Colonoscopic removal of adenomatous, premalignant polyps is effective in preventing colorectal carcinoma and consequent death [1, 2]. In routine clinical practice, it is not possible to reliably distinguish adenomatous polyps from hyperplastic polyps, without malignant potential, using conventional white light colonoscopy [3–6]. The current standard is therefore to remove all colorectal polyps for histological examination [7]. As approximately one-third of all colonic polyps is hyperplastic [8–10], a considerable number of polypectomies is performed superfluously, unnecessarily increasing costs and risk of complications [11].
Reliable real-time differentiation of colonic polyps during colonoscopy could guide decisions to apply selective polypectomy or a resect-and-discard approach. These strategies, leaving small polyps in situ or discarding them after removal, require a high negative predictive value (NPV) of 90% or higher, as misinterpretation might lead to inadequate surveillance recommendations or erroneously leaving adenomatous polyps in situ [12].

Previous studies have shown that probe-based confocal laser endomicroscopy (pCLE) could achieve a high post-hoc (i.e. after the endoscopic procedure) diagnostic accuracy when performed by expert pCLE endoscopists [13–16]. In order for pCLE to be broadly implemented, it is important that accurate realtime (i.e. during the endoscopic procedure) differentiation of colorectal polyps can be learned rapidly by endoscopists routinely performing screening and surveillance colonoscopies. A recent learning curve study indicated that a fair accuracy for post-hoc interpretation of pCLE images was achieved after a brief training of pCLE inexperienced endoscopists [17]. However, in that study, images obtained by a pCLE experienced endoscopist were used, thereby surpassing the notoriously difficult acquisition of interpretable images, probably due to difficulty in stabilizing the probe [15,18].

This study aimed to assess the accuracy of real-time pCLE used by two experienced colonoscopists during their first 50 pCLE evaluations of colorectal polyps, to assess the NPV for detecting neoplasia in small polyps and to compare these results to post-hoc pCLE evaluation.

Methods
Study design, setting, and patients
We performed a single-center, prospective cohort study at the University Medical Center Utrecht, an academic hospital in the Netherlands. Patients aged 45 years or older with a high a priori risk for colorectal polyps undergoing colonoscopy between November 2012 and April 2014 were included. A high a priori risk was based on the indication for colonoscopy, including changed bowel habits, occult rectal blood loss, iron deficiency anemia, surveillance after previous colorectal polyps, and suspicion of colorectal polyps raised by PET- or CT-scan. Patients with inflammatory bowel disease, familial polyposis syndromes, fluorescein allergy or non-correctable coagulation disorders (including use of oral anticoagulants that could not be discontinued temporarily) were excluded. In addition, patients were excluded if bowel preparation was insufficient (Boston Bowl Preparation Scale (BBPS) score ≤6) or if no colorectal polyps were detected. As characterization of sessile serrated adenomas/polyps (SSA/Ps) with pCLE needs further investigation, we chose to exclude SSA/Ps.

Based on two previous studies which indicated that maximum accuracy was already achieved before the 60th interpretation of pCLE images [15,19], we decided to include patients until both endoscopists had interpreted self-obtained images of at least 50 polyps.

Outcome measures
Primary outcome measure was the diagnostic accuracy of real-time pCLE for differentiation of colorectal polyps and detection of neoplasia. For differentiation of polyps, a simplified classification was used, categorizing polyps as non-neoplastic, adenomatous or carcinomatous, including high grade dysplasia (HGD). Histopathologic evaluation performed by an expert gastrointestinal pathologist was considered to be the gold standard. Secondary outcome measures were the NPV of real-time pCLE for neoplasia in small colorectal polyps (≤5 mm) and the accuracy of post-hoc pCLE evaluation for differentiation of colorectal polyps and detection of neoplasia.

