

Application of a Naegele's Formula Adapted to the Long Count Mayan Calendar to Calculate the Expected Date of Birth During a Leap Year

¹Ugo Indraccolo, MD, PhD.

¹Complex Operative Unit of Obstetrics and Gynecology, Maternal-Fetal Department, Hospital of Gubbio and Gualdo Tadino, ASL 1 Umbria, Email: ugo.indraccolo@libero.it,
ORCID: <https://orcid.org/0000-0002-7660-6864>

ABSTRACT

Objective: To evaluate whether the Naegele formula applied to the Mayan calendar can improve the accuracy of due date prediction.

Methods: A database of pregnant women who gave birth during the leap year 2016 was analyzed (post hoc analysis). The date of the last menstruation (confirmed by ultrasound) was converted to the Mayan date using an online converter. The Naegele formula was adapted to the Mayan calendar and applied to the date of the last menstruation on the Mayan calendar. The resulting Mayan calendar date was converted back to the Gregorian calendar. Discrepancies between the actual due date and that predicted by the traditional Naegele formula and by adding 280 days to the last menstruation were compared with the discrepancies obtained by applying the Mayan calendar-based formula.

Results: The pregnancy duration predicted by the Mayan calendar-based formula better approximates the actual pregnancy duration than other methods in the entire database of 601 cases. In normal pregnancies, the Naegele formula deviates from the actual due date by an average of -0.982 days (± 3.548), the Mayan calendar-based formula deviates from it by an average of -0.254 days (± 3.481), while adding 280 days to the date of the last menstrual period deviates from it by an average of 0.247 days (± 3.487) ($p < 0.001$ for both comparisons). In further subgroup analyses, the Mayan calendar-based formula appears to be more accurate and equally precise than the other methods.

Conclusions: The Naegele formula adapted to the Mayan calendar improves the estimation of the expected due date compared to the Naegele's formula.

Key words

Birth date, pregnancy, Naegele's formula, Maya calendar.

INTRODUCTION

A normal human pregnancy lasts approximately 280 days. From an anthropological view, authors [1] suggest that the duration of a physiological pregnancy in humans has been progressively decreased through evolution, with the aim to develop a large brain fetus at the cost of delivering an immature and non-autonomous baby. This insight implies that the pregnancy duration may have varied with the evolution of the human brain.

The 280-day duration of a normal human pregnancy was already known in the 19th century, as reported by Professor Naegele of Heidelberg [2-4]. Naegele believed that pregnancy must last a multiple of the ideal ovarian cycle (28 days, based on his studies, $\times 10 = 280$ days), assuming that the conception could occur immediately after menstruation.

For this reason, he proposed a simple rule, still known today as Naegele's formula, consisting of adding one year, subtracting three months, and adding one week to the date of the last menstruation (first day), thus obtaining a rough estimate of the expected date of delivery, after approximately 280 days of gestation.

It is not entirely clear [2,3] why Naegele chose the procedure of subtracting three months and adding one week to the date of the last menstruation. Some authors [2,3] report that he was inspired by the botanist Hermann Boerhaave of Leiden, who in 1744 observed that a physiological pregnancy in a woman should last ten lunar months, equivalent to approximately 280 days, also referring to what is reported in the Holy Bible. This observation would have coincided with Naegele's hypothesis that the duration of pregnancy should correspond to a multiple of the normal ovarian cycle.

It is currently acknowledged that a pregnancy can be defined as "full term" between 37+0 and 41+6/7 weeks of gestation [5], further distinguishing between early term, full term, and post-term based on neonatal outcomes. Healthy newborns from singleton pregnancies and delivered between 39+0/6 and 40+6/7 weeks (full term) have a slightly better prognosis, especially respiratory, than newborns born before 39 weeks or after 40+6/7 weeks [6]. This implies that the optimal duration of physiological pregnancy in humans is between 273 and 286 days, with an (arithmetic) mean duration of 279.5 days. In this way, the range of normal pregnancy duration would include the fluctuations observed in different populations of women, and the errors occurring in conception timing, which is floating in especially in irregular menstrual cycles women [4].

