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Supplementary material

Artificial intelligence based polyp size measurement in gastrointestinal endoscopy using the auxiliary water jet as a reference

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Figure 1s*: 3D model of the CT-colonography that was used in this study.*

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Appendix 1s Methods

Silicone-based colon model

A 3D model based on a CT colonography was edited with Blender graphics software (Blender Foundation, Amsterdam, Netherlands) to include polyps of known sizes (**Figure 1s**). In total, 28 polyps differing in size and Paris classifications were distributed inside. A negative shape of the edited 3D model was printed using "BioMed Amber" resin in a "Form 3B" printer (Formlabs, Somerville, Massachusetts, United States). After ultraviolet light curing and further post-processing, the 3D-printed parts were coated with a layer of acrylic paint (approximate thickness of 20 micromillimeters) to improve the surface smoothness of the 3D-printed parts. The parts were placed inside cylinder-shaped cups, and molding silicone (Reschimica R PRO 10, Florence, Italy) was injected around the 3D-printed parts. When the silicone was cured, the 3D-Printed parts were removed from the inside, leaving the artificial silicone colon (**Figure 2s**).

***Figure 2s**: Examples of images made by endoscopists in the silicone-based colon. The presented polyp has a size of 4.6 mm. The left image represents visual size estimation, the middle image represents biopsy forceps-based estimation, and the right image is the measurement based on the auxiliary water jet.*

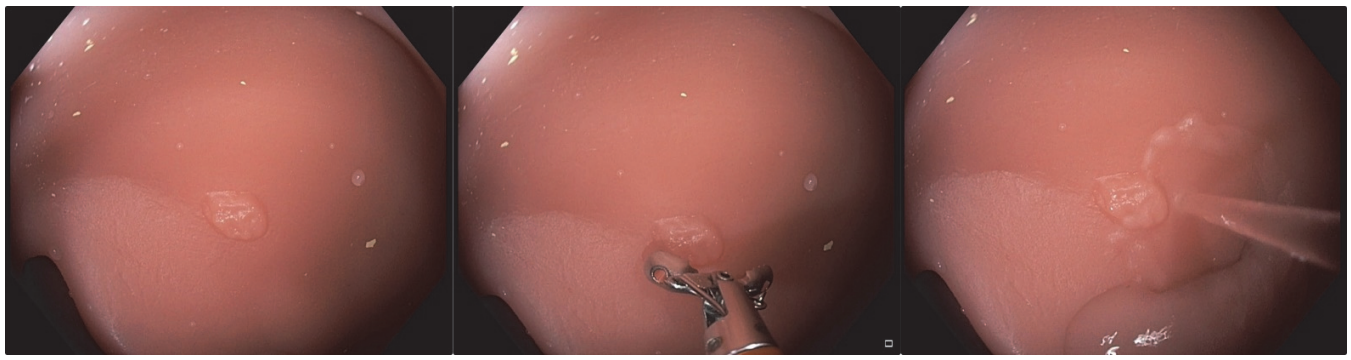

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Table 1s: Characteristics of the polyps included in the silicone colon model.

Polyp	Size [mm]	Size Category	Paris Classification
S1	2.01	<5	0-Is
S2	2.08	<5	0-Is
S3	2.16	<5	0-Is
S4	2.29	<5	0-Is
S5	2.30	<5	0-Is
S6	2.40	<5	0-Is
S7	2.67	<5	0-IIa
S8	3.18	<5	0-Is
S9	3.51	<5	0-IIa
S10	3.71	<5	0-Is
S11	3.83	<5	0-IIa
S12	4.21	<5	0-Ip
S13	4.38	<5	0-IIa
S14	4.62	<5	0-Is
S15	5.32	5-10	0-Is
S16	5.59	5-10	0-IIb
S17	5.70	5-10	0-Is
S18	5.84	5-10	0-IIa
S19	6.03	5-10	0-IIa
S20	6.37	5-10	0-Ip
S21	9.52	5-10	0-IIa
S22	10.21	>10	0-Ip
S23	10.51	>10	0-IIa
S24	11.34	>10	0-Is
S25	12.50	>10	0-IIa
S26	16.84	>10	0-Is
S27	19.02	>10	0-Is
S28	19.18	>10	0-Ip

