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Estimation of Monthly Probability of Conception based on Lindley Conditional Risk of Intercourse

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Abstract: Several researchers have tried to study the relationship between timing and frequency of intercourse with the monthly probability of conception based on prospective data. However, in reality, the data on pattern of intercourse and days of ovulation in each woman is hardly available. In that condition, it is imperative to compute the monthly probabilities of conception theoretically. Assuming Lindley distribution for the conditional risk of intercourse (i.e. increasing hazard rate for intercourse), we have tried to calculate the probabilities of all possible coital patterns and associated probabilities of conception on the four days of fertile period. Then, these calculated probabilities are utilized to estimate monthly probability of a conception.

Keywords: Lindley distribution, Conditional risk of intercourse, Probability of conception, Fertile period, Increasing hazard rate.

1 Introduction

Probability models describing quantitative aspects of human reproduction are interest of several researchers. Although, the process of human reproduction is very complex but simple probability models can help in numerical study of the features of the reproduction process. The couples who would like to have next child soon and those who want to avoid pregnancies are often curious about knowing how long they might suppose to wait for the conception and what are the chances of avoiding pregnancies for a year. Although, their intentions are different, both questions can be answered through determining the probability of conception in a menstrual cycle. Here, conception is defined as pregnancy which lasted six weeks or more after ovulation. In the process of ovulation, ovum is released from the ovary. Then it enters into fallopian tube where, it contacts to sperm and gets fertilized.

There are multiple factors influencing probability of conception directly or indirectly. The age of the couple, frequency and timing of intercourse, length of fertile period, the viability of sperm and ovum and overall sperm count affects directly. Apart from these, nutritional status of women, exposure to smoking, drinking and recreational drugs and previous pregnancy affects it indirectly. Women can conceive only during short period of the menstrual cycle. Women have substantial chance of conceiving near the days of ovulation. There is no uniformity in the chance of conception on the different days before and after the ovulation. The average duration of the fertile period is also uncertain. Evidences show that the fertile period ranges from 2 days per menstrual cycle to 10 days or more ([5], [6], [14], [21], [23], [24], [26], [28], [29]). It is also known that even if an intercourse occurs during the fertile period, there is no surety that conception will occur definitely in the menstrual cycle. Since the fertile period is not known precisely, the intercourses occur somewhat randomly over the cycle and there is no surety of occurrence of conception even in presence of intercourse during the fertile period. The occurrence of conception during a menstrual cycle becomes an event of random nature and consequently, it has a probability associated with it. Timing of ovulation and viability of ovum and sperm are beyond the

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human control. Hence, our paper confines its attention to the relationship of timing and frequency of intercourse with the probability of conception in a menstrual cycle.

Various researchers have studied about the probability of conception on different days of menstrual cycle ([1], [2], [6], [15], [16], [17], [24], [27]) under various assumptions. However, all these studies are based on prospective data on coition on different days relative to ovulation in a menstrual cycle and contain a small sample of women who agreed to become an object for the study. In fact, such data for general populations are not available in literature especially due to difficulty in determining the exact day of ovulation of a female in the surveyed population. Hence, some population scientist tried to compute the probability of conception through statistical models. Lachenbruch [11] tried to simulate the probability of intercourse on particular day when the sampling the days of intercourse in a menstrual cycle is done without replacement and calculated probability of conception in a menstrual cycle. Later, Glaser and Lachenbruch [9] derived probability of conception assuming coital patterns as a renewal process, with coital acts representing "points" of renewal. They derived their results by assuming the probability distribution of conditional risk of Intercourse (CRI) as exponential distribution and Weibull distribution. Venkatacharya & Roy [20] developed a procedure to calculate monthly probabilities of conception from age-specific marital fertility rates and some other biological parameters. Further Bongaarts [4] gave a new method for the calculation of mean and variance of fecundability using data on first birth interval. Later Mode [13] proposed a method for calculating fecundability as a function of set of coital patterns and assumed markov chain model of coital pattern with two states (0 for no coital act and 1 for coital act). Recently, Yadava et al., [30] utilized the concept of markov chain for the theoretical estimation of probability of coition on different days of a menstrual cycle near the day of ovulation. The above paper also considered coital act as periodic events.

