A Systematic Approach to Standardizing the Visual Appearance of Endometriotic Lesions for Artificial Intelligence Recognition

Running title: Visual ontology of endometriosis

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Abstract

Introduction: Numerous studies have shown that the diagnostic performance and reproducibility of visual recognition of endometriosis during laparoscopy are poor. The use of artificial intelligence seems relevant for exhaustive lesion recognition. Standardization of the visual classification of lesions, in the form of an ontology is an essential prerequisite to enable medical experts to annotate surgical data consistently and subsequently allow engineers to train and build an artificial intelligence tool for endometriosis recognition.

Material and methods: A systematic search was conducted in the MEDLINE (via PubMed), EMBASE, and the Cochrane Library databases up to May 2022 aiming to identify studies describing the laparoscopic visual appearance of superficial endometriosis, endometriomas, and deep infiltrating endometriosis. The accumulated data in the literature concerning the visual appearance of the different forms of endometriosis were used to create an ontology that could be used for artificial intelligence applications.

Results: Out of 932 articles screened, 35 studies were selected on the basis of the inclusion criteria of human subjects with histologically confirmed endometriosis lesions visualized via laparoscopy. The selected studies were reviewed to develop a visual ontology of endometriosis lesions observed via laparoscopy. The lesions were categorized into 4 classes and further subdivided into 11 subclasses: superficial (black, red, white, or subtle), adhesions (dense or filmy), deep (obliteration, retraction, or deformation), and ovarian (endometrioma or chocolate fluid). The positive predictive value (PPV) varied across lesion types: black lesions (PPV 47–97%), red lesions (PPV 33–100%), white lesions (PPV 20–81%), and ovarian endometriosis (PPV 42–98%). Nonspecific lesions such as adhesions (PPV 16–50%) and subtle superficial lesions (PPV 0–67%) presented lower PPVs. Deep endometriosis lesions, often buried within organs, required indirect signs (obliteration, retraction, deformation) for identification.

Conclusion: The visual ontology proposed in this systematic search could facilitate the detection and classification of endometriosis lesions using artificial intelligence. This study highlights the challenges of reaching a consensus on lesion recognition and classification in AI projects due to the diverse visual presentations of endometriosis.

Introduction

Laparoscopy allows for direct visual and histological assessment of endometriosis and is the only procedure that can definitively exclude the disease when imaging examinations are normal or inconclusive (1–3). However, numerous studies have shown that the diagnostic performance and reproducibility of visual recognition of endometriosis during laparoscopy are poor (4–8). The great diversity and subtle nature of the lesions, their small size, the variety of possible lesion locations and the fact that they can be buried within organs or behind the peritoneum are all factors that limit their recognition by surgeons and the standardization of surgical procedures (9–11). In addition, diagnostic accuracy is highly dependent on the surgeon's level of experience and training in endometriosis surgery, leading to substantial inter-operator variability and further limiting reproducibility (9,12).

In this context, the use of artificial intelligence, particularly machine learning, seems relevant for exhaustive lesion recognition and standardization of surgical procedures. The accuracy of image recognition using artificial intelligence has dramatically increased in recent years (13). In a recently published proof-of-concept study, our group demonstrated the feasibility of automatic visual recognition of endometriosis during laparoscopy using artificial intelligence (14). The implementation of such an artificial intelligence project faces many obstacles, one of which is the absence of a reference system for the visual recognition of endometriosis lesions during laparoscopy. Standardization of the visual classification of lesions, in the form of an ontology (a class-based organization with representation, formal naming, and definitions), is therefore an essential prerequisite to enable medical experts to annotate surgical data consistently and subsequently allow engineers to train and build an artificial intelligence tool for endometriosis recognition.

The objective of this study was to conduct a systematic search of the of the literature regarding the laparoscopic visual descriptions of endometriosis lesions and to propose a

standardized visual ontology that can serve as a reproducible framework for expert annotation and for AI-based lesion recognition.

Materials and methods

Literature search

We conducted a systematic search of the literature using the PRISMA 2020 criteria (Page et al., 2021). Two of the authors (A.N. and F.D.) independently searched the MEDLINE (via PubMed), EMBASE, and the Cochrane Library databases until May 2022 aiming to identify studies describing the laparoscopic visual appearance of superficial endometriosis, endometriomas, and deep infiltrating endometriosis. The complete search strategy—including all Boolean queries, the database-specific adaptations, and the rationale for term selection—is given in **Supplementary Material 1**. To ensure comprehensiveness, we also manually screened the reference lists of all included articles for additional studies meeting the inclusion criteria. The protocol for this literature search was registered in the PROSPERO international prospective register of systematic reviews (Registration number: PROSPERO 2022 CRD42022354949).

Inclusion and exclusion criteria

We selected articles published in English in scientific journals with guaranteed peer review and book chapters. Articles were only retained when their abstract clearly suggested that the authors aimed to provide a structured or intentional description of the laparoscopic appearance of endometriotic lesions.

Eligibility criteria

We included randomized controlled trials, prospective or retrospective cohort studies, literature reviews and meta-analyses. Case reports, case series and letters to the editor were also included, provided that they reported relevant information.

Selection of studies

Two of the authors (A.N. and F.D.) independently conducted the first selection by eliminating articles whose title or abstract suggested that they dealt with themes too far from the scope. After this initial screening, the full texts of the remaining articles were examined, and all relevant articles and their references were carefully analyzed to identify any material possibly suitable for inclusion in the study.

Positive Predictive Values

When available, positive predictive values (PPVs) were extracted or derived from the included studies as the proportion of visually identified lesions that were histologically confirmed as endometriosis. For each lesion type, PPVs were calculated based on the data reported by the original authors, using histological confirmation as the reference standard. Due to heterogeneity in study designs and reporting, PPVs are presented as ranges (minimum–maximum) rather than pooled estimates.

Ontology

The accumulated data in the literature concerning the visual appearance of the different forms of endometriosis were used to create an ontology that could be used for artificial intelligence applications. The ontology is used to limit the complexity and organize the data into classes with representation, formal naming, and definitions. It is a formal explicit description of classes and their properties in a domain of discourse. An ontology together with a set of individual instances of classes constitutes a knowledge base (15). The aim of this way of organizing the data is to precisely define the parameters that allow the different types of endometriosis to be differentiated visually. This step is crucial in the context of machine learning for obtaining reasoned learning on the basis of real knowledge (16).

Video Database

To support the development of the present classification system, we relied on an international multicenter database of laparoscopic videos specifically created for our broader artificial

intelligence project (IRB: 58723-4/2016/EKU). This database includes prospectively recorded surgical procedures from four expert centers, with standardized exploratory sequences of the pelvic cavity. In the context of the present study, the video dataset was used for two main purposes: (i) to informally verify that each lesion described in the literature could be assigned to a specific class within the proposed ontology, ideally in a non-ambiguous manner; and (ii) to extract representative still frames used to illustrate the different lesion types. A detailed description of the video database and its structure is provided in the companion article submitted alongside this manuscript.

Results

Studies included

The initial literature search revealed 932 articles (**Figure 1**). After an initial reading of the titles and abstracts, 42 articles were deemed relevant, and the manuscripts of 41 articles were read in full. The manuscript of one article dating from 1989 could not be obtained (17). Following this reading, 35 articles were included in this search (**Table 1**). Most articles relevant to the visual description of endometriosis via laparoscopy concern superficial endometriosis, with only a few articles concerning other visual appearances (microscopic endometriosis, adhesions, endometrioma or deep endometriosis).

Superficial endometriosis

Black superficial lesions (typical)

Superficial endometriosis is classically defined as infiltration of the peritoneum to a depth of less than 5 mm. Several authors have also proposed a limit of 2 mm or less, defining depths between 3 and 4 mm as intermediate infiltrations (18). These superficial endometriotic lesions include a wide variety of visual manifestations that are often classified as typical (or black lesions) or atypical or nonpigmented (other lesion types) (19–21).

The black superficial lesions, which are easily identifiable, are the most frequently and earliest described lesions in the literature (**Table 2**). The prevalence of these lesions in patients undergoing laparoscopy for infertility and/or pelvic pain is approximately 40% according to two studies (21,22). These typical lesions have excellent diagnostic value for the presence of endometriosis when identified by a surgeon during laparoscopy; most studies have shown a positive predictive value (PPV) over 85% based on histological confirmation (20–25).

Histologically, typical black lesions are the result of old tissue bleeding followed by the retention of blood pigments. They therefore contain a combination of glands, stroma and intraluminal debris surrounded by a fibromuscular matrix (26,27).

