range constraints. In a final step, the partial volume layer that forms between air and tagged fluid is determined. The processed total colonic lumen consists of gas, tagged

fluid, and partial volume layer regions. A median filtering technique is applied to the extracted regions to remove morphological irregularity caused by image noise and artifacts. Gas volume and fluid volume are calculated by summing the voxels with selected labels.

Total colonic volume was recorded in each case for the position (supine or prone) with the best overall distention. Fluid and gas volumes were also recorded. Automated colonic length was also generated along the centerline, which was recorded to adjust for potential differences in total colonic volume related to differences in length by calculating length-adjusted colonic volumes. An empirically-derived target volume threshold of 2000 ml was used as a general indicator of adequate colonic distention, which was derived from previous research ¹¹.

The Student's t-test was performed to determine whether the absolute and adjusted colonic distention volumes were statistically significant between the room air and CO₂ cohorts, with a p value of less than 0.05 being statistically significant.

Results

Assessment of total colonic volume using the automated QA tool was performed in all 300 patients without technical failure. Small differences in patient demographics with respect to height ($p=0.68$), sex ($p=0.42$), weight ($p=0.66$) and BMI ($p=0.20$) were not statistically significant between the two groups. Only the age difference between the two groups was statistically significant, with the DoD group being older by two years on average ($p<0.01$), which is of doubtful clinical significance (Fig 2). The mean overall colonic volume ($\pm$ SD) for individuals receiving patient-controlled room air and automated CO₂ was 1809 ± 513 mL and 2223 ± 686 mL, respectively ($p<0.01$) (Figure 3A). The mean residual fluid ($\pm$ SD) for the room air and CO₂ groups was 243 ± 154 mL and 163 ± 133 mL, respectively ($p<0.01$) (Figure 3A). The mean colonic gas volume for the room air and CO₂ groups ($\pm$ SD) was 1576 ± 430 mL and 2060 ± 606 mL, respectively ($p<0.01$) (Figure 3A).

Using an empirically-derived total colonic volume threshold of 2000 ml, 49 (32.7%) of the 150 room air cases and 92 (61.3%) of the 150 CO₂ cases were above this cut-off. Mean colonic length along the centerline was 181 cm for the room air (DoD) group and 191 cm for the CO₂ group. After adjusting for differences in colon length, the mean adjusted colonic volume (mL/cm) between the two respective groups was 10 ± 2 mL/cm for the room air technique, and 12 ± 3 mL/cm for CO₂ ($p<0.01$) (Figure 3B).

Significant differences were noted in terms of which patient position produced better distention according to method. For the room air technique, the prone position produced better distention than the supine in 78.7% (118/150) of patients ($p<0.01$); conversely, the supine position was better in 66% (99/150) of CO₂ patients ($p<0.01$) (Figure 4). Beyond the derived volumes, qualitative visual differences in the 3D volume maps between the patient positions for room air and CO₂ complemented the numerical volume differences when viewed in a side-by-side fashion (Figure 5). For example, the rectosigmoid region was often relatively under-distended for supine room air cases, whereas suboptimal distention of the transverse colon was generally more apparent on the prone CO₂ cases (Figure 5).

Discussion

Optimal or at least adequate colonic distention is one of the key parameters for successful CTC evaluation, along with appropriate bowel preparation, CT scanning and robust 3D/2D interpretation software. Inadequate distention is a major factor for important false negative results at CTC, which can be further exacerbated by the other aforementioned quality issues. During the early period after the introduction of CTC, manual room air distention was generally employed due to its ubiquitous availability, low-cost nature, and the longstanding experience with the barium enema.^{12–14} However, as automated CO₂ systems developed, certain advantages of this approach over room air became apparent over time. For example, the risk of perforation, albeit very low with manual room air, approached zero with refined low-pressure automated CO₂ machines.¹⁰ CO₂ also results in significantly decreased post-procedural discomfort due to its rapid reabsorption through the colon wall, both at CTC and colonoscopy.^{8, 15} In addition, CT technologists familiar with both techniques generally prefer automated CO₂ over manual room air insufflation due to a clearer end point for scanning and decreased need for coaching (if patient-controlled).⁸

Prior studies have also shown an overall improvement in colonic distention with automated CO₂ compared with room air.^{7, 8} However, assessment of distention quality in these studies was based on limited semi-quantitative scoring that sampled only intermittent portions of the colon. Typically, readers subjectively scored segments according to discrete degrees of luminal distention rather than on a continuous scale. Our automated and operator independent QA tool study employed allowed a more objective and absolute measure that takes the entire colonic volume into account. This automated QA tool was recently validated by comparing distention at CTC according to supine, prone, and decubitus positions.¹¹ Our findings confirm that automated CO₂ provides consistently better distention than manual room air. The improvement in overall distention with CO₂ was over 400 ml in volume on average. These results have important implications for diagnostic performance. In conjunction with the other aforementioned advantages concerning safety, comfort, and convenience, automated CO₂ clearly represents the preferred method for luminal distention at CTC.

