Polyp Measurement Reliability, Accuracy, and Discrepancy: Optical Colonoscopy versus CT Colonography with Pig Colonic Specimens[1]

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Purpose: To prospectively evaluate the reliability and accuracy of optical colonoscopy and computed tomographic (CT) colonography in polyp measurement, by using direct measurement as the reference standard, and to understand the basis for measurement discrepancy between both modalities.

Materials and Methods: Eighty-six simulated polyps that ranged from 3 to 15 mm were constructed by using pig colons obtained from an abattoir. Approval of the animal care and use committee for the study was not required. CT colonographic measurement was performed by two independent radiologists by using two-dimensional (2D) optimized multiplanar reformatted planes and three-dimensional (3D) endoluminal views. Optical colonoscopic measurement was performed by two independent gastroenterologists by using open biopsy forceps. Interobserver agreement, measurement error, measurement discrepancy defined as the result of subtracting the optical colonoscopic measurement from the CT colonographic measurement, and false-mismatch (ie, designation of matched polyps as mismatched between both modalities) rates according to different matching criteria were analyzed.

Results: Intraclass correlation coefficients were 0.879 (95% confidence interval: 0.780, 0.930) for optical colonoscopy, 0.979 (95% confidence interval: 0.956, 0.989) for 2D CT colonography, and 0.985 (95% confidence interval: 0.976, 0.990) for 3D CT colonography. The mean standardized polyp size ± standard deviation for each observer was 76.3% ± 14.7 and 85.3% ± 18.8 for optical colonoscopy, 104.6% ± 11.6 and 101.6% ± 10.1 for 2D CT colonography, and 114% ± 12.4 and 113.4% ± 13.2 for 3D CT colonography. These values indicated that there was a statistically significant difference among the methods ($P < .001$). Measurement discrepancy was not proportional to polyp size. A percentage-of-error criterion showed increasing false-mismatch rates with decreasing polyp size, whereas a fixed margin-of-error criterion resulted in more uniform false-mismatch rates across polyp size.

Conclusion: CT colonography is more reliable and accurate than optical colonoscopy for polyp measurement. A fixed margin-of-error criterion is better than a percentage-of-error criterion for polyp matching between CT colonography and optical colonoscopy with open biopsy forceps.

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Polyp size is, clinically, the single most important feature of a colorectal polyp because it serves as a rough surrogate of the risk of carcinoma and dictates patient care (1–4). An accurate assessment of polyp size is, therefore, essential for proper care of patients with colorectal polyps. Both optical colonoscopy and computed tomographic (CT) colonography are known to produce variable degrees of error in polyp measurement (4–11); however, to our knowledge, the reliability and accuracy of the use of these two modalities in polyp measurement have never been conclusively compared. An understanding of the measurement error of optical colonoscopy and CT colonography, particularly the basis for the measurement discrepancy between both modalities, is also critical for accurate polyp matching in the validation of the diagnostic performance of CT colonography compared with optical colonoscopy. Imprecise polyp matching can be a major source of error and uncertainty in the evaluation of the diagnostic performance of CT colonography (12,13).

Although polyp matching may occasionally be straightforward, particularly in populations with low polyp prevalence (14), it is generally not as simple as it may initially seem (12,15). To account for the measurement errors inherent in optical colonoscopy and CT colonography, various polyp size-matching algorithms have become available to allow a systematic approach to polyp matching. To our knowledge, however, there has been no study on the discrepancy in polyp measurement between CT colonography and optical colonoscopy and a preferred size-matching algorithm. Therefore, the purpose of our study was to prospectively evaluate the reliability and accuracy of optical colonoscopy and CT colonography in polyp measurement, by using direct measurement as the reference standard, and to understand the basis for measurement discrepancy between both modalities.

Advances in Knowledge

- CT colonography is more reliable (intraclass correlation coefficient of 0.979 for two-dimensional CT colonography and 0.985 for three-dimensional CT colonography vs 0.879 for optical colonoscopy) and accurate than optical colonoscopy in polyp measurement.
- A fixed margin-of-error criterion is better than a percentage-of-error criterion for polyp matching between CT colonography and optical colonoscopy with open biopsy forceps.

Materials and Methods

Pig Colonic Specimens and Reference Standard

The animal care and use committee of University of Ulsan College of Medicine, Seoul, Korea, did not require their approval for the study. Eighteen pig colonic specimens, each approximately 55–60 cm in length, were prepared from fresh pig colons that were commercially available at an abattoir (Fig 1). Colons were cleansed of fecal matter, and the mucosal surface was checked for the absence of polyplike protruding structures by two individuals (E.K.C. and J.K.H.). Five simulated sessile polyps were made in each colon by these two individuals by using a previously described method (16) of puckering the mucosa of an inverted colon and securing it with sutures. Attempt was made to make the polyps round. The five simulated polyps were arranged to be linearly located, with an approximate 10-cm distance between adjacent polyps. The order of polyp size, categorized into polyps of 5 mm or smaller, 6–9 mm, and 10 mm or larger, in each colon was randomized.