Atypical superficial lesions

John Fallon et al. first described nonblack endometriotic lesions as colorless "amenorrheic" lesions in 1950 (28). In 1969, Karnaki published an age-dependent appearance starting with an initial water blister (29). By 1980, this was seen as common in adolescents (30). In 1986, Jansen et al. and Russell reported that more than half of patients who underwent laparoscopic surgery for endometriosis had atypical nonpigmented lesions (19). The different lesions described were as follows: white opacification of the peritoneum, 81% of which were histologically confirmed as endometriosis; "red flamelike" lesions also histologically confirmed in 81% of the biopsies; "glandular excrescences" (67% histologically confirmed); subovarian adhesions (50% histologically confirmed); "yellow–brown patches" (47% histologically confirmed); and circular peritoneal defects (45% histologically confirmed).

In the decade following this 1986 description, these so-called "atypical" or "subtle" lesions were widely reported by many authors, who used a wide variety of different terminologies to describe them (**Table 3**). Several authors have distinguished typical black lesions from other lesions; these lesions are therefore described as atypical, whereas others speak of pigmented, nonpigmented and undefined lesions (31–33). Finally, many authors, to

varying degrees and nuances, have used qualifiers by color: "black," "red," "white" and "subtle." Each lesion color comprises numerous subtypes whose differentiation is very difficult to clearly appreciate through the articles (26,34–39). The diagnostic value of identifying these atypical lesions by laparoscopic surgeons is highly variable depending on the article and the type of lesion. It seems to be generally lower than that of typical black lesions (**Table 4**). However, the PPV for the identification of red lesions seems to be greater than that for other types of atypical lesions (19,23,24).

Atypical lesions each have a different visual appearance and histological characterization, which calls into question the value of grouping them in a common class (20,26,27,40–42). Red lesions are thus active, proliferative endometriosis lesions consisting of glands and stroma with developed neovascularization and are often associated with recent intralesional bleeding (20,27,41,43). On the other hand, white lesions are poorly vascularized, often inactive, often nonproliferative, and consist mainly of fibrosis and some degree of pigmentation (41). The whitish opacity of the peritoneum consists of a retroperitoneal endometrial glandular structure associated with a poorly developed stroma surrounded by fibrotic tissue (27,40). Sometimes a hemosiderin blood pigment is present, which results in the appearance of yellow–brown or café-au-lait patches.

Visual ontology of superficial lesions

The synthesis of data from the literature allowed us to establish a visual ontology of superficial endometriosis lesions, as shown in **Figure 2**. The lesions are thus divided into 5 visual classes: microscopic (invisible), subtle, red, black and white. Some classes include the main subtypes found in the literature (10 in all); an attempt has been made to group the synonyms assumed in the articles under a single subtype. A synthetic description of the histology of each subtype is also provided.

Adhesions

In the context of endometriosis, adhesions are usually differentiated according to their density and transparency (19,20,44,45). Therefore, adhesions can be dense or filmy, depending on their transparency, and some filmy adhesions can act as bridges for vessels. The 1985 revised American Fertility Society (AFS) classification takes up this distinction, granting a different number of points for the two types of adhesions (46). Adhesions have no specific characteristics that would allow them to be differentiated from adhesions of infectious or surgical origin (which are also frequently observed in patients with endometriosis). Although they can occur at any location in the peritoneal cavity, subovarian adhesions are more specifically described for endometriosis by many authors (6). They are thought to be the consequence of an inflammatory reaction induced by active lesions (27). Because they are not very specific, the rate of histological confirmation of the endometriotic nature of adhesions is generally low, ranging from 16 to 50%, depending on the study (**Table 5**).

Endometriomas

Very few articles have described the laparoscopic visual characteristics of endometriomas, which are classically recognized on imaging before surgery (by MRI or ultrasound) (47). In 1991, Vercellini et al. reported that endometriomas could be visually recognized laparoscopically with a set of 4 criteria: (i) had an ovarian cyst measuring less than 12 cm, (ii) had adhesions to the pelvic sidewall and/or broad ligament, (iii) had typical black superficial lesions on the surface, and (iv) had thick chocolate-colored "tarry" contents (48). According to the present study, these characteristics allow identification by surgeons in 97.5% of patients with histological confirmation. In a 1990 study of 41 ovarian cysts, Martin and Berry noted that 5 cysts (12%) were wrongly considered to be endometriomas during surgery, whereas on histology, they were corpus lutea or corpus albicans (49). The authors gave their laparoscopic description of the endometrioma as follows: "flattened white internal lining with irregular raised red or red and brown streaks scattered throughout the internal wall" (49). Other

studies also reported excellent PPVs for the recognition of endometriomas by surgeons via laparoscopy (79.5 to 97.7% (**Table 6**)) (48,50–53).

Deep endometriosis

Fewer than 10 studies have described the visual appearance of deep endometriosis during laparoscopy (54). Usually, deep endometriosis is recognized primarily by clinical examination and palpation or by medical imaging (magnetic resonance imaging (MRI) or ultrasound), which is increasingly sensitive (22,24,55). As early as 1979, the American Fertility Society (AFS) classified the presence of dense adhesions obliterating the cul-de-sac as a criterion for the severity of endometriosis (56). In 1990, Cornillie et al. reported that because of two-dimensional vision and limited palpation sensitivity, the depth of deep endometriosis lesions is difficult to assess by laparoscopy (18). According to these authors, retraction of the peritoneum at the surface is the only clue for identifying lesions. In a subsequent publication, Koninckx and Martin retrospectively analyzed 136 deep endometriotic lesions (histological slides and laparoscopy photographs). They concluded that there were three forms of deep endometriosis: (i) a conical form, suggesting an infiltration mechanism; (ii) a form covered with adhesions, suggesting a retraction mechanism; and (iii) a spherical form, most of which is buried under the peritoneum. The authors also noted that the volume of lesions of types (ii) and (iii) could not be properly appreciated visually from the peritoneal cavity since they were buried under adhesions and within the peritoneum itself, respectively (57). Later, Donnez et al. described two additional procedures for identifying deep endometriotic lesions via laparoscopy: obliteration of the space and deformation of the organs (58,59).

The matter of visualizing deep endometriosis has also arisen more recently. Several authors have reported that certain deep endometriotic lesions, particularly rectal nodules, are identifiable only by palpation and cannot be visualized (60–62). Roman et al. estimated that in approximately 25% of patients undergoing bowel resection, there are nonvisible but palpable

satellite lesions measuring up to 1 cm that may be more than 2 cm away from the initial identified lesion (10).

Visual ontology of endometriosis

The data cited above were correlated with our surgical video database to establish correspondences with the different types of lesions observed to verify that each lesion could be reasonably assigned to a specific class, with minimal ambiguity. This work made it possible to construct a visual ontology of endometriosis according to 4 visual classes, which were subdivided into 11 subclasses (**Figure 3**). Superficial endometriosis was further subdivided into 8 additional visual categories (considering that endometriosis on the normal peritoneum (invisible) is not a visual category and that the 'black' category does not contain any additional subcategory) (**Figure 2**).

Discussion

We have presented a systematic search of the visual descriptions of endometriotic lesions under laparoscopy. This article represents the methodological foundation of a broader AI-based project whose next stage involved the automatic segmentation and classification of endometriotic lesions using deep learning (14). Here, we focus specifically on the conceptual and visual framework required to ensure robust and reproducible human annotation — a critical yet often neglected prerequisite in AI model development. This structured ontology, grounded in surgical expertise, enables the precise definition of classes that guide image annotation and improve model interpretability.

In this search, we propose a focused visual ontology with 4 main visual classes, which may serve as the basis for the automatic detection and recognition of endometriosis via artificial intelligence. With respect to superficial endometriosis, our search of the literature revealed that many terms have been used to describe variations in color and shape. Although the depth of infiltration cannot be reliably assessed from the peritoneal cavity alone, and the designation of

a lesion as “superficial” may therefore be uncertain, we chose to retain this category within the ontology. This decision was motivated by its widespread clinical use, its relevance for surgical decision-making, and the need for the ontology to remain interpretable by a broad range of clinicians. We retained 4 main visual subclasses according to the 3 most commonly used colors (black, red, white), and the other lesions were grouped together as "subtle endometriosis." Although the term subtle has already been used in the literature to describe any form of superficial endometriosis other than black, we have chosen to use it to describe lesions that do not correspond to any of the three dominant colors. We chose not to use the term atypical, as we felt that there were too many different visual aspects of endometriosis for any one form to be considered typical. It would appear that these forms are the least frequently histologically confirmed and can therefore legitimately be described as subtle. We then used findings from our video database to subdivide the main classes, obtaining a total of 9 classes. It was clear from the literature and our videos that a distinction had to be made between dense and filmy adhesions. With respect to the description of deep endometriosis, 3 visual subclasses, which are most often found in the literature (deformation, retraction, obliteration), were distinguished. This differentiation is debatable because it appears obvious when reviewing our video database that these visual aspects are not mutually exclusive but are often associated to various degrees. Notably, deep endometriotic lesions are frequently centered on one or more superficial lesions, and this visual aspect is sometimes easier to detect. Finally, with respect to ovarian endometriosis, we have used the consensual term "endometrioma," although it should be noted that this type of cyst is not always directly visible because it can be hidden beneath the ovarian cortex and can be confused with a hemorrhagic corpus luteum.

