HHS Public Access

Author manuscript

Am J Obstet Gynecol. Author manuscript; available in PMC 2024 April 29.

Published in final edited form as:

Am J Obstet Gynecol. 2023 May ; 228(5): 557.e1–557.e10. doi:10.1016/j.ajog.2023.01.014.

Predicted probabilities of live birth following assisted reproductive technology using United States national surveillance data from 2016 to 2018

Audrey J. Gaskins, ScD,

Department of Epidemiology, Rollins School of Public Health, Emory University, Atlanta, GA

Division of Reproductive Health, National Center for Chronic Disease Prevention and Health Promotion, Centers for Disease Control and Prevention, Atlanta, GA

Yujia Zhang, PhD,

Division of Reproductive Health, National Center for Chronic Disease Prevention and Health Promotion, Centers for Disease Control and Prevention, Atlanta, GA

Jeani Chang, PhD,

Division of Reproductive Health, National Center for Chronic Disease Prevention and Health Promotion, Centers for Disease Control and Prevention, Atlanta, GA

Dmitry M. Kissin, MD, MPH

Division of Reproductive Health, National Center for Chronic Disease Prevention and Health Promotion, Centers for Disease Control and Prevention, Atlanta, GA

Abstract

BACKGROUND: As the use of in vitro fertilization continues to increase in the United States, up-to-date models that estimate cumulative live birth rates after multiple oocyte retrievals and embryo transfers (fresh and frozen) are valuable for patients and clinicians weighing treatment options.

OBJECTIVE: This study aimed to develop models that generate predicted probabilities of live birth in individuals considering in vitro fertilization based on demographic and reproductive characteristics.

STUDY DESIGN: Our population-based cohort study used data from the National Assisted Reproductive Technology Surveillance System 2016 to 2018, including 196,916 women who underwent 207,766 autologous embryo transfer cycles and 25,831 women who underwent 36,909 donor oocyte transfer cycles. We used data on autologous in vitro fertilization cycles to develop models that estimate a patient's cumulative live birth rate after all embryo transfers (fresh and frozen) within 12 months after 1, 2, and 3 oocyte retrievals in new and returning patients. Among patients using donor oocytes, we estimated the cumulative live birth rate after their first, second, and third embryo transfers. Multinomial logistic regression models adjusted for age, prepregnancy

Corresponding author: Audrey J. Gaskins, ScD. audrey.jane.gaskins@emory.edu.

The authors report no conflict of interest.

body mass index (imputed for 18% of missing values), parity, gravidity, and infertility diagnoses were used to estimate the cumulative live birth rate.

RESULTS: Among new and returning patients undergoing autologous in vitro fertilization, female age had the strongest association with cumulative live birth rate. Other factors associated with higher cumulative live birth rates were lower body mass index and parity or gravidity ≥1, although results were inconsistent. Infertility diagnoses of diminished ovarian reserve, uterine factor, and other reasons were associated with a lower cumulative live birth rate, whereas male factor, tubal factor, ovulatory disorders, and unexplained infertility were associated with a higher cumulative live birth rate. Based on our models, a new patient who is 35 years old, with a body mass index of 25 kg/m^2, no previous pregnancy, and unexplained infertility diagnoses, has a 48%, 69%, and 80% cumulative live birth rate after the first, second, and third oocyte retrieval, respectively. Cumulative live birth rates are 29%, 48%, and 62%, respectively, if the patient had diminished ovarian reserve, and 25%, 41%, and 52%, respectively, if the patient was 40 years old (with unexplained infertility). Very few recipient characteristics were associated with cumulative live birth rate in donor oocyte patients.

CONCLUSION: Our models provided estimates of cumulative live birth rate based on demographic and reproductive characteristics to help inform patients and providers of a woman's probability of success after in vitro fertilization.