Study procedures and definitions
All patients provided informed consent to participate in the study. Bowel preparation was performed with a split dose polyethylene glycol (PEG) solution. Colonoscopies were performed under conscious sedation. Two staff endoscopists (PS and LM) performed all colonoscopies using a standard colonoscope. During withdrawal, all detected polyps were sequentially assessed with white light, narrow-band imaging (NBI), and pCLE. In the case of multiple rectal polyps with hyperplastic appearance, we included only the largest of these, like we do in routine clinical practice, where we send only one of these polyps for histopathologic evaluation to check whether it is adenomatous or not. Kudo pit pattern [20] and NICE classification [21] were used to classify polyps with NBI. After macroscopic evaluation, fluorescein (5 mL, 10%) was administered intravenously and the pCLE probe (Cellvizio®, Mauna Kea Technologies) was inserted through the working channel of the colonoscope. Intravenous butyl-scopolamine was used at the discretion of the endoscopist to reduce colonic motility. We decided not to use a cap attached to the end of the colonoscope, as this is not standard practice in our center. Recording of pCLE images was performed by the coordinating investigator (TB) as demanded by the endoscopist. After use of pCLE, all polyps were removed for histopathologic evaluation.

The endoscopists were instructed on the use of the pCLE system and the interpretation of pCLE images in the colon according to the Miami classification system [18]. After obtaining and real-time interpreting pCLE images of 50 polyps per endoscopist, these images were interpreted post-hoc by a panel of gastroenterologists and gastrointestinal pathologists. The post-hoc panel also attended a training session on pCLE image interpretation. Four gastroenterologists and one pathologist interpreted all images of 50 polyps obtained by one endoscopist and an identical panel interpreted all images of 50 polyps obtained by the other endoscopist. Two gastroenterologists were in both panels, meaning they both interpreted pCLE images of 100 polyps in order to establish whether the maximization of accuracy occurred before or after 50 evaluations.

A BBPS of ≥6 was considered sufficient; a BBPS ≥8 was considered a good bowel preparation. Locations of the polyps were either the right-sided colon (including the transverse colon and splenic flexure) or the left-sided colon. The macroscopic form of the polyps was categorized into (sub)pedunculated, sessile
or flat polyps. Image quality was scored by the endoscopist, based on the estimation whether the pCLE images were of sufficient quality to establish the right diagnosis. Image quality was categorized into ‘good’ (definite and clear crypt and vessel visualization during pCLE procedure), ‘fair’ (definite, but unclear, crypt and vessel visualization) and ‘poor’ (uncertain crypt and vessel visualization), as adapted from Kuiper et al. [22].

**Statistical analysis**

All statistical analyses were performed using Statistical Packages for Social Sciences version 22 (IBM Corp, Armonk, NY, United States).

Data are presented as mean with standard deviation or median with range and compared with chi-squared test or Student’s t test, according to the nature of their distribution. Chi-squared test was used for comparison of accuracy between subgroups. To assess interobserver variability, we calculated Fleiss’ Kappa for the post-hoc panel [23].

**Medical ethics review**

The study protocol was reviewed by the Medical Ethics Committee of the UMC Utrecht in accordance with the Medical Research Involving Human Subjects Act and was exempted from monitoring.

**Results**

After exclusion of 12 patients without polyps, we included 52 patients (Table 1). Bowel preparation was good in 71% of cases and sufficient in 29% of cases. A mean number of two polyps per patient (range 1 – 8) were assessed with pCLE. A total of 113 polyps were evaluated with pCLE, of which 13 were excluded because of failure to obtain pCLE imaging (n = 2), failure to retrieve polyps for histopathologic evaluation (n = 10), or histologic diagnosis of SSA/P (n = 1). Of the 100 included polyps, 61 were smaller than 6 mm, and 47 polyps were located in the proximal colon. The majority (65%) were sessile polyps, and 73% of polyps contained neoplasia.

The accuracy of real-time pCLE for differentiation of polyps was 76% (Table 2) compared to 73% for NBI. pCLE accuracy was 74% in the first 50 cases and 78% in the last 50 cases (P = 0.64). The accuracy of NBI was higher for left-sided polyps and for polyps ≥10 mm. Accuracy of pCLE increased with size and was 71% in polyps < 10 mm (55/77) versus 91% in polyps ≥ 10 mm (21/23, P = 0.05). Adenomas were correctly identified with pCLE in 53 of 68 cases (78%) versus 19 of 27 non-neoplastic polyps (70%, P = 0.72). Only five polyps containing HGD or carcinoma were included, of which four were identified with pCLE (80%).

The percentage correct diagnoses with pCLE was 45% (13/29) for poor quality images, 86% (44/51) for fair quality images, and 95% (19/20) for good quality images (P < 0.01). For NBI, the accuracy was 62% in polyps with poor quality pCLE images, 71% in the case of fair quality, and 95% in the case of good quality images (P = 0.33).

