Original Article

Comparison of telerobotic and conventional ultrasonography in children: a crossover bicentric pilot study

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Background: The MELODY system allows for performing ultrasonography on a patient remotely and has been proposed to assess disease characteristics in the context of the coronavirus disease 2019 (COVID-19) pandemic. The aim of this interventional crossover study was to address the feasibility of the system in children aged 1 to 10 years old.

Methods: Children underwent ultrasonography with a telerobotic ultrasound system followed by a second conventional examination by a different sonographer.

Results: In total, 38 children were enrolled, and 76 examinations were performed, with 76 scans analyzed. The mean [standard deviation (SD)] age of participants was 5.7 (2.7) years (range, 1–10 years). We found substantial agreement between telerobotic and conventional ultrasonography [κ=0.74 (95% CI: 0.53–0.94), P<0.005]. The mean (SD) duration was longer for telerobotic than conventional examinations [26.0 (2.5) *vs.* 13.9 (11.2) min, P<0.0001]. Abdominal organs and abnormalities were similarly visualized on telerobotic and conventional ultrasonography. Cardiac echocardiography provided reliable diagnoses, with non-significantly different measurements with both techniques, although the visualization score was significantly higher with conventional than telerobotic ultrasonography (P<0.05). On lung analysis, both examinations identified consolidations and pleural effusion, whereas visualization and total lung score were similar with the 2 techniques. Overall, 45% of parents reported that their children felt less pressure with the telerobotic system.

Conclusions: Telerobotic ultrasonography may be effective, feasible, and well-tolerated in children.

Keywords: Ultrasound echography; telemedicine; children; telerobotic; robot

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Introduction

Point of care ultrasonography (US) has become an effective, accurate, radiation-free diagnostic tool that can be used in real time to evaluate patients with respiratory, cardiac, or abdominal symptoms (1-4). In the context of the coronavirus disease 2019 (COVID-19) pandemic, US appeared to be one of the most useful and effective means of assessing the severity of COVID-19. For example, several publications have shown the effectiveness of this imaging technique for managing pulmonary conditions, pneumonia being the most frequent complication, occurring in 30% to 80% of cases, with potential for risk of an adverse prognosis (5-7). According to medical consensus, US is the first-line imaging technique for children for whom CT-induced radiation should be avoided as much as possible, in accordance with the As Low As Reasonably Achievable (ALARA) principle (8). However, despite the increasing widespread use of US in children, regional hospitals may not have the required expertise in US, particularly for cardiac and lung pediatric expertise. Consequently, children may need to be transferred to reference hospitals, thus increasing the risk of delayed diagnosis and worsening symptoms in fragile children.

Highlight box

Key findings

- Telerobotic US in children gives similar results as conventional US for assessing lung, cardiac and abdominal abnormalities.

What is known and what is new?

- What is known: point of care US is an effective, accurate, radiation-free diagnostic tool in children. Telerobotic US has been found effective in adults for obstetrical, cardiac, or abdominal US expertise.
- What does this manuscript add: we showed that telerobotic US is effective, feasible, and well tolerated in children as early as 1 year old for assessing cardiac, abdominal and lung abnormalities.

What is the implication, and what should change now?

- The results of this study pave the way to provide access of US for children in rural and remote communities with lack of imaging access. Larger studies including infants and newborns are needed to determine the cost-effectiveness of remote sonography.

The “MELODY”, remote system developed by AdEchoTech, is a CE-Mark-approved robotic telemedicine end-to-end solution that allows a medical expert to remotely perform US in hospital or in consultation several hundred/thousand kilometers away from the reference center. It offers access to exploration and diagnostic capabilities to remote populations requiring US. The MELODY system allows for optimizing cardiac, lung or abdominal US expertise wherever located at all times. Although the MELODY system has been found effective in adults (9-12), it has not been tested and hence not approved for pediatric use.

In this study, we aimed to assess the feasibility of the MELODY remote system for thoracic, abdominal, and cardiac US in children and to compare its results with those of conventional US. We present this article in accordance with the TREND reporting checklist (available at https://tp.amegroups.com/article/view/10.21037/tp-22-569/rc).

Methods

Participants

Children aged 1 to 10 years who required lung, abdominal or cardiac US in 2 regional hospitals, in the pediatric department of the Centre Hospitalier Intercommunal de Créteil and the Centre Hospitalier Intercommunal de Villeneuve Saint Georges, were offered inclusion in this study. Children were included from March 2021 to November 2021.

Telerobotic system

The MELODY system in adults was described previously (10). Briefly, the system is a 3 degrees-of-freedom robot located in the patient’s room. It is designed to hold an external ultrasound transducer and allows experts to control the robot and the attached transducer easily and quickly from a remote location. The expert site, located at a distance, is provided with the MELODY Expert system and consists of a mock transducer and an electronic control box. All fine movements of the mock transducer held by the sonographer similar to conventional US are reproduced by