Keywords

assisted reproduction; infertility; in vitro fertilization; live birth

Introduction

Assisted reproductive technologies (ARTs), including in vitro fertilization (IVF) with or without intracytoplasmic sperm injection (ICSI), have become one of the main treatment modalities for couples facing fertility problems.[1] In the United States, as of 2019, IVF contributes to >2% of all infants born.[2] Since 1995, the Centers for Disease Control and Prevention (CDC) has been collecting data on ART procedures performed in fertility clinics in the United States.[3] Annually, the CDC produces several reports (eg, clinic specific, state specific, and national) based on these data,[2,4] of which the clinic-specific report gives a potential patient an idea of their average probabilities of success, stratified by age group. However, because many other characteristics may affect the success of IVF, there is interest from patients and providers in developing clinical models that can estimate the individualized cumulative probability of a live birth before starting treatment and after any subsequent treatment cycles.[5]

Although previous IVF prediction models have been developed,[6] most models are using older data (before 2010) and predict the probability of a live birth after a fresh embryo transfer (ET).[7–11] In addition, the practice of IVF is rapidly changing, including the important contribution of embryo cryopreservation and subsequent treatment cycles to cumulative live birth rates (CLBRs).[1,12] Other changes in practice that have changed the profile of ART cycles include the increased use of frozen and thawed ET cycles, ICSI, preimplantation genetic testing (PGT), and elective single ET.[13–15] Therefore, it is important

for prediction models to reflect the current state of practice.[16] Moreover, donor oocytes are being increasingly used[17]; however, very few previous studies have identified factors that predict IVF outcomes in donor oocyte recipients.[18,19]

This analysis aimed to develop models that can predict CLBRs in patients undergoing autologous and donor oocyte IVFs according to demographic and reproductive characteristics using US national surveillance data between 2016 and 2018.

Materials and Methods

We used data from the CDC's National Assisted Reproductive Technology Surveillance System (NASS), which contains information on approximately 98% of all IVF cycles performed in the United States.[4] To verify the accuracy of reporting, a random sample of fertility clinics is selected annually for data validation. Discrepancy rates are <5% for most fields.[4] All fresh and frozen IVF cycles using autologous or donor oocytes reported to NASS during 2016 to 2018 were eligible for this analysis. Long-term banking cycles where the intent was to cryopreserve embryos for use in ≥12 months were excluded. Epidemiologic research using NASS data is approved by the institutional review board at the CDC.

We focused on 3 patient populations to develop the clinical models: (1) new patients, defined as having no history of ovarian stimulation, undergoing autologous ART who had an intended oocyte retrieval in 2016 or 2017; (2) return patients, who had a history of ovarian stimulation before 2016 or 2017, undergoing autologous ART who had at least 1 additional intended oocyte retrieval in 2016 or 2017; and (3) patients who used fresh or frozen donor oocytes for the first time for an ET cycle in 2016 or 2017. New and return patients with an oocyte retrieval in 2018 and donor oocyte patients who had their first transfer in 2018 were excluded as they did not have 12 months of follow-up to calculate CLBR.

Demographic, reproductive, and clinical characteristics routinely collected in NASS were considered for inclusion in the models based on the availability of data (eg, frequency of missingness) and their known association with CLBR. The following variables were considered: patient age, body mass index (BMI), parity, gravidity, infertility diagnosis, race and ethnicity, smoking status of the female partner, age of the male partner providing sperm, and most recent antimüllerian hormone (AMH) level. Of the variables included in our final model, only BMI had missing data (18%) and was imputed. Furthermore, we used multiple imputation to account for the missingness of some key descriptive variables, such as race and ethnicity (36%), sperm source (14%), number of oocytes retrieved (8.6%), and use of PGT (10.9%) (see Supplemental Materials and Methods for more details on the multiple imputation), but these variables were not included in the final model. In brief, the variables that were dropped from further consideration had a high amount of missing data, had little to no association with live birth, and/or were parameters that would be unknown to patients who have yet to start their IVF cycle. A more detailed description of the variable inclusion process is provided in the Supplemental Materials and Methods.

