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Agreement between an Expert in Physiological Interpretation of Cardiotocographs (CTG) and the Tweris Mini CTG Artificial intelligence (AI) App in recognizing and managing different types of fetal hypoxic stress and abnormal CTG patterns

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ABSTRACT

Introduction: Tweris Mini is a visual analysis Artificial Intelligence (AI) application designed to detect different types of fetal hypoxic stress, and common abnormal fetal heart rate patterns on Cardiotocograph (CTG) images. It is based on the classification system recommended by the International Expert Consensus Guidelines on Physiological Interpretation of Cardiotocograph published by over 50 CTG experts from more than 20 countries.

Objective: This study aims to evaluate the degree of agreement between the expert who pioneered the physiological interpretation of Cardiotocograph in 2006, and was on the editorial board of the international expert consensus guidelines, and the Tweris Mini App in classifying different types of fetal hypoxic stress and abnormal Cardiotocograph patterns, along with their proposed management.

Materials & Methods: A total of 100 anonymized CTG traces were randomly selected, representing no hypoxia (NH) and various types of fetal hypoxic stress: chronic (C), gradually evolving compensated (GC), gradually evolving decompensated (GD), subacute (S), and acute (A). Specific abnormal CTG patterns, including atypical sinusoidal (AS), typical sinusoidal (TS), and ZigZag (ZZ) patterns. The expert classified the traces and provided the following management recommendations: continue labour (CO), reduce stress (RS), or expedite birth (EB). Two independent obstetricians used the Tweris Mini App to classify the same CTG traces and the recommended management by the Tweris Mini AI App. The Cohen Kappa was used for statistical analysis to determine the level of agreement.

Results: The overall degree of agreement between the Tweris Mini App and the expert was 94%, with complete (100%) agreement relating to acute hypoxic stress, ZigZag and atypical sinusoidal (Poole Shark Teeth) patterns. The Cohen Kappa statistic for diagnostic agreement was 0.92 (95% CI: 0.83-0.99, $p<.001$). The agreement between the Tweris Mini App and the expert regarding the recommended management reached 98%. The Cohen Kappa statistic for management was 0.96 (95% CI: 0.94-0.98, $p<.001$.

Conclusion: There was excellent agreement (>90%) between the Tweris Mini App and the expert, who pioneered Physiological Interpretation of CTG in both diagnosing different types of fetal hypoxic stress and recommending optimum management. Our findings suggest that the Tweris AI Mini App has a high reliability to be used as diagnosis & decision support tool in clinical practice.

Keywords; cardiotocograph (CTG); physiological CTG interpretation; artificial intelligence (AI); types of hypoxic stress Tweris Mini App (TMA); ZigZag pattern.

Introduction

Cardiotocograph (CTG) is ubiquitously used in obstetric practice to recognise fetal heart rate changes in response to ongoing uterine contractions. If the features of decompensation of fetal central organs are timely recognised on the CTG trace, then, immediate and appropriate actions could be taken to reduce the stress and/or expedite birth to improve perinatal outcomes without increasing unnecessary intrapartum interventions such as emergency caesarean sections and operative vaginal births to the mother. In order to avoid hypoxic-ischaemic encephalopathy (HIE) and its long term sequalae such as cerebral palsy, learning difficulties and / or intrapartum-related perinatal deaths on one hand, and to avoid complications of unnecessary intrapartum operative interventions to the mother, accurate diagnosis of different types of fetal hypoxic stress and abnormal patterns that indicate an underlying pathology is crucial. Unlike other branches in clinical medicine where new technology is only introduced into clinical practice as routine standard of care following rigorous research, very unfortunately, CTG was directly introduced into clinical practice in 1960s without any prior robust scientific research or randomised controlled trials. Lack of sound scientific foundation and knowledge to differentiate features of fetal compensation from decompensation on the CTG trace, opened the doors to confusion, anxiety and over-reaction. The large void of knowledge of fetal physiology leading to iatrogenic anxiety due to the failure to conduct robust research prior to introducing technology was soon filled by the erroneous opinions CTG "experts" in advanced economies. Presumption of knowledge led to the features which were normal physiological cardioprotective reflex responses to reduce fetal myocardial workload (fetal heart rate decelerations) being illogically considered as "reassuring" or "non-reassuring" or "abnormal" based on the apparent morphology or arbitrarily pre-determined time limits. These gross errors were perpetuated by several CTG guidelines, leading to an overall classification of CTG traces into "Normal, Suspicious, Pathological"[1,2] or "Category I, II or III"[3] despite repeated Cochrane Systematic Reviews concluding a significant increase in the rate of caesarean sections and operative vaginal births (vacuum and forceps) without any improvement in perinatal outcomes[4].

False positive rate of traditional "Normal, Suspicious, Pathological" CTG Classifications

It is now well recognised by systematic reviews and metanalysis that randomly grouping different features of the fetal heart rate into pre-defined categories, due to lack of understanding of basic fetal pathophysiology has a high false positive rate of 98%[5], which corroborates the findings of Karin Nelson et al, in 1996 who analysed > 150,000 CTG traces and their resultant perinatal outcomes. They reported that, even in the presence of repetitive late decelerations and reduced baseline fetal heart rate variability, 99.8% of neonates were born with normal umbilical cord pH[6]. Therefore, contemporary scientific evidence suggests that performing unnecessary operative interventions due to "obstetrician's distress" following the observation of "concerning" CTG patterns are totally unnecessary as these "concerning features" are not associated with neonatal metabolic acidosis in > 99.8% of cases. This may explain the exponential increase in the rate of caesarean sections since the introduction of CTG into routine clinical practice in 1968 without any concomitant reduction in the rates of cerebral palsy or perinatal deaths[7].