Our study is an attempt to theoretically estimate probability of conception near the days of ovulation in a menstrual cycle for different coital pattern assuming four days fertile period. Next we have computed the probability of conception in one menstrual cycle through these estimated probabilities. Here we used the concept adopted by Glaser and Lachenbruch [9] and instead of using exponential and Weibull distribution, we considered here Lindley distribution as a CRI and came upon with different expressions of probability for different coital pattern in the fertile period. The thought behind choosing Lindley distribution in this paper is described as follows: if the probability of intercourse on a given day is independent or rapidly increases with the length of time since the last intercourse (solid lines in Fig 1), these types of coital pattern is considered by Glaser and Lachenbruch [9]. However, in some couples, the rate of increase in probability of intercourse with the time since last intercourse is slower than that with exponential increase (dotted line as shown in Fig 1). This type of coital pattern is better explained by Lindley distribution.

2 Formulation of Model and Results

For the purpose of our model the process of sexual union is described as follows: there is certain period of time until next coitus after each episode of intercourse, is called inter-coital interval. Thus, the pattern of coition over the whole menstrual cycle describes a successive event of coitus separated by the inter-coital interval between every act of intercourse. Here, we have assumed that the whole process of sexual union works on continuous time scale with the unit of measurement in days.

There are two ways of looking to reach at the solution of the problem considered, we may count the number of events of intercourse within a menstrual cycle or measure the inter-coital time length. Both coital frequency and inter-coital lengths are related to each other. To understand this relation, two random variables have been defined:

$N(t)$ be the number of events of intercourse occurring within an interval of time t,

Li be the length of time between i^{th} and $(i+1)^{th}$ intercourse.

In fact, the average coital frequency per time t is the length of time divided by the average interval between successive coital acts, then

$$E\,[N(t)\,] = t/(E(L)) \tag{1}$$

This relationship between coital frequency and inter-coital interval can be more generalized in the following way:

$$P[N(t) < r] = P[\textstyle\sum_{i=0}^{r-1} L_i > t] \tag{2}$$

i.e. the probability of occurrence of less than r acts of intercourse in t days equals the probability that the length of time until the rth intercourse must be greater than t days. Thus, both the probabilities are uniquely related to each other.

In order to find the probability of conception there must be occurrence of coital act during the four days fertile period. Here we did not consider whether one or more act of intercourse take place on any day. It has been assumed that there would be no chance of conception if the intercourse occur beyond fertile period. Since the fertile period lasts 4 days, there are 4^2=16 possible patterns of intercourse during this period. Then it is legitimate to find the probabilities associated with the timing and frequency of coital pattern during this period. Furthermore, we also require the conditional probability of conception on any day given coitus on that day and ovulation on particular day D. Next, we have computed monthly probabilities of conception under Lindley conditional risk of intercourse with varying parameter values.

To characterize the probability distribution of the length of inter-coital interval, we may theorize that the probability of intercourse on a given day increases as the time elapsed since last coitus increases. Our assumption is plausible as the probability of intercourse on a given day is greater if the three days passed since last intercourse than if the four days have been passed. Wood [26] named these types of sexual behavior as pressure cooker model of sexual behavior. Glaser and Lachenbruch [9] called the probability of intercourse on any day since last intercourse the conditional risk of intercourse (CRI) which is equivalent to hazard rate for intercourse $h(t)$ given no coitus occurred in last $(t-1)$ days. Using concept of survival analysis, the probability density function $f(l)$ of length of inter-coital interval can always be found as:

$$f(l) = h(l) \exp\left[-\int_0^l h(y) ds\right] \tag{3}$$

Our formulation of behavior of the CRI enables us to find the appropriate probabilities necessary to calculate the probability of intercourse on given days of the cycle and uniquely specifies the probability distribution of inter-coital interval. Furthermore, this distribution is uniquely related to the distribution of the frequency of intercourse in a fixed time period.