For all models, we focused on the cycle-level outcome of live birth delivery, which was defined as the birth of one or more live infants. In both new and return autologous oocyte

patients, we calculated the CLBR for all fresh or frozen ET cycles that occurred within 12 months of the patient's oocyte retrieval. In the NASS data, all ET cycles are linked to the specific oocyte retrieval the embryo originated from by oocyte retrieval date and patient identifier, thus allowing us to calculate the 12-month time window from retrieval to transfer. In new donor oocyte patients, we calculated the CLBR for up to 3 ET cycles that occurred within 12 months of their first ET cycle.

Among new IVF patients, a cumulative logistic regression or multinomial regression model was used to estimate the probability of live birth after 1, 2, and ≥3 ETs that occurred within 12 months of a woman's first oocyte retrieval.[20] For our models in new patients, the denominator was all new patients with intended oocyte retrievals, and the outcome had 4 levels: (1) if the first transfer resulted in live birth, (2) if the first transfer did not result in live birth but the second transfer resulted in live birth, (3) if the first and second transfers did not result in live birth but the third transfer resulted in live birth, and (4) if there was no birth for all transfers or there was no transfer within 12 months (reference group). Of note, most patients with no ET within 12 months had oocyte retrievals that were not successful—in other words, their retrieval was canceled because of poor response, they had no oocytes retrieved, or they had no viable embryos created. We did not remove the patients and cycles that did not progress to ET because this would have artificially inflated the CLBR estimates.

Assuming that the contribution of transfer to live birth varies but contributions of predictors are similar across transfers, we used the common slope approach to develop our models. The option "cumlogit" was used, which renders the same slope for all covariates and different intercepts for each outcome group. Second and third multinomial regression models were run for all transfers occurring within 12 months of a woman's second and third oocyte retrieval. To obtain the CLBR after the second or third retrieval and after up to 1, 2, and ≥3 ET cycles, we applied equations proposed by Luke et al (see Supplemental Materials and Methods for more details).[7] In addition, these equations were applied to calculate the CLBR after 3 oocyte retrievals and up to 1, 2, and ≥3 ET cycles. Among return IVF patients, we used a similar methodology. Logistic regression models were used to estimate the probability of live birth after a donor oocyte recipient patient's first, second, and third ET cycle. To obtain the CLBR after the second and third ET cycles, we applied the equations proposed by Luke et al.[7]

To determine the most appropriate way to model patient age, we plotted the empirical live birth rates by age and determined that a quadratic function was likely sufficient to model the nonlinear association between CLBRs and age. Next, we estimated the best-fitting power term using the PROC MODEL function in SAS (SAS Institute, Cary, NC). Patient BMI was modeled as a quadratic function across all models. To reduce the influence of outliers in the multivariable models, we truncated ages <20 and >46 years in new patients, <24 and >48 in return patients, <25 and >50 years in donor oocyte recipients as <1% of women fell outside these cutoffs. Across all models, we truncated BMIs <17 and >45 kg/m^2, for the same reasons as age. Infertility diagnoses, including male factor, tubal factor, endometriosis, ovulatory disorder, diminished ovarian reserve (DOR), uterine factor, other (ie, recurrent pregnancy loss, medical contraindication to pregnancy, use of a gestational carrier, or testing for genetic abnormality in an embryo), and unexplained were modeled as indicator variables

as >1 option can be reported. Gravidity and parity were each modeled as 3-level categorical variables (0, 1, and ≥2).

