PURPOSE Cancer is becoming increasingly prevalent among the group of treatable diseases in African countries. There is a shortage of clinicians and pathologists available for cancer diagnosis and treatment. These limited resources must be efficiently used to maximize the number of patients treated. One of the critical factors in treatment efficiency is the correct and timely diagnosis of specimens by pathologists. However, there is currently a significant shortage of cancer care clinicians in Africa and an even more considerable shortage of pathologists. This article presents an example in which telepathology was used to mitigate the lack of pathologists in Cameroon.

METHODS The telepathology workaround was implemented in a district hospital based in Cameroon’s Adamawa region, where a European surgeon provides cancer treatment. A small histology laboratory there is run by one histotechnologist who processes surgical biopsies into histology slides. As there are no pathologists on site, these slides are digitally scanned using a mobile phone and a whole slide imaging (WSI) scanner. The slides are then shared electronically with a volunteering pathologist in Europe who provides a diagnostic report.

RESULTS From 2018 to July 2019, specimens for 101 patients were photographed through an iPhone connected to a microscope eyepiece producing several individual images per specimen. From July 2019 to December 2020, slides from 282 patients were scanned using WSI and digitally transmitted.

CONCLUSION WSI on hematoxylin and eosin histology slides for remote diagnosis can increase cancer treatment efficacy and reduce overtreatment of tumors clinically suspicious for malignancy in under-resourced countries with a lack of pathologists.

BACKGROUND Demography and Health Care Status
Cameroon’s population of 26.4 million in 2020 is young, with a median age of 17.7 years and an average age of 22.1 years in 2010 (Table 1).1,2

Cancer in Cameroon. In Cameroon, cancer contributes to more than 4% of deaths.1 The incidence of cancer in the country, estimated by age-standardized incidence rates of 44.35 per 100,000 for men and 62.35 for females, can be broken down into 13.8% breast cancer, followed by 13.8% cervical cancer, 11.9% non-Hodgkin lymphoma, 7.3% prostate cancer, 6.9% Kaposi sarcoma, 2.9% liver cancer, 2.9% colorectal cancer, 2.8% soft tissue cancers, 2.4% ovarian cancer, and 2.3% skin cancer.1 The absolute number of patients with cancer in Cameroon was estimated to be 25,000 cases a year. Diagnosis of cancer relies on histology in nearly 80% of cases, cytology in 10%, and clinical diagnosis in 10%. The total number of new cases in 2020 was 20,745, with breast cancer leading for both sexes at 20.1% of the total, cervical 13.4%, prostate 10.6%, and in males, liver 9.1%, and colorectal 5.6% (Appendix Table A1).4

Pathology in Cameroon. In 2016, the number of pathologists in Cameroon was estimated to be 0.28 pathologists per million inhabitants and 0.23 cytotechnicians per million.5 The highest number of pathologists in African countries was 4.45 per million.5 The number of surgical biopsies per year in Cameroon is 501-1,000, and there are 100-5,000 fine-needle aspiration procedures registered.5

Pathology and Medical Services in Hopital District de Tchibati, Ngoubela
The district hospital, owned and run by the Oeuvre Santé de l’Eglise Evangelique du Cameroun (OSEEELC), offers a broad spectrum of medical services to about 100,000 inhabitants.6 There are between three and four medical doctors serving in....
the hospital and the affiliated sanitary stations. These doctors have experience in oncologic surgery and treatment, which requires histopathology and cytopathology. The head of the laboratory’s technical staff in the hospital had three years of training in histopathology in Benin but focuses primarily on microscopic reports for malaria and tuberculosis. There is no

### Key Objective
Can a telepathology practice be set up in a low-resource setting that does not have an on-site pathologist?

### Knowledge Generated
In a district hospital in Cameroon with no pathologists on site, a histotechnologist processes and images slides, initially using a mobile phone and subsequently using a whole slide imaging (WSI) scanner. These slides are then reviewed by a volunteering Austrian pathologist, who provides a report to the treating team in Cameroon.

### Relevance
WSI of histology slides allows remote pathology diagnosis that can be effectively implemented in under-resourced countries, thus allowing proper utilization of available resources to treat cancer. Additionally, WSI proved to be faster and had greater likelihood of providing a diagnostic image than mobile phone images taken through the lens of the microscope.