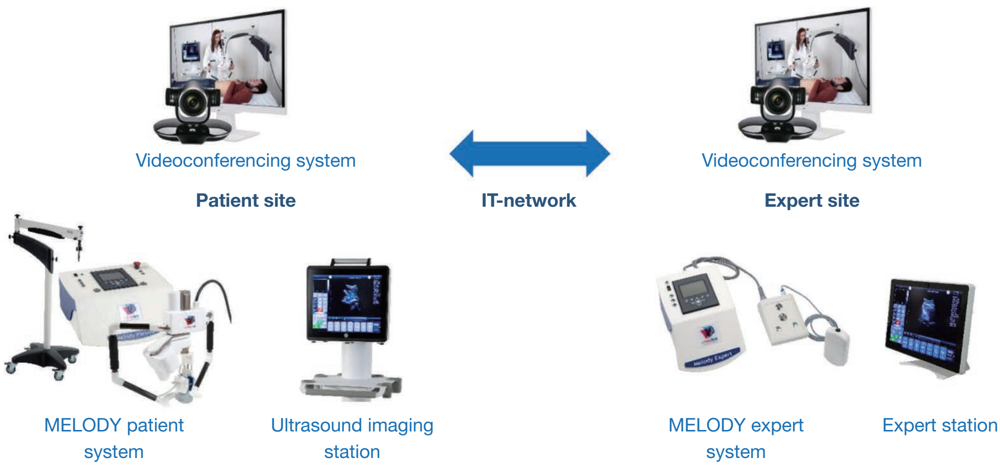

Figure 1 System and service architecture of MELODY remote system. The MELODY Patient System consists of a robot, a control panel, and a floor stand. The ultrasound transducer is clamped to the robot. The control panel is connected to the internet and receives signals from the expert site. The signals are translated and sent to the servo motors on the robot, which in turn move the transducer, mimicking the motion of the expert radiologist at the expert site. The videoconferencing system is ideally suited to a tele-ultrasound examination, offering simple operation and excellent communication regarding placement of the robot and the child between the patient and expert sites. The MELODY Expert system consists of a mini control panel and a fictive probe. The shape of the fictive probe resembles an ultrasound transducer and is held and moved by the expert as they might use an ultrasound transducer.

the scanning transducer via the robot at the patient site. In this study, the robot was equipped with the MELODY TE7 Mindray ultrasound system (AdEchoTech, Naveil, France). The following probes were used: for abdominal US, a convex probe C5-2s (2 to 5 MHz); for lung US, a linear probe L14-6Ns (6 to 14 MHz); and for cardiac US, a SP5-1s (1.1 to 4.4 MHz) and P7-3s (3 to 7 MHz) probe (Mindray, Shenzhen, China).

Adaptation of the MELODY system for children

The MELODY system for children was derived from the MELODY system for adults (*Figure 1*). Several adjustments were required to facilitate the acceptability of the device by children. The patient assistants were pediatric caregivers (*Figure 2A*) with specific skills in using the MELODY system with children, including advanced training in pediatrics, sensitivity, and empathy but also effective communication and listening when working with parents. To adapt the patient site for children, the room was redesigned with colorful stickers on the walls and the robot (*Figure 2B,2C*). As for adults, parents and children could easily see and communicate with the expert sonographer via the videoconferencing system (TE30 All-in-One, HD Videoconferencing Endpoint; Huawei Technologies, Shenzhen, China) (*Figure 2C*). To reduce the pressure exerted on the chest, a soft material was placed under the base of the robot, and a new protocol was developed for fixing the probes for pediatric use (*Figure 2D*).

Trial design

This was prospective interventional crossover study (ClinicalTrials.gov: NCT04776174) of 10 months (from March 2021 to November 2021). With a prescription from the referring clinician and after obtaining informed consent, children initially underwent scanning with a telerobotic Mindray TE7 ultrasound system. During the whole examination, the site assistant remained close to the child, positioning the robotic arm according to the indications of the remote sonographer. Also, during the examination, the parent(s) remained with their child.

Within 3 hours, after the telerobotic examination, children underwent scanning with the conventional Mindray TE7 system ((Mindray, Shenzhen, China) by another, similarly experienced and qualified sonographer with blinding to the findings of the telerobotic examination. Ten senior expert sonographers participated in this study, including 4 experts in lung US (pediatricians), 4 in abdominal US (radiologists) and 2 in cardiac US