Our ontology includes a wide range of lesion types, including subtle or nonpigmented forms whose clinical relevance remains uncertain. We consider this to be a faithful reflection of real-life surgical experience. Furthermore, comprehensive lesion recognition is a prerequisite

for any diagnostic application. This approach may also enable future studies to correlate lesion subtypes or volumes with symptoms or outcomes, thereby refining our understanding of their clinical significance.

In a previously published companion paper (14), this visual ontology was applied to develop an AI-based system for automated recognition of endometriosis lesions during laparoscopy. To illustrate how the lesion-specific predictive values reported in the literature relate to automated recognition, **Table 7** provides a contextual comparison between the positive predictive values (PPVs) of surgeons visual diagnosis and the precision achieved by the AI model trained using this ontology.

One might reasonably expect that lesion types with the highest PPVs in the literature—reflecting higher histological specificity for endometriosis—would also be those most accurately recognized by AI. This assumption appears to hold true to some extent for black superficial lesions, as well as for white and subtle lesions, for which AI precision values are broadly consistent with the ranges of human PPVs reported in the literature.

In contrast, the markedly lower AI precision observed for red superficial lesions is unexpected given their relatively high PPVs in several surgical series. This discrepancy may reflect the limited visual specificity of red coloration in laparoscopy, where erythema, vascular structures, inflammation, or bleeding are ubiquitous and may confound automated recognition. A similar observation applies to ovarian endometriosis, where AI precision appears lower than human PPVs, potentially related to the explicit separation of endometriomas and chocolate fluid as distinct visual classes in the AI study, whereas these entities are often implicitly grouped together in surgical practice and in the literature.

Conversely, AI-based recognition of adhesions demonstrated relatively high precision despite low PPVs reported in the literature based on systematic histological confirmation. This apparent contradiction highlights a fundamental difference in reference standards: while the

literature evaluates visual diagnosis against a histological ground truth, the AI model was trained and evaluated using expert visual annotations as its reference standard. For lesions with poor histological specificity but consistent visual patterns, such as adhesions, this visually defined ground truth may therefore overestimate AI performance when compared with a histological reference standard.

Computer vision methods based on machine learning can classically accomplish 4 types of tasks on an image: (i) classification (e.g., presence or absence of endometriosis); (ii) object detection (e.g., spatial localization of endometriosis by a bounding box); (iii) semantic segmentation (e.g., precise delimitation of an endometriosis lesion pixelwise); and (iv) instance segmentation (e.g., precise delimitation of different endometriosis lesions). This type of project requires the implementation and training of an artificial neural network. This training is necessarily guided by human identification of the structures to be recognized. In concrete terms, this will require surgeons to precisely identify and annotate endometriosis lesions on a massive number of laparoscopic images (typically, between 10,000 and 100,000). A simple, consensual and exhaustive ontology is an essential prerequisite for this work. Notably, this massive number of images makes it unreasonable to attempt to histologically verify the presence of endometriosis for each lesion. Therefore, the veracity of the annotation will depend exclusively on the PPV of visual lesion identification. According to the present literature ~~review~~ search, the PPV varies according to the type of lesion: excellent for endometriomas and black lesions but much weaker for adhesions and subtle lesions, which are not very specific for endometriosis (19,22,23,44,48). These PPV values must be interpreted with caution. Histological confirmation is known to be imperfect: false negatives may result from superficial sampling, tissue degradation, or difficulties in histological interpretation. Even lesions considered highly specific, such as endometriomas or black peritoneal implants, may lack identifiable endometrial tissue. In this review, no predefined standards were applied regarding histological confirmation,

as the included studies varied widely in their methods and reporting. This heterogeneity represents a limitation of our approach, which relied on the authors' statements of histological confirmation. Identifying deep endometriosis on the surface of organs is sometimes difficult but is nonetheless possible by indirect means involving three methods: retraction and/or deformation of the organs involved and obliteration of the spaces.

This work combines a structured literature review with the construction of a visual ontology, offering a rigorous and reproducible framework for the annotation of endometriosis lesions. By integrating historical classifications with detailed visual descriptors, it lays a solid foundation for the development of AI-based recognition tools. However, this approach has several limitations. The video database was used informally to verify the robustness of the proposed ontology and to generate illustrative images. However, this approach did not follow a formal methodological framework. A more rigorous validation, involving independent expert review and a data saturation process, could be considered in future work. Additionally, the majority of included studies were published between the late 1980s and early 2000s, reflecting historical perspectives that may not fully align with current surgical understanding. Moreover, the reliance on histological confirmation introduces a potential risk of false negatives, particularly in the case of subtle or superficial lesions. Finally, several included studies originated from the same authors or institutions, particularly among older publications, raising the possibility of overlapping patient populations. Although this could affect the reliability of aggregated quantitative data, we only reported ranges (minimum–maximum), thereby minimizing the impact of such potential redundancies.

This search thus reveals predictable difficulties for visual identification without anatomopathological verification: (i) a predictable lack of veracity for certain nonspecific lesions, (ii) a reproducibility between annotators negatively impacted by a high number of classes and a differentiation between fragile classes, and (iii) a difficult delimitation of lesions

whose contours may be poorly marked (subtle lesions, deep lesions), especially in the absence of tactile feedback such as palpation of indurations during laparoscopy.

In addition to highlighting the foreseeable difficulties, this literature search confirms the relevance of the project. Three objectives emerge from the design of an endometriosis recognition algorithm: (i) to improve the PPV for the recognition of subtle lesions in particular; (ii) to achieve a diagnostic performance equivalent to that of an expert, regardless of the surgeon's level of experience; and (iii) to increase the completeness of lesion excision during the surgical procedure.

In conclusion, the present study established a systematic and relatively simple but complete ontology of the different visual aspects that endometriosis exhibits during laparoscopy. By synthesizing heterogeneous descriptions from the literature into a coherent framework, this ontology addresses a critical prerequisite for reproducible visual interpretation, expert annotation, and both clinical and research applications.

Ethics Statement

The protocol for this literature search was registered in the PROSPERO international prospective register of systematic reviews (Registration number: PROSPERO 2022 CRD42022354949).

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Authors' roles

N.B. and M.C. developed the original design.

The acquisition, analysis and interpretation of the data were conducted by F.D. and A.N.

A.N., F.D. and H.A. wrote the first draft of the report.

All the authors contributed to the writing of the final manuscript.

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Conflicts of interest

Nicolas Bourdel is the CEO of SurgAR, and the other authors declare that they have no competing interests related to this study.

Competing interest(s)

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References

1. Nice. National Institute for health and Care Excellence. Endometriosis:diagnosis and management. Clinical guideline. 2017.

2. Fauconnier A, Borghese B, Huchon C, Thomassin-Naggara I, Philip CA, Gauthier T, et al. [Epidemiology and diagnosis strategy: CNGOF-HAS Endometriosis Guidelines]. Gynecol Obstet Fertil Senol. mars 2018;46(3):223-30. doi:10.1016/j.gofs.2018.02.012 PubMed PMID: 29548620.

3. Becker CM, Bokor A, Heikinheimo O, Horne A, Jansen F, Kiesel L, et al. ESHRE guideline: endometriosis†. Human Reproduction Open. 1 janv 2022;2022(2):hoac009. doi:10.1093/hropen/hoac009

4. Russell WMW. Aberrant portions of the Mullerian duct found in an ovary. Johns Hopkins Hosp Bull. [Internet]. 10 mars 1899 [cité 16 déc 2023]. Disponible sur: https://babel.hathitrust.org/cgi/pt?id=uva.3470085735&view=1up&seq=20

5. Nezhat F, Allan CJ, Nezhat C, Martin DC. Nonvisualized endometriosis at laparoscopy. Int J Fertil. déc 1991;36(6):340-3. PubMed PMID: 1684957.

6. Albee RB, Sinervo K, Fisher DT. Laparoscopic excision of lesions suggestive of endometriosis or otherwise atypical in appearance: relationship between visual findings and final histologic diagnosis. J Minim Invasive Gynecol. févr 2008;15(1):32-7. doi:10.1016/j.jmig.2007.08.619 PubMed PMID: 18262141.

7. Fernando S, Soh PQ, Cooper M, Evans S, Reid G, Tsaltas J, et al. Reliability of visual diagnosis of endometriosis. J Minim Invasive Gynecol. déc 2013;20(6):783-9. doi:10.1016/j.jmig.2013.04.017 PubMed PMID: 24183270.

8. McGuinness B, Nezhat F, Ursillo L, Akerman M, Vintzileos W, White M. Fallopian tube endometriosis in women undergoing operative video laparoscopy and its clinical implications. Fertil Steril. nov 2020;114(5):1040-8. doi:10.1016/j.fertnstert.2020.05.026 PubMed PMID: 32826047.