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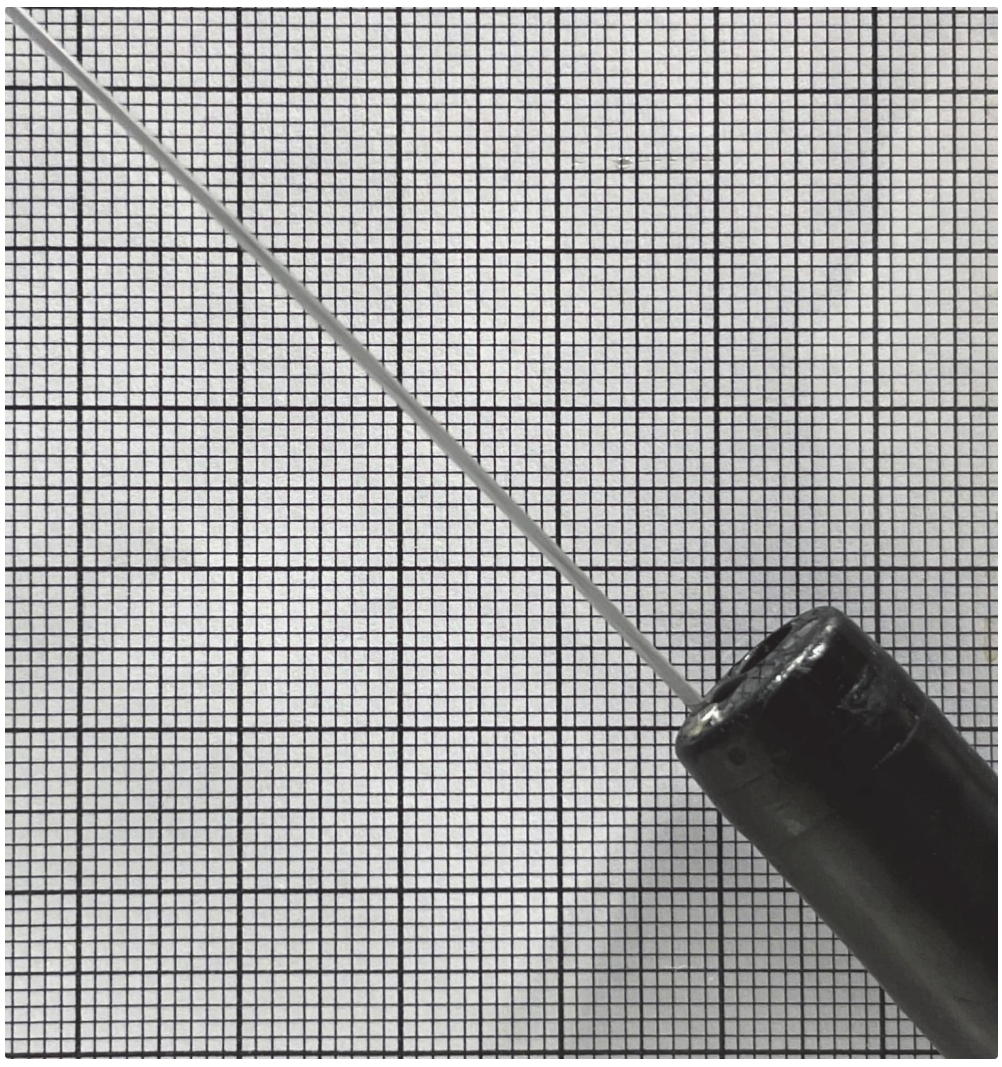
Appendix 2s *Mathematical model of the water jet*

A set of measurements was made with the endoscopic system to create a mathematical model of the water jet. Specifically, to establish a relation between the physical and pixel-wise lengths and diameters. The colonoscope was held by an adjustable 3D-printed holder in a container box equipped with a millimeter scale sheet used for reference. Four different experiments were performed, and 20 (10 from above and 10 from the side) images for each were recorded. The pixel-wise dimensions were measured multiple times on every image. Their values were compared to the reference millimeter scale (**Figure 3s**).

Figure 3s: *Image of the colonoscope and water jet placed over the millimeter scale sheet. The image was additionally processed to increase the contrast between the scale sheet and the water jet.*



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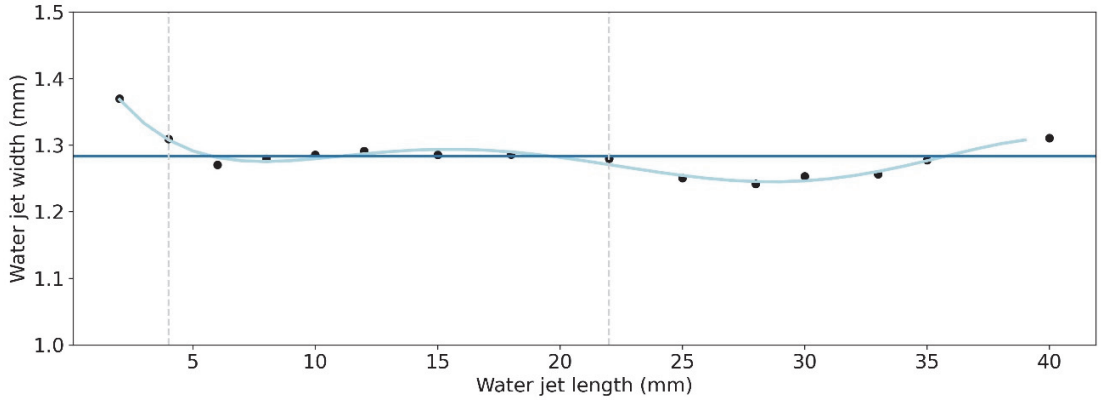
The 4 experiments performed were:

1. The colonoscope was placed horizontally over the millimeter sheet, and a camera was placed 5 cm away from the colonoscope. The pump was set to the highest pressure and flow rate. We measured the mean water jet width (diameter) in the 20 images (**Figure 4s**). Since after 40 mm of length, the water jet starts to disperse and the measurements become inconvenient, the measurements were performed up to the 40mm length. The mean water jet width was 1.28mm (SD +/-0.08mm).

Figure 4s: *Resulting plot of water jet width measurements. Each black point represents a mean value of 20 measurements at the corresponding water jet length. The horizontal blue line represents the mean water-et width of all measurements collected (1.28 mm).*



2. The colonoscope was rotated 45 degrees upward from the horizontal plane to evaluate the effect of gravity on the water jet. The pump was set to the highest pressure and flow rate. We measured no significant effect of gravity on the water jet over the length from 2 to 30mm.

3. The colonoscope was placed horizontally, but the pump's flow rate was set to the lowest. We measured that the flow rate had the highest impact on the water jet dimensions, which became apparent after 15 mm of water jet length. For this reason, we adopted the highest flow rate in our experiments.

4. The colonoscope was placed horizontally, and a flat board was placed perpendicularly in front of the colonoscope. In this case, we were interested in the length of the water jet on the endoscopic image (in pixels) and its change over different distances between the board and the colonoscope. The sheet was first placed 2 mm from the colonoscope camera lenses, and the water jet was used. The sheet was incrementally moved away from the colonoscope (2 mm increments), and 10 images were collected for each increment. We correlated the distance between the board and the colonoscope and the water jet length in pixels.

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Appendix 3s *Reference standard for determining polyp size in routine colonoscopies*

Images containing polyps with polypectomy instruments in proximity were identified retrospectively. The longest segments of the polyp and the instrument's tip were measured and compared pixelwise, as previously explored by several works [1-3]. The same process was repeated on 10 different images for each polyp, and the average of results was taken as the final size of the given polyp.The exact polypectomy instruments used during the examinations were measured with digital calipers to determine their exact size in millimeters. Alongside the biopsy forceps (Boston Scientific, Radial Jaw 4 - Standard Capacity, P/N: M00513400, Boston Scientific, Marlborough, United States), two types of cold snares were used for resection (CrossSnare Zero, P/N: POL1-Z2-12-23-220, Fujifilm, Tokyo, Japan, and Exacto cold snare, P/N: BX00711115, Steris, Basingstoke, United Kingdom).

Appendix 4s *Polyp size calculation formula*

The following formula is used to calculate the polyp size:

$$S_P = 1.28\,[mm] * \frac{MAX\,(W_{BB}, H_{BB})[px]}{f(L_{WJ})[px]}$$

S_P *- Size of a polyp in millimeters;*

$1.28\,[mm]$ *- The mean diameter of the water jet in millimeters;*

W_{BB} *- Width of the bounding box in pixels;*

H_{BB} *- Height of the bounding box in pixels;*

$MAX\,(W_{BB}, H_{BB})$ *- Function that returns the greater between* W_{BB} *and* H_{BB} *in pixels;*

L_{WJ} *- Length of the water jet in pixels. Calculated as:*

$$L_{WJ} = \sqrt{(x_0 - x_c)^2 + (y_0 - y_c)^2}$$

x_0, y_0 *- Coordinates of the fixated initial point of the water jet ("The root point");*
x_c, y_c *- Coordinates of the center-of-mass point of the water jet splash area segmented by the second algorithm;*
$f(L_{WJ})$ *- Function that for input length gives an output width of the water jet in pixels*

$$f(L_{WJ}) = -0.39152\,L_{WJ} + 0.00013\,L_{WJ}^2 + 236.98414$$

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Figure 5s: *Binary size-classification accuracy of different sizing methods. Each pair of bar plots represents the performance of a sizing method on a specific size class. For 5mm or less, 54 measurements were evaluated, 28 for the 5-10mm class and 28 for 10mm or greater.*