The reference standard of direct measurement was used to obtain polyp size, which was the maximum diameter of the polyps in millimeters. Measurement was performed with a combination of a ruler and a bore gauge by an individual (E.K.C.). The colon was then reinverted, and one end was tied with sutures. An acrylic container with a simulated anus made of a plastic bottle neck was constructed. A pair of thin parallel walls of sigmoid shape made of acrylic material was placed in the container to orient the colon in a slightly sigmoid configuration. Each of the 18 specimens was separately placed between the sigmoid-shaped walls. After pulling the untied end of the colon through the simulated anus, it was inverted over the edge of the simulated anus and fixed with a rubber band.

A rectal catheter with a retention balloon was introduced into the colon through the simulated anus. The balloon was inflated and pulled back until it formed an airtight seal with the anal opening. The colon was then manually inflated with room air. A mixture of 20 L of 100% soybean oil and 20 mL of iodized oil, which produced an attenuation value of approximately −110 HU, was made to simulate the attenuation of abdominal fat and was poured into the container after the inflation of the colon until the colon was completely submerged. To prevent flotation, the colon was fastened before the oil mixture was poured by fixing the tied end to the bottom of the container and applying strips of clear adhesive tape along the course of the colon.

CT Colonography and Interpretation of Findings

CT was performed with a 16-detector row CT scanner (Somatom Sensation 16; Siemens Medical Solutions, Erlangen, Germany) with the following pa-

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Abbreviations:
3D = three-dimensional
2D = two-dimensional

Author contributions:
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rameters: 120 kV; 50 mAs; beam collimation, 16 detector rows with 0.75-mm section thickness; reconstructed section thickness, 1 mm; reconstruction interval, 0.7 mm; beam pitch, 1; gantry rotation time, 0.5 second; and field of view, 35 cm. During scanning, the container was positioned so that the overall long axis of the colon was oriented along the z-axis of the scanner.

Both two-dimensional (2D) and three-dimensional (3D) endoluminal measurements of the polyps were performed with a commercial CT colonographic system (Advantage 4.2_06; GE Healthcare, Waukesha, Wis). These measurements were obtained by two independent radiologists (S.H.P. [radiologist 1], with experience in approximately 500 cases, and S.S.L. [radiologist 2], with experience in approximately 100 cases) who were blinded to the size range and specific size of polyps but were aware that five polyps that were located approximately 10 cm from each other were present. The 2D measurement was performed in an optimized 2D plane, which was an arbitrary multiplanar reformatted oblique plane that allowed a view of the maximum polyp diameter as determined by each observer independently. Window width and window level were set at 1500 HU and −400 HU for the 2D measurement. Care was particularly taken to avoid measuring beyond the edge of the polyp during 3D measurements. Measurements were determined to the nearest millimeter.

Optical Colonoscopy

Optical colonoscopy was performed with a video colonoscope (CF 240L; Olympus Optical, Tokyo, Japan) by two independent gastroenterologists (J.S.B. [gastroenterologist 1] and J.Y.J. [gastroenterologist 2], who each had experience in approximately 2000 examinations) immediately after CT scanning and removal of the oil mixture. Optical colonoscopy was performed after CT scanning to follow the typical examination sequence that was used in most clinical CT colonographic studies. The oil mixture was removed because otherwise it would have collapsed the colonic specimen during optical colonoscopy, and optical colonoscopy would not have been possible.

The two gastroenterologists were blinded to the size range and specific size of polyps but were aware that five polyps were present that were located approximately 10 cm from each other. The colonoscope was introduced through the simulated anus, and the examination was performed in a manner similar to that of an examination in a human. The maximum linear size of the polyp was measured, by comparison, with a fully open biopsy forceps (8 mm) (FB-24U-1; Olympus Optical) and was recorded in millimeters. The forceps was held as close as possible to the polyp.

Data and Statistical Analysis

After optical colonoscopy, the colonic specimen was disassembled. After the colonic specimen was inverted inside out, polyps were remeasured by using a combination of a ruler and a bore gauge by an individual (E.K.C.). Four polyps that showed size differences between the initial measurement and the remeasurement were excluded. The remaining 86 polyps (25 polyps of 3–5 mm, 38 polyps of 6–9 mm, and 23 polyps of 10–15 mm) were included in the analysis (Figs 2, 3).