Assuming the increasing form of CRI: $h(t) = (\theta^2\,(1+t))/(\theta+1+\theta t)$, then

$$f(l) = \frac{\theta^2}{\theta+1}\,(1+l)\exp(-\theta l), \qquad l > 0,\ \theta > 0 \tag{4}$$

And the mean and variance of the length of inter-coital interval become:

$$E(L) = \frac{(\theta+2)}{\theta\,(\theta+1)} \tag{5}$$

$$Var\,(L) = \frac{(\theta^2 + 4\theta + 2)}{\theta^2\,(\theta+1)^2} \tag{6}$$

This distribution is known as one parameter Lindley distribution. It is widely used in modelling life time data sets, and reliability studies. It have been proved in literature that under some circumstances Lindley distribution gives better fit over exponential distribution [8]. For the illustration of our results we must choose numerical values of the parameters that would, hopefully, be found in human populations. For example, let us assume 24 non-menstrual days per menstrual cycle and average number of coital acts per 24 days is 6. Then the average inter-coital interval will be 4 days. Therefore, the corresponding parameters of the distribution of the inter-coital interval will be estimated as follows:

$$E(L) = \frac{(\theta+2)}{\theta\,(\theta+1)}$$

$$\frac{(\theta+2)}{\theta\,(\theta+1)} = 4$$

$$\theta = 0.425 \tag{7}$$

Table 1 depicts the probabilities that the interval between successive intercourse ends on a given day, measured from the last coitus under Lindley distribution with expected inter-coital interval of 4 days. It is worth to mention that the probabilities of subsequent coitus within a given day, under Lindley distribution ($\theta = 0.425$), are low for first day, then maximized on the second day (since last coitus) and thereafter declines monotonically as time passes.

Next we must find the probabilities of coitus over the fertile period for all possible coital patterns that could lead to conception in a particular menstrual cycle. There can be 16 possible patterns of the coital patterns. To derive these probabilities, we require $g(t)$ to be the length of time t until next intercourse. In renewal theory this is referred to backward recurrence time. The chance of no coitus in the period of length s starting at time t will be:

$$P\{(N(t+s)-N(t))=0\}=P\{g(t)>s\} \tag{8}$$

For any CRI, the limiting distribution of $g(t)$ as $t\to\infty$ will be:

$$P\{g(t)>x\}=\int_x^\infty \frac{(1-F(r))}{\mu}dr \tag{9}$$

where μ is expected value of CRI and $F(r)$ be the cumulative distribution function of CRI [7]. If we ignore period of menses, the remaining non menstrual days may reasonably be considered to be process occurring for a long time. Therefore, the results from renewal theory can be applied as $t\to\infty$.

$\mu=\frac{(\theta+2)}{\theta\,(\theta+1)}$ and

$F(r)=1-\frac{(\theta+1+\theta r)}{(\theta+1)}\exp(-\theta r)\,,\; r>0,\; \theta>0$

Hence, we have

$$P\{g(t)>x\}=\frac{\theta}{(\theta+2)}\int_x^\infty(\theta+1+\theta r)\exp(-\theta r)\,dr \tag{10}$$

$$P\{g(t)>x\}=\frac{(\theta+2+\theta x)}{(\theta+2)}\exp(-\theta x) \tag{11}$$

And since $P\{g(t)>0\}=1$, as probability of no intercourse in the interval length zero will always be equal to one. Hence, we have

$$P\{g(t)\le x\}=1-\frac{(\theta+2+\theta x)}{(\theta+2)}\exp(-\theta x) \tag{12}$$

Further, conditional probability of conception on any day given that intercourse take place on that day and ovulation on day D is required. For this purpose, the two models that were used are given in Table 2. Model A could correspond to a peaked fertile period; Model B to a broader fertile period. The values for Model A was suggested by R.G. Potter to Peter A. Lachenbruch , while those for Model B was postulated by Lachenbruch [11] to give a broader fertile period.