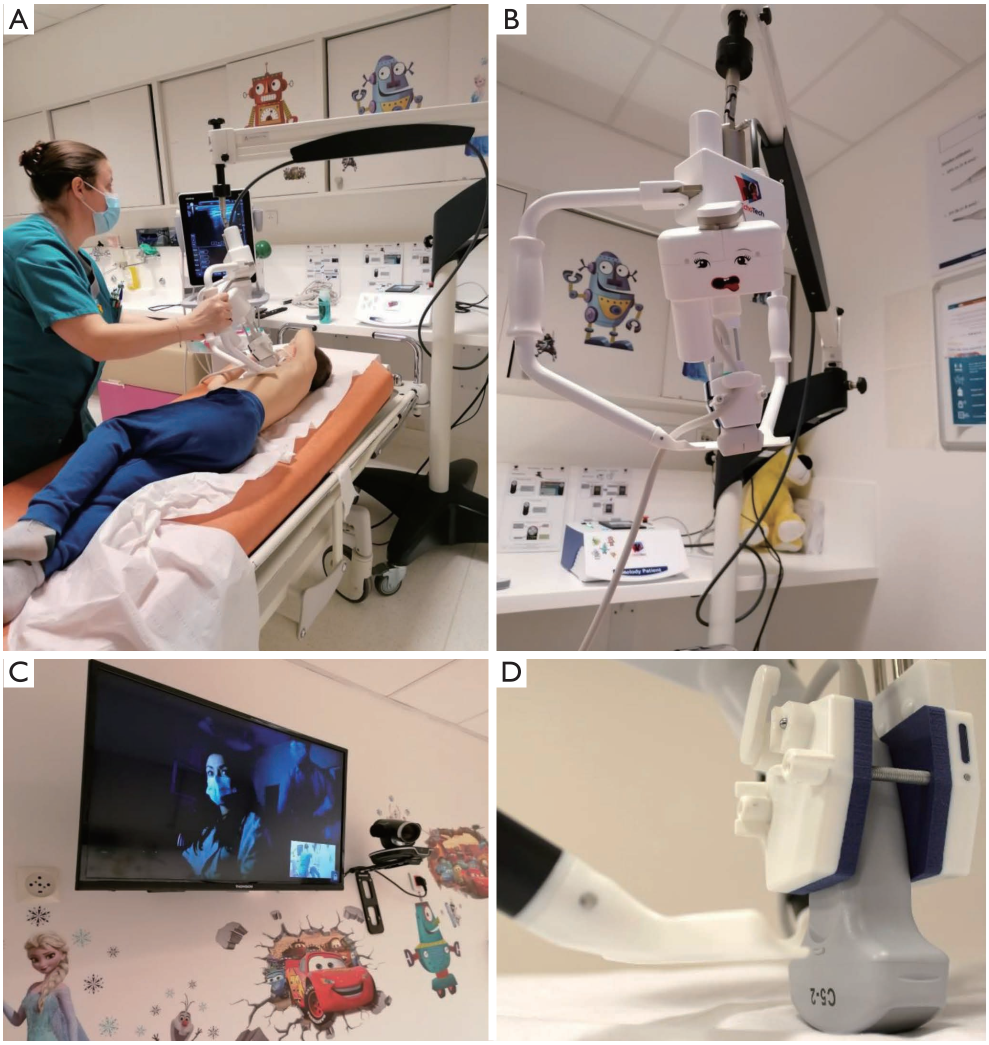

Figure 2 Adaptation of the MELODY system for children. To facilitate the acceptability of the device by children, the patient assistants were pediatric caregivers with specific skills in using the MELODY system with children (A). The patient site was redesigned with wall stickers for children (B,C). To reduce the system pressure on the child's chest, a soft material was added under the base of the robot (A) and a new protocol for fixing the probe was implemented (D).

(pediatricians). Among expert sonographers, 1 expert in lung US performed the 10 telerobotic examinations, whereas the others performed 5 telerobotic, then 5 conventional examinations.

Examinations were performed carefully according to the recommendations of good clinical practice in radiology, cardiology, and pulmonology (1,13). Three evaluation grids were designed according to the type of examination (cardiac, abdominal and lung). For abdominal US, the following organs/parts of the abdomen were scanned: gallbladder and bile ducts, liver, portal vein, spleen, pancreas, kidneys, and bladder. For cardiac US, apical 4/f5-chamber views were used to obtain images of the heart and vascular structures, measure the right and the left atrium in diastole, measure the left ventricle in systole and diastole with the calculation of ejection fraction, and eventually detect aortic mitral or tricuspid valve leaks, valve remodeling and aortic stenosis by color and pulsed wave Doppler. The image quality was qualitatively scored from 1 (very poor) to 5 (excellent), and a visualization score, expressed as a percentage, was calculated with respect to the reference echocardiogram (12). For lung US, all parts of the lungs were scanned (14). A total lung US (LUS) score was calculated as described (15). Briefly, 6 lung regions of interest, delineated by a parasternal line, anterior axillary line, posterior axillary line, and paravertebral line, were examined on each side. All regions were characterized, and a score based on aeration from normal (0 score) to complete loss of lung aeration (3 scores) was calculated. The LUS score was calculated as the sum of the 12 regional scores.

Images from telerobotic and conventional examinations were analyzed independently from by a single board-certified clinical practitioner (for lung US) and radiologist (for abdominal US) and cardiologist (for cardiac US), with blinding to the findings of the corresponding examination. A standardized reporting form (Supplementary file) was used to assess whether structures could be sufficiently visualized by both techniques.

Patient assessment

After completion of both telerobotic and conventional scans, the child's parents completed a survey based on that of Adams *et al.* (11) regarding their experience with the telerobotic examination. Participants were asked to indicate their agreement with the following 4 statements by using a 5-point Likert scale: (I) if my child had to have another ultrasound procedure, I would agree that it should be done with the telerobotic system; (II) I felt comfortable communicating with the sonographer remotely using the video conferencing system; (III) I felt comfortable knowing that someone in another room was controlling the ultrasound probe; (IV) I felt that my child had less pressure on the abdomen/thorax during the robotic ultrasound than during the conventional ultrasound.

Sonographer and patient site assistant assessment

Similarly, after each telerobotic examination, sonographers were asked to indicate their agreement with the following statements by using a 5-point Likert scale: (I) the audio was of sufficient quality to allow me to communicate properly with the patient site assistant; (II) the patient site assistant and I were able to communicate effectively in relation to the probe or patient positioning; (III) handling the remote ultrasound probe resulted in less physical strain than scanning a similar patient using conventional ultrasound. Patient site assistants indicated their level of agreement with the following statements: (I) the audio was of sufficient quality to allow me to communicate properly with the sonographer; (II) the sonographer and I were able to communicate effectively in relation to the probe or patient positioning; (III) holding the MELODY system caused moderate to severe physical strain (e.g., I felt tired or sore while holding the MELODY system) (11).

Ethics

The experimental protocol was reviewed and approved by the French National Agency for Medicines and Health Products Safety (ANSM, 2020-A03185-34) and French Ethics Committee (CCP, 2020-100 B). Informed consent for the study was obtained from all patients' parents or legal guardians, and this study was conducted in accordance with the Declaration of Helsinki (as revised in 2013).

Statistical methods

We used GraphPad Prism 8 (GraphPad Software, La Jolla, CA, USA) for statistical analysis. Data are presented with descriptive statistics, including means [standard deviation (SD)] and mean differences for continuous variables and frequencies (%) for categorical variables. Measurements of structures from conventional and telerobotic examinations were compared by Wilcoxon test, with agreement assessed by the kappa (κ) coefficient. $P<0.05$ was considered statistically significant.

Results

Clinical features

A total of 80 examinations were performed, including 20 cardiac, 20 lung and 40 abdominal examinations (*Figure 3*). One patient was excluded because of agitation (fear of the telerobotic installation) and another because of withdrawal of parents' consent after inclusion. Ultimately, 76 scans could be analyzed. The mean (SD) age of participants was 5.7 (2.7) years (range, 1–10 years); 5 (13%) participants were infants (1–2 years old), 12 (32%) toddlers (3–5 years old) and 21 (55%) children (6–10 years old).

Agreement between conventional and telerobotic operators

For the 76 scans analyzed, interobserver correlation showed substantial agreement between telerobotic and conventional US [κ=0.74 (95% CI: 0.53–0.94), $P<0.005$]. Interobserver agreement could not be assessed separately for abdominal, cardiac and lung US because of the small number of examinations performed in each category.