It seems that the Maya knew a method to predict the expected date and even the time of childbirth [7], probably thanks to their calendar.

The Mayan calendar (Long Count) better approximates the length of the solar year than the Gregorian calendar, which is used to calculate the expected date of birth using the Naegele formula. The Mayan calendar divides the year into 18 months of 20 days (four weeks of five days each), to which are added five "unlucky" days (because they cannot be accounted in any month). The Gregorian calendar, on the other hand, divides the year into four months of 30 days, one month of 28 or 29 days, and seven months of 31 days, for a total of 52 weeks of seven days plus one (or two, in leap years) remaining days out of the count of weeks. Furthermore, the Mayan calendar (Long Count) approximates the length of the lunar month

better than the Gregorian calendar, from which Naegele likely developed his formula. A lunar month lasts an average of 29.53 days. In the Mayan calendar, a lunar month corresponds to approximately six five-day weeks (with an error of approximately +0.47 days), while in the Gregorian calendar, it corresponds to four seven-day weeks (with an error of approximately -1.53 days).

The aim of this study is to verify whether a formula similar to Naegele's, but applied to the Mayan calendar (Long Count), is able to predict the date of birth with greater accuracy than the traditional formula based on the Gregorian calendar, taking into account that not all normal births occur within 280 days, and assuming that the pregnancy in humans should last approximately 10 lunar months, as Naegele had assumed when developing his formula for estimating the due date.

MATERIAL AND METHODS

A post hoc study was planned through re-analysis of an existing (unpublished) database collected prospectively from a primary care Italian birth spot (which is an Obstetric and Gynecology Division dedicated to the care of mostly normal pregnancies in a low-level of complexity care hospital). Specifically, the reassessment of the internal birth database for 2016 (a leap year) from Città di Castello Hospital (ASL 1 Umbria, Italy), created prospectively in 2016 for internal monitoring of birth trends, was planned.

The database includes all births that occurred in 2016 and contains the following information:

- the date of delivery;
- the first day of the last menstrual period, corrected by ultrasound according to the 2015 Italian Guidelines (valid in 2016) [8];
- the patient's parity;
- the patient's date of birth;
- the mode of delivery;
- any pathologies that arose during pregnancy.

Overall, the database includes 605 cases.

After excluding cases with missing data, the estimated due date was calculated using:

1. the classic Naegele formula;
2. the Naegele formula adapted to the Mayan calendar (using the free converter available at <https://pauahtun.org/Calendar/tools.html> - last accessed July 31, 2025). This converter uses the GMT (Goodman-Martínez-Thompson) correlation constant, which is commonly used for converting Gregorian dates to Mayan dates;
3. the simple addition of 280 days to the date of the first day of the last menstrual period, as easily accomplished by numerous online calculators and software of ultrasound machines.

Naegele's formula adapted to the Mayan calendar has been defined as follows: First day of the last menstruation + 5 days ("unlucky," equivalent to a Mayan week) – 4.35 Mayan months (equivalent to three mean lunar months, rounded to 29 days, according to the logic Naegele likely applied, approximating the length of the lunar month to the 28/29 or 30 or

31 days of the Gregorian month). The quantity 0.35 of a Mayan month corresponds to 7 Mayan days, so Naegele's formula adapted to the Mayan calendar, more simply, becomes: First day of the last menstruation on a Mayan date, -2 Mayan days = presumed Mayan day of delivery; Mayan month of the last menstruation - 4 Mayan months = presumed Mayan month of delivery. Mayan year of the last menstruation + 1 Mayan year = presumed Mayan year of delivery.

Subsequently, the resulting Mayan date was converted back to the Gregorian calendar using the same converter (<https://pauahtun.org/Calendar/tools.html>).

The database was then divided into two subgroups.