In order to calculate chance of coital pattern we need the probabilities: $g(k)>1$, : $g(k)>2$, : $g(k)>3$ and : $g(k)>4$ for k=D-2, D-1, D, D+1. These probabilities can be calculated through equation (11). Consider a coital pattern where coitus takes place on 2nd and 3rd day in the four days fertile period. It is immaterial whether one or more than one coitus take place on any days. The probability of this pattern is calculated by:

$$\begin{aligned}&P[\mathit{coitus\ takes\ place\ on\ 2nd\ \&\ 3rd\ days}]\\ &\quad= P[\mathit{one\ or\ more\ coitus\ take\ place\ on\ 2nd\ day}]\\ &\quad * P[\mathit{one\ or\ more\ coitus\ take\ place\ on\ next\ day}] * P[\mathit{no\ coitus\ for\ at\ least\ one\ day}]\end{aligned}$$

$$=[P(g(t)>1)-P(g(t)>2)]\,P(g(t)\le 1)\,P(g(t)>1) \tag{13}$$

If c_1, c_2, c_3 and c_4 represents the probability of conception if intercourse takes place on days D-2, D-1, D and D+1 respectively and ovulation on day D, the associated probability of conception corresponding to above coital pattern (2nd & 3rd day) is calculated as follows:

$$= P[Conception\ on\ 2nd\ day\ of\ the\ fertile\ period] + P[No\ conception\ on\ 2nd\ day\ but\ conception\ on\ 3rd\ day\ of\ the\ fertile\ period]$$

$$= c_2 + (1 - c_2)c_3 \quad (14)$$

Similarly, probabilities of other possible coital patterns and associated probabilities of conceptions are presented in the Table 3.

Next the monthly probability of conception for Lindley conditional risk of intercourse can be obtained by sum of product of probabilities obtained from equation (13) and (14) for the all 16 possible coital patterns. These probabilities for varying values of parameters of Lindley CRI under Model A and B are illustrated in the Table 4 and corresponding variation in expected inter-coital interval is shown in Fig 2.

As seen in Table 4, under both Model A and B, the monthly probabilities of conception increases with increasing value of parameter θ. It is worthwhile to mention that the monthly probability of conception is more under peaked fertile period (Model A) than that of broader fertile period (Model B). Table 4 clearly shows that for the varying value of parameters, there is noticeable change in the monthly probability of conception and expected inter-coital length. It can also be observed that there would be exponential rate of decline in the average length between successive intercourses with the rise in the value parameter (θ) (Fig 2). Initially on increasing the value of parameter, the expected inter-coital length falls rapidly and the rise in the probability of conception is slow. However, when $\theta > 0.425$, the average inter-coital length decline slowly and the upsurge in probability of conception is fast. For $\theta = 0.8$, the monthly probability on conception lies between 0.31 to 0.36 and corresponding expected length of inter-coital interval equals to 2 days. As the expected length of inter-coital interval becomes 4 days ($\theta = 0.425$), the monthly probability of conception drops down to 0.19 to 0.21. Likewise, when the average inter-coital length changes to 9.2 days, the monthly probability of conception reduces to 0.09-0.10.

3 Discussion

Usual fecundability estimates fluctuate from 0.11 to 0.33 and this variation is present among both type of women who are either using any contraceptives or without any contraceptive ([3], [10], [12], [18], [22], [25]). Our model can provide these estimates for all aged women based on expected length of time since last coitus. The probabilities of coital pattern computed differently from that of Glaser and Lachenbruch [9]. Here we have considered 4 days fertile period for simplicity. Our model can also be extended for the 6 days fertile period as suggested by Wilcox et al. [24]. The marked change in the monthly probabilities of conception with little change in the parameter values reflects the effect of various patterns of intercourse. The timing of intercourse is crucial for both types of couple who want to avoid pregnancy and those who want another child soon. However, couples must have some idea of timing of ovulation so that they may change their pattern of intercourse according to their desire.

The expected length of inter-coital interval vary with age as the frequency of intercourse goes down with increasing age [19]. Hence, based on estimates of average length of time between successive coitus, frequency and timing of intercourse may provide us the monthly probability of conception through the help of this study. However, our model is not ultimate as we overlooked several potential covariates (age, nutritional status, lifestyle factors, and prenatal factors etc., time dependency) in our model affecting fecundability. In the example presented here, the number of non-menstrual days was fixed at 24 days. In reality, the length of menstrual cycle as well as days of menses is highly variable from women to women. Therefore, in order to realize human reproduction behavior, there is a need to extend these results and incorporate unobserved confounding variable that are overlooked here completely.