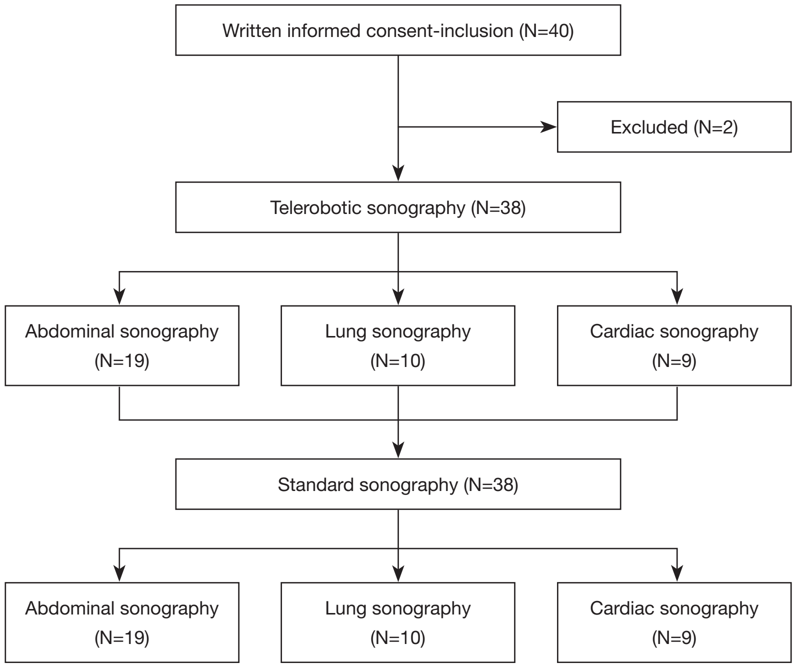

Figure 3 Flow chart of the participants in the study.

Imaging findings

The imaging findings are summarized in *Table 1*. Abdominal organs and abnormalities were similarly visualized on telerobotic and conventional US except for the spleen and pancreas (95% and 79% for telerobotic and conventional US, respectively). The "Mickey mouse" sign was not identified in 3 cases with the telerobotic system as compared with 2 with conventional US. Two pathological findings (increased kidney size) were identified on abdominal US regardless of the system used.

On lung analysis, both techniques identified consolidations and pleural effusion in 6 cases. Visualization and total lung score, calculated as described (15), were similar with telerobotic and conventional US.

Cardiac echocardiography provided reliable diagnoses and non-significantly different measurements with both techniques, although the visualization scores were significantly higher with telerobotic than conventional US ($P<0.05$). However, despite no major missing diagnoses reported with the 2 techniques, atrial septal defect and patent foramen oval were seen with only telerobotic US in one patient.

Patient assessment

Telerobotic US was mostly well accepted (*Table 2*). Most participants agreed that they felt comfortable communicating with the remote sonographer using the videoconferencing system. They were also not affected by the knowledge that another person in a different location (expert site) was controlling the ultrasound probe. Overall, 45% of parents reported that their children felt less pressure with the telerobotic than conventional system. Two patients experienced pain during telerobotic examination. No severe adverse event was reported.

Sonographer and patient site assistant assessment

The mean (SD) duration for telerobotic examination was 26.0 (12.5) min (range, 18–30 min), longer than conventional examination [13.9 (11.2) min (range, 9–15 min), $P<0.0001$]. The audio quality with the videoconferencing system was sufficient to allow sonographers and patient site assistants to communicate regarding patient positioning and placement of the robotic probe holder (*Table 2*). Posters with representations of the different positions of the probe for abdominal, cardiac and lung US designed by the expert sonographers were a great help for the patient site assistants.

Most of the sonographers were not fully convinced that manipulating the mock transducer was less constraining than the conventional system. However, many (57%)

Table 1 Comparison of image assessment by telerobotic and conventional US

Visualization of organs and abnormalities	Telerobotic US (N=38)	Conventional US (N=38)	P value
Abdominal US	N=19	N=19	
Gall bladder, n [%]	19 [100]	19 [100]	1.0000
Biliary tract, bile/hepatic duct, n [%]	19 [100]	18 [95]	1.0000
"Mickey mouse" sign, n [%]	16 [84]	17 [89]	0.5637
Lung, n [%]	19 [100]	19 [100]	1.0000
Kidney, n [%]	19 [100]	19 [100]	1.0000
Spleen, n [%]	18 [95]	18 [95]	1.0000
Pancreas, n [%]	15 [79]	15 [79]	1.0000
Abnormality detected, n [%]	2 [20]	2 [20]	1.0000
Type of abnormality	Abnormal kidney size	Abnormal kidney size	–
Duration (min), mean (SD)	26.0 (15.7)	15 (15.5)	0.0393
Lung US	N=10	N=10	
Consolidation, n [%]	6 [60]	6 [60]	1.0000
Depth (cm), mean (SD)	1.2 (0.4)	1.5 (0.6)	0.3356
Extent (intercostal spaces), mean (SD)	2.2 (1.2)	2.3 (1.1)	0.6109
Pleural effusion, n [%]	6 [60]	6 [60]	1.0000
Total lung score, mean (SD)	8.3 (8.3)	8.8 (8.6)	0.7465
Visualization score, mean (SD)	54.6 (5.7)	57.5 (3.9)	0.2421
Duration (min), mean (SD)	31.7 (6.6)	13.8 (4.0)	0.0020
Cardiac US	N=9	N=9	
Measurements, mean (SD)			
LA	19.9 (6.3)	24.1 (5.6)	0.1168
Aorta	18.4 (4.4)	18.4 (4.2)	0.7699
LVDD	35.2 (5.6)	36.1 (6.4)	0.3209
LVSD	20.1 (5.3)	22.1 (4.2)	0.0167
SF	46.2 (11.5)	41 (13.3)	0.0004
LVEF	71.3 (15.1)	68.6 (6.2)	0.5540
IVST	6.2 (1.5)	8.9 (9.9)	0.4473
PWT	5.8 (1.2)	8.1 (10.1)	0.5561
Abnormality detected, n [%]	2 [22]	0 [0]	0.0339
Type of abnormality	Atrial septal defect; patent foramen oval	–	
Visualization score, mean (SD)	18.9 (3.6)	23.1 (10.5)	0.0117
Duration (min), mean (SD)	19.7 (5.9)	11.7 (3.6)	0.0078

US, ultrasound scan; SD, standard deviation; LA, left atrium; LVDD, left ventricular tele diastolic diameter; LVSD, left ventricular tele systolic diameter; SF, shortening fraction; LVEF, left ventricular ejection fraction; IVST, interventricular septum thickness; PWT, posterior wall thickness. The Wilcoxon test was used to evaluate differences between the 2 techniques.