Group 1: pregnancies and physiological deliveries at term.

It includes cases characterized by:

- spontaneous delivery;
- absence of pregnancy pathologies;
- absence of induction of labor;
- gestational age between 37+0 and 41+6 weeks.

Group 2: non-physiological pregnancies and/or deliveries. It includes pregnancies characterized by at least one of the following conditions:

- presence of pregnancy pathologies;
- non-physiological delivery;
- induction of labor;
- delivery occurred before 37+0 weeks or after 41+6 weeks.

We planned to verify whether, in Group 1, the deviation in days between the presumed date of delivery and the actual date of delivery was significantly different using the Naegele formula based on the Mayan calendar than the traditional formula based on the Gregorian calendar, coming closer to the result obtained by simply adding 280 days to the date of the last menstrual period.

The two-tailed Student's t-test for paired data was used, with a p-value ≤ 0.05 considered statistically significant.

A subsequent subgroup analysis of Group 2, using the same approach reported above, was planned to verify how the estimates of the expected due date behaved in each obstetric circumstance. This was done using the same two-tailed Student's t-test statistic for paired data, taking care to verify, before making inferences, whether the data were normally distributed (Shapiro-Wilk test). If the subgroup data were not normally distributed, the two-tailed Wilcoxon test for paired data, with continuity correction, was applied.

Statistical analyses were performed using the free software KyPlot, version 5.0.

The study was approved by the Independent Ethics Committee of the Umbria Region on June 18, 2025 (EC protocol 2467/25). Each patient provided written signed consent to the processing and making available their health data in an anonymous and aggregated form, at the time of

database construction. The signed consent forms were included in the medical charts. Since this was a post-hoc analysis, the consent obviously had not able to include information about the processing of such data for the specific purposes of this study.

RESULTS

605 patients were evaluated. Four cases were excluded from the analysis due to incomplete data.

The remaining 601 cases were divided according to the presence of a normal pregnancy and labor (Group 1, 279 patients) or a non-normal pregnancy and/or birth (Group 2, 322 patients). Labor induced, whether pharmacologically or mechanically, including induction by amniorexis, was also considered non-normal. Conversely, premature rupture of membranes was not considered a pathological condition, as it precedes the onset of normal labor and is associated with other pathological conditions only in cases of non-normal pregnancy and/or birth.

Figure 1 summarizes the STROBE-flowchart for the database subgroups organization.

Table 1 reports the main descriptive characteristics of the studied population.

The mean pregnancy duration across the entire database was 278.023 days (± 11.006). According to the estimated due date calculated using the Naegele formula, the estimated pregnancy duration across the entire database would be 281.426 days (± 0.734). According to the estimated due date calculated using the Naegele formula applied to the Mayan calendar, the estimated pregnancy duration across the entire database would be 278.998 days (± 0.091).

Considering the entire database and comparing the expected date with the actual date of delivery, the Naegele formula deviates from the actual date of delivery by an average of 1.701 days (± 5.524), the formula based on the Mayan calendar deviates from it by an average of 0.488 days (± 5.504), while adding 280 days to the date of the last menstrual period deviates from it by an average of 0.988 days (± 5.503). Across the entire database, an exact match between the expected date and the actual date of delivery was observed in 1.5% of cases (19/601) with the Naegele formula, in 5.5% of cases (33/601) with the formula based on the Mayan calendar, and in 5.8% of cases (35/601) with the simple addition of 280 days.

The mean pregnancy duration in the Group 1 (full normal term pregnancies, who delivered spontaneously) was 279.505 days (± 6.977). According to the estimated due date calculated using the Naegele formula, the estimated pregnancy duration in the Group 1 would be 281.470 days (± 0.885). According to the estimated due date calculated using the Naegele formula applied to the Mayan calendar, the estimated pregnancy duration in the Group 1 would be 278.996 days (± 0.060).