### TABLE 1. Results

| Category        | Topic                                | Data                                                                 |
|-----------------|--------------------------------------|----------------------------------------------------------------------|
| **Dates**       | Start of production of glass slides  | January 12, 2018                                                      |
|                 | Photography by iPhone               | January 13, 2018 to January 23, 2018—17 cases in presence of pathologist |
|                 | Scanning slides                     | February 9, 2018 to June 23, 2019—210 cases remote                   |
| **Cases**       | Glass slides per case               | January 7                                                             |
|                 | Single images per case              | 3-23 (mean 7.3)                                                       |
|                 | Panoramic (wide screen) images per case | 0-9                                                                 |
|                 | Scans per case                      | 1-7 (one per glass slide)                                            |
| **Reports**     | Recording of reports               | Systematized October 2018                                             |
|                 | Evaluable reports of photographed slides | 101                                                                  |
|                 | Evaluable reports of scanned slides | 282                                                                  |
| **Specimens**   | Origin of specimen                  | Grouped according to organs: Appendix Figure A1                      |
| **Procedure**   | Methods of taking tissue for histology | **iPhone imaging** and **WSI**                                      |
|                 | Cytology                            | 0                                                                    |
|                 | Biopsy, needle core                 | 11                                                                   |
|                 | Biopsy, shave or punch              | 56                                                                   |
|                 | Excision                            | 25                                                                   |
|                 | Resection                           | 9                                                                    |
| **Diagnoses**   | Category of disease                | Benign: 32, Malignant: 53, Intermediate: 14, Nondiagnostic: 2       |
| **Quality Control** | Technical necessity of repetition | Repeats: 3, 10                                                       |
| **Certainty**   | Levels of diagnostic certainty     | Relevance of histopathological diagnosis: Figure 4                   |
|                 | Diagnostic                          | Directly guides therapy                                              |
|                 | Differential only                   | Additional diagnostic modalities necessary                           |
|                 | Nondiagnostic                       | Histopathology cannot achieve a conclusion                           |

Abbreviation: WSI, whole slide imaging.
histopathologist available. Before acquiring scanning capability, excised formalin-fixed specimens have been hand-transported to Austria by volunteers on their return journey for preparation, processing, and reporting in their laboratory.

**METHODS**

**Production of Slides**

In January 2018, a histology laboratory for the production of slides was founded in the hospital of Ngaoubela (Table 2). The equipment and reagents for the first months were donations from hospitals in Austria and Germany and a distributor of pathology laboratory equipment in Austria.

**Digital Pathology and Remote Diagnosis**

For 18 months, a technician used an iPhone camera to take images of the slides (Fig 1). In early July 2019, a portable slide scanner, Ocus by Grundium (Tampere, Finland), was obtained (Fig 2). A volunteering high school graduate was educated together with the laboratory technician. An operating handbook was produced by the volunteer and the pathologist (Appendix Table A2).

The whole process is illustrated in Figure 3. Specifics of the pathologist reports are in Table 2. Cases are documented for analysis (Table 3).

**FIG 1.** There was a short period of instruction by a pathologist staying in the hospital in Ngaoubela for 3 weeks. This pathologist left detailed written instruction for continued excision and imaging after the stay. The technician was also taught to capture slide images through the microscope eyepiece using an iPhone.

**TABLE 2.** Structure of Reports

| Subject Transferred From Request | Content |
|----------------------------------|---------|
| Patient data                     | a) First name and last name<br>b) Age<br>c) Sex<br>d) Place of residence<br>e) Occupancy<br>f) Mobile number |
| Referring physician              | a) Name<br>b) Hospital |
| Dates                            | a) Date of operation<br>b) Date of arrival in local laboratory |
| ID of report                     | Consecutive number and year |
| Clinical information             | a) Localization of specimen in the body<br>b) Kind of operation<br>c) Relevant symptoms<br>d) Duration of disease<br>e) Suspicion of diagnosis |
| Laboratory information           | a) Size of specimen<br>b) Weight of specimen<br>c) Color and consistency<br>d) Number of blocks |
| Image of slides                  | Slides are photographed together with request form |
| Report by pathologist            | |
| Dates                            | a) Date of reception of images or scans<br>b) Date of reception of request |
| Subject                          | No. of slides documented in image of request |
| Description                      | Of histopathologic criteria |
| Diagnosis                        | According to WHO nomenclature |
| Classification                   | TNM, if possible |
| Comment                          | a) Differential diagnoses<br>b) Technical issues, if relevant<br>c) Pathogenetic issues, if therapeutically relevant<br>d) Therapeutic suggestions, if required |
RESULTS

Referenced Time Delimiters

Six dates are recorded per case as it evolves, as can be seen in Table 4 (Table 1: Results).