9. Maheux-Lacroix S, Belanger M, Pinard L, Lemyre M, Laberge P, Boutin A. Diagnostic Accuracy of Intraoperative Tools for Detecting Endometriosis: A Systematic Review and Meta-analysis. J Minim Invasive Gynecol. févr 2020;27(2):433-440.e1. doi:10.1016/j.jmig.2019.11.010 PubMed PMID: 31760118.

10. Roman H, Merlot B, Forestier D, Noailles M, Magne E, Carteret T, et al. Nonvisualized palpable bowel endometriotic satellites. Hum Reprod. 18 févr 2021;36(3):656-65. doi:10.1093/humrep/deaa340 PubMed PMID: 33432338; PubMed Central PMCID: PMC7891810.

11. Martin DC. Endometriosis Concepts and Theories [Internet]. Richmond, Virginia, Resurge Press. Working Copy. 2023 [cité 16 déc 2023]. Disponible sur: https://www.danmartinmd.com/files/endotheory.pdf

12. Fernando S, Soh PQ, Cooper M, Evans S, Reid G, Tsaltas J, et al. Reliability of visual diagnosis of endometriosis. J Minim Invasive Gynecol. 2013;20(6):783-9. doi:10.1016/j.jmig.2013.04.017 PubMed PMID: 24183270.

13. Russakovsky O, Deng J, Su H, Krause J, Satheesh S, Ma S, et al. ImageNet Large Scale Visual Recognition Challenge. Int J Comput Vis. 1 déc 2015;115(3):211-52. doi:10.1007/s11263-015-0816-y

14. Netter A, Noorzadeh S, Duchateau F, Abrao H, Desternes J, Peyras J, et al. Initial Results in the Automatic Visual Recognition of Endometriosis Lesions by Artificial Intelligence During Laparoscopy: A Proof-of-Concept Study. J Minim Invasive Gynecol. 3 sept 2025;S1553-4650(25)00317-6. doi:10.1016/j.jmig.2025.08.027 PubMed PMID: 40912397.

15. Gruber TR. A translation approach to portable ontology specifications. Knowledge Acquisition. 1 juin 1993;5(2):199-220. doi:10.1006/knac.1993.1008

16. Fensel D. Ontologies. In: Fensel D, éditeur. Ontologies: A Silver Bullet for Knowledge Management and Electronic Commerce [Internet]. Berlin, Heidelberg: Springer; 2001 [cité 12 févr 2023]. p. 11-8. Disponible sur: https://doi.org/10.1007/978-3-662-04396-7_2 doi:10.1007/978-3-662-04396-7_2

17. Weitzman GA, Buttram VC. Classification of endometriosis. Obstet Gynecol Clin North Am. mars 1989;16(1):61-77. PubMed PMID: 2664623.

18. Cornillie FJ, Oosterlynck D, Lauweryns JM, Koninckx PR. Deeply infiltrating pelvic endometriosis: histology and clinical significance. Fertil Steril. juin 1990;53(6):978-83. doi:10.1016/s0015-0282(16)53570-5 PubMed PMID: 2140994.

19. Jansen RP, Russell P. Nonpigmented endometriosis: clinical, laparoscopic, and pathologic definition. Am J Obstet Gynecol. déc 1986;155(6):1154-9. doi:10.1016/0002-9378(86)90136-5 PubMed PMID: 2947467.

20. Nisolle M, Paindaveine B, Bourdon A, Berlière M, Casanas-Roux F, Donnez J. Histologic study of peritoneal endometriosis in infertile women. Fertil Steril. juin 1990;53(6):984-8. doi:10.1016/s0015-0282(16)53571-7 PubMed PMID: 2351237.

21. Walter AJ, Hentz JG, Magtibay PM, Cornella JL, Magrina JF. Endometriosis: correlation between histologic and visual findings at laparoscopy. Am J Obstet Gynecol. juin 2001;184(7):1407-11; discussion 1411-1413. doi:10.1067/mob.2001.115747 PubMed PMID: 11408860.

22. Martin DC, Hubert GD, Vander Zwaag R, el-Zeky FA. Laparoscopic appearances of peritoneal endometriosis. Fertil Steril. janv 1989;51(1):63-7. doi:10.1016/s0015-0282(16)60429-6 PubMed PMID: 2521327.

23. Stripling MC, Martin DC, Chatman DL, Zwaag RV, Poston WM. Subtle appearance of pelvic endometriosis. Fertil Steril. mars 1988;49(3):427-31. doi:10.1016/s0015-0282(16)59767-2 PubMed PMID: 3342893.

24. Mettler L, Schollmeyer T, Lehmann-Willenbrock E, Schüppler U, Schmutzler A, Shukla D, et al. Accuracy of Laparoscopic Diagnosis of Endometriosis. JSLS. 2003;7(1):15-8. PubMed PMID: 12722993; PubMed Central PMCID: PMC3015470.

25. Marchino GL, Gennarelli G, Enria R, Bongioanni F, Lipari G, Massobrio M. Diagnosis of pelvic endometriosis with use of macroscopic versus histologic findings. Fertil Steril. juill 2005;84(1):12-5. doi:10.1016/j.fertnstert.2004.09.042 PubMed PMID: 16009147.

26. Martin DC. Laparoscopic Appearance of Endometriosis [Internet]. Second Edition. Richmond: Resurge Press; 1990 [cité 12 févr 2023]. Disponible sur: https://www.danmartinmd.com/files/coloratlas1990.pdf

27. Donnez J, Squifflet J, Casanas-Roux F, Pirard C, Jadoul P, Van Langendonckt A. Typical and subtle atypical presentations of endometriosis. Obstet Gynecol Clin North Am. mars 2003;30(1):83-93, viii. doi:10.1016/s0889-8545(02)00054-2 PubMed PMID: 12699259.

28. Fallon J, Brosnan JT, Meyers J, Manning JJ. The clinical aspects of endometriosis. Ann West Med Surg. juill 1950;4(7):321-5. PubMed PMID: 15419623.

29. Karnaki K. Theories and known observations about hormonal treatment of endometriosis-in-situ, and endometriosis at the enzyme level. Arizona Med. janv 1969;1969; January:37-41.

30. Goldstein DP, De Cholnoky C, Emans SJ. Adolescent endometriosis. J Adolesc Health Care. sept 1980;1(1):37-41. doi:10.1016/s0197-0070(80)80007-6 PubMed PMID: 6458589.

31. Balasch J, Creus M, Fábregues F, Carmona F, Ordi J, Martinez-Román S, et al. Visible and non-visible endometriosis at laparoscopy in fertile and infertile women and in patients with chronic pelvic pain: a prospective study. Hum Reprod. févr 1996;11(2):387-91. doi:10.1093/humrep/11.2.387 PubMed PMID: 8671229.

32. Buchweitz O, Poel T, Diedrich K, Malik E. The diagnostic dilemma of minimal and mild endometriosis under routine conditions. J Am Assoc Gynecol Laparosc. févr 2003;10(1):85-9. doi:10.1016/s1074-3804(05)60240-x PubMed PMID: 12555000.

33. Kennedy S, Bergqvist A, Chapron C, D'Hooghe T, Dunselman G, Greb R, et al. ESHRE guideline for the diagnosis and treatment of endometriosis. Hum Reprod. oct 2005;20(10):2698-704. doi:10.1093/humrep/dei135 PubMed PMID: 15980014.

34. Vernon MW, Beard JS, Graves K, Wilson EA. Classification of endometriotic implants by morphologic appearance and capacity to synthesize prostaglandin F. Fertil Steril. nov 1986;46(5):801-6. PubMed PMID: 3781000.

35. Brosens I, Puttemans P, Deprest J. Appearances of endometriosis. Baillieres Clin Obstet Gynaecol. déc 1993;7(4):741-57. doi:10.1016/s0950-3552(05)80461-4 PubMed PMID: 8131313.

36. Donnez J, Nisolle M, Casanas-Roux F. Peritoneal endometriosis: two-dimensional and three-dimensional evaluation of typical and subtle lesions. Ann N Y Acad Sci. 30 sept 1994;734:342-51. doi:10.1111/j.1749-6632.1994.tb21764.x PubMed PMID: 7978936.

37. Shafik A, Ratcliffe N, Wright JT. The importance of histological diagnosis in patients with chronic pelvic pain and laparoscopic evidence of endometriosis. Gynaecological Endoscopy. 2000;9(5):301-4. doi:10.1046/j.1365-2508.2000.00366.x

38. Wood C, Kuhn R, Tsaltas J. Laparoscopic diagnosis of endometriosis. Aust N Z J Obstet Gynaecol. août 2002;42(3):277-81. doi:10.1111/j.0004-8666.2002.00277.x PubMed PMID: 12230063.