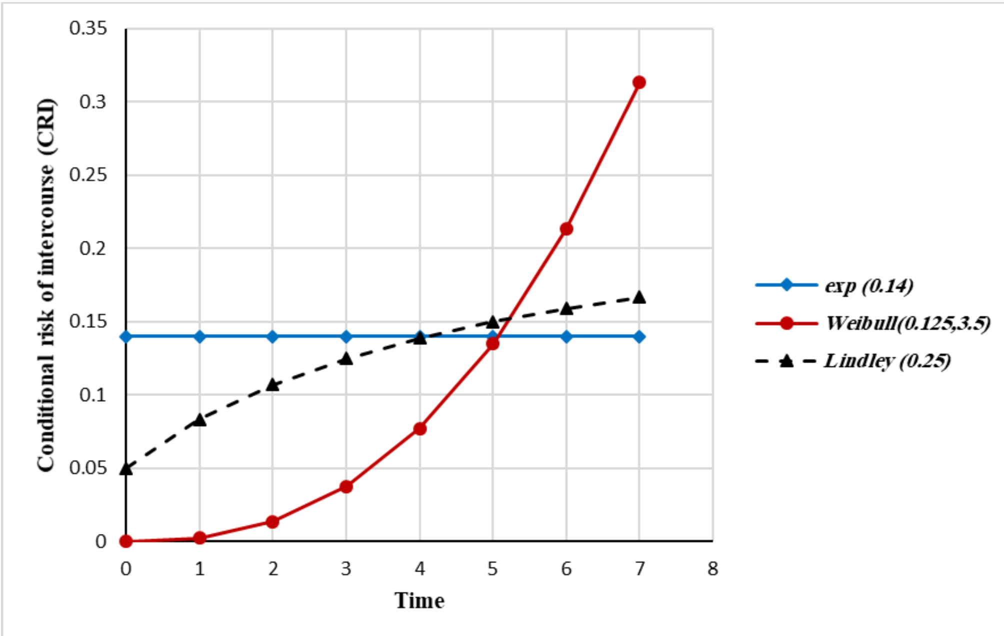

Fig. 1: CRI for different distribution with common average inter-coital length= 7.2. Here solid CRI are assumed by Glaser and Lachenburgh (1969) and dotted CRI are considered in this paper.

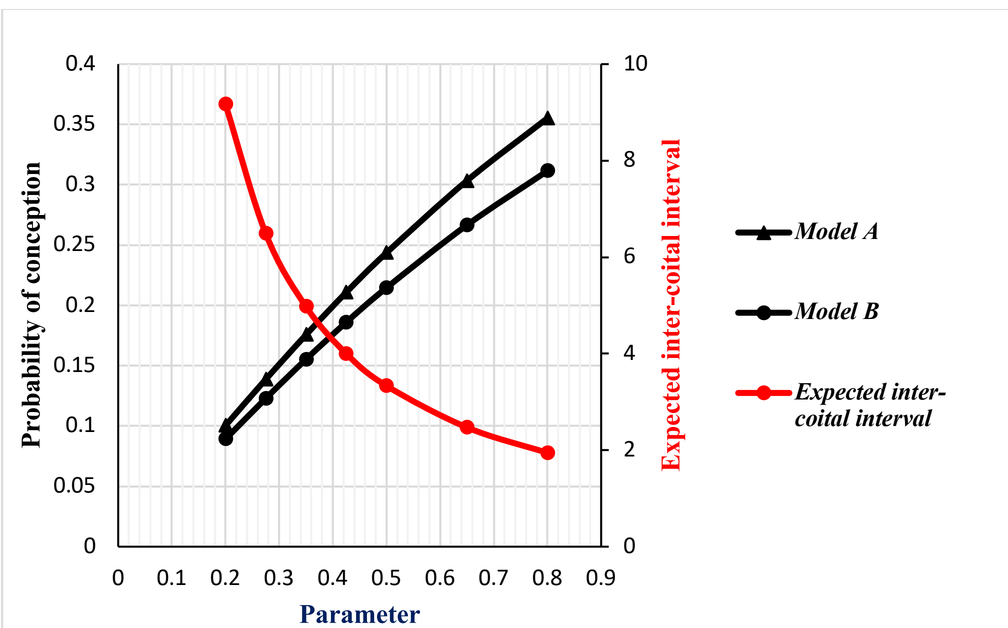

Fig.2: Variation of monthly probabilities of conception and expected inter-coital interval according to variation in the parameter (θ)

Table 1: Probabilities that the interval between successive intercourse end on a given day, as measured from the last intercourse for Lindley distribution with mean=4

Interval end on day	Probability of intercourse during interval based on Lindley distribution ($\theta = 0.425$)
1	0.15
2	0.17
3	0.16
4	0.13
5	0.10
6	0.08
7	0.08
8	0.04
≥9	0.11

Table 2: Chance of conception by day of intercourse given ovulation on day D.