In the subgroup of physiological pregnancies with spontaneous delivery at term (Group 1), the Naegele formula deviated on average by 0.982 days (± 3.548) from the actual date of delivery, the Mayan calendar formula deviated on average by -0.254 days (± 3.481), while adding 280 days to the date of the last menstrual period deviated on average by 0.247 days (± 3.487). In Group 1, exact coincidence between the expected and actual date of delivery was observed:

in 3.9% of cases (11/279) with the Naegele formula, in 8.2% of cases (23/279) with the Mayan calendar formula, and in 7.9% of cases (22/279) with the addition of 280 days.

The mean pregnancy duration in the Group 2 (non physiological pregnancies and/or births) was 276.739 days (± 13.444). According to the estimated due date calculated using the Naegele formula, the estimated pregnancy duration in the Group 2 would be 281.388 days (± 0.570). According to the estimated due date calculated using the Naegele formula applied to the Mayan calendar, the estimated pregnancy duration in the Group 2 would be 279.000 days (± 0.112).

In the subgroup of non physiological pregnancies and/or births (Group 2), the Naegele formula deviates on average by 2.325 days (± 6.730) from the actual date of delivery, the formula based on the Mayan calendar deviates on average by 1.130 days (± 6.636), while the addition of 280 days to the date of the last menstruation deviates on average by 1.630 days (± 6.723). In this subgroup, the coincidence between the expected date and the actual date of delivery was 2.5% (8/322) with the Naegele formula, 3.1% (10/322) with the Mayan calendar formula, 4.0% (13/322) with the addition of 280 days to the date of the last menstruation.

The values of the mean discrepancies, expressed in days, obtained with the formula based on the Mayan calendar were compared with those of the Naegele formula and with those resulting from the simple addition of 280 days to the first day of the last menstrual period. Results are reported in Table 2, for Groups 1, 2, and for all sub-groups arranged from Group 2 (Figure 1). All these comparisons were significant.

Figures 2 shows the Bland-Altman plots for the entire database, for full normal pregnancies (Group 1), and for cases of non-normal pregnancies and/or births (Group 2). The Mayan calendar-based formula shows a slightly better accuracy in predicting the exact date of birth than the traditional Naegele's formula.

DISCUSSION

This study demonstrates that the Mayan calendar-based formula predicts the actual due date slightly more accurately than the Naegele formula based on the Gregorian calendar and seems equally effective as the on add of 280 days to the first day of the last menstrual period.

This result is related to the slight underestimation of the due date of the Mayan calendar formula, compared to the 280 days due date, believed to be the end of the pregnancy. This slight underestimation is closer to the actual due date found in the sample of pregnant women assessed in this study. Those pregnant women have an average duration of gestation of approximately 279 days for physiological pregnancies (Group 1) and approximately 278 days for non-physiological pregnancies (Group 2).

This database was collected from patients treated in a low-risk obstetric care setting. This setting seemed particularly suitable for assessing truly normal pregnancies, minimizing potential confounding factors resulting from the medicalization of labor [9,10] that can affect the outcome of normal pregnancies in large birth centers.

Furthermore, a leap year was chosen to test the Gregorian calendar, a condition that theoretically increases the annual approximation error from one to two days (366 instead of 365 days).

Naegele's idea that the duration of normal pregnancy in the human species should be a multiple of the ovarian cycle overlapping with the mean lunar cycle is merely speculative, although it is possible that a modest influence on the rhythmicity of menstruation [11] and consequently on the time of conception [12] is associated with the lunar cycle in women. Regardless of the moon, however, the observed effect of the Mayan calendar formula in predicting the actual date of birth would suggest that the Maya may indeed have used a rule of thumb to estimate the time of birth, similar to what is done today in Western countries using the Naegele formula or the addition of 280 days. Therefore, the historical hypothesis [7] that the Mayans were able to predict at least the date of birth may have some basis in truth.