Single Images vs Whole Slide Imaging

Comparing the two methods of iPhone imaging and whole slide imaging (WSI) by the recorded dates yields the following plots. Figure 5 shows the distributions of each date interval across cases, and Figure 6 shows the visualization of stacking each interval, by case.

DISCUSSION

Low economic resources in Cameroon limit the use of anticancer therapies. Therefore, an efficient application of drugs is mandatory, requiring precise diagnosis. Cameroon faces a lack of pathologists, limiting such access. There is a global opportunity for training pathologists and technicians in Cameroon to improve diagnoses.

Because of the unique availability of cancer therapy and the shortage of diagnosticians, a local histopathology laboratory was established to enable remote diagnostics. All efforts were made to establish a valid diagnostic system according to current guidelines under the existing resource constraints. Slide quality was limited in some cases because of paraffin inconsistency because of inability to maintain consistent appropriate temperatures during processing, caused mainly by power company supply irregularities. Some sections had to be repeated up to 13 times, resulting in delays of weeks.

Special or immunohistochemical stains, except hematoxylin and eosin, could not be performed because of specimen infrequency and personnel shortage. The lack of these techniques resulted in false or missing diagnoses.

Taking single images by using a camera through the eyepiece of a microscope offers the choice of 5,000-10,000 images per 1 cm² tissue on a slide. Discerning lesioned areas from normal tissue is essential and requires understanding and knowledge of microanatomy and pathologic changes in a tissue. In two of six hysterectomy specimens, diagnosis was impossible because normal myometrium was considered pathologic and selected for imaging. In two cases, the diagnosis could only be made in one of several images.

Images must be focused manually on the iPhone screen attached to the eyepiece of the microscope. Detailed knowledge of cellular features facilitates focusing. Smaller magnifications (4x objective) were out of focus more frequently than larger magnifications.
Compared to photographs of slides via iPhone, WSI provides significant advantages including the lesion's orientation, inclusion of all regions in a single slide, and rapid screening, since evaluating a WSI can take a few minutes by an experienced pathologist. This led to an increase in the portion of cases considered diagnostic rather than differential only (Fig 3). This represents an increased ability to provide correct and specific treatment for patients, improving outcomes and conserving resources.

Because of the changing coverage of the telecom companies, and data capacities of about 5 GB per day, transmission is limited. Durations of several hours for transfer of one WSI must be considered in case of malfunctioning power supply.

Patient data are transferred in anonymous folders by Dropbox. Data in transit are transported with Transport Layer Security, secured by Advanced Encryption Standard encryption with at least 128 Bit. A two-step login is available in this system. The Telegram images do not include patient data. The Telegram app also offers secret chats using end-to-end encryption, which could be organized to transfer patient data in the future.

The goal of fewer than 90 days from onset of symptoms to initiation of treatment was often exceeded because of diagnosis time. The period contributing most to the delay is between the access date and the scan date (Figures 5 and 6, red).

The main problem of the whole process is the unreliable municipal power supply, affecting the speed and reliability of slide preparation profoundly. Together with the low

**FIG 3.** Step 1: The workflow begins with the surgeon in Cameroon excising the specimen and sending the tissue for processing. Step 2: The technician processes the specimen in Cameroon to create H&E slides. Step 3: The slides are digitized by photographing through the microscope eyepiece (phase I) or via slide scanner (phase II). Step 4: The images are uploaded to cloud storage. Step 5: The pathologist in Austria reviews the images and generates the pathology reports. Step 6: The reports are uploaded to cloud storage and sent via instant messaging to the surgeon in Cameroon. H&E, hematoxylin and eosin.
frequency of specimens, the preparation of slides is limited to a maximum of once per week, which can be delayed because of unpredictable power loss. Processing requires an uninterrupted power supply for at least 12 hours; otherwise, it must be continued manually or repeated. Digital processes are protected by batteries and affected to lesser degree (Appendix Fig A1).

In the intervening time between the iPhone cases, performed in 2019, and the set of WSI cases presented, from the later half of 2020, there was significant restructuring of the laboratory in Cameroon, including personnel changes. This could contribute to the minor reduction in average processing time seen between Figures 5 and 6 in red.

The most beneficial outcome of changing to WSI from iPhone images lay in increased diagnostic confidence (Figure 4). Pathologist reading of the case was minorly hastened (Figures 5 and 6, orange).

In conclusion, histopathologic and cytopathologic diagnoses are mandatory for the therapy of malignant tumors, especially for chemotherapy. As there is a shortage of pathologists in Cameroon, a telepathology project was initiated, initially using single images by using a mobile phone camera through the eyepiece of a microscope, subsequently by using WSI taken with a single slide scanner. Images were transferred via Internet for remote pathologic diagnoses. Despite having hematoxylin and eosin slides only, the rate of nondiagnostic images could be reduced from 16.8% to 5.5% by applying the WSI scanning technique, which is a valuable tool for reducing unnecessary therapies. Compared to mobile phone imaging, WSI had a faster overall turnaround time and proved more likely to be diagnostic.