Figure 1

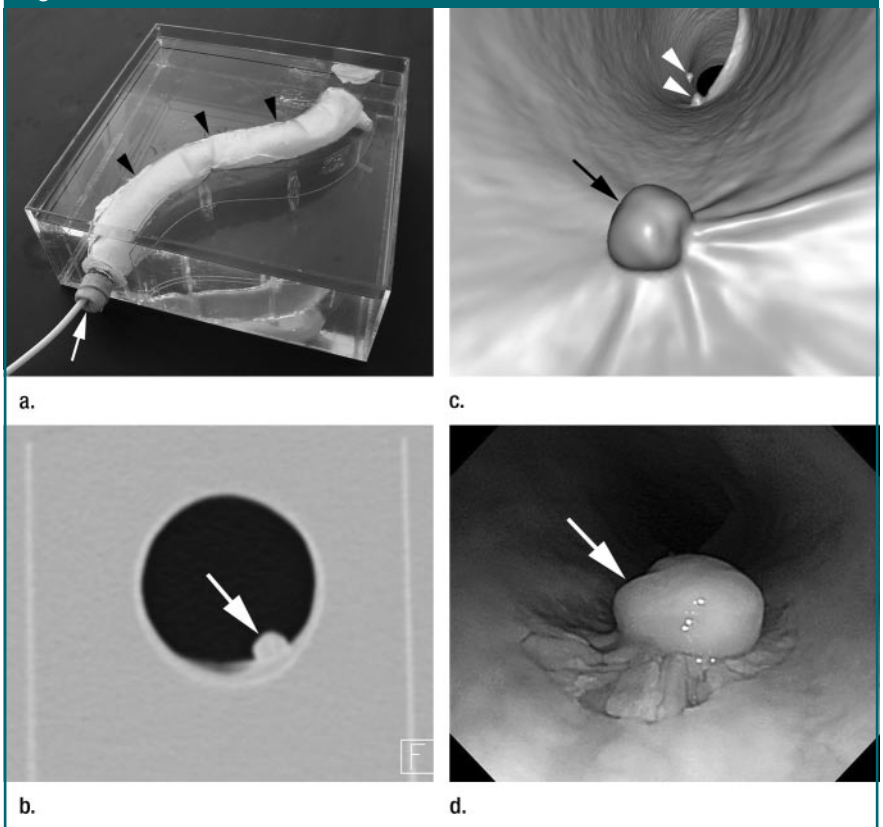

Figure 1: Pig colonic specimen and simulated polyps. **(a)** Pig colon of sigmoid configuration (arrowheads) is placed in an acrylic container that is filled with a mixture of 20 L of 100% soybean oil (Ottogi, Anyang, Korea) and 20 mL of iodized oil (Lipiodol; Laboratoire Guerbet, Aulnay-Sous-Bois, France). A rectal catheter used for colonic insufflation during CT colonography that was placed through the simulated anus (arrow) is observed. Optical colonoscopy also was performed through the simulated anus. **(b)** Cross-sectional 2D CT colonographic image (window width, 1500 HU; window level, −400 HU) shows a 10-mm simulated polyp (arrow). **(c)** Endoluminal CT colonographic image shows the corresponding polyp (arrow) and the next two polyps (arrowheads). **(d)** Optical colonoscopic image obtained after CT colonography shows the corresponding polyp (arrow).

Interobserver agreement for each measurement method was analyzed by using the intraclass correlation coefficient. For the analysis of measurement accuracy, the standardized polyp size, defined as measured size divided by reference size multiplied by 100%, and the absolute measurement error, defined as the result of subtracting the reference size from the measured size, were obtained for each observer and method and were compared among the three methods by using a linear mixed model to account for the observers.

The distribution of measurement discrepancy, defined as the result of subtracting the optical colonoscopic measurement from the CT colonographic measurement, across polyp size was examined by using the Bland-Altman plot and the Spearman correlation analysis between the absolute value of the measurement discrepancy and the polyp size.

The false-mismatch (ie, designation of matched polyps as mismatched) rates in the comparison between CT colonography and optical colonoscopy according to the different matching criteria were analyzed for each observer combination (ie, radiologist 1 vs gastroenterologist 1, radiologist 1 vs gastroenterologist 2, radiologist 2 vs gastroenterologist 1, and radiologist 2 vs gastroenterologist 2). A percentage-of-error criterion (ie, discrepancy in size in terms of percentage of polyp size at optical colonoscopy) with matching threshold values in increments of 10% and a fixed margin-of-error criterion (ie, discrepancy in size in terms of absolute size in millimeters) with various matching threshold values from 0 to 5 mm were evaluated. Statistical analysis was performed with software (SAS, version 9.1; SAS Institute, Cary, NC). A difference with a P value of less than .05 was considered to be statistically significant.