Furthermore, it's conceivable that, in Mayan culture, a significant discrepancy between the expected and actual due date was interpreted as an unfavorable sign or associated with an increased risk of adverse pregnancy outcomes. From this perspective, the expected due date may have served as a surveillance and care tool in an era when other diagnostic tools were unavailable.

Currently, several reliable diagnostic tools are available to identify at-risk pregnancies, without waiting for them to result in a birth date different from the expected one. Additionally, it is intuitive that the greater the difference between the expected and actual due date, the greater the likelihood of obstetric pathology, whether for biological reasons or medical interventions. Therefore, the results of the present study have only limited practical value. They suggest that a version of the Naegele formula based on the Mayan calendar may be a slightly more accurate tool for estimating the actual due date than simply adding 280 days to the first day of the last menstrual period or using the Naegele formula, in especially in leap years.

It would therefore be useful to go beyond the observation limit of a single leap year in a single center to consolidate findings and expand them to non-leap years, while also being able to compare the results of due date predictions adjusted for different populations or for potential variables that could influence the term of a physiological pregnancy in humans. For example, Bergsjø et al. [13] reported that the mean pregnancy duration in the Scandinavian population between 1976 and 1980 was approximately 281 days, while Derraik et al. [14] reported that shorter women had shorter pregnancy durations than taller women.

Furthermore, a proportion of the variability of the estimated due date, given Naegele's assumption that it must be a multiple of the lunar cycle, would be also logically related to the variability of the lunar month, thus influencing the actual due date.

Finally, it is likely that there is a systematic error in online converters, and that this error may be added to the error of the GMT correlation coefficient. Many correlation coefficients have been reported in the literature for the conversion from Gregorian dates to Mayan dates [15]. As pointed out by Gaspani in 2013 [15], the standard deviations (or standard errors) of these correlations are unknown. Among these correlation coefficients, the GMT one is recognized as the most reliable [16] and had been seemed to be the better one for allowing the estimates for the purposes of this study.

Legends

Table 1: Descriptive statistics

	Whole database (601 cases)	Full normal pregnancies and birth (Group 1) (280 cases)	Non full normal pregnancies and/or birth (Group 2) (321 cases)
<u>Age</u>	32.01 ±5.635	32.6 ±5.509	31.8 ±5.539
<u>Nulliparity</u>	379 63.1%	246 87.9%	133 41.4%
<u>Premature rupture of membranes</u>	139 23.1%	68 24.3%	71 22.1%
<u>Pregnancies complications</u>			
-Previous cesarean	87 14.5%	/	87 27.1%
-Dystocia	54 9.0%	/	54 16.8%
-Gestational diabetes	43 7.2%	/	43 13.4%
-Hypertensive disorders of pregnancy	19 3.1%	/	19 5.9%
-Fetal growth restriction – low for gestational date fetus	8 1.3%	/	8 2.5%
-Placental abruption	4 0.7%		4 1.2%
-Abnormal cardiotocography	32 5.3%	/	32 10.0%
-Meconium stained amniotic fluid	11 1.8%	/	11 3.4%
-Breech presentation	13 2.1%	/	13 4.0%
-Twin pregnancy	7 1.2%	/	7 2.2%
-Others	51 8.2%	/	51 15.9%
<u>Overall Cesareans</u>	166 27.6%	/	166 51.7%
<u>Planned Cesareans</u>	58	/	58

	9.7%		18.1%
<u>Unplanned Cesareans</u>	108 18%	/	108 33.6%
<u>Operative vaginal deliveries</u>			
-Vacuum extraction	27 4.5%	/	27 8.4%
-Forceps delivery	2 0.3%	/	2 0.6%
-Shoulder dystocia	2 0.3%	/	2 0.6%
<u>-Labour induction</u>	84 14.0%	/	84 26.2%

Description of main characteristics of the sample (mean with standard deviation or rate)