39. Stegmann BJ, Sinaii N, Liu S, Segars J, Merino M, Nieman LK, et al. Using location, color, size, and depth to characterize and identify endometriosis lesions in a cohort of 133 women. Fertil Steril. juin 2008;89(6):1632-6. doi:10.1016/j.fertnstert.2007.05.042 PubMed PMID: 17662280; PubMed Central PMCID: PMC2505050.

40. Chatman DL. Pelvic peritoneal defects and endometriosis: Allen-Masters syndrome revisited. Fertil Steril. déc 1981;36(6):751-6. doi:10.1016/s0015-0282(16)45921-2 PubMed PMID: 6458517.

41. Brosens IA, Cornillie FJ. Peritoneal endometriosis. Morphological basis of the laparoscopic diagnosis. Contrib Gynecol Obstet. 1987;16:125-37. PubMed PMID: 2961504.

42. Becker CM, Laufer MR, Stratton P, Hummelshoj L, Missmer SA, Zondervan KT, et al. World Endometriosis Research Foundation Endometriosis Phenome and Biobanking Harmonisation Project: I. Surgical phenotype data collection in endometriosis research. Fertil Steril. nov 2014;102(5):1213-22. doi:10.1016/j.fertnstert.2014.07.709 PubMed PMID: 25150390; PubMed Central PMCID: PMC4230690.

43. Vasquez G, Cornillie F, Brosens IA. Peritoneal endometriosis: scanning electron microscopy and histology of minimal pelvic endometriotic lesions. Fertil Steril. nov 1984;42(5):696-703. doi:10.1016/s0015-0282(16)48193-8 PubMed PMID: 6237941.

44. Moen MH, Halvorsen TB. Histologic confirmation of endometriosis in different peritoneal lesions. Acta Obstet Gynecol Scand. juill 1992;71(5):337-42. doi:10.3109/00016349209021069 PubMed PMID: 1326207.

45. Brosens I. Diagnosis of endometriosis. Semin Reprod Endocrinol. 1997;15(3):229-33. doi:10.1055/s-2008-1068752 PubMed PMID: 9383831.

46. Revised American Fertility Society Classification of Endometriosis: 1985. Fertility and Sterility. 1 mars 1985;43(3):351-2. doi:10.1016/S0015-0282(16)48430-X

47. Bazot M, Daraï E. Diagnosis of deep endometriosis: clinical examination, ultrasonography, magnetic resonance imaging, and other techniques. Fertil Steril. 2017;108(6):886-94. doi:10.1016/j.fertnstert.2017.10.026 PubMed PMID: 29202963.

48. Vercellini P, Vendola N, Bocciolone L, Rognoni MT, Carinelli SG, Candiani GB. Reliability of the visual diagnosis of ovarian endometriosis. Fertil Steril. déc 1991;56(6):1198-200. doi:10.1016/s0015-0282(16)54744-x PubMed PMID: 1743347.

49. Martin DC, Berry JD. Histology of Chocolate Cysts. Journal of Gynecologic Surgery. janv 1990;6(1):43-6. doi:10.1089/gyn.1990.6.43

50. Nezhat C, Nezhat F. Reliability of the visual diagnosis of ovarian endometriosis? Fertil Steril. juill 1992;58(1):223-4. doi:10.1016/s0015-0282(16)55174-7 PubMed PMID: 1624016.

51. Brosens IA, Puttemans PJ, Deprest J. The endoscopic localization of endometrial implants in the ovarian chocolate cyst. Fertil Steril. juin 1994;61(6):1034-8. doi:10.1016/s0015-0282(16)56752-1 PubMed PMID: 8194613.

52. Stratton P, Winkel CA, Sinaii N, Merino MJ, Zimmer C, Nieman LK. Location, color, size, depth, and volume may predict endometriosis in lesions resected at surgery. Fertil Steril. oct 2002;78(4):743-9. doi:10.1016/s0015-0282(02)03337-x PubMed PMID: 12372450.

53. Kazanegra R, Zaritsky E, Lathi RB, Clopton P, Nezhat C. Diagnosis of stage I endometriosis: comparing visual inspection to histologic biopsy specimen. J Minim Invasive Gynecol. avr 2008;15(2):176-80. doi:10.1016/j.jmig.2007.10.005 PubMed PMID: 18312987.

54. Wykes CB, Clark TJ, Khan KS. Accuracy of laparoscopy in the diagnosis of endometriosis: a systematic quantitative review. BJOG. nov 2004;111(11):1204-12. doi:10.1111/j.1471-0528.2004.00433.x PubMed PMID: 15521864.

55. Martin DC. CO2 laser laparoscopy for endometriosis associated with infertility. J Reprod Med. déc 1986;31(12):1089-94. PubMed PMID: 3098974.

56. The American Fertility Society. Classification of Endometriosis. Fertility and Sterility. 1 déc 1979;32(6):633-4. doi:10.1016/S0015-0282(16)44409-2

57. Koninckx PR, Martin DC. Deep endometriosis: a consequence of infiltration or retraction or possibly adenomyosis externa? Fertil Steril. nov 1992;58(5):924-8. doi:10.1016/s0015-0282(16)55436-3 PubMed PMID: 1426377.

58. Donnez J, Nisolle M, Casanas-Roux F, Brion P, Da Costa Ferreira N. Stereometric evaluation of peritoneal endometriosis and endometriotic nodules of the rectovaginal septum. Hum Reprod. janv 1996;11(1):224-8. doi:10.1093/oxfordjournals.humrep.a019024 PubMed PMID: 8671191.

59. Donnez J, Nisolle M, Smoes P, Gillet N, Beguin S, Casanas-Roux F. Peritoneal endometriosis and « endometriotic » nodules of the rectovaginal septum are two different entities. Fertil Steril. sept 1996;66(3):362-8. PubMed PMID: 8751730.

60. Badescu A, Roman H, Aziz M, Puscasiu L, Molnar C, Huet E, et al. Mapping of bowel occult microscopic endometriosis implants surrounding deep endometriosis nodules infiltrating the bowel. Fertil Steril. févr 2016;105(2):430-434.e26. doi:10.1016/j.fertnstert.2015.11.006 PubMed PMID: 26613653.

61. Badescu A, Roman H, Barsan I, Soldea V, Nastasia S, Aziz M, et al. Patterns of Bowel Invisible Microscopic Endometriosis Reveal the Goal of Surgery: Removal of Visual Lesions Only. J Minim Invasive Gynecol. 2018;25(3):522-527.e9. doi:10.1016/j.jmig.2017.10.026 PubMed PMID: 29097234.

62. Redwine DB, Hopton E. Bowel Invisible Microscopic Endometriosis: Leave It Alone. J Minim Invasive Gynecol. 2018;25(3):352-5. doi:10.1016/j.jmig.2018.01.017 PubMed PMID: 29373842.

Tables and Figures

Figure 1: PRISMA 2020 flow diagram

Figure 2: Visual ontology for superficial endometriosis

Figure 3: Visual ontology for endometriosis

Table 1: Studies included in the review

Table 2: Histological confirmation rates of typical black lesions

Table 3: Terminologies used to describe the different types of atypical endometriosis lesions