Figure 2

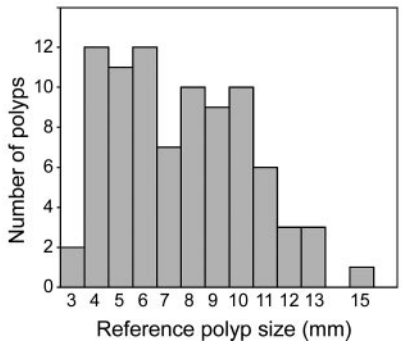

Figure 2: Histogram shows the number of polyps (total, 86 polyps), arranged according to reference size, that were included in the analysis.

Figure 3

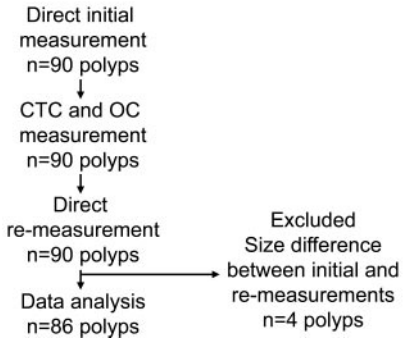

Figure 3: Flow diagram for polyps included in the study. *OC* = optimal colonoscopy.

Results

Interobserver Agreement

Intraclass correlation coefficients were 0.879 (95% confidence interval: 0.780, 0.930) for measurement with optical colonoscopy, 0.979 (95% confidence interval: 0.956, 0.989) for that with 2D CT colonography, and 0.985 (95% confidence interval: 0.976, 0.990) for that with 3D CT colonography. These values indicate that interobserver agreement is better with CT colonography compared with optical colonoscopy for polyp measurement.

Measurement Accuracy and Error

The mean standardized polyp size ± standard deviation for optical colonoscopy was 76.3% ± 14.7 and 85.3% ± 18.8 for gastroenterologists 1 and 2, respectively. For 2D CT colonography, it was 104.6% ± 11.6 and 101.6% ± 10.1 for radiologists 1 and 2, respectively. For 3D CT colonography, it was 114% ± 12.4 and 113.4% ± 13.2 for radiologists 1 and 2, respectively. With 2D CT colonography, standardized polyp size was the most accurate. Measurements with optical colonoscopy were significantly smaller than they were with both 2D CT colonography and 3D CT colonography ($P < .001$). Measurement with 3D CT colonography was significantly larger than it was with 2D CT colonography ($P < .001$).

Table 1

False-Mismatch Rates between 2D CT Colonographic and Optical Colonoscopic Measurement with Percentage-of-Error Criterion

	Polyp Size-matching Threshold Values*									
Polyp Size (mm)	0%	≤30%	≤40%	≤50%	≤60%	≤70%	≤80%	≤90%	≤100%	≤150%
All ($n = 86$)	85.8 ± 6.6	46.8 ± 12.2	33.4 ± 11.7	18 ± 10.9	15.4 ± 9.1	10.2 ± 4.5	5.8 ± 0.9	5.2 ± 0.6	1.2 ± 1.3	0 ± 0
≤5 ($n = 25$)	85 ± 3.8	59 ± 17.7	47 ± 13.2	32 ± 16.3	32 ± 16.3	16 ± 3.3	16 ± 3.3	16 ± 3.3	4 ± 4.6	0 ± 0
6–9 ($n = 38$)	88.2 ± 9.7	50.7 ± 13.5	37.5 ± 15.1	17.8 ± 11.9	12.5 ± 8.4	11.2 ± 10	1.3 ± 1.5	1.3 ± 1.5	0 ± 0	0 ± 0
≥10 ($n = 23$)	82.6 ± 6.2	27.2 ± 9.6	12 ± 5.5	3.3 ± 4.2	2.2 ± 2.5	2.2 ± 2.5	2.2 ± 2.5	0 ± 0	0 ± 0	0 ± 0

Note.—Data are the mean false-mismatch rates ± standard deviation in percentages for the four observer combinations (ie, radiologist 1 vs gastroenterologist 1, radiologist 1 vs gastroenterologist 2, radiologist 2 vs gastroenterologist 1, and radiologist 2 vs gastroenterologist 2) when each size-matching threshold value is used. A false mismatch denotes the designation of matched polyps as mismatched.

* The discrepancy in size was in terms of percentage of polyp size at optical colonoscopy.