To assess the predictive ability of the models, we computed a C-statistic using the SAS macro "MultAUC."[21] Unlike the logistic model to which only 1 C-statistic is computed, in multinomial regression models, there are multiple C-statistics computed for each level of the outcome vs the reference. As the SAS macro is unable to handle datasets with multiple imputation, we used the average imputed BMI value for model fitting. The SAS macro is not currently able to provide an area under the curve or use the bootstrap method to obtain optimism-corrected C-statistic. We created calibration plots to show the agreement between observed and predicted CLBR for patients after 1, 2, and 3 oocyte retrievals. The observed probability of live birth for each retrieval was obtained in patients by age using Kaplan-Meier estimates, the number of patients with a live birth within 12 months of oocyte retrieval at a given age divided by the total number of patients at a given age. To generate the predicted CLBRs by patient age, first, we estimated each patient's predicted CLBR using the parameters shown in Supplemental Tables 1 to 3 in combination with the patient's specific values for each covariate. Next, we calculated the mean predicted CLBRs by patient age. Last, the observed and predicted CLBRs after a second and third oocyte retrieval in autologous oocyte patients and after a second and third ET in donor oocyte recipients were calculated using the Luke formula.[7]

Results

A total of 196,916 women (152,426 new patients and 44,490 return patients) who underwent autologous ART and 25,831 donor oocyte recipients were included in our analysis (Table 1). Women undergoing autologous ART were most often between 30 and 40 years (74%), were non-Hispanic White (64%), and had no previous pregnancy (50%) or live birth (73%). The most common infertility diagnoses were male factor (32%), DOR (28%), and other reasons (20%). Most women undergoing donor oocyte ART were between 41 and 59 years (59%), were non-Hispanic White (61%), had no previous pregnancy (48%) or live birth (75%), and had a diagnosis of DOR (67%). The autologous ART patients underwent 207,766 autologous ET cycles, and the donor oocyte recipients underwent 36,909 transfer cycles in 2016–2018 (Table 2). Most included cycles were frozen (60% for autologous and 46% for donor) and singe-embryo (59% for autologous and 65% for donor) transfers. ICSI was the most common fertilization method (75% for autologous and 68% donor), and PGT was used in more than a quarter of ET cycles (38% for autologous and 27% for donor). The unadjusted live birth rate per ET cycle was 43% for autologous and 49% for donor oocyte patients.

The predicted probability of live birth increased with patient age from 20 to 30 years and steadily declined after 30 years (Figure 1, A). Patient BMI had a nonlinear association with CLBR (Supplemental Figure 1, A). The success rates remained relatively constant for BMIs 17 to 25 kg/m^2 but had a negative relation with CLBR for BMIs >25 kg/m^2. In descending order of magnitude, new patients diagnosed with ovulatory disorder, unexplained, male factor, and tubal factor infertility had higher odds of live birth, whereas patients with DOR, uterine factor, and other reasons had lower odds of live birth compared with patients

without that infertility diagnosis (Figure 2; Supplemental Table 1). Parity and gravidity were inconsistently associated with live birth (Supplemental Table 1). Our model predicted that a new patient who is 35 years, with a BMI of 25 kg/m^2, no previous pregnancy or live birth, and an unexplained infertility diagnosis, has a 48%, 69%, and 80% CLBR after 1, 2, and 3 oocyte retrievals and all ETs (fresh or frozen) in the following year (Figure 3). These CLBRs are 43%, 64%, and 76%, respectively, if an otherwise identical patient has a BMI of 35 kg/m^2; 29%, 48%, and 62%, respectively, if this same patient (with a BMI of 25 kg/m^2) has an infertility diagnosis of DOR; and 25%, 41%, and 52%, respectively, if this same patient (with a BMI of 25 kg/m^2 and unexplained infertility) was 40 years old.

Among return patients, female age also had a nonlinear association with CLBR with success rates peaking around 30 years and steeply declining (Figure 1, B). The negative association between higher BMI and lower CLBR was less consistent in return compared with new patients (Supplemental Figure 1, B). Return patients with one or more previous pregnancies or live births had higher odds of live birth than nulligravid and nulliparous return patients (Supplemental Table 2). The effect of infertility diagnoses on CLBR was consistent in direction and magnitude in new and return patients such that patients with ovulatory disorders had the highest predicted CLBR and patients with DORs had the lowest predicted CLBR (Supplemental Table 2). Figure 3, B, displays the predicted probabilities of live birth for return patients for various characteristics.