In addition to the difference in overall distention, there was a striking difference in supine versus prone distention. For room air, it stands to reason that the prone position generally demonstrates increased colonic volume, since additional pumps of air are often added after the supine series and colonic absorption of room air is negligible. For CO₂, prone distention is likely diminished compared with supine related to partial compression from body girth, which is not overcome by the low-pressure settings. This supine versus prone observation was previously reported by Michel et al. based on subjective assessment.¹⁶ The decreased distention in the prone position with automated CO₂ is further exacerbated by obesity, making decubitus positioning necessary in many of these cases.^{11, 17}

The approximately 10 cm difference in mean colonic length between the two groups was unexpected, as they were reasonably well matched asymptomatic screening cohorts. Colonic length does vary somewhat according to gender, age, and even BMI,¹⁸ and even more substantial changes are seen between groups where colonoscopy is incomplete versus

complete;¹⁹ however, most of these factors do not apply for our patient cohorts. It is conceivable that some of the difference was due to foreshortening related to under-distention in the room air cohort, although it is uncertain if any meaningful length change occurs with distention. Even with the length discrepancy between the study groups in our study, colonic distention remained significantly different after adjusting for length.

There are several limitations associated with the study. Most important is the temporal difference between the two cohorts, which was largely unavoidable related to the preferred or available distention technique at the time. There were also slight differences in the demographic make-up of the cohorts (eg, mean age), which were likely not of clinical relevance. A randomized controlled trial would be ideal but impractical, especially as our standard of care had changed from room air to CO₂, based on improved patient comfort, safety, technologist preference, and anecdotal experience suggesting that CO₂ was a better method for distention.⁸ Although the increased luminal fluid seen in the room air (DoD) cohort may have accentuated the differences in gas volumes, the overall luminal distention (ie, gas + fluid) was nonetheless considerably improved in the CO₂ (UW) cohort.

In conclusion, this is the first quantitative study that assesses the true volumetric differences in colorectal distention between the room air and CO₂ techniques. By using a novel QA tool that rapidly and objectively provides volumetric data, we have shown that CO₂ is clearly superior to room air in terms of total colonic distention, even when adjusting for colon length. In addition, there are clear differences in the relative distention between supine and prone according to distention technique, with a logical explanation. This study provides objective evidence to the pre-existing biases in data suggesting the superiority of CO₂. In conjunction with the other established advantages of improved safety, decreased post-procedural discomfort, and ease of use, our findings support the use of CO₂ as the preferred front-line distention technique for CTC.

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A **B****Figure 1. Colonic distention techniques**

A. Apparatus for manual room air insufflation, consisting of a rectal catheter, tubing, and handheld bulb for air insufflation.

B. Automated CO₂ device (PROTOCO₂L, Bracco Diagnostics), which controls rate and monitors intraluminal pressure for continuous low-pressure delivery as needed.

Figure 2.

Quantitative differences in the demographic make-up of the two cohorts. Only the age difference between the two groups was statistically significant with the DoD population being approximately 2 years older ($p < 0.01$). This small age difference, however, is of doubtful clinical relevance.

Figure 3. Colonic volumes between CO₂ and room air cohorts with 150 subjects in each group
A. Bar graph shows that mean non-length adjusted total colonic volume in the CO₂ group is significantly greater than the room air cohort (2222 ± 686 mL vs. 1809 ± 513 mL; $p < 0.01$). Additionally, this shows the total amount of air between the two groups was statistically significant and the amount of fluid was also statistically significant with the DOD population having more residual fluid. ($p < 0.01$).

B. Bar graph shows that the length-adjusted mean total colonic volume (mL/cm) is also significantly greater in the CO₂ group than room air (11.6 ± 2.6 mL/cm vs. 9.9 ± 2.4 mL/cm; $p < 0.01$) (note that the y-axis does not begin at zero).

Figure 4.

Bar graph shows which position (prone or supine) demonstrated better colonic distention between the room air and CO₂ groups. Note that for room air, the prone view is typically better, whereas the opposite is true for CO₂ (see discussion).

Figure 5.

3D colon map images in four typical cases obtained with room air (**A** and **B**) and CO₂ (**C** and **D**) show the supine series on the left and prone series on the right for each case, including the luminal volume measurements. Note the improvement in distention on prone relative to supine for the room air cases (**A** and **B**), especially in the rectosigmoid region. For CO₂ (**C** and **D**), the supine distention is generally superior to prone, especially in the transverse colon region. The overall degree of distention is also generally greater with CO₂ compared with room air.