Figure 4

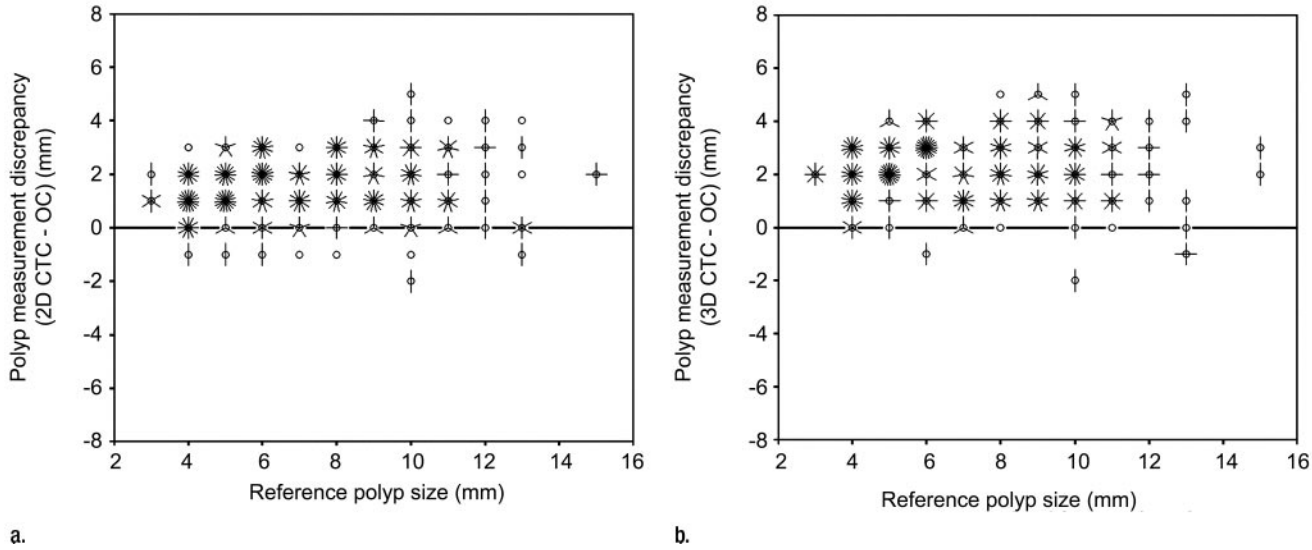

Figure 4: Bland-Altman plots show distribution of polyp measurement discrepancy between CT colonography and optical colonoscopy, defined as the result of subtracting the optical colonoscopic measurement from the CT colonographic measurement, across the reference polyp sizes. Results from all four observer combinations are included. Each petal represents one polyp. **(a)** Discrepancy between 2D CT colonographic and optical colonoscopic measurement and **(b)** discrepancy between 3D CT colonographic and optical colonoscopic measurement are shown. The discrepancies are asymmetric across the zero-difference line, and there is a general shift toward positive values. The distribution of the measurement discrepancy is not proportional to polyp size.

Table 2

False-Mismatch Rates between 3D CT Colonographic and Optical Colonoscopic Measurement with Percentage-of-Error Criterion

	Polyp Size-matching Threshold Values*									
Polyp Size (mm)	0%	≤30%	≤40%	≤50%	≤60%	≤70%	≤80%	≤90%	≤100%	≤150%
All (n = 86)	95.1 ± 1.7	59.3 ± 10.8	47.1 ± 11.4	33.7 ± 14.1	31.1 ± 11.1	25.6 ± 10.1	16 ± 7.1	15.1 ± 6.7	4.1 ± 0.7	0.9 ± 1.1
≤5 (n = 25)	92 ± 4.6	78 ± 11.5	72 ± 9.2	52 ± 18.5	52 ± 18.5	41 ± 10.5	39 ± 12.8	39 ± 12.8	12 ± 4.6	3 ± 3.8
6–9 (n = 38)	97.4 ± 0	58.6 ± 9.9	48 ± 19	39.5 ± 16.8	34.9 ± 11.4	29.6 ± 14.5	9.2 ± 6.3	8.6 ± 7	1.3 ± 1.5	0 ± 0
≥10 (n = 23)	94.6 ± 2.2	40.2 ± 12	18.5 ± 2.2	4.3 ± 6.1	2.2 ± 2.5	2.2 ± 2.5	2.2 ± 2.5	0 ± 0	0 ± 0	0 ± 0

Note.—Data are mean false-mismatch rates ± standard deviation in percentages for the four observer combinations (ie, radiologist 1 vs gastroenterologist 1, radiologist 1 vs gastroenterologist 2, radiologist 2 vs gastroenterologist 1, and radiologist 2 vs gastroenterologist 2) when each size-matching threshold value is used. A false mismatch denotes the designation of matched polyps as mismatched.