Table 2 Survey responses from parents, sonographers, and site assistants after telerobotic US

Item	Strongly agree	Agree	Neither disagree nor agree	Disagree	Strongly disagree
Parents					
If my child had to have another ultrasound procedure, I would agree that it should be done with the telerobotic system	23 [61]	10 [26]	3 [8]	1 [3]	0 [0]
I felt comfortable communicating with the sonographer remotely using the video conferencing system	31 [82]	5 [13]	0 [0]	1 [3]	1 [3]
I felt comfortable knowing that someone in another room was controlling the ultrasound probe	28 [74]	7 [18]	0 [0]	2 [5]	0 [0]
I felt that my child had less pressure on the abdomen/thorax during the robotic ultrasound than during the conventional ultrasound	8 [21]	9 [24]	14 [37]	5 [13]	1 [3]
Sonographers					
The audio was of sufficient quality to allow me to communicate properly with the patient site assistant.	34 [90]	3 [8]	1 [3]	0 [0]	0 [0]
The patient site assistant and I were able to communicate effectively in relation to probe or patient positioning	31 [82]	3 [8]	2 [5]	2 [5]	0 [0]
Handling the remote ultrasound probe resulted in less physical strain than scanning a similar patient using conventional ultrasound	1 [3]	2 [5]	22 [58]	10 [26]	3 [8]
Patient site assistants					
The audio was of sufficient quality to allow me to communicate properly with the sonographer.	37 [97]	0 [0]	1 [3]	0 [0]	0 [0]
The sonographer and I were able to communicate effectively in relation to the probe or patient positioning.	38 [100]	0 [0]	0 [0]	0 [0]	0 [0]
Holding the MELODY system caused moderate to severe physical strain (e.g., I felt tired or sore while holding the MELODY system)	2 [5]	4 [11]	10 [26]	15 [39]	7 [18]

Data are n [%]. US, ultrasound scan.

patient site assistants did not report pain while manipulating the MELODY system (*Table 2*).

Discussion

In the present study, we show that with some technical adjustments, together with a customization of the robot, telerobotic US was feasible in children >1 year old for at least 3 main US sites (lung, heart, and abdomen). As for adults (10-12), for children, the remote system gave similar results and diagnosis as conventional US and was well accepted and tolerated by children.

Although the present study was the first to involve children, 3 original studies have assessed the feasibility of the MELODY telerobotic system and compared it to conventional US (one for prenatal and 2 others for adult cardiac and abdominal examinations) (9-12) The first study examined the feasibility of a telerobotic approach for performing remote prenatal sonographic scans in 30 participants. It found excellent agreement (>90%) in the measurements, with 80% of fetal structures visualized by the telerobotic system. Overall, 97% of patients agreed that the robotic system should be used again for another US procedure if necessary (10). In the second study, US was performed in 41 cardiac patients. Overall, the quality of views was better with conventional than telerobotic cardiac US, but the measurements were similar in 93% to 100% of cases. As in the first study, the authors found no statistically significant difference between the performance of the 2 techniques. Indeed, most of the valve leaks or aortic stenoses (86%) were detected by the telerobotic system, and no false positive diagnoses were reported (12). The third study sought to assess the feasibility of abdominal US using the MELODY system in 18 patients. Again, despite a few under- or overestimated measurement points, the visualization of the organs was similar for both telerobotic and conventional techniques. Similarly, the patients were ready and willing to undergo such an examination if necessary (11). As for these 3 previous studies, we demonstrated substantial agreement between telerobotic and conventional US in children for abdominal, cardiac, and also lung US (which for the latter was not previously studied in adults). We also showed that telerobotic US was as efficient as conventional US to visualize organs and measure and detect abnormalities. However, similar to adult studies (10), for children, some lesions unequivocally identified by the telerobotic system were not identified by conventional US, which emphasizes the importance of the sonographer's experience.

One of the main issues in remote US procedures is communication between the physician and the patient but also between the robot and the physician. The physician must be able to have the same physical perception as if he/she were in direct contact with the patient. To ensure this, the physician should use equipment with a high degree of accuracy and, particularly for children, a high level of safety (16,17). Here we show that the child MELODY system provided sufficient quality to allow children, parents and sonographers to adequately communicate together with high-quality image feedback to the remote operator.

Comparably to adult studies, children's acceptability of the telerobotic remote system was good. The robot could have frightened the children, resulting in difficulties performing the examination. However, except for one child, this was not the case in our study. Among the reasons for this good acceptance, the decoration of the room and the robot but also the training of the assistant in care of the child are important aspects to consider for routine use.

The duration of examinations was longer for the telerobotic than conventional US. This discrepancy is likely due to the lack of experience of expert sonographers in handling the telerobotic ultrasound system. Because the use of the MELODY system was not in routine use for children (one of the main reasons for this pilot study), not all the experts had sufficient time to get used to the equipment and familiarize themselves with the tool. However, similar to adult studies (10), some lesions identified by the telerobotic system were surprisingly not detected by conventional US, which emphasizes the importance of the sonographer's experience.

Except for thoracic US, the average time to perform telerobotic US was <30 min. This duration is higher than the time required for conventional lung US for the medical staff but remained shorter for patients who do not have to travel far. Indeed, the telerobotic system can provide access to US expertise where not available and therefore limit the transfer of patients to another center for these examinations.

The application of lung US has expanded to the pediatric population and now provides accurate, reliable, and easily recognizable results for the diagnosis and monitoring of respiratory disease (13,18). In the context of the COVID-19 pandemic, telerobotic systems were proposed for the screening or diagnosis of pneumonia in SARS-CoV-2 infection in adults (19). Here we show that lung US can be performed remotely in children and thus provide safe access to lung US expertise in a resource-limited environment.