Probability of conception	Date of Intercourse			
	D-2	**D-1**	**D**	**D+1**
Model A	0.05	0.3	0.5	0.05
Model B	0.1	0.2	0.3	0.2

Model A is suggested by R.G.Potter
Model B is suggested by Peter A. Lachenbruch

Table 3: Intercourse pattern during the four days fertile period, their probabilities and associated probability of conception if ovulation occurs on day D

Intercourse pattern during the four days fertile period	Probability of intercourse pattern	Associated probability of conception
None take place	$P(g(t) > 4)$	0
One takes place: Day 1	$P(g(t) \leq 1)\, P(g(t) > 3)$	c_1
Day 2	$[P(g(t) > 1) - P(g(t) > 2)]\, P(g(t) > 2)$	c_2
Day 3	$[P(g(t) > 2) - P(g(t) > 3)]\, P(g(t) > 1)$	c_3
Day 4	$[P(g(t) > 3) - P(g(t) > 4)]$	c_4
Two take place: Days 1,2	$[P(g(t) \leq 1]^2\, P(g(t) > 2)$	$c_1 + (1 - c_1)c_2$
Days 1,3	$P(g(t) \leq 1)[P(g(t) > 1) - P(g(t) > 2)]\, P(g(t) > 1)$	$c_1 + (1 - c_1)c_3$
Days 1,4	$P(g(t) \leq 1)[P(g(t) > 2) - P(g(t) > 3)]$	$c_1 + (1 - c_1)c_4$
Days 2,3	$[P(g(t) > 1) - P(g(t) > 2)]\, P(g(t) \leq 1)\, P(g(t) > 1)$	$c_2 + (1 - c_2)c_3$
Days 2,4	$[P(g(t) > 1) - P(g(t) > 2)]^2$	$c_2 + (1 - c_2)c_4$
Days 3,4	$[P(g(t) > 2) - P(g(t) > 3)]\, P(g(t) \leq 1)$	$c_3 + (1 - c_3)c_4$
Three take place: Days 1,2,3	$P(g(t) \leq 1)^3\, P(g(t) > 1)$	$c_1 + (1 - c_1)c_2 + (1 - c_1)(1 - c_2)c_3$
Days 1,3,4	$P(g(t) \leq 1)^2[\, P(g(t) > 1) - P(g(t) > 2)]$	$c_1 + (1 - c_1)c_3 + (1 - c_1)(1 - c_3)c_4$
Days 2,3,4	$[\, P(g(t) > 1) - P(g(t) > 2)]\, P(g(t) \leq 1)^2$	$c_2 + (1 - c_2)c_3 + (1 - c_2)(1 - c_3)c_4$
Days 1,2,4	$P(g(t) \leq 1)^2[\, P(g(t) > 1) - P(g(t) > 2)]$	$c_1 + (1 - c_1)c_2 + (1 - c_1)(1 - c_2)c_4$
Four take place: Days 1,2,3,4	$P(g(t) \leq 1)^4$	$c_1 + (1 - c_1)c_2 + (1 - c_1)(1 - c_2)c_3 + (1 - c_1)(1 - c_2)(1 - c_3)c_4$

Table 4: **Monthly probabilities of conception for Lindley conditional risk of intercourse with varying values of parameters under model A and B.**

	Parameter(θ)						
	0.20	**0.275**	**0.35**	**0.425**	**0.50**	**0.65**	**0.80**
Model A	0.1004	0.1387	0.1756	0.2108	0.2436	0.3034	0.3552
Model B	0.0892	0.1229	0.1553	0.1860	0.2146	0.2666	0.3115

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Declaration: *The views expressed by the author in this paper are his own and not that of the Government of India.*

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