* The discrepancy in size was in terms of percentage of polyp size at optical colonoscopy.

The mean, median, and range of the absolute measurement error for optical colonoscopy were −1.6 mm, −2 mm, and −4 to 1 mm, respectively, for gastroenterologist 1 and −1.1 mm, −1 mm, and −4 to 2 mm, respectively, for gastroenterologist 2. For 2D CT colonography, these values were 0.3 mm, 0 mm, and −1 to 3 mm, respectively, for radiologist 1 and 0.1 mm, 0 mm, and −1 to 2 mm, respectively, for radiologist 2. For 3D CT colonography, these values were 0.9 mm, 1 mm, and −1 to 3 mm, respectively, for radiologist 1 and 0.8 mm, 1 mm, and −1 to 3 mm, respectively, for radiologist 2. With 2D CT colonography, the least absolute measurement error was observed. With optical colonoscopy, a significantly larger absolute measurement error was observed in the negative-value direction (ie, size underestimation) than was observed with 2D CT colonography ($P <$ .001). With 3D CT colonography, a significantly larger absolute measurement error was observed in the positive-value direction (ie, size overestimation) than was observed with 2D CT colonography ($P <$ .001).

Measurement Discrepancy between CT Colonography and Optical Colonoscopy

The polyp measurement discrepancy (ie, the result of subtracting the optical colonoscopic measurement from the CT colonographic measurement) was asymmetric across the zero-difference line (Fig 4). There was a general shift toward positive values, with the mean, median, and range of the measurement discrepancy of

1.5 mm, 2 mm, and −2 to 5 mm, respectively, for 2D CT colonography versus optical colonoscopy and 2.2 mm, 2 mm, and −2 to 5 mm, respectively, for 3D CT colonography versus optical colonoscopy (Fig 4). The distribution of the measurement discrepancy was not proportional to polyp size, with a statistically significant but very weak correlation between the absolute value of the measurement discrepancy and polyp size for 2D CT colonography versus optical colonoscopy ($r = 0.184$, $P = .001$) (Fig 4a) and no statistically significant correlation for 3D CT colonography versus optical colonoscopy ($r = 0.089$, $P = .098$) (Fig 4b).

A percentage-of-error criterion showed an increasing false-mismatch rate with decreasing polyp size (Tables 1, 2). When a 50% margin of error from colonoscopic size criterion was used for 2D CT colonography versus optical colonoscopy, the mean false-mismatch rate for the four observer combinations was 32% for polyps 5 mm or smaller ($n = 25$) (44%, 16%, 48%, and 20% for each observer combination, respectively), 17.8% for polyps of 6–9 mm ($n = 38$) (31.6%, 7.9%, 23.7%, and 7.9% for each observer combination, respectively), and 3.3% for polyps 10 mm or larger ($n = 23$) (8.7%, 0%, 4.3%, and 0% for each observer combination, respectively). For 3D CT colonography versus optical colonoscopy, the values were 52% for polyps 5 mm or smaller (68%, 36%, 68%, and 36% for each observer combination, respectively), 39.5% for polyps of 6–9 mm (55.3%, 23.7%, 52.6%, and 26.3% for each observer combination, respectively), and 4.3% for polyps of 10 mm or larger (4.3%, 0%, 13%, and 0% for each observer combination, respectively). A fixed margin-of-error criterion, on the other hand, resulted in more uniform false-mismatch rates when polyps of 6–9 mm and of 10 mm or larger were considered (Tables 3, 4). The most stringent polyp size-matching threshold values that did not produce false mismatch are summarized in Table 5.

Table 3

False-Mismatch Rates between 2D CT Colonographic and Optical Colonoscopic Measurement with Fixed Margin-of-Error Criterion

Polyp Size (mm)	Polyp Size-matching Threshold Values*					
	0 mm	≤1 mm	≤2 mm	≤3 mm	≤4 mm	≤5 mm
All ($n = 86$)	85.8 ± 6.6	50.9 ± 14.3	21.5 ± 8.3	3.5 ± 1.7	0.6 ± 0.7	0 ± 0
≤5 ($n = 25$)	85 ± 3.8	37 ± 12.8	6 ± 4	0 ± 0	0 ± 0	0 ± 0
6–9 ($n = 38$)	88.2 ± 9.7	55.9 ± 15.4	25.7 ± 12.8	2.6 ± 0	0 ± 0	0 ± 0
≥10 ($n = 23$)	82.6 ± 6.2	57.6 ± 14.4	31.5 ± 11.4	8.7 ± 6.2	2.2 ± 2.5	0 ± 0

Note.—Data are the mean false-mismatch rates ± standard deviation in percentages for the four observer combinations (ie, radiologist 1 vs gastroenterologist 1, radiologist 1 vs gastroenterologist 2, radiologist 2 vs gastroenterologist 1, and radiologist 2 vs gastroenterologist 2) when each size-matching threshold value is used. A false mismatch denotes the designation of matched polyps as mismatched.