The massive SARS-CoV-2 pandemic has highlighted the importance of developing telemedicine solutions and the need for advanced teleoperated equipment. Indeed, a simple but effective medical procedure may significantly improve patients' care in difficult environments, far from the patient's location or when expertise is missing. The cost of the telerobotic ultrasound system used in the present study is comparable to a high-end ultrasound system. The complete telemedicine system integrates a "mid-range" ultrasound scanner that has been optimized for remote US. Further studies are required to determine the cost-effectiveness of remote sonography. They should consider the increased time and human resources associated with the technique balanced with the possibility of minimizing the number of patient transports to larger and/or expert centers but also the ability to provide abdominal, cardiac or lung imaging expertise for children, which are particularly lacking in smaller hospitals independent of the COVID-19 pandemic. Another consideration is the inclusion of remote sonography in fee schedules, recognizing the additional resources that telerobotic US currently involves. However, this requires the establishment of agreements between hospitals that might not be easily adopted in every healthcare system. A recent economic evaluation of Canadian adults compared US service delivery models: the cost of telerobotic US was significantly reduced as compared with travelling to another community for all examinations (20).

There are several limitations related to the inherent study design. First, the small number of patients per ultrasound procedure combined with the loss of 2 patients (4 examinations) did not allow for detailed interobserver agreement. Second, the telerobotic US system always preceded conventional US, but the telerobotic sonographers were not aware of the results of the conventional US performed by a different sonographer. Third, there were always 2 different operators for the same patient (telerobotic and conventional US). It was crucial that the operators not be the same to avoid bias in the interpretation. Besides, the experts performed both conventional and remote US with homogeneous results. Finally, we limited the study to children over age 1 year, thus excluding neonates and preterm babies who may benefit from this new technique. Necessary adjustments such as placing a soft material under the base of the robot in contact with the child should be performed before using MELODY remote system in infants under 4 kg and warrant further studies. Further studies are needed. They should focus on only one type of US (abdominal, cardiac or lung) in different ages, including infants and newborns. Different service delivery models should be assessed: telerobotic US with or without an itinerant sonographer and compared to examination by an itinerant sonographer without telerobotic US and travel to another community for all examinations.

Conclusions

We show that telerobotic US is feasible, gives similar results as conventional US and is well tolerated in children over age 1 year for assessing lung, cardiac and abdominal abnormalities. As for adults, for children, this technique may be promising to provide access to diagnostic US services in rural and remote communities with lack of access to healthcare services, thereby reducing disparities and improving equal access to care.

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Footnote

Reporting Checklist: The authors have completed the TREND reporting checklist. Available at https://tp.amegroups.com/article/view/10.21037/tp-22-569/rc

Data Sharing Statement: Available at https://tp.amegroups.com/article/view/10.21037/tp-22-569/dss

Conflicts of Interest: All authors have completed the ICMJE uniform disclosure form (available at https://tp.amegroups.com/article/view/10.21037/tp-22-569/coif). The authors have no conflicts of interest to declare.

Ethical Statement: The authors are accountable for all aspects of the work in ensuring that questions related to the accuracy or integrity of any part of the work are appropriately investigated and resolved. The experimental protocol was reviewed and approved by the French National Agency for Medicines and Health Products Safety (ANSM, 2020-A03185-34) and French Ethics Committee (CCP, 2020-100 B). Informed consent for the study was obtained from all patients' parents or legal guardians, and this study was conducted in accordance with the Declaration of Helsinki (as revised in 2013).

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Supplementary

Supplementary appendix: standardized reporting form for abdominal, cardiac and lung analysis

Identification	
Numéro patient	
Initiales du patient	|__| Nom |__| Prénom
Date de naissance (jj/mm/aaaa)	|__|__| / |__|__| / |__|__|__|__|
Date de l'examen	|__|__| / |__|__| / |__|__|__|__|
Heure de début de l'échographie	|__|__| h |__|__| min
Type d'échographie	☐ Classique ☐ Télé-échographie
Indication	
Nom du médecin	

Vésicule biliaire et voies biliaires		
1. Aspect	☐ Normal ☐ Calculs biliaires	☐ Epaississement des parois ☐ Sludge
2. Visualisation de la voie biliaire principale, et des canaux hépatiques	☐ Oui	☐ Non
Foie		
3. Morphologie	☐ Normale	☐ Dysmorphie
4. Parenchyme homogène	☐ Oui	☐ Non
5. Parenchyme hétérogène	☐ Oui	☐ Non
6. Hyperéchogène	☐ Oui	☐ Non
7. Hypoéchogène	☐ Oui	☐ Non
8. Echogénicité normale	☐ Oui	☐ Non
9. Lésion focale	☐ Oui	☐ Non
10. Dimension crânio-caudale du foie droit (longueur du foie) sur la coupe foie-rein	|__|__|__| mm	+/– |__|__| DS
11. Dimension crânio-caudale du foie gauche sur la coupe VSHG	|__|__|__| mm	+/– |__|__| DS
Coupes axiales:		
12. VSH au confluent cave	☐ Vu	☐ Non vu
13. bifurcation porte	☐ Vu	☐ Non vu
14. coupe «Mickey Mouse»	☐ Vu	☐ Non vu
15. vésicule biliaire	☐ Vu	☐ Non vu
Coupes longitudinales:		
16. foie gauche	☐ Vu	☐ Non vu
17. vésicule biliaire	☐ Vu	☐ Non vu
18. tronc porte	☐ Vu	☐ Non vu
19. foie/rein	☐ Vu	☐ Non vu