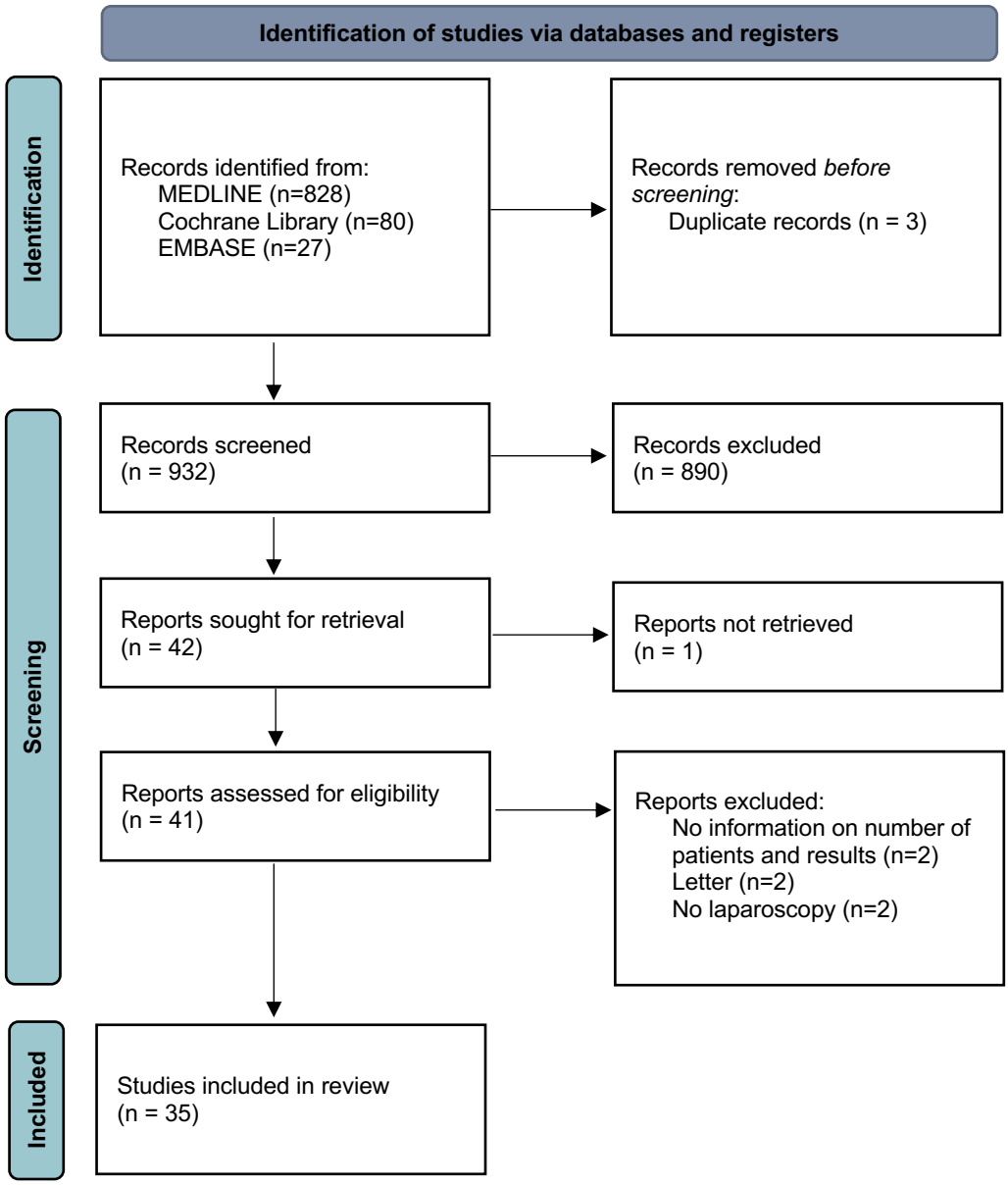
Table 4: Positive predictive value (PPV) of visual diagnosis of atypical endometriosis lesions at laparoscopy

Table 5: Positive predictive value (PPV) of visual diagnosis of adhesions in the context of endometriosis

Table 6: Positive predictive value (PPV) of visual diagnosis of endometriomas at laparoscopy

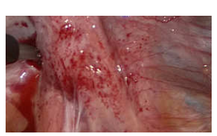
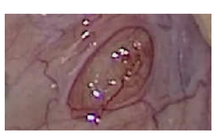
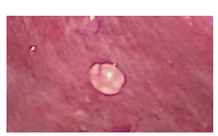
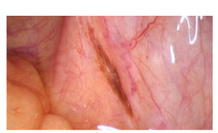
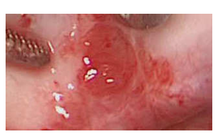
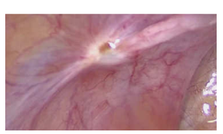
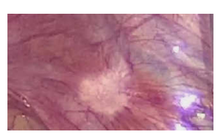
Table 7: Contextual comparison between visual diagnosis from surgeons (positive predictive value from the literature) and AI-based lesion recognition (precision)

Supplementary Material 1 : Literature Search Strategy


Identification of studies via databases and registers
Identification
Records identified from:
MEDLINE (n=828)
Cochrane Library (n=80)
EMBASE (n=27)
Records removed *before screening*:
Duplicate records (n = 3)
Screening
Records screened
(n = 932)
Records excluded
(n = 890)
Reports sought for retrieval
(n = 42)
Reports not retrieved
(n = 1)
Reports assessed for eligibility
(n = 41)
Reports excluded:
No information on number of patients and results (n=2)
Letter (n=2)
No laparoscopy (n=2)
Included
Studies included in review
(n = 35)

SUPERFICIAL ENDOMETRIOSIS

Evolution in time

Color	**INVISIBLE**	**SUBTLE**				**RED**		**BLACK**	**WHITE**
Type/ macroscopic description	**Normal peritoneum**	**Petechial peritoneum Hypervascularization**	**Peritoneal defect /Pseudo-pockets**	**Clear vesicle**	**Yellow-brown patches**: *- café au lait*	**Papular/Glandular excressence**: - polypoid - apparently solid - fine vascularization of surrounding peritoneum. - translucent - resemble the mucosal surface of the endometrium	**Red vesicle/red vesicular excrescences/ Red flamelike lesions**: - Elevated blister or bleb -pink to red -extravasation of blood beyond the limits	**Typical black lesion:** - Powder-burn - gunshot - puckered lesion - bluish	Fibrotic nodule / White opacification
histology		Numerous red blood cells, rare endometrial glands, hypervascularization	endometrial glands in 50%	Connective tissue with sparse endometrial glands	Enclosed implant surrounded by fibrosis + heamosiderin from blood pigment	One or more active distended endometrial glands surrounded by stroma and its vascularization and covered by mesothelium		Enclosed implant surrounded by fibrosis (with intraluminal debris and haemosiderin)	the white, fibrous, sometimes calcified scar representing inactive and healed lesions
									 
Vascularization and activity	Unknown activity and vascularization	Variable activity and vascularization				High activity and vascularization		Low activity Medium vascularization	Low activity Low vascularization

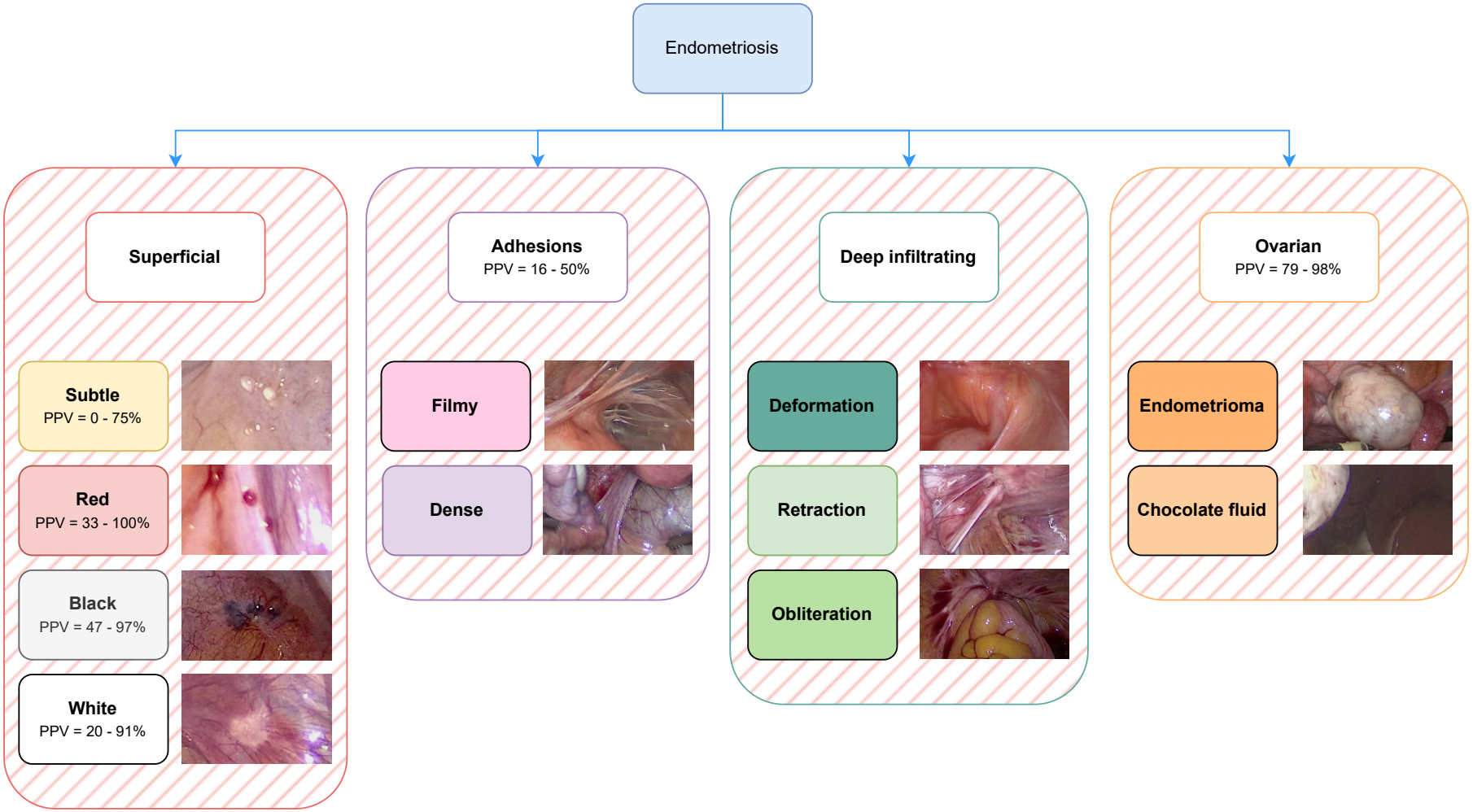

Endometriosis
Superficial
Subtle
PPV = 0 - 75%
Red
PPV = 33 - 100%
Black
PPV = 47 - 97%
White
PPV = 20 - 91%
Adhesions
PPV = 16 - 50%
Filmy
Dense
Deep infiltrating
Deformation
Retraction
Obliteration
Ovarian
PPV = 79 - 98%
Endometrioma
Chocolate fluid