Few recipient characteristics were associated with CLBR in new donor oocyte patients. Recipient age and BMI had weak, negative, inconsistent associations with CLBR (Figure 1, C; Supplemental Figure 1, C). Tubal factor, uterine factor, and unexplained infertility were the only infertility diagnoses that were associated with lower CLBR after 1 ET (Supplemental Table 3); however, after 2 ETs, only tubal factor, ovulatory disorders, and other reasons were associated with CLBRs. No infertility diagnosis was associated with CLBR after 3 ETs. Higher gravidity was associated with higher CLBR safter 1 ET but not after 2 or 3 transfers. Parity of the donor oocyte recipient was not associated with CLBR in any of the models. As evidenced from Figure 3, C, the predicted cumulative probability of live birth for donor oocyte recipients was high, between 82% and 88%, after up to 3 ETs, and this did not vary significantly by recipient age, BMI, or infertility diagnosis.

The computed C-statistic among new patients ranged from 0.69 to 0.78, indicating a good capacity to discriminate between patients with high and low probabilities of success (Supplemental Table 4). Among return patients, the range of the computed C-statistic values was even higher (0.72–0.82). In contrast, the models among donor oocyte patients yielded C-statistics of 0.54 to 0.57, indicating poor discrimination ability. The calibration plots showed high agreement between the observed and predicted CLBR across ages among all 3 patient populations (Supplemental Figure 2).

Comment

Principal findings

Using national data from 2016 to 2018, our study provides the most up-to-date estimates of the cumulative probability of live birth based on demographic and reproductive

characteristics for new and return autologous oocyte patients and donor oocyte recipient patients undergoing IVF in the United States. Moreover, additional detail is provided on the CLBR after each additional ET cycle within 12 months of oocyte retrieval to allow for further insight into a patient's expected outcomes.

Results of the study in the context of other observations

Although a wide variety of clinical prediction models for IVF have been developed,[6] our model has several important distinctions. Most previous models have only estimated live birth rates after a single or multiple fresh ET cycles.[7–11] There is growing use of frozen ET cycles, which are now more common than fresh ETs.[1,12] Moreover, most existing models were fit using older data—from cycles completed more than 10 years ago—which does not reflect current practices.[7,22] For example, there has been increasing use of ICSI,[13] PGT,[14] and elective single ET for the past 2 decades,[15] all of which have influenced IVF success rates. In addition, there are instances where prediction models were developed for use in a specific patient population[23] or clinic.[24] Although this may be advantageous in certain scenarios, our goal was to provide useful information to as many potential IVF patients as possible by capitalizing on the NASS database, which contains approximately 98% of IVF cycles performed in the United States.[25]

To date, the most similar clinical model comes from McLernon et al[26] who used data from the Society for Assisted Reproduction and Technology Clinic Outcome Reporting System 2014–2016 to develop a pre- and post-treatment model of CLBR after IVF. Similar to our study, they used a validated database that encompassed almost all of the nonbanking fresh and frozen IVF cycles in the United States during that period. Furthermore, they focused on a similar outcome—CLBR after 3 oocyte retrievals and all transfers from each oocyte retrieval in the following 12 months. However, there were several important differences. First, we used data from more recent years, 2016 to 2018, to develop our models. Furthermore, we did not apply as many exclusion criteria. We included women without infertility as a reason for IVF treatment and women who used PGT and donor sperm. This resulted in a larger sample size for both our new (152,426 vs 88,613) and return (44,490 vs 24,735) patient populations, which is likely representative of a wider scope of patients. Moreover, we included a third patient population, women undergoing donor oocyte IVF (n=25,831), to further enhance the generalizability of our findings to the widest scope of patients. In addition to providing the CLBR after a complete cycle (defined as all ETs within 12 months of the oocyte retrieval), we also estimated CLBR after each ET to provide further granularity on success rates to patients. Scenarios in which this may be useful include patients with too few embryos to support multiple transfers from a single retrieval or patients who only have insurance coverage for 1 transfer. Although the factors included in our models were similar (including age, BMI, parity, and specific infertility diagnoses), we did not include AMH or any posttreatment factors, such as number of oocytes retrieved. This was done to ensure that we could provide estimates of success to as many potential IVF patients as possible, even those who had yet to obtain a full infertility workup and may not know their AMH concentration. Despite these differences, our models achieved similar discriminatory ability and produced similar estimated probabilities of success to the McLernon study.