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Veine portale		
20. Visualisation de la veine portale dans l'axe longitudinal de la veine splénomésentérique	□ Oui	□ Non
Rate		
21. Aspect	□ Normal	□ Anormal
22. Taille du grand axe (longueur)	|__|__|__| mm	+/− |__|__| DS
Pancréas		
23. Aspect	□ Normal	□ Anormal
Reins		
24. Aspect	□ Normal	□ Anormal
25. Longueur rein droit	|__|__|__| mm	+/− |__|__| DS
26. Longueur rein gauche	|__|__|__| mm	+/− |__|__| DS
27. Diamètre antéro-postérieur du pyélon droit	|__|__|__| mm	
28. Diamètre antéro-postérieur du pyélon gauche	|__|__|__| mm	
29. Epaississement paroi pyélique	□ Oui	□ Non
30. Dilatation urétérale	□ Oui	□ Non
31. Différenciation cortico-médullaire bien visualisée	□ Oui	□ Non
Vessie		
32. Aspect	□ Normal	□ Anormal
33. Sédiments urinaires	□ Oui	□ Non
Autre		
34. Appendicite	□ Oui	□ Non
35. Si oui diamètre	|__|__| mm	
36. Invagination intestinale iléo-caecale	□ Oui	□ Non
36.1. Si oui diamètre	|__|__|__| mm	
37. Invagination intestinale iléo-iléale	□ Oui	□ Non
37.1. Si oui diamètre	|__|__|__| mm	
38. Epanchement intra-abdominal	□ Oui	□ Non

Fin d'examen	
39. Heure de fin de l'échographie	|__|__| h |__|__| min
40. Examen normal	□ Oui □ Non
40.1. Si non, quelles sont les anomalies	
41. Score de visualisation globale	□ 1 □ 2 □ 3 □ 4 □ 5

Score:
1: visualisation très faible; 2: visualisation faible; 3: visualisation moyenne; 4: visualisation bonne;
5: visualisation très bonne

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Si télé-échographie, merci de compléter les informations suivantes:	
42. Problèmes de connexion internet durant l'examen	◻ Oui ◻ Non
42.1. Si oui, décrire	
43. Difficultés pour positionner l'arceau pendant l'examen	◻ Oui ◻ Non
43.1. Si oui, ces difficultés sont-elles liées à:	◻ Dimension de l'arceau non adaptée ◻ Bras robotisé pas suffisamment maniable ◻ Autre
44. Difficultés à réaliser l'examen à cause de l'agitation de l'enfant	◻ Oui ◻ Non
45. Autres difficultés rencontrées pendant l'examen	

Mesures en Temps Mouvement ParaSternal Grand Axe			
1. Oreillette gauche	|__|__| mm	◻ NF	
2. Aorte	|__|__| mm	◻ NF	
Fonction Ventricule gauche ParaSternal Grand Axe			
3. DTDVG : diamètre télédiastolique du ventricule gauche	|__|__| mm	◻ NF	
4. DTSVG : diamètre télésystolique du ventricule gauche	|__|__| mm	◻ NF	
5. FR : fraction de raccourcissement	|__|__| %	◻ NF	
6. FE VG : fraction d'éjection du ventricule gauche Teicholz	|__|__| %	◻ NF	
7. SIV d : épaisseur du septum interventriculaire diastolique	|__|__| mm	◻ NF	
8. PP d : épaisseur de la paroi postérieure diastolique	|__|__| mm	◻ NF	
Fonction Ventricule droit			
9. DTDVD (ParaSternal Grand Axe): diamètre télédiastolique du ventricule droit	|__|__| mm	◻ NF	
10. TAPSE	|__|__| mm	◻ NF	
Valve aortique			
11. Tricuspide	◻ Oui	◻ Non	◻ NF
12. Diamètre coronaire gauche TCG	|__|__| mm	◻ NF	
13. Diamètre coronaire droite	|__|__| mm	◻ NF	
14. Doppler pulsé chambre de chasse, vitesse maximale	|__|,|__| m/s	◻ NF	
15. Fuite aortique	◻ Oui	◻ Non	◻ NF
16. Sténose aortique	◻ Oui	◻ Non	◻ NF
Aorte ascendante			
17. Anneau aortique	|__|__| mm	◻ NF	
18. Sinus de Valsalva	|__|__| mm	◻ NF	
19. Jonction sinotubulaire	|__|__| mm	◻ NF	
20. Portion tubulaire ascendante	|__|__| mm	◻ NF	

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Valve pulmonaire			
21. Anneau pulmonaire	|__|__| mm	□ NF	
22. Doppler pulsé valve pulmonaire, vitesse maximale	|__|,|__| m/s	□ NF	
23. Sténose	□ Oui	□ Non	□ NF
24. Fuite pulmonaire, vitesse maximale protodiastole	|__|,|__| m/s	□ NF	
25. Fuite pulmonaire, PAPm	|__|__| mmHg	□ NF	
26. Tronc et bifurcation	□ Normal	□ Anormal	□ NF
Valve mitrale			
27. Morphologie 2 piliers dans le ventricule gauche	□ Normal	□ Anormal	□ NF
28. Fuite mitrale	□ Oui	□ Non	□ NF
29. Sténose mitrale	□ Oui	□ Non	□ NF
30. Doppler mitral E/A	E/A = |__|,|__|	□ NF	
31. Doppler tissulaire mitral E/Ea	E/Ea = |__|,|__|	□ NF	
Valve tricuspide			
32. Morphologie	□ Normal	□ Anormal	□ NF
33. IT fuite tricuspide, vitesse maximale	|__|,|__| m/s	□ NF	
34. Grade IT (1-4)	|__|	□ NF	
35. PVDS	|__|__| mmHg	□ NF	
Crosse aortique D/G			
36. Crosse aortique	□ Gauche	□ Droite	□ NF
37. Doppler continu sur l'isthme aortique	□ Normal	□ Anormal	□ NF
Shunt intracardiaque			
38. Existence d'un shunt	□ Oui	□ Non	□ NF
38.1. Si oui, de quel type	□ Communication interventriculaire (CIV) □ Communication interauriculaire (CIA) □ Canal artériel (CA) □ Autre	 □ NF	
38.1.1. Si autre, lequel ?	□ NF		
39. Vélocité doppler continu du shunt	|__|,|__| m/s		
Autre			
40. Retour veineux systémique	□ Normal	□ Anormal	□ NF
41. VCSG	□ Oui	□ Non	□ NF
42. Retour veineux pulmonaire	□ Normal	□ Anormal	□ NF
43. Epanchement péricardique	□ Oui	□ Non	□ NF
44. Rythme	□ Normal	□ Anormal	□ NF
45. Autres			