Table 1: Studies included in the review			
Authors, year	**Country**	**Type of study**	**Sample size - Population type**
Chatman *et al.,* 1981	USA	Prospective, descriptive	635 patients. Laparoscopy for pelvic pain and infertility.
Vasquez *et al.,* 1984	Belgium	Prospective, descriptive	37 patients. Laparoscopy for infertility.
Murphy *et al.,* 1986	USA	Prospective, descriptive	15 peritoneal biopsies. Laparoscopy for infertility.
Jansen *et al.,* 1986	Australia	Prospective, descriptive	137 biopsies, 77 patients. Laparoscopy for infertility, pelvic pain or tubal sterilization.
Vernon *et al.,* 1986	USA	Prospective, descriptive	14 patients Laparoscopy for endometriosis resection
Stripling *et al.,* 1988	USA	Retrospective, descriptive	109 patients - 164 biopsies. Laparoscopy with postoperative diagnosis of endometriosis.
Redwine, 1988	USA	Prospective, descriptive	33 patients. Laparoscopy for pelvic pain.
Redwine, 1989	USA	Literature review	-

Martin *et al.,* 1989	USA	Retrospective then prospective, descriptive	1440 patients. Laparoscopies performed by the same surgeon.
Nisolle *et al.,* 1990	Belgium	Prospective, descriptive	118 patients. Laparoscopy for infertility.
Cornillie *et al.,* 1990	Belgium	Prospective, descriptive	179 patients. Laparoscopy for infertility and/or pelvic pain.
Moen *et al.,* 1992	Norway	Prospective, descriptive	153 patients. Laparoscopy for infertility or pelvic pain.
Nezhat and Nezhat, 1992	USA	Prospective, descriptive	216 "hemorrhagic cysts".
Wiegerinck *et al.,* 1993	Belgium	Prospective, descriptive	40 patients. Laparoscopy before and 6 months after cessation of medical treatment of endometriosis.
Brosens *et al.,* 1993	Belgium	Literature review	-
Brosens *et al.,* 1994	Belgium	Prospective, descriptive	51 patients. Laparoscopy in patients with "chocolate cysts
Balasch *et al.,* 1996	Spain	Prospective, descriptive	100 patients - 119 biopsies. Laparoscopy for infertility, pelvic pain or tubal sterilization.
Donnez *et al.,* 1996	Belgium	Prospective, descriptive	Number of patients not specified.

			Laparoscopy for pelvic pain or infertility.
Brosens *et al.,* 1997	Belgium	Literature review	-
Shafik *et al.,* 2000	United Kingdom	Prospective, descriptive	62 patients - 150 biopsies. Laparoscopy for pelvic pain.
Walter *et al.,* 2001	USA	Prospective, descriptive	44 patients. Laparoscopy for pelvic pain.
Stratton *et al.,* 2002	USA	Prospective, descriptive, multicenter	65 patients - 189 biopsies. Laparoscopy for pelvic pain then laparoscopy 6 months later.
Wood *et al.,* 2002	Australia	Retrospective, descriptive	215 patients. Laparoscopy with postoperative diagnosis of endometriosis.
Redwine, 2003	USA	Literature review	-
Buchweitz *et al.,* 2003	USA	Retrospective, descriptive	118 patients - 311 biopsies. Laparoscopy for pelvic pain or infertility.
Donnez *et al.,* 2003	USA	Review of literature	-
Mettler *et al.,* 2003	Germany	Retrospective, descriptive	164 patients. Laparoscopy for suspected endometriosis.
Wykes *et al.,* 2004	USA	Literature review	-

Marchino *et al.,* 2005	Italy	Prospective, descriptive	54 patients, 122 biopsies. Laparoscopy for pelvic pain.
Nascu *et al.,* 2006	Canada	Prospective, descriptive	37 patients. Laparoscopy for pelvic pain
Albee et al., 2008	USA	Prospective, descriptive	512 patients, 2005 biopsies. Laparoscopy for pelvic pain.
Kazanegra *et al.,* 2008	USA	Retrospective, descriptive	156 patients, 238 biopsies. Laparoscopy for pelvic pain.
Stegmann *et al.*, 2008	USA	Prospective, descriptive	133 patients, 611 biopsies. Laparoscopy for pelvic pain
Khan *et al.,* 2013	Japan	Retrospective	151 patients with endometriosis - 62 women without visible endometriosis
Gubbels et al., 2020	USA	Retrospective, descriptive	142 patients. Laparoscopy for chronic pelvic pain.

Table 2: Histological confirmation rates of typical black lesions			
Authors, year	**Frequency, %.**	**Number of biopsies**	**PPV, %.**
Stripling *et al.,* 1988	-	95	97
Martin *et al.,* 1989	46	35	94
Nisolle *et al.,* 1990	-	86	93
Moen *et al.* 1992	-	25	76
Walter *et al.* 2001	40	20	85
Stratton *et al.* 2002	-	-	47
Mettler *et al.* 2003	-	-	92
Marchino *et al. 2005*	-	-	64
Stegmann *et al.*, 2008	-	150	62

PPV = Positive Predictive Value

Table 3: Terminologies used to describe the different types of atypical endometriosis lesions		
	Terminologies	**Authors, year**
Red lesions	*Red*	Martin et al., 1989 Stratton et al., 2002 Shafik et al., 2000 Vernon et al., 1986 Stegmann *et al.*, 2008
	Vesicular red	Walter et al., 2001 Moen et al., 1992 Brosens et al., 1997
	Red papule	Wiegerinck et al., 1993 Brosens et al., 1997
	Pink lesions	Shafik et al., 2000
	Reddish brown	Vernon et al., 1986
	Red flamelike lesions	Jansen et al., 1986 Nisolle et al., 1990 Donnez et al., 1996 Brosens et al., 1997
	Red polypoid lesions	Martin et al., 1989 Stripling et al., 1988
	Peritoneal petechiae	Nisolle et al., 1990 Donnez et al., 1996 Brosens et al., 1997
	Hemosiderin	Stripling et al., 1988
	Hemorrhagic lesions	Marchino et al., 2005

		Brosens et al., 1997
	Hypervascularized area	Nisolle et al., 1990 Donnez et al., 1996 Brosens et al., 1997
	Glandular growths	Jansen et al., 1986 Nisolle et al., 1990 Donnez et al., 1996
White lesions	*White opacities*	Jansen et al., 1986 Nisolle et al., 1990 Donnez et al., 1996 Stratton et al., 2002 Shafik et al., 2000 Brosens et al., 1997
	White scars	Martin et al., 1989 Stripling et al., 1988
	Scar tissue	Wood et al., 2002 Walter et al., 2001 Moen et al., 1992 Marchino et al., 2005
	White vesicles	Martin et al., 1989
	Macula	Wiegerinck et al., 1993
Subtle lesions	*Yellow-brown Patches*	Jansen et al., 1986 Nisolle et al., 1990 Donnez et al., 1996 Walter et al., 2001 Moen et al., 1992
	Peritoneal defects	Jansen et al., 1986

		Nisolle et al., 1990 Donnez et al., 1996 Walter et al., 2001 Stratton et al., 2002 Moen et al., 1992 Chatman et al., 1981 Brosens et al., 1997
	Cribriform peritoneum	Brosens et al., 1997
	Peritoneal pouches	Martin et al., 1989 Marchino et al., 2005.
	Clear vesicles	Martin et al., 1989 Moen et al., 1992
	Brown vesicles	Martin et al., 1989
	Brown fibrotic lesions	Martin et al., 1989
	Vesicular lesions	Wood et al., 2002 Walter et al., 2001 Shafik et al., 2000 Marchino et al., 2005
	Papular lesions	Marchino et al., 2005
Subovarian adhesions		Jansen et al., 1986 Nisolle et al., 1990 Donnez et al., 1996 Walter et al., 2001 Brosens et al., 1997

Table 4: Positive predictive value (PPV) of visual diagnosis of atypical endometriosis lesions at laparoscopy

Authors, year	Types of lesions							
	Red	**White**	**Yellow-brown**	**Peritoneal defects**	**Glandular**	**Vesicle**	**Papule**	**Hemorrhagic**
Chatman *et al.,* 1981	-	-	-	30,3% (192/635)	-	-	-	-
Jansen *et al.,* 1986	81% (13/16)	81% (45/52)	47% (9/18)	45% (5/11)	67% (14/21)	-	-	-
Stripling *et al.,* 1988	75%	91%	-	-	-	-	-	-
Martin *et al.,* 1989	Polypoid: 75% (9/12) Flat: 33% (4/12) Raised: 33% (2/6)	80% (16/20)	-	-	-	-	-	-

Moen *et al.,* 1992	Red or clear papules: 57% (13/23)		-	12% (3/26)	-	-	-	-
Walter *et al.,* 2001	61% (11/18)	25% (8/32)	50% (1/2)	0% (0/3)	-	0% (0/10)	-	-
Walter *et al.,* 2001	Atypical lesions: 62% (23/37)							
Stratton *et al.,* 2002	55%	66%	-	50% (7/14)	Other colors :75%.			
Stegmann *et al.*, 2008	57%	59%	-	-	-			
	Mixed color lesions : 76%							
Marchino *et al.,* 2005	-	20%	-	0%	-	62%	54%	25%
Albee et al., 2008	Atypical lesions: 24%							
Mettler *et al.,* 2003	100%	31%	-	-	-	-	-	-
Buchweitz *et al.,* 2003	Non-pigmented: 63%. Undefined" lesions: 52%.							