For the first 25 cases of both endoscopists, the image quality was poor in 32% (16/50), fair in 48% (24/50), and good in 20% (10/50) of cases. During the second 25 cases, the image quality was poor in 26% (13/50), fair in 54% (27/50), and good in 20% (10/50) of cases. This difference was not significant (P = 0.78). Image quality was better in 39 polyps ≥ 5 mm (18% poor, 51% fair, 31% good) than in 61 polyps ≤ 5 mm (36% poor, 51% fair, 13% good, P = 0.04). For right-sided polyps, image quality was poor in 36%, fair in 49% and good in 15%, whereas the image quality was poor in 23%, fair in 53% and good in 24% of left-sided polyps (P = 0.25).
For real-time pCLE, overall accuracy for detecting neoplasia was 77%, with a sensitivity of 88%. Sensitivity in polyps <10 mm was 71% and sensitivity in polyps ≤5 mm was 65%, meaning pCLE identified 24 of 37 neoplastic polyps ≤5 mm. The NPV in polyps ≤5 mm was 58%, as only 18 of 31 polyps considered non-neoplastic with pCLE were actually non-neoplastic.

The mean accuracy amongst the six gastroenterologists and two pathologists in the post-hoc panel, blinded for endoscopic features, was 62%, ranging from 58% to 66% (Table 3). The accuracy was not different between pathologists (60%) and gastroenterologists (62%, P = 0.68). The accuracy for detecting neoplasia was 70%, ranging from 62% to 76%. In polyps <10 mm, the mean accuracy was 67%. Two gastroenterologists evaluated pCLE images of all 100 cases. For both, the accuracy was similar during the first and last 50 cases (66% vs. 66% for gastroenterologist 1 and 62% vs. 60% for gastroenterologist 4, respectively). The accuracy in the post-hoc panel increased according to the quality of the images from 48% in the case of poor quality to 63% in the case of fair quality and 78% in the case of good quality. Fleiss Kappa was 0.315 and 0.317 for images obtained by the first and second endoscopist, respectively, indicating fair interobserver agreement within the post-hoc panels. Mean sensitivity of post-hoc pCLE for detection of neoplasia was 69% in polyps <10 mm and 63% in polyps ≤5 mm. The NPV in polyps ≤5 mm was 54%.

**Discussion**

In their first 50 cases, two experienced colonoscopists using real-time pCLE achieved an accuracy of 76% for differentiation of colorectal polyps and an accuracy of 77% for detecting neoplasia. The NPV of real-time pCLE for detecting neoplasia in colorectal polyps ≤5 mm was only 58%. The accuracy of post-hoc pCLE in a blinded panel of gastroenterologists and pathologists was 62% for differentiation of polyps and 70% for detec-

<table>
<thead>
<tr>
<th>Accuracy</th>
<th>NBI (%)</th>
<th>P value</th>
<th>NBI+pCLE (%)</th>
<th>P value</th>
</tr>
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<tr>
<td>Total</td>
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<td>0.822</td>
<td>76/100 (76.0)</td>
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<td>38/50 (76.0)</td>
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<td>33/47 (70.2)</td>
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<tr>
<td>Left sided</td>
<td>44/53 (83.0)</td>
<td>0.918</td>
<td>43/53 (81.1)</td>
<td></td>
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<tr>
<td>Size</td>
<td>0.014</td>
<td>0.086</td>
<td>0.232</td>
<td></td>
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<tr>
<td>0–5 mm</td>
<td>39/61 (63.9)</td>
<td>0.033</td>
<td>42/61 (68.9)</td>
<td>&lt;0.001</td>
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<td>6–9 mm</td>
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<td>13/16 (81.3)</td>
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<td>≥10 mm</td>
<td>22/23 (95.7)</td>
<td></td>
<td>21/23 (91.3)</td>
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<td>(Sub)pedunculated</td>
<td>21/24 (87.5)</td>
<td></td>
<td>21/24 (87.5)</td>
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<td>19/27 (70.4)</td>
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<td>53/68 (77.9)</td>
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<tr>
<td>Good</td>
<td>19/20 (95.0)</td>
<td></td>
<td>19/20 (95.0)</td>
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</tr>
</tbody>
</table>

1 For NBI.
2 For NBI+pCLE.

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**Table 3** Accuracy of real-time pCLE.