Fallacies of morphology of fetal heart rate (FHR) decelerations

National and International Guidelines which have been erroneously advising frontline midwives, obstetricians and nurses to illogically focus on the morphology of fetal heart rate decelerations, and to classify them into "early, variable, late, typical, atypical, complicated, uncomplicated, reassuring, non-reassuring' had failed to appreciate the inherent flaws of relying on pattern recognition. It should have been obvious to those who produced these guidelines that focussing on pattern recognition of isolated FHR changes to classify CTG traces into "Normal, Suspicious, Pathological" without incorporating the knowledge of fetal pathophysiology, to differentiate features suggestive of compensatory stress response from the onset of decompensation would lead to human errors in both classification and management resulting in poor maternal and perinatal outcomes.

Poor inter and intra-observer agreements with traditional ("Normal, Suspicious, Pathological") classification systems.

It is not surprising that several scientific publications have highlighted both inter and intra-observer disagreements in recognition of fetal heart rate changes, especially morphology of decelerations, with the range of agreements between very poor to modest (Kappa 0.3-.0.6)[8-13]. It is obvious that if frontline clinicians do not agree on the observed patterns, this will lead to a different classification resulting in variation in their interventions and outcomes. It was erroneously presumed that the variation in outcomes and increasing unnecessary emergency caesarean sections were due to the lack of knowledge and skills of frontline clinicians to recognise CTG patterns. However, scientific evidence has illustrated that even the presumed "CTG experts" and those who had assumed themselves as "experts" in CTG interpretation, including those appeared as expert witnesses in courts to provide medico-legal opinions due to such presumed expertise on CTG interpretation experienced the same pitfalls of pattern recognition[14-,16]. In fact, these presumed experts, changed their own CTG classification they had provided earlier, once the knowledge of neonatal outcomes were revealed to them[16]. This illustrates the simple fact that reliance on clinicians with presumed expertise on CTG interpretation without the knowledge of fetal pathophysiology but have the benefit of the hindsight to provide medico-legal opinions, may lead to injustice to both the parents of the damaged or deceased children and frontline clinicians[17-19].

It is not surprising that the effectiveness of electronic fetal heart rate monitoring has been recently questioned by some authors[20-22]. However, it appears that many authors have failed to appreciate that the CTG technology per se has no problems, but its introduction into clinical practice without robust scientific evidence, and perpetuation of historical errors by some CTG Guidelines which focus on the morphology of fetal heart rate decelerations, without incorporating the knowledge of fetal pathophysiology, is the underlying "root cause" of the perceived ineffectiveness of electronic fetal heart rate monitoring[17-19].

Therefore, there is an urgent need to move away from focussing on the morphology of decelerations, and on classifying individual CTG features in isolation to avoid the flaws of pattern recognition to reduce the inter and intra-observer disagreements and the resultant variation in management.

Physiological Interpretation of CTG: a new concept in 2006, born out of a crisis

Physiological interpretation of CTG involves application of the knowledge of fetal pathophysiology whilst interpreting CTG traces and classifying CTG traces based on the features of suggestive of different types of hypoxic stress and recognising features of non-hypoxic causes of fetal compromise, and differentiating features of fetal compensation from decompensation[23-25]. This was in response to an intrapartum fetal monitoring crisis at a a leading teaching hospital in London, UK where several babies had sustained hypoxic-ischaemic encephalopathy (CTG) due to the use of "normal, suspicious, pathological" classification system and resultant CTG misinterpretation[23]. One of the authors (EC) was appointed as the labour ward lead consultant in 2005 following this iatrogenic intrapartum fiasco to help train the staff on the basics of CTG interpretation and to help improve perinatal outcomes[23]. A subsequent publication by the team from this hospital had admitted that lack of knowledge and lack of training contributed 13 out of 14 babies who had sustained a severe hypoxic-ischaemic encephalopathy (HIE)[26,27]. Therefore, out of this crisis, the concept of physiological interpretation of the CTG, was born in 2006 to prevent avoidable hypoxic-ischaemic encephalopathy (HIE) and its long term sequalae such as cerebral palsy and learning difficulties and perinatal deaths as well as to reduce unnecessary intrapartum operative interventions. There have been several publications since its inception to confirm the proof of concept[28-63.] Hospitals which had implemented the concepts of physiological interpretation of CTG had shown approximately a 50% reduction in the rate of HIE and emergency caesarean sections after the introduction of physiological interpretation of CTG[32,43,35,54]. More than 150 Physiological CTG Masterclasses were conducted in over 20 countries from 2006 to 2025 to disseminate knowledge and to prevent avoidable harm to mothers and babies. The first International Expert Consensus Guidelines on Physiological Interpretation of CTG was published in 2018[64], which was revised in 2024 in response to emerging scientific evidence[65].