Table 2: Inferential statistics

Whole database (601 cases)		Naegele's formula mean difference 1.701 days ±5.524	280-day method mean difference 0.988 days ±5.503
	Maya formula mean difference 0.488 days ±5.504	p<0.001	p<0.001
Full normal pregnancy and birth (Group 1) (279 cases)		Naegele's formula mean difference 0.982 days ±3.548	280-day method mean difference 0.247 days ±3.487
	Maya formula mean difference -0.254 days ±3.481	p<0.001	p<0.001
Non normal pregnancy and/or birth (Group 2) (322 cases)		Naegele's formula mean difference 2.325 days ±6.730	280 days method mean difference 1.630 days ±6.723
	Maya formula mean difference 1.130 days ±6.723	p<0.001	p<0.001
Planned Cesareans (75 cases)		Naegele formula mean difference 4.700 days ±4.187	280 days method mean difference 5.407 days ±4.218
	Maya formula mean difference 4.207 days ±4.203	p<0.001	p<0.001

Unplanned Cesareans (90 cases)		Naegele's formula mean difference 1.610 days ±8.098	280 days method mean difference 0.956 days ±8.117
	Maya formula mean difference 0.462 days ±8.116	p<0.001	p<0.001
Operative vaginal deliveries (31 cases)		Naegele's formula mean difference 0.871 days ±3.462	280 days method mean difference 0.081 days ±3.495
	Maya formula mean difference -0.419 days ±3.495	p<0.001	p<0.001*
Labour induction (84 cases)		Naegele's formula mean difference -0.720 days ±6.992	280 days method mean difference -1.429 days ±6.985
	Maya formula mean difference -1.929 days ±6.985	p<0.001	p<0.001

Values are expressed as means and standard deviations. Comparisons were made between the mean discrepancies (expressed in days) among the estimated due date predicted by the Naegele formula, predicted by the Naegele formula applied to the Mayan calendar, and predicted by adding 280 days to the first day of last period. Distributions were tested for normality using the Shapiro-Wilk test. If the series were non-normally distributed, the two-tailed Wilcoxon test, for paired data, with continuity correction, was applied. Otherwise, comparisons were made with the two-tailed Student t-test for paired data.

*The two-tailed Wilcoxon test for paired data, without continuity correction, was applied due to the finding of equal standard deviations between the two series.