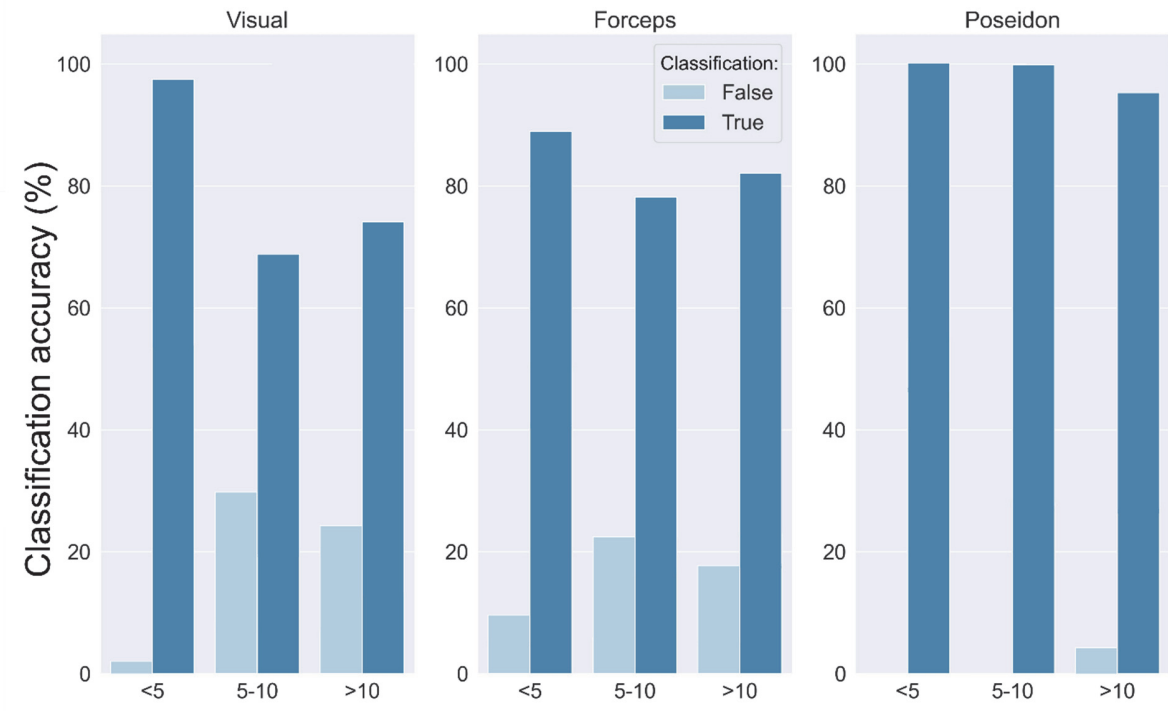

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Table 2s: Baseline characteristics of evaluated polyps from clinical routine. SSL, sessile serrated lesion.

Characteristic		Value
Polyps, n		29
Examinations, n		17
Size, n (%)		
	< 5 mm	17 (58.6)
	5 - 10 mm	10 (34.5)
	> 10 mm	2 (6.9)
Paris classification, n (%)		
	0-Is	6 (20.7)
	0-IIa	21 (72.4)
	0-IIb	2 (6.9)
Pathology, n (%)		
	Adenoma	20 (69)
	Hyperplastic	4 (13.8)
	SSL	4 (13.8)
	Other	1 (3.4)
Examiner and polyps, n (%)		
	I	16 (55.2)
	II	10 (34.5)
	III	3 (10.3)

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Table 3s: Characteristics of the polyps from clinical routine.

Polyp	Size [mm]	Size Category	Paris Classification
P1	2.26	<5	0-IIa
P2	2.62	<5	0-IIa
P3	3.06	<5	0-IIa
P4	3.12	<5	0-Is
P5	3.17	<5	0-IIb
P6	3.39	<5	0-IIa
P7	3.56	<5	0-IIb
P8	3.65	<5	0-IIa
P9	3.72	<5	0-IIa
P10	3.74	<5	0-IIa
P11	3.79	<5	0-IIa
P12	3.87	<5	0-IIa
P13	3.96	<5	0-IIa
P14	4.01	<5	0-IIa
P15	4.11	<5	0-IIa
P16	4.55	<5	0-IIa
P17	4.91	<5	0-IIa
P18	5.28	5-10	0-IIa
P19	5.82	5-10	0-IIa
P20	5.89	5-10	0-IIa
P21	6.05	5-10	0-IIa
P22	6.15	5-10	0-IIa
P23	6.23	5-10	0-IIa
P24	6.29	5-10	0-IIa
P25	7.14	5-10	0-IIa
P26	7.18	5-10	0-IIa
P27	7.60	5-10	0-IIa
P28	12.47	>10	0-Is
P29	13.68	>10	0-IIa