Tweris CTG Mini App (AI): A decision and management Support Tool

There have been several attempts to incorporate artificial intelligence (AI) solutions in clinical medicine, especially in areas which involve pattern recognition such as radiology and histopathology. CTG interpretation also involves pattern recognition and therefore, teams from France, UK, Serbia and Germany collaborated to develop the Tweris CTG AI Mini App (named after Toueris, a protective goddess of childbirth and fertility in Ancient Egyptian Religion). The aim was twofold: to protect the inherited intelligent potential of human fetuses from CTG misinterpretation and to protect their mothers from unnecessary intrapartum operative interventions due to overaction to CTG patterns as a result of lack of knowledge (https://tweris.com/our-solution/).Tweris Mini CTG AI App is based on the classification recommended by the latest international expert consensus statement on physiological interpretation of CTG[65], and the Tweris CTG AI Mini App (TMA) is being continuously upgraded based on submission of data from clinicians and several hospitals from in Europe, Asia, China, and the Middle East to continuously improve its accuracy. Recent publication has suggested a significant improvement in inter-observer agreement as compared to traditional classification systems[66].

Objective

Our objective was to evaluate the degree of agreement between the expert who pioneered the physiological interpretation of CTG in 2006, and was on the editorial board of the international expert consensus guidelines, and the Tweris Mini CTG AI App in classifying different types of fetal hypoxic stress and abnormal CTG patterns, along with their proposed management.

Materials & Methods

ALGORITHM DEVELOPMENT

The dataset comprises CTG photos classified by 2 experts in physiological CTG analysis into 9 different categories including no hypoxia (NH), various types of fetal hypoxic stress: chronic (C), gradually evolving compensated (GC), gradually evolving decompensated (GD), subacute (S), and acute (A), and specific abnormal CTG patterns, including atypical sinusoidal (AS), typical sinusoidal (TS), and ZigZag (ZZ) patterns.

The dataset contains a total of 5724 images, with 2061 images representing NH and 3663 images representing the other conditions.

To classify fetal heart rate (FHR) conditions based on Cardiotocography (CTG) images, we developed a Convolutional Recurrent Neural Network (CRNN) model designed to extract both spatial and temporal features. The images were resized to 448x224 pixels, pre-processed through adaptive thresholding, background normalization, and standard augmentation techniques to enhance robustness. The model architecture integrates stacked convolutional layers with batch normalization and max-pooling, followed by three bidirectional LSTM layers to capture sequential dependencies. A series of fully connected layers concludes the model, with softmax output for multi-class classification across nine FHR conditions. The model was trained using 5-fold cross-validation, with weighted categorical crossentropy loss to address class imbalance. Optimization was performed using the Adam optimizer (learning rate = 0.0001), and dropout regularization was applied to mitigate overfitting. Training was conducted on an NVIDIA GeForce RTX 2070 GPU using CUDA acceleration.

For each prediction made, the model provided a recommendation for appropriate clinical management, based on the International Expert Consensus Guidelines on Physiological CTG Interpretation.

A total of 100 anonymized CTG trace segments, each lasting 15 to 20 minutes, were randomly selected and compiled into a new set of images, distinct from those used to train the algorithm. The classification table recommended by the latest International Expert Consensus Guidelines on Physiological Interpretation of CTG produced by > 50 CTG Experts from > 20 countries in October 2024[65] was used in the study. The expert, who pioneered Physiological Interpretation of CTG in 2006 classified the traces using the above guideline and also provided the following management recommendations: continue labour (CO), reduce stress (RS), or expedite birth (EB). This expert was a member of the CTG Guideline produced by the International Federation of Gynecology and Obstetrics (FIGO) in 2015, and International Expert Consensus Guidelines on Physiological Interpretation of CTG in 2018 and 2024. He was a course co-ordinator of the Intrapartum Fetal Surveillance Course of the Royal College of Obstetricians & Gynaecologists (RCOG) from 2014 to 2019, and he has conducted over 100 physiolgical CTG Masterclasses in over 20 countries. Moreover, he has authored four textbooks, and edited two textbooks on Physiological Interpretation of CTGs. Two independent obstetricians (MG & NK) used the Tweris Mini CTG AI App to classify the same CTG traces and the recommended management by the Tweris Mini CTG AI App. The Cohen Kappa was used for statistical analysis to determine the level of agreement. Ethics approval was not required because this was a retrospective study with no patient identifiable data, and with no interventions.

Results

The overall degree of agreement between the Tweris Mini App and the expert was 94%, with complete (100%) agreement relating to acute hypoxic stress, ZigZag and atypical sinusoidal (Poole Shark Teeth) patterns. The agreement for the recognition of features of both chronic hypoxia and subacute hypoxia was 93%. One case, which was classified as chronic hypoxia by the expert was classified as decompensated gradually evolving hypoxia by the Tweris Mini App (Figure 1). There was 66% agreement for the classification of decompensated gradually evolving hypoxia, as the Tweris Mini CTG AI App classified one case as compensated gradually evolving hypoxia (Figure 2), and the second CTG as subacute hypoxia (Figure 3). The agreement for true sinusoidal pattern secondary to chronic fetal anaemia and acidosis was only 50%, as the Tweris Mini CTG AI App classified 50% of cases of typical sinusoidal patterns as chronic hypoxia. However, when it was re-tested on a segment of the CTG trace without ongoing shallow decelerations, Tweris Mini CTG AI App correctly identified the "Typical sinusoidal Pattern" (Figure 4). The Cohen Kappa statistic for diagnostic agreement was 0.92 (95% CI: 0.83-0.99, $p<.001$).