* The discrepancy in size was in terms of absolute size.

Table 4

False-Mismatch Rates between 3D CT Colonographic and Optical Colonoscopic Measurement with Fixed Margin-of-Error Criterion

Polyp Size (mm)	Polyp Size-matching Threshold Values*					
	0 mm	≤1 mm	≤2 mm	≤3 mm	≤4 mm	≤5 mm
All ($n = 86$)	95.1 ± 1.7	71.2 ± 10.5	41.3 ± 14.3	14 ± 1.3	2.3 ± 0.9	0 ± 0
≤5 ($n = 25$)	92 ± 4.6	74 ± 11.5	29 ± 10.5	3 ± 3.8	0 ± 0	0 ± 0
6–9 ($n = 38$)	97.4 ± 0	71.1 ± 10.7	48.7 ± 18.3	18.4 ± 4.8	2.6 ± 2.2	0 ± 0
≥10 ($n = 23$)	94.6 ± 2.2	68.5 ± 9.7	42.4 ± 12	18.5 ± 2.1	4.3 ± 0	0 ± 0

Note.—Data are mean false-mismatch rates ± standard deviation in percentages for the four observer combinations (ie, radiologist 1 vs gastroenterologist 1, radiologist 1 vs gastroenterologist 2, radiologist 2 vs gastroenterologist 1, and radiologist 2 vs gastroenterologist 2) when each size-matching threshold value is used. A false mismatch denotes the designation of matched polyps as mismatched.

* The discrepancy in size was in terms of absolute size.

Discussion

In our study, with CT colonography, better interobserver agreement (ie, reliability) and less measurement error in polyp measurement were observed than were observed with optical colonoscopy. In general, at optical colonoscopy, polyp size was underestimated; the measured mean size ± standard deviation was 76.3% ± 14.7 and 85.3% ± 18.8 of the reference size for each observer. This result coincided with results of previous in vitro studies (8–10). Image distortion in the periphery of an endoscopic field that is associated with the wide-angle lens of an endoscope can cause size underestimation (5,11). Shortening of the polyp is expected with asymmetric polyps unless the long axis of the polyp is oriented perpendicularly to the viewing direction of the colonoscope. Although efforts were made to maintain close proximity of the forceps to the polyp during measurement, failure to do so by even the slightest margin would in theory lead to some degree of underestimation. Findings in in vivo studies suggest an overestimation of polyp size with optical colonoscopy; however, the reference measurement, which is obtained after polyp removal, in the studies most likely represents an underestimation of the true polyp size in the in vivo state (5,7).

Given the higher reliability and accuracy with CT colonography compared with those values with optical colonoscopy in polyp measurement—values that were demonstrated in our in vitro study—CT colonography is expected to serve as a better guide for the care of patients with colorectal polyps in clinical practice. Of the methods evaluated in our study, 2D CT colonographic measurement in an optimized multiplanar refor-

matted plane was the most accurate. In contrast to the relatively fast and easy performance of 3D CT colonographic measurement, 2D measurement in an optimized multiplanar reformatted plane performed manually is a cumbersome task and is generally not used in clinical practice. Although 3D measurement resulted in slight overestimation of polyp size in our study, 3D measurement was more accurate than measurement with standard orthogonal 2D planes, mainly because of its instinctive visualization of the long axis of the polyp (4). Therefore, the 3D technique may be preferred as the primary method for polyp measurement in CT colonographic practice.

However, 3D measurement has limitations. There may be differences between different CT colonographic systems. The accuracy of 3D measurement applies only to the 3D endoluminal view but does not apply to 3D techniques with image distortion, such as "virtual dissection" (17,18). With 3D measurement, underestimation also of the lesion size is observed when a polyp is partially obscured by the fluid adjacent to the lesion or by partial collapse of the colon.

Achievement of accurate polyp matching between CT colonography and optical colonoscopy is critical in the determination of sensitivity of CT colonography. In a comparative study of CT colonography and optical colonoscopy, a false mismatch (ie, designation of matched polyps as mismatched) leads to an underestimation of the sensitivity of CT colonography, whereas a false match (ie, designation of mismatched polyps as matched) results in an overestimation of the sensitivity. To achieve a systematic consistent approach to polyp matching, various size-matching algorithms, which include a 50% margin of error from colonoscopic size (14,19–21) and an absolute criterion of a 3- or 4-mm margin of error (22–25), have been adopted in previous studies. Customized size-matching algorithms also have been used. These algorithms include a 50% margin of error at the lower bound and any size larger than that of the lesion seen at colonoscopy (26) and within a 90%, 70%, and 50% margin of error for polyps of 5 mm or smaller, polyps of 6–9 mm, and polyps of 10 mm or larger, respectively, measured at colonoscopy (27).