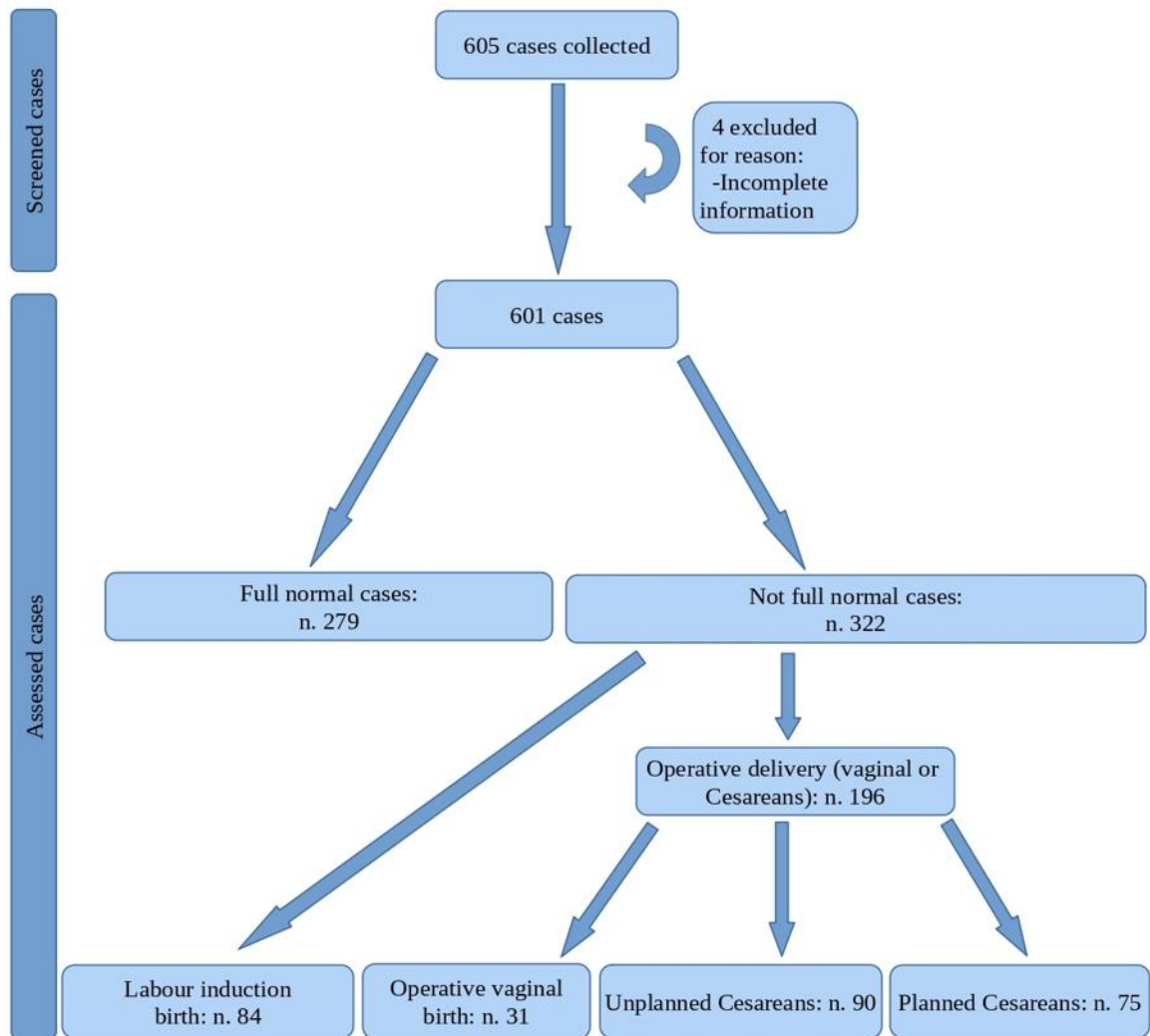


Figure 1: STROBE (STrengthening the Reporting of OBservational studies in Epidemiology) flow-chart.