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The macroscopic appearance of the polyps undoubtedly contributed to the real-time diagnoses, especially for larger polyps with a higher a priori likelihood of neoplasia.

The quality of the pCLE images in our study was low in 29% of all polyps and in 36% of polyps ≤ 5 mm, for which pCLE could be relevant with regard to a resect-and-discard strategy. Although objective definition of image quality is difficult, the quality was probably lower than in the study by Shahid and colleagues and other previous studies, in which experts obtained the images [14–16, 24–26] (Table 4). As a consequence, post-hoc sensitivity and accuracy were higher in previous studies than in our study, apart from the study by Kuiper et al. [22], in which the endoscopists were as inexperienced in obtaining pCLE images as in our study. As expected, the difference in NBI accuracy between polyps with poor and fair pCLE image quality was smaller (62% and 72%, respectively) than the difference in accuracy of pCLE in polyps with poor and fair image quality (45% and 86%, respectively). However, the accuracy of NBI in polyps with good quality pCLE images was as high as the accuracy of pCLE (95%). Possibly, these polyps were more easily assessed with NBI as well. Another explanation might be that judgment of the quality of the images by the endoscopist was biased by the certainty of the diagnosis with NBI, which aided a correct pCLE diagnosis.

The accuracy of real-time pCLE in this study was only slightly higher than for NBI, although pCLE was always performed after NBI, both performed by the same operator. This suggests that pCLE has no or only limited benefits to NBI. In addition, both experienced colonoscopists in this study were not able to meet the recommended sensitivity and NPV thresholds for detecting neoplasia in colorectal polyps [12]. This might be due to their ongoing learning curve, but a previous study has shown a short learning curve for pCLE interpretation [17]. In addition, accuracy was not different between the first 50 and the last 50 of 100 cases evaluated by two post-hoc panel members in our study. Therefore, it is unlikely that insufficient pCLE interpretation caused the low sensitivity. As Shahid et al. and Kuiper et al. previously suggested [22, 24], obtaining high-quality images is crucial for the accuracy of pCLE. The association we found between image quality and pCLE accuracy, both real-time and post-hoc, supports this hypothesis.

Our study is the first to investigate the use of real-time pCLE for differentiation of colorectal polyps in non-expert users, closely resembling the way the technique should ideally be implemented in routine clinical practice. We evaluated pCLE as an additional technique to NBI for detection of neoplasia in colorectal polyps, allowing immediate revision of pCLE images. The comparison with results of the post-hoc panel allowed estimation of the contribution of endoscopic features to the accuracy of pCLE.

The small sample size is a limitation of our study and the results should therefore be interpreted with caution. As mentioned above, the learning curve for the interpretation of pCLE images was probably already completed within the sample size of this study, but the learning curve to obtain pCLE images might not. This is however not just a limitation of our study,
but it is also an outcome, reflecting a difficulty of the technique. Of note, the long inclusion period might have prolonged the learning curve and is therefore a limitation of our study. In addition, the brief hands-on training that was provided to both endoscopists might have been insufficient, although it was performed in accordance with the standard Cellvizio® instruction. Based on this, it may well be that the requirement of a longer training period is a potential limitation of pCLE implementation. In this study, we did not use a cap attached to the colonoscope, which may help to stabilize the probe. Another limitation of our study is the relatively large sizes and high rate of neoplasia of the polyps, which probably affected the accuracy of real-time diagnoses. To assess the use of pCLE in a resect-and-discard strategy, investigation of small polyps is necessary. This was not the primary aim of our study, but we included more than 60% small polyps. Sensitivity and NPV for detecting neoplasia in small polyps were quite low and a larger sample size probably would not have contributed essentially to the outcome.

In conclusion, the accuracy of real-time pCLE was comparable to NBI and not sufficiently high to reliably differentiate colorectal polyps. The NPV was well below the 90% that is required to use pCLE in a ‘resect-and-discard’ strategy. In the current era of high definition endoscopes and digital chromoendoscopy, we estimate that the additional value of using pCLE in the colon is likely to be limited. Difficulty in obtaining high-quality pCLE images hampers straightforward implementation in routine clinical practice.

### Competing interests

None

### References