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Qualité des images	
46. Parasternale grand axe	□ 1 □ 2 □ 3 □ 4 □ 5
47. Parasternale petit axe	□ 1 □ 2 □ 3 □ 4 □ 5
48. Sous-costale	□ 1 □ 2 □ 3 □ 4 □ 5
49. Suprasternale	□ 1 □ 2 □ 3 □ 4 □ 5
50. Apicale 4/5 cavités	□ 1 □ 2 □ 3 □ 4 □ 5

Score:
1: visualisation très faible; 2: visualisation faible; 3: visualisation moyenne; 4: visualisation bonne;
5: visualisation très bonne

Fin d’examen	
51. Heure de fin de l’échographie	|__|__| h |__|__| min □ NF
52. Examen normal	□ Oui □ Non □ NF

Si télé-échographie, merci de compléter les informations suivantes:	
53. Problèmes de connexion internet durant l’examen	□ Oui □ Non □ NF
53.1. Si oui, décrire	□ NF
54. Difficultés pour positionner l’arceau pendant l’examen	□ Oui □ Non □ NF
54.1. Si oui, difficultés liées à	□ Dimension de l’arceau non adaptée □ Bras robotisé pas suffisamment maniable □ Autre □ NF
55. Difficultés à réaliser l’examen à cause de l’agitation de l’enfant	□ Oui □ Non □ NF
56. Autres difficultés rencontrées pendant l’examen	□ NF

Score de visualisation des structures élémentaires (section longitudinale et un ou plusieurs espaces intercostaux)	
57. PSD: postérieur-supérieur droit	□ 1 □ 2 □ 3 □ 4 □ 5
58. PID: postérieur-inférieur droit	□ 1 □ 2 □ 3 □ 4 □ 5
59. PSG: postérieur-supérieur gauche	□ 1 □ 2 □ 3 □ 4 □ 5
60. PIG: postérieur-inférieur gauche	□ 1 □ 2 □ 3 □ 4 □ 5
61. LSD: latéro-supérieur droit	□ 1 □ 2 □ 3 □ 4 □ 5
62. LID: latéro-inférieur droit	□ 1 □ 2 □ 3 □ 4 □ 5
63. ASD: antéro-supérieur droit	□ 1 □ 2 □ 3 □ 4 □ 5
64. AID: antéro-inférieur droit	□ 1 □ 2 □ 3 □ 4 □ 5
65. ASG: antéro-supérieur gauche	□ 1 □ 2 □ 3 □ 4 □ 5
66. AIG: antéro-inférieur gauche	□ 1 □ 2 □ 3 □ 4 □ 5
67. LSG: latéro-supérieur gauche	□ 1 □ 2 □ 3 □ 4 □ 5
68. LIG: latéro-inférieur gauche	□ 1 □ 2 □ 3 □ 4 □ 5

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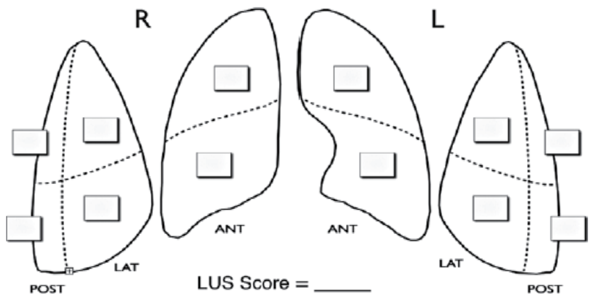
69. Score global de visualisation	|__|__| / 60

1: visualisation très faible; 2: visualisation faible; 3: visualisation moyenne; 4: visualisation bonne;
5: visualisation très bonne

Score pulmonaire total	
70. LUS score = somme des différentes zones (voir schéma ci-dessous)	|__|__| / 36
	**0: Poumon normal** (lignes A, quelques lignes B isolées) **1: Perte modérée d'aération pulmonaire** -multiples lignes B espacées (≥3 lignes B par champ) **2: Perte sévère d'aération pulmonaire** -lignes B confluentes **3: Consolidations**

Consolidation	
71. Présence d'une consolidation	◻ Oui ◻ Non
71.1. Si oui, mesure de la profondeur maximale (distance entre la ligne pleuro-pulmonaire et le début de la zone hyperéchogène postérieure)	|__|__| cm
71.2. Si oui, mesure de l'étendue maximale définie par le nombre d'espaces intercostaux concernés	|__|

Epanchement pleural			
72. Présence d'un épanchement pleural	◻ Oui	◻ Non	
72.1. Si oui, quel côté	◻ Gauche	◻ Droite	
72.2. Si oui, aspect	◻ Anéchogène	◻ Débris Hyperéchogène	◻ Cloisonné
72.3. Mesurer l'épaisseur maximale de l'épanchement (distance entre la plèvre pariétale et le poumon)	|__|__| cm		

Fin d'examen	
73. Heure de fin de l'échographie	|__|__| h |__|__| min
74. Examen normal	◻ Oui ◻ Non
74.1. Si anormal, diagnostic	

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Si télé-échographie, merci de compléter les informations suivantes:	
75. Problèmes de connexion internet durant l'examen	◻ Oui ◻ Non
75.1. Si oui, décrire	
76. Difficultés pour positionner l'arceau pendant l'examen	◻ Oui ◻ Non
76.1. Si oui, difficultés liées à	◻ Dimension de l'arceau non adaptée ◻ Bras robotisé pas suffisamment maniable ◻ Autre
76.1.1. Si autre, quelle(s) difficulté(s)?	
77. Difficultés à réaliser l'examen à cause de l'agitation de l'enfant	◻ Oui ◻ Non
78. Autres difficultés rencontrées pendant l'examen	

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