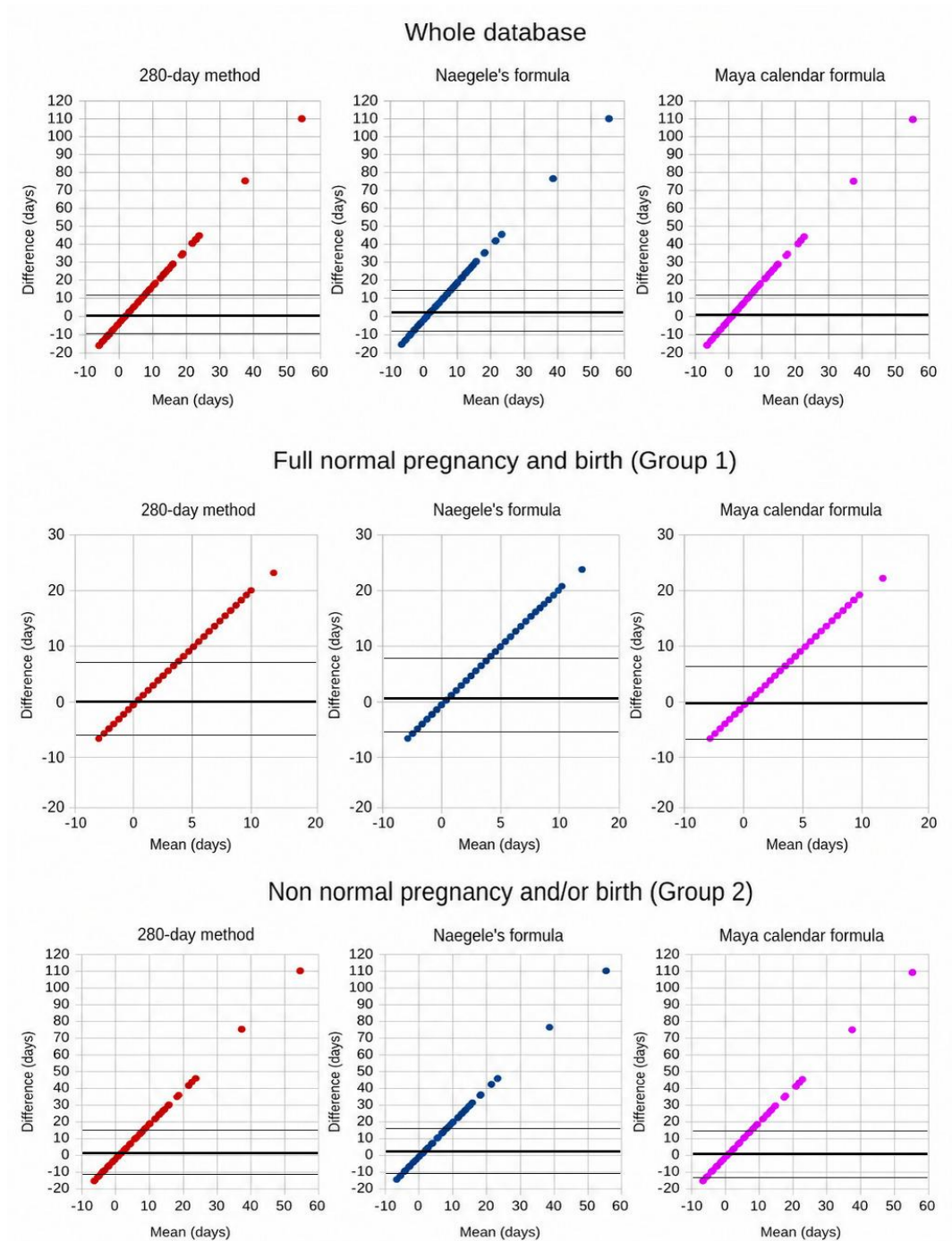


Figure 2: The Bland-Altman plots for the entire database

Bland-Altman plots for the whole database (upper boxes, 601 cases), for the full normal pregnancy and birth cases (intermediate boxes, Group 1 – 279 cases) and for the non normal pregnancies and or/birth (lower boxes, Group 2 – 322 cases). The deeper black lines refer to the mean values of differences (bias) while the thinner black lines refer to the 95% confidence intervals.

CONCLUSION

The formula based on the Mayan calendar is slightly more accurate than the Naegele formula, applied to the Gregorian calendar in predicting the actual due date, with same accuracy as other methods of due date estimating. Applying a formula similar to Naegele's using the Mayan calendar could therefore allow for a better estimate of the expected due date in especially in leap years. This can be achieved by converting Gregorian dates to Mayan dates and, using Naegele's modified formula, converting Mayan dates to Gregorian dates.

Availability of data and materials

The whole database can be shared in anonymized form, and can be provided upon reasonable request by mailing to the corresponding author of the article.

Competing interest

The author has not any competing interest to disclose.

Funding

This study did not receive any external funding.

Authorship' disclosure

Indraccolo

This study was entirely driven by the unique author, Ugo Indraccolo, who was responsible for its conception, design, execution, analysis, interpretation and dissemination.

Generative artificial intelligence (AI) and AI-assisted technologies disclosure

The article has been translated from Italian to English by using Google Translater. The English text was carefully reviewed for the congruence by the corresponding author.

Figures 2 was generated using ChatGPT (<https://chatgpt.com/>) by asking the AI to merge all graphics created by using LibreOffice Calc 7.0.3.1. The mean difference lines and their confidence intervals line were added to the merged figures by using Paint.

Acknowledgments

None

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