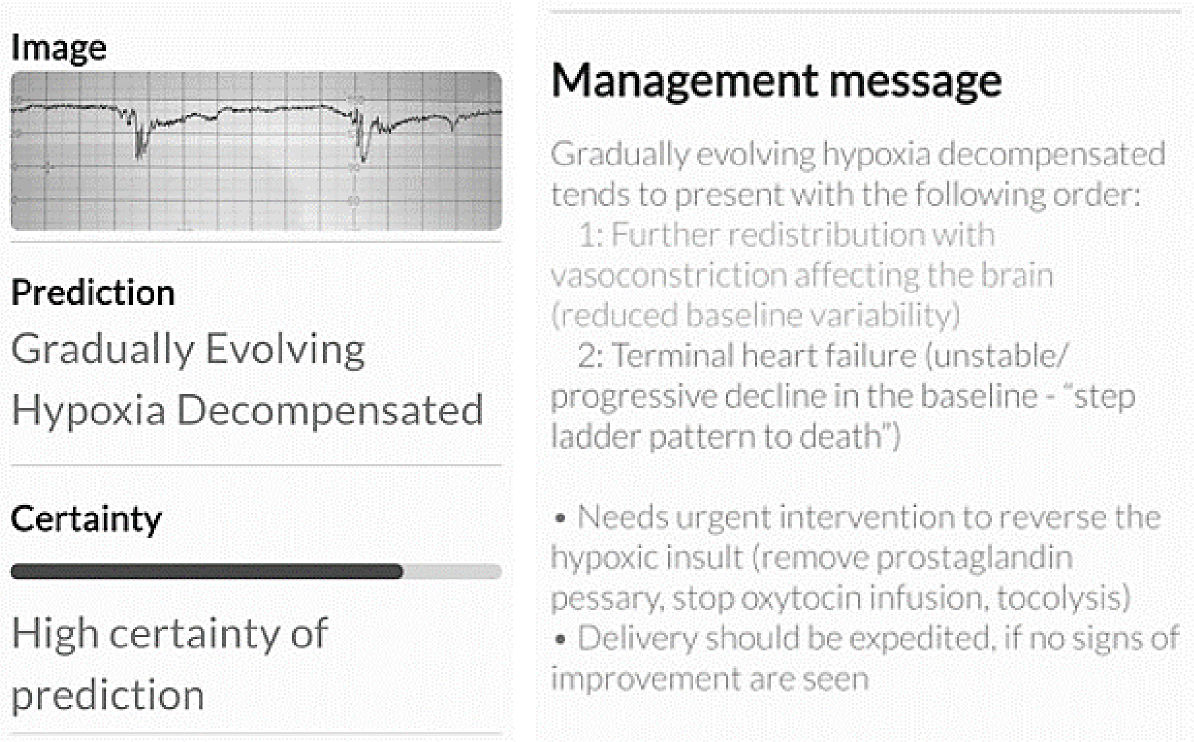

Figure 1. CTG trace classified as "chronic hypoxia" by the expert, was classified as a "decompensated gradually evolving hypoxia" by the Tweris Mini CTG AI App. Note the management message is similar to the expert's management plan.