Table 5

Most Stringent Polyp Size-matching Threshold Values That Did Not Produce False Mismatch between CT Colonography and Optical Colonoscopy

Measurement Method and Polyp Size (mm)	Percentage-of-Error Criterion*	Fixed Margin-of-Error Criterion (mm)†
2D CT colonography vs optical colonoscopy		
≤5	−20 to 150	−1 to 3
6–9	−20 to 100	−1 to 4
≥10	−20 to 90	−2 to 5
3D CT colonography vs optical colonoscopy		
≤5	0–200	0–4
6–9	−20 to 140	−1 to 5
≥10	−20 to 90	−2 to 5

Note.—The discrepancy in size is defined as the result of subtracting the polyp size at optical colonoscopy from the polyp size at CT colonography.

* The discrepancy in size was in terms of percentage of polyp size at optical colonoscopy.

† The discrepancy in size was in terms of absolute size.

Our results suggest that the most commonly used criterion of a 50% margin of error from the size at optical colonoscopy is not an appropriate size-matching criterion. Because the measurement discrepancy between CT colonography and optical colonoscopy is not proportional to polyp size, the 50% criterion will be too strict for small polyps, which include polyps of 6–9 mm, and will result in high false-mismatch rates despite a low false-mismatch rate for polyps of 10 mm or larger, as demonstrated in our study. Furthermore, the criterion is too generous as the lower bound of the size-matching criteria. A fixed margin-of-error criterion, on the other hand, is a more appropriate size-matching algorithm, as it results in more uniform false-mismatch rates for polyps of 6 mm or larger. An optimal size-matching algorithm is one that produces the least number of false mismatches and false matches. Although it is not possible to directly assess the false-match rate for a given matching threshold value, a lower false-match rate is expected with a more stringent size-matching threshold value.

Therefore, our results suggest that a discrepancy of −2 to 5 mm (ie, the most stringent fixed margin-of-error criterion that was observed not to produce a false mismatch) may be a better size-matching criterion for polyps of 6 mm or larger when one uses CT colonographic measurement and optical colonoscopic measurement with the open biopsy forceps. The criterion, however, is by no means definitive because it has not been tested by using a separate data set. The clinical applications of our study can be limited to only the polyps of the size ranges used in the experiment. Polyps greater than 15 mm, however, are more easily matched and therefore may not require a systematic size-matching algorithm.

Our study had limitations. First, this study does not reflect all aspects of an in vivo human examination. Measurements of polyps in an in vivo setting may show more variability. True polyps are intrinsically more variable in morphologic features than are simulated polyps. Location of a polyp with regard to haustral folds, colonic curvature, and different degrees of colonic distention may affect the measurement; however, all the polyps in our study were located on the haustral surface of an optimally distended and almost straight segment of the colon. The technical difficulty of optical colonoscopy in humans when compared with studies in specimens also may contribute to the variability and relative inaccuracy of optical colonoscopic measurements in vivo. In vivo studies, however, have disadvantages because of the technical unfeasibility of obtaining an accurate reference measurement. In vivo optical colono-

scopic measurement even with the use of a calibrated flexible linear probe is far from perfect (4). Second, we did not make comparisons between CT colonography and optical colonoscopy with a linear calibrated probe. We only used the open biopsy forceps because such measurement is the most commonly used measuring method for research studies and clinical practice, and the linear probe is in fact rarely used (1). Third, the results may apply only to the CT colonographic system that was tested in our study.

In conclusion, CT colonography is more reliable and accurate than is optical colonoscopy with open biopsy forceps in polyp measurement. With 3D CT colonography, a slight overestimation in the measurement of polyp size occurs, and with open biopsy forceps, underestimation occurs. A fixed margin-of-error criterion is better than a percentage-of-error criterion for polyp matching between CT colonography and optical colonoscopy with open biopsy forceps.

Practical application: The measurement error of CT colonography and optical colonoscopy shown in our study provides a useful reference for more accurate estimation of the size and, ultimately, the risk of malignancy of a colorectal polyp in clinical practice. Diagnostic performance of CT colonography can be more accurately evaluated by using a fixed margin-of-error criterion, which will facilitate the evidence-based practice of CT colonography.

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