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**TABLE 3. Recording of Report Data**

| Patient identification for reference—local pathologist |
|--------------------------------------------------------|
| Patient ID | First name | Last name | Age | Sex |
|-------------|-------------|------------|-----|-----|
| Case ID     | Sequentially assigned |
| Timeline    | See Table 4 |
| Procedure   | Cytology | Biopsy, core or punch or shave | Excision | Resection |
| Origin (organ) of specimen | See Appendix Figure A1 |
| Diagnosis   | Malignant | Benign | Intermediate |
| Relation of clinical suspicion to pathologic diagnosis | Concordant | Discordant | Clinically indifferent | No clinical information |

**TABLE 4. Explanation of Recorded Dates of Checkpoints on the Progress of Each Case**

| Time—Date | Description |
|-----------|-------------|
| D1        | Day of operation (puncture, excision, and resection of specimen) |
| D2        | Arrival of specimen at the local histology laboratory |
| D3        | Date of imaging, through manual images (phase I) or scanner (phase II) |
| D4        | Availability of images on cloud service in Europe |
| D5        | Availability of patient data and request in Europe (excluded from graphs because of irrelevant differences to D4) |
| D6        | Date of report and its transmission (always identical) |

**FIG 4.** Diagnostic certainty of single image versus whole slide imaging cases: 101 camera image cases and 273 whole slide imaging cases. Some cases lacked a recorded category and are excluded. Diagnostic: exact diagnosis—therapy can be based on diagnosis. Differential only: differential diagnoses—therapy is influenced by diagnosis in context with further clinical analyses. Nondiagonsable: no diagnosis possible—no therapy guidance. %: percent of cases in certainty groups 1-3, N: absolute number of cases in certainty groups 1-3. iPhone, single images by using iPhone camera; WSI, whole slide imaging.
**FIG 5.** Box and whisker chart comparing the distributions of the length of each interval between recorded dates describing case progression as listed in Table 3: (A) iPhone data (cases 129-229) and (B) WSI data (cases 412-531). iPhone, single images by using iPhone camera; WSI, whole slide imaging.

**FIG 6.** Stacked area graph by case for (A) iPhone data (cases 129-229) and (B) WSI data (cases 412-531), where the total summed height at each point represents the total number of days from procedure to final pathology report. Each color represents the individual contribution to total time from each interval between recorded dates of case progression, as defined in Table 1. iPhone, single images by using iPhone camera; WSI, whole slide imaging.

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AUTHORS' DISCLOSURES OF POTENTIAL CONFLICTS OF INTEREST

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**APPENDIX**

![Graph](image.png)

**FIG A1.** Distribution of the biopsied organs. The total number of specimens is 383; 101 iPhone (camera) cases and 282 WSI cases. Absolute numbers were used. Eight recorded cases did not have a tissue of origin recorded and are omitted here. Derm = skin; GI = gastrointestinal; Gyn = uterus including cervix, ovary, and gestational pathology; Hep = liver; Lymph = lymph nodes; Oral = head and neck; Uro = kidney, urinary tract, and prostate; breast includes male and female; soft tissue includes bone. WSI, whole slide imaging.