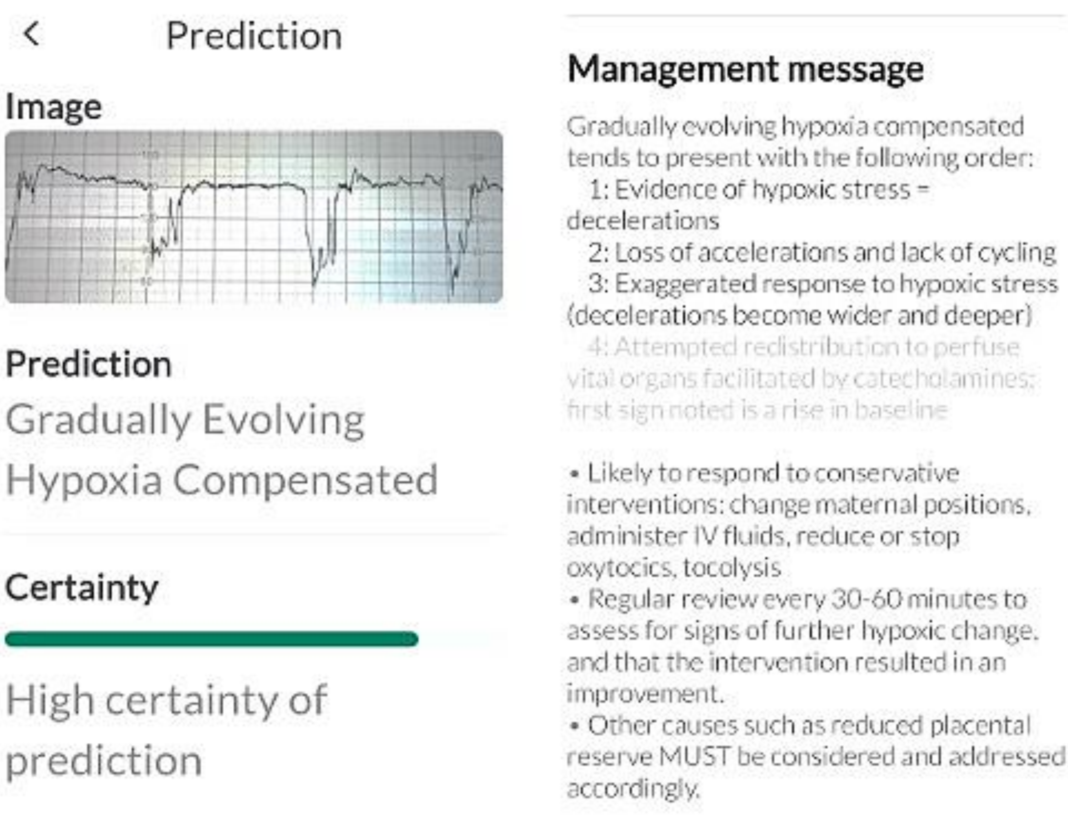

Figure 2. CTG trace which was classified as "decompensated gradually evolving hypoxia" by the expert was classified as "compensated gradually evolving hypoxia" by the Tweris Mini CTG AI App. However, the management message is to reduce the ongoing stress as that of the expert.

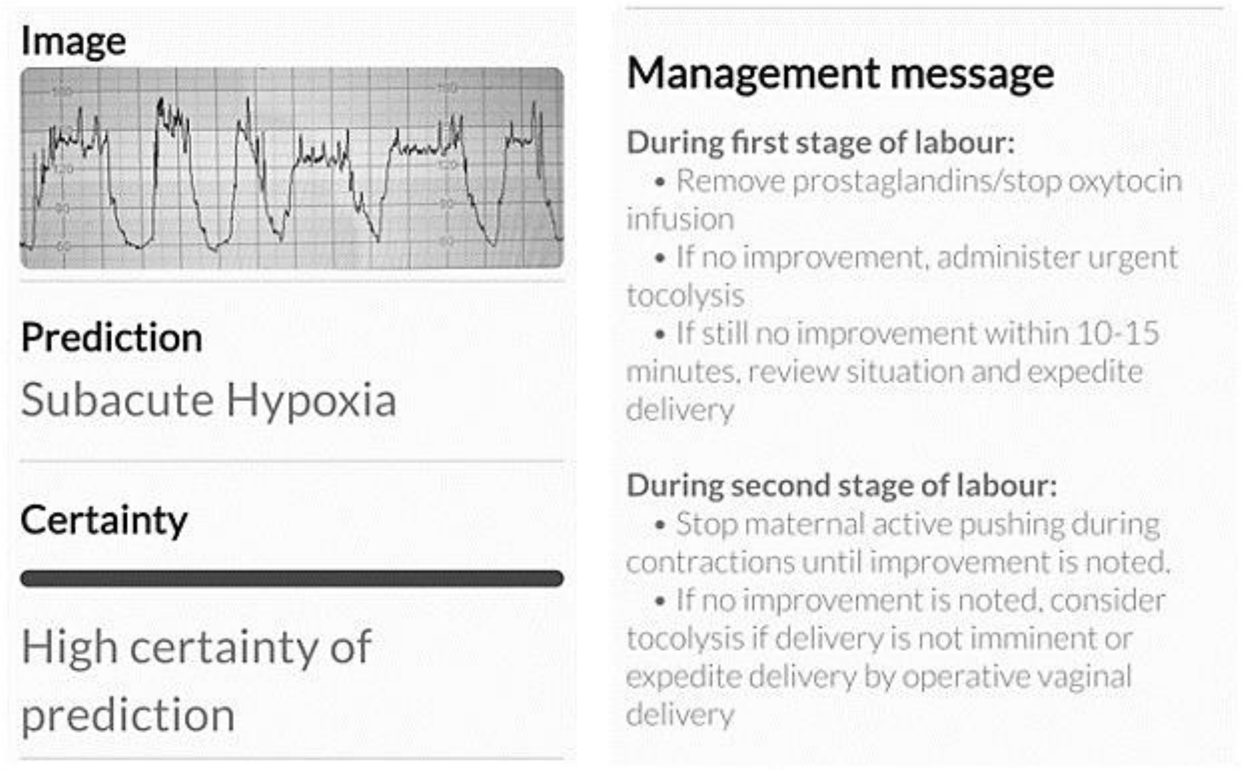

Figure 3. CTG trace which shows a combination of features suggestive of gradually evolving hypoxia and subacute hypoxic stress. The Tweris Mini CTG AI App diagnosed this as "subacute hypoxia". However, the management message was similar to the expert.