Although our models in new and return patients undergoing autologous IVF performed well, as evidenced by C-statistics ranging from 0.69 to 0.82, the donor oocyte recipient model did not have a good discriminatory ability. This is likely because all of the recipient characteristics included in the model were only weakly associated with CLBR and the sample size was more limited. The CLBRs for donor oocyte IVF patients were high regardless of recipient characteristics. Future models in this population may want to consider adding donor characteristics or evaluating other recipient factors to further enhance the performance.

Strengths and limitations

First, because our data were derived from a large database meant for surveillance, we were limited by the accuracy of the data inputted by individual providers and clinics. Moreover, we were not able to include some potentially important predictors of success because either they were not reliably or routinely collected or they had too much missing data. For example, a wealth of literature supports an association between smoking and worse IVF outcomes[27]; however, we did not find this to be strongly associated with CLBRs in our dataset likely because of underreporting. For the donor oocyte recipient models, we also lacked information on donor characteristics, most notably donor age, which may have improved our discriminatory capabilities. Furthermore, we explicitly decided not to include race and ethnicity in our models because of concerns about the validity of this variable and how results would be interpreted.[28] Markers of ovarian reserve, such as AMH, may also be more relevant for inclusion in future models as clinical and at-home testing for this biomarker become more standardized and routine.[29]

Because of the nature of the NASS database, we were unable to identify women who were treated at >1 clinic. Although we expected this to be uncommon, it may have resulted in some patients being counted more than once. Although we included 8 infertility diagnoses in our models, some of these, such as unexplained infertility and infertility because of other reasons, are heterogeneous. Because of the lower number of patients who had 2 or 3 oocyte retrievals, our ability to predict CLBR in these patients was slightly lower. Nevertheless, the C-statistics from these models still indicated good discriminatory ability. Finally, our CLBRs after the second and third ETs may be conservative estimates. The only patients who had a second and third ET within 12 months of their oocyte retrieval are patients whose first ET cycle failed and, thus, may be lower prognosis patients. In addition, these patients would likely be using their second, third, fourth, or higher-choice embryos for these transfers, which may have resulted in lower success rates. Moreover, many patients did not attempt a second or third ET during the timeframe (for various unknown reasons), even though they had supernumerary embryos available. Had they cycled and had we been able to include their outcomes in this analysis, it could have boosted CLBRs within a year; however, this usage pattern reflects the reality of IVF in the United States; therefore, our estimated success rates reflected this.

Conclusions and future research directions

Using a large, national dataset encompassing nearly all IVF cycles in the United States, our study developed clinical models for use in new and return patients undergoing autologous

IVF and donor oocyte recipient patients to provide individualized estimates of cumulative probability of live birth after multiple fresh and frozen ETs. These models will be used to update the IVF success estimator tool on the CDC website (https://www.cdc.gov/art/ivf-success-estimator/index.html) that can help inform patients and providers of a woman's probability of having a live birth after IVF.

Supplementary Material

Refer to Web version on PubMed Central for supplementary material.

Acknowledgments

This study was supported by the Centers for Disease Control and Prevention. The findings and conclusions in this report are those of the authors and do not necessarily represent the official position of the Centers for Disease Control and Prevention.