**TABLE A1.** Political and Administrative Situation, Demography, and Health Care

| Feature                                    | Sub-feature                        | Value                                      |
|--------------------------------------------|------------------------------------|--------------------------------------------|
| Population                                 | Ethnic groups                      | 250                                        |
|                                            | Languages                          | 230                                        |
|                                            | Population density in rural areas  | 15.9 inhabitants per km²                    |
|                                            | like Adamawa                       |                                             |
|                                            | Location of the hospital           |                                             |
|                                            | Population density in Litoral       | 141.5 inhabitants per km²                  |
|                                            | region, home of the capital        |                                             |
| Socioeconomic and sanitary situation       | Incidence of poverty in Adamawa    | 47.1%                                      |
|                                            | Rural areas                        | 8.9%                                       |
|                                            | Access to potable water in 2011    | 88.5%                                      |
|                                            | Urban population                   | 60.6%                                      |
|                                            | Adamawa                            |                                             |
| Access to communication technologies       | Mobile telephones in 2018          | 76% of the population                      |
|                                            | Internet                           | 25%                                        |
|                                            | Social networks                    | 14%                                        |
|                                            | Computer access for health facilities | 32.1%                                      |
|                                            | Whole Cameroon                     | 19.1%                                      |
|                                            | Adamaa                             |                                             |
| Organization of health care sector         | Structured in 3 levels, public     | Seven central and seven general hospitals  |
|                                            | funding                             |                                             |
|                                            | Ministry of public health (MINSANTE)| 16 regional hospitals                      |
|                                            | Provincial (intermediate level)     | 145 district hospitals                      |
|                                            | Peripheral level (districts)       | 228 district medical centers               |
|                                            | Private sector—clinics and NGOs    | 2016 integrated health centers mainly urban areas |
|                                            | Denominational sector              | Predominantly Catholic and Protestant churches|
| Awareness of cancer in Cameroon           | Cancer control                     | National Cancer Control Program 2003¹²:   |
|                                            | Cancer registry                    | Planned committees for education, prevention, registration, diagnosis, treatment, research, finance, and public relations Based on data from Yaoundé, Douala, and Bamenda, covering 25% of the population |
| Pathology in Cameroon                     | Availability of services           | Institutes in Yaoundé, Douala, and Bamenda Estimated number of residents: 2-4¹²|

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### TABLE A2. Methods

| Phase                  | Step                      | Details                                                                                                                                                                                                 |
|------------------------|---------------------------|---------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------|
|                        |                           | **Production of slides**                                                                                          |                                                                                       |
|                        | Grossing                  | Performed by a surgeon, being aware of UICC staging requirements and a technician, who also is educated in specimen preparation, slide cutting, histopathology laboratory organization, storage of biologic material and slides, and documentation |
|                        | Fixation                  | 4% formalin, ready to use                                                                                                                                                                            |
|                        | Paraffin blocks           | Commercially available embedding cassettes                                                                                                 |
|                        | Slides                    | Commercially available noncovered glass slides, stored locally                                                 |
|                        | Stains                    | Staining: Tissue Stainer COT 20 HE only                                                                                                   |
|                        |                           |                                                                                       |                                                                                       |
|                        |                           | **Photography of slides**                                                                                      |                                                                                       |
|                        | Microscope                | Olympus BH2 (donation, German hospital)                                                                                           |
|                        | Adapter for phone camera on an ocular Camera | SWAROVSKI PA-i5 Adapter for iPhone 5/5S (donation)                  | Single images through eyepiece of microscope: 3-20 per case                                                                                   |
|                        | Images                    | Panoramic images: wide-angle images up to 10 per case Size 1-3 MB, maximum 46 MB per case, average 15 MB                              |
|                        |                           |                                                                                       |                                                                                       |
|                        |                           | **Scanning of slides**                                                                                      |                                                                                       |
|                        | Scanner                   | Portable device: Ocus by Grundium: capacity: One slide, scanned in 30-200 seconds, resulting in series of images with thumbnail (2-6 GB), temporarily stored in the scanner, compressed to ScanScope Virtual Slides (*.svs) size 35-500 MB each for transfer, Laptop for operation of scanner—instead of Internet cause of inconsistent access |
|                        | Scanned images            | UPS to protect scanner: Voltaic V72LV88 Laptop Battery and V88 USV Powerbank 24,000 mAh                                                 |
|                        |                           |                                                                                       |                                                                                       |
|                        |                           | **Remote transferring and diagnostics**                                                                         |                                                                                       |
|                        | iPhone photographs and Request Form | Dropbox file hosting service—shared with the pathologist Telegram—messaging service from local hard disk (Cameroon) Aperio ImageScope and QuPath-0.2.3 software |
|                        | WSI scans viewer for analysis of scans |                                                                                       |                                                                                       |
|                        |                           |                                                                                       |                                                                                       |
|                        |                           | **Reporting and documentation**                                                                             |                                                                                       |
|                        | Request                   | Form, filled by hand by the surgeon, glass slides (1-4 per case) placed on it for JPG file, stored in common Dropbox folder |
|                        | Report (for details, see Table 2) | *.pdf file in common Dropbox folder named by lab ID                                                                                       |
|                        | Storage of information    | Dropbox cloud and copy on hard disk of pathologist                                                                                          |
|                        |                           |                                                                                       |                                                                                       |
|                        |                           | **Data administration**                                                                                      |                                                                                       |
|                        | Recording of report data (Table 3) | Selected contents of each report for reference and statistical analysis in an Excel file by pathologist |

Abbreviations: HE, hematoxylin and eosin; UICC, Union for International Cancer Control; UPS, uninterruptable power supply; WSI, whole slide imaging.