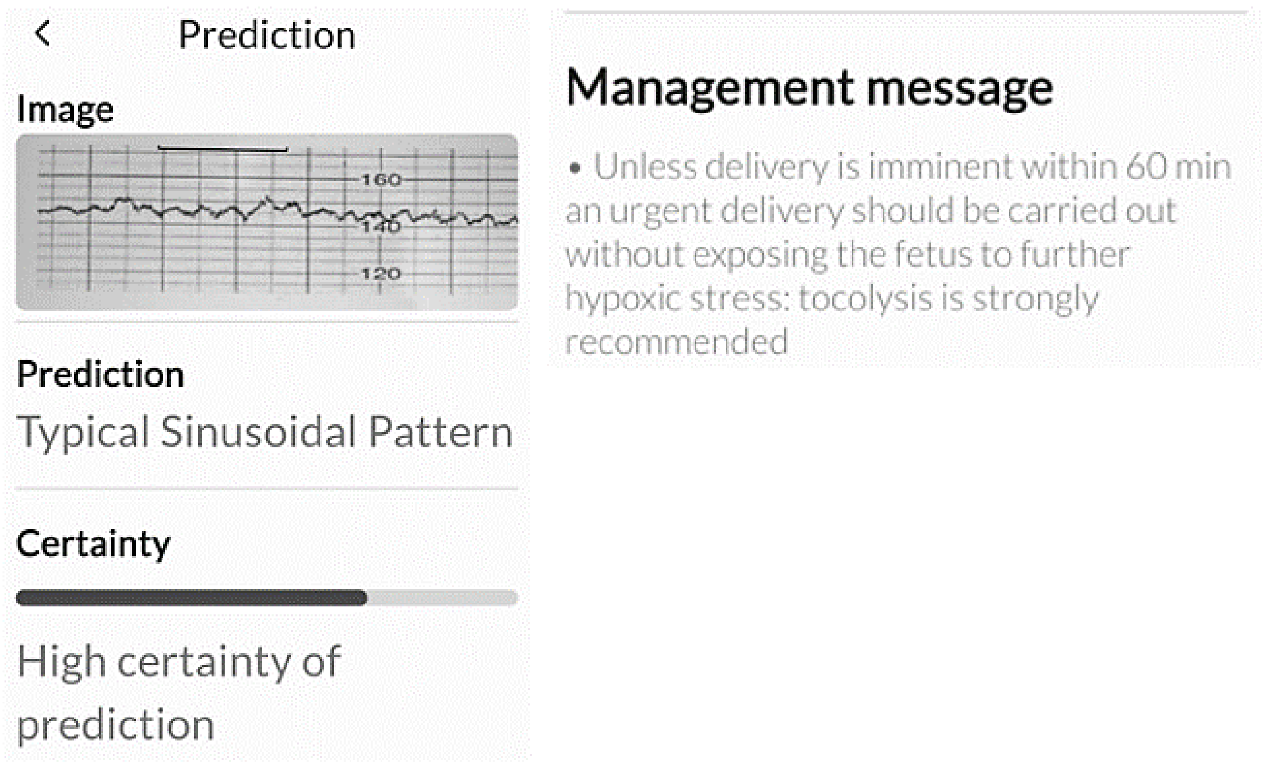

Figure 4. CTG trace which as classified as "typical sinusoidal pattern" by the expert. This was initially classified as "chronic hypoxia" by the Tweris Mini CTG AI App, with similar management message. However, when the CTG segment devoid of shallow decelerations were presented, the Tweris Mini CTG AI App correctly classified it as "Typical Sinusoidal Pattern".

The agreement between the Tweris Mini App and the expert regarding the recommended management reached 98%. The discrepancy was observed only in two cases where the Tweris Mini CTG AI App recommended "reduction of stress" instead of expediting birth, and to continue observation instead of reducing stress. The Cohen Kappa statistic for management was 0.96 (95% CI: 0.94-0.98, $p<.001$).

Discussion

To our best knowledge, this is the first study which analysed the diagnostic agreement and management plan between the expert who pioneered the concepts of pathophysiological interpretation in their daily clinical practice, as well as the Tweris Mini CTG AI App (TMA), which has been exclusively trained on the principles of physiological interpretation of CTG.

Among the 6 cases of diagnostic disagreement, the TMA had under-classified 2 cases: one case as a decompensated gradually evolving hypoxia (GD) instead of chronic hypoxia (C), and another case as a compensated gradually evolving hypoxia (GC) instead of decompensated gradually evolving hypoxia (GD).The under-classification of chronic hypoxia (C) as decompensated gradually evolving hypoxia may have resulted in the reduction in stress instead of expediting birth. However, in the absence of improvement after reduction of stress (i.e., administration oof tocolytics), delivery would have been accomplished, albeit approximately 30 minutes later. It is very likely that the TMA "under-classified" due to the recognition of ongoing shallow decelerations as "tardy" decelerations and increase in the baseline with reduced variability as decompensated gradually evolving hypoxic stress. In all other remaining cases of disagreement between the TMA and the expert (TMA diagnosing GD and S instead of GC, ZZ instead of S, C instead of TS, S instead of GD, and GD instead of C), the recommended management by the expert and the TMA would have remained the same. This includes expediting birth for cases of C or TS, and reduction of hypoxic stress for ZZ, S, and GD, followed by either continuation of labour if improvement occurred or expedited birth if there was no improvement. Therefore, the ultimate management plan would not have altered, resulting in consistent maternal and perinatal outcomes.

Our earlier study concluded that instead of grouping random features of fetal heart rate into different categories and focussing on morphology of decelerations, using a combination of features (chronic hypoxia, subacute hypoxia and chorioamnionitis) or a sequence of features (gradually evolving hypoxia – compensated or decompensated) by the application of the knowledge of fetal pathophysiology significantly increased the inter-observer agreement between midwives and obstetricians[66]. This study confirms that high level of agreements between the expert who pioneered the concept of physiological interpretation of CTG and the Tweris Mini CTG AI App could be achieved for both diagnosis and recommended management actions (94% and 98%, respectively), by programming the AI based on the principles of international expert consensus guidelines on physiological interpretation of CTG. Consistent diagnosis and appropriate management is likely to contribute to improvements in maternal and perinatal outcomes.