Table 5: Positive predictive value (PPV) of visual diagnosis of adhesions in the context of endometriosis		
Authors, year	Number of biopsies	Histological confirmation
Jansen *et al.,* 1986	4	50%
Nisolle *et al.,* 1990	-	50%
Moen *et al.,* 1992	19	16%
Walter *et al.,* 2001	18	28 %
Donnez *et al.,* 2003	-	50%

Table 6: Positive predictive value (PPV) of visual diagnosis of endometriomas at laparoscopy		
Authors, year	**Number of cysts**	**Histological confirmation**
Martin and Berry, 1990	41 suspected endometriomas	88 %
Vercellini *et al.* 1991	218 "typical" endometriomas	97,7%
Nezhat and Nezhat, 1992	216 hemorrhagic cysts	< 2cm: 100%. 2-6cm: 0%. 6-12cm: 50%. 12-20cm: 85%.
Brosens *et al.,* 1994	51	Typical Endometriomas: 89% Atypical endometriomas: 42%.
Stratton *et al.,* 2002	NS	88%
Kazanegra *et al.,* 2008	73 "typical" endometriomas	79,5%

Table 7: Contextual comparison between visual diagnosis from surgeons (positive predictive value from the literature) and AI-based lesion recognition (precision)

		PPV from literature (min–max, %)	Precision from AI-based recognition[a]
	Superficial Black	47 - 97%	0.900
	Superficial Red	33 - 100%	0.200
	Superficial White	20 - 91%	0.714
	Superficial Subtle	0 - 75%	0.583
	Filmy adhesions	16 - 50%[b]	0.739
	Dense adhesions	16 - 50%[b]	0.805
	Deep Endometriosis	N/A	0.593
	Ovarian Endometrioma	79 - 98%	0.222
	Ovarian chocolate fluid	N/A	0.661

[a] The AI performance values reported in this table are extracted from a previously published study and are provided for contextual comparison only. AI precision was calculated using expert visual annotations as the reference standard.

[b] In the AI-based study, adhesions were analyzed separately as dense and filmy, whereas the literature reviewed here does not allow reliable estimation of PPVs for these subtypes, and adhesions are therefore reported as a single combined category.
PPV = Positive Predictive Values

Supplementary Material 1 – Literature Search Strategy

1. Overview of the Literature Search

This supplementary file details the methodology used to identify published descriptions of the laparoscopic visual appearance of endometriosis lesions. The aim of the search was to gather information necessary for the development of a visual classification system intended for future use in artificial intelligence-based lesion recognition.

A structured search was conducted in three major biomedical databases: MEDLINE (via PubMed), EMBASE, and the Cochrane Library, covering publications from inception to May 2022. The process followed PRISMA 2020 guidelines (Page et al., 2021).

2. Search Strategy and Queries

Searches were tailored for each database and focused on the three main anatomical subtypes of endometriosis: superficial peritoneal lesions, ovarian endometriomas, and deep infiltrating endometriosis. For each type, customized Boolean queries were constructed to capture relevant laparoscopic descriptions.

The Boolean queries were entered into PubMed and EMBASE without field-specific restrictions (e.g., [Title/Abstract]), in order to maximize sensitivity. The aim was to retrieve all potentially relevant studies, even if the visual descriptors of lesions appeared outside of the title or abstract.

2.1 MEDLINE (via PubMed)

- Superficial endometriosis: "laparoscopy" AND "endometriosis" AND ("peritoneal lesions" OR "visual appearance" OR "description")
- Endometriomas: "laparoscopy" AND "endometrioma" AND ("description" OR "appearance")

- Deep infiltrating endometriosis: "laparoscopy" AND ("deep endometriosis" OR "deep infiltrating endometriosis") AND ("description" OR "appearance" OR "Douglas pouch obliteration" OR "cul-de-sac obliteration")

Additional queries were conducted to enhance the sensitivity of the search, particularly for superficial endometriosis. These included variations in terminology and additional synonyms to reflect different descriptors used across the literature:

- Superficial endometriosis (extended): "laparoscopy" AND "endometriosis" AND ("peritoneal lesions" OR "superficial endometriosis" OR "atypical lesions" OR "petechial lesions" OR "powder burn" OR "subtle lesions" OR "faint lesions" OR "red flame" OR "white vesicle" OR "visual description" OR "macroscopic aspect" OR "appearance" OR "description")
- Endometriomas (extended): "laparoscopy" AND ("endometrioma" OR "ovarian cyst" OR "chocolate cyst" OR "endometriotic cyst") AND ("appearance" OR "chocolate fluid" OR "capsule aspect" OR "cyst content" OR "macroscopic features" OR "description")
- Deep infiltrating endometriosis (extended): "laparoscopy" AND ("deep endometriosis" OR "deep infiltrating endometriosis" OR "retroperitoneal fibrosis") AND ("description" OR "appearance" OR "obliteration" OR "retraction" OR "deformation" OR "fibrotic nodule" OR "bowel involvement" OR "pouch of Douglas" OR "rectovaginal septum" OR "ureteral stenosis" OR "scar-like lesion" OR "tethering")

Note on Adhesions

Although no specific Boolean query was constructed exclusively for adhesions, descriptions of adhesions were frequently encountered during the full-text review of articles retrieved through the broader search strategies targeting superficial, ovarian, and deep endometriosis. When such descriptions were relevant, visually detailed, and accompanied by histological confirmation of endometriosis at adhesion sites, the information was retained and integrated into the ontology.

2.2 EMBASE

- Superficial endometriosis: 'laparoscopy' AND 'endometriosis' AND ('peritoneal lesion*' OR 'visual appearance' OR 'description')
- Endometriomas: 'laparoscopy' AND 'endometrioma' AND ('description' OR 'appearance')
- Deep infiltrating endometriosis: 'laparoscopy' AND ('deep endometriosis' OR 'deep infiltrating endometriosis') AND ('description' OR 'appearance' OR 'Douglas pouch obliteration' OR 'cul-de-sac obliteration')

2.3 Cochrane Library

- Combined query (less structured interface): laparoscopy AND endometriosis AND ("peritoneal lesion" OR "appearance" OR "description" OR "cul-de-sac obliteration")

3. Inclusion and Exclusion Criteria

Studies were included if they met the following criteria:

- Published in English in peer-reviewed scientific journals or academic book chapters,
- Explicitly aimed to describe or characterize the laparoscopic visual appearance of endometriotic lesions (superficial, ovarian, or deep), based on information in the title or abstract,
- Included histological confirmation of endometriosis in human subjects.

Articles were excluded if they:

- Did not describe the visual appearance of lesions,
- Lacked histological confirmation,
- Focused exclusively on imaging or experimental models,
- Were editorials, opinion pieces, or unrelated to the surgical appearance of endometriosis.

4. Eligible Study Designs

The following types of studies were eligible for inclusion: randomized controlled trials, prospective or retrospective cohort studies, case series, case reports, systematic reviews, meta-analyses, and relevant book chapters. Letters to the editor were included only when they provided detailed laparoscopic descriptions supported by histological findings.

5. Study Selection Process

Two authors (A.N. and F.D.) independently screened all titles and abstracts retrieved by the search. Articles were only retained when their abstract clearly suggested that the authors aimed to provide a structured or intentional description of the laparoscopic appearance of endometriotic lesions. Studies with only incidental or anecdotal visual mentions were excluded. For potentially eligible articles, full texts were reviewed in detail. Disagreements were resolved by discussion. Reference lists of selected articles were manually searched to avoid missing relevant studies.

6. Data Quality Consideration

The goal of this literature search was to collect and organise descriptive data regarding the visual presentation of endometriotic lesions. Given the descriptive and exploratory purpose of the review, no formal quality appraisal (e.g., risk of bias assessment) was performed. The value of each article was judged based on the relevance and clarity of its visual descriptions rather than its study design or level of evidence.