The strengths of the study include being the first in scientific literature which compared the performance of the Tweris Mini CTG AI App with the pioneer who developed the concepts of physiological interpretation of CTG. The CTG traces were randomly selected consisting of different types of fetal hypoxic stress and abnormal fetal heart rate patters of clinical significance (Figure 5). Moreover, the traces were independently analysed by two obstetricians (MG and NK) using the TMA to ensure objectivity and to avoid any bias. We acknowledge that our study has some limitations. It is a retrospective study and therefore, it has all the drawbacks of retrospective studies. However, all the studies performed to assess inter-observer variability in CTG interpretations were retrospective. We included management decisions to further improve the clinical relevance of our study.

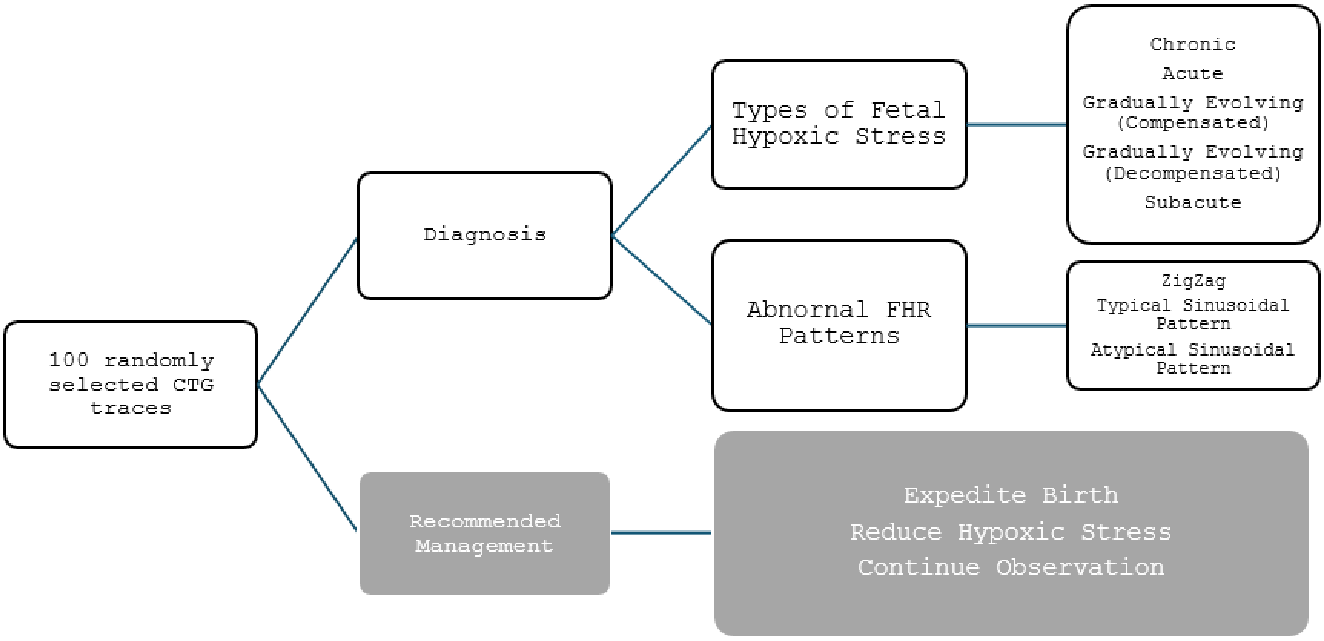

Figure 5. Types of Hypoxic Stress and Abnormal Fetal Heart Rate (FHR) patterns and Recommended management presented to both the expert and the Tweris Mini CTg AI App.

Several studies have highlighted significant inter and intra-observer variability in the classification of CTG traces[8-16,67-69]. It has been reported from several countries which use "normal, suspicious, pathological" classification system that CTG misinterpretation has contributed to significant harm (severe hypoxic-ischaemic brain injuries and perinatal deaths) to babies in > 50% of cases[70-77].More recently, four consecutive 'Each Baby Counts" Reports has highlighted that CTG misinterpretation contributed to > 50% of all cases on severe hypoxic-ischaemic brain injuries as well as intrapartum stillbirths and early neonatal deaths in the UK[78-81]. The medico-legal costs relating to CTG misinterpretation alone, have been reported as £6.7 million/day in the United Kingdom by the NHS Resolution, which is a body which has been set up to indemnify the NHS against litigation[82]. Therefore, it is hoped that by significantly eliminating significant inter and intra-observer variations reported with visual interpretation of CTG traces, the Tweris CTG AI App will reduce both human and financial costs of CTG Misinterpretation.

It may be argued that the use of computerised analysis of intrapartum cardiotocographs have been shown to be ineffective in improving perinatal outcomes or reducing emergency caesarean sections by randomised controlled trials. However, this argument is deeply flawed because both the INFANT Trial[83] and the FM-Alert Trial[84] were both based on illogical CTG guidelines which grouped random features into different categories (Normal, Suspicious, Pathological and Normal, Intermediary, Abnormal, respectively)[83,84].They did not include consider the principles of physiological interpretation of CTG and did not consider different types of fetal hypoxic stress or fetal responses to stress. Moreover, both the INFANT Trial and FM-Alert Trial did not exclude pre-existing fetal compromise such as chronic hypoxia. Therefore, due to these inherent flaws from the outset, it was not surprising that the INFANT Trial and the FM-Alert Trial reported absence of any benefit with computerised analysis of intrapartum cardiotocographs.

In contrast, the Tweris Mini CTG AI App is based on the principles of physiological interpretation of CTG, and the algorithm is trained to recognise a combination of features (chronic hypoxia and subacute hypoxia) and sequence of changes (compensated or decompensated gradually evolving hypoxia). Moreover, the Tweris Mini CTG AI App has also be trained on recognising abnormal patterns such as the ZigZag and the Poole Shark Teeth

Patterns. Therefore, the authors believe that by significantly eliminating significant inter and intra-observer variations reported with visual interpretation of CTG traces, and being based on the sound principles of physiological interpretation of CTG, the Tweris CTG AI App will help reduce both human and financial costs of CTG Misinterpretation.

Conclusion

There was excellent agreement between the Tweris Mini App and the expert who pioneered the concepts of physiological interpretation of CTG in both diagnosing different types of fetal hypoxic stress and recommending labour management (Figure 6). This suggests that the Tweris Mini CTG AI App has a high reliability in clinical practice to function as both diagnostic and management support tool for frontline clinicians.

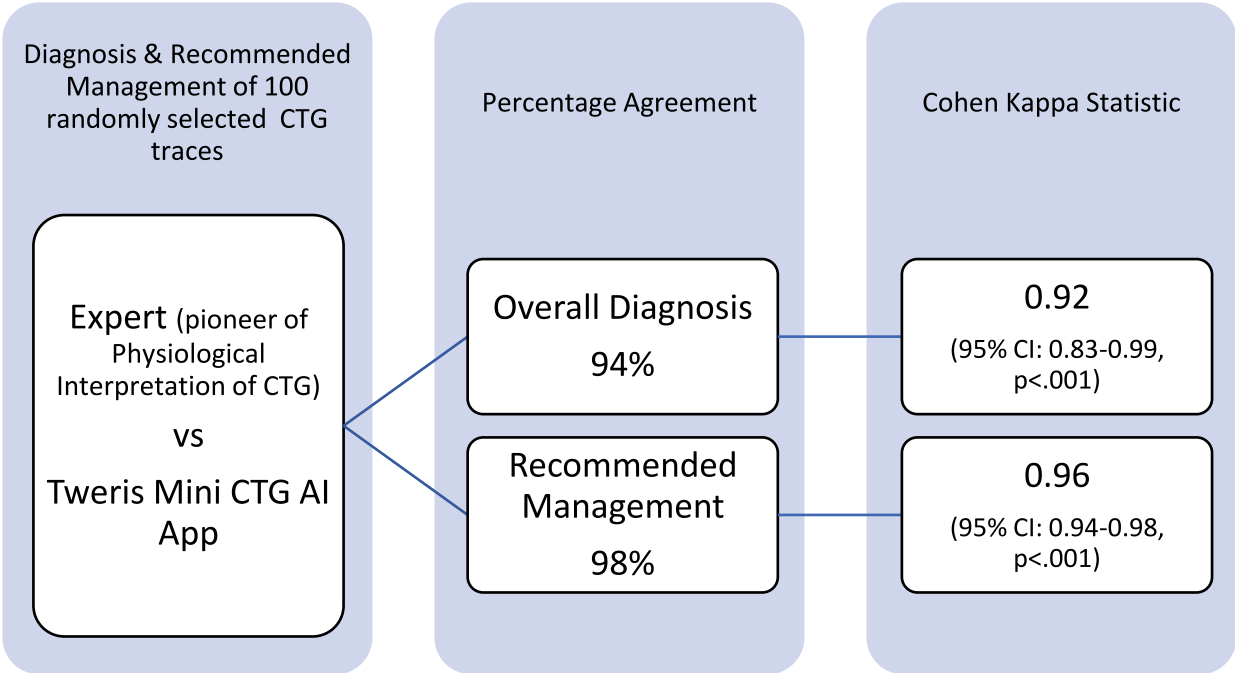

Figure 6. Agreement between the pioneer of Physiological Interpretation of CTG and Tweris Mini CTG AI App.

Contribution to Authorship:

EC conceptualized the project, and LV and EC designed the study. EC classified the CTG traces. NK and MG independently analyzed the CTG traces using the Tweris Mini App. LV analyzed the data, and NZ was involved in the technical development of the Tweris Mini App. All authors contributed to the writing of the manuscript and reviewed and approved the final manuscript.

Conflict of Interest:

EC is a member of the Editorial Board, and LV is a member of the International Expert Panel for the International Expert Consensus Statement on Physiological Interpretation of CTG. LV, EC and NK are the co-founders of the Tweris AI Project which is hosted and supported by Start-up Incubator Paca Est, France. Tweris Mini App has been currently made available free of charge in Apple and Android Stores for midwives and obstetricians with its aim to improve perinatal outcomes and to reduce unnecessary intrapartum operative interventions due to CTG misinterpretation (https://tweris.com/our-solution/).

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