References

1. Chambers GM, Dyer S, Zegers-Hochschild F, et al. International Committee for Monitoring Assisted Reproductive Technologies world report: assisted reproductive technology, 2014†. Hum Reprod 2021;36:2921–34. [PubMed: 34601605]
2. Sunderam S, Zhang Y, Jewett A, Kissin DM. State-specific assisted reproductive technology surveillance, United States. Data Brief. Atlanta, GA: National Center for Chronic Disease Prevention and Health Promotion; 2021. Available at: https://www.cdc.gov/art/state-specific-surveillance/2019/pdf/State-Specific-ART-Surveillance-U.S.-2019-Data-Brief-h.pdf.
3. Centers for Disease Control and Prevention, American Society for Reproductive Medicine, Society for Assisted Reproductive Technology, RESOLVE. Assisted reproductive technology success rates. Atlanta, GA: United States Department of Health and Human Services; 1997:1995.
4. Centers for Disease Control and Prevention. 2019 Assisted reproductive technology fertility clinic and national summary report. Atlanta, GA: United States Department of Health and Human Services; 2021.
5. van Loendersloot L, Repping S, Bossuyt PM, van der Veen F, van Wely M. Prediction models in in vitro fertilization; where are we? A mini review. J Adv Res 2014;5:295–301. [PubMed: 25685496]
6. Ratna MB, Bhattacharya S, Abdulrahim B, McLernon DJ. A systematic review of the quality of clinical prediction models in in vitro fertilisation. Hum Reprod 2020;35:100–16. [PubMed: 31960915]
7. Luke B, Brown MB, Wantman E, et al. A prediction model for live birth and multiple births within the first three cycles of assisted reproductive technology. Fertil Steril 2014;102:744–52. [PubMed: 24934487]
8. Nelson SM, Lawlor DA. Predicting live birth, preterm delivery, and low birth weight in infants born from in vitro fertilisation: a prospective study of 144,018 treatment cycles. PLoS Med 2011;8:e1000386. [PubMed: 21245905]
9. Templeton A, Morris JK, Parslow W. Factors that affect outcome of in-vitro fertilisation treatment. Lancet 1996;348:1402–6. [PubMed: 8937279]
10. Dhillon RK, McLernon DJ, Smith PP, et al. Predicting the chance of live birth for women undergoing IVF: a novel pretreatment counselling tool. Hum Reprod 2016;31:84–92. [PubMed: 26498177]
11. Vaegter KK, Lakic TG, Olovsson M, Berglund L, Brodin T, Holte J. Which factors are most predictive for live birth after in vitro fertilization and intracytoplasmic sperm injection (IVF/ICSI) treatments? Analysis of 100 prospectively recorded variables in 8,400 IVF/ICSI single-embryo transfers. Fertil Steril 2017;107:641–8.e2. [PubMed: 28108009]
12. Christianson MS, Stern JE, Sun F, et al. Embryo cryopreservation and utilization in the United States from 2004–2013. F S Rep 2020;1:71–7. [PubMed: 34223221]

13. Boulet SL, Mehta A, Kissin DM, Warner L, Kawwass JF, Jamieson DJ. Trends in use of and reproductive outcomes associated with intracytoplasmic sperm injection. JAMA 2015;313:255–63. [PubMed: 25602996]
14. Roche K, Racowsky C, Harper J. Utilization of preimplantation genetic testing in the USA. J Assist Reprod Genet 2021;38:1045–53. [PubMed: 33904009]
15. Styer AK, Luke B, Vitek W, et al. Factors associated with the use of elective single-embryo transfer and pregnancy outcomes in the United States, 2004–2012. Fertil Steril 2016;106:80–9. [PubMed: 26997248]
16. Jenkins DA, Martin GP, Sperrin M, et al. Continual updating and monitoring of clinical prediction models: time for dynamic prediction systems? Diagn Progn Res 2021;5:1. [PubMed: 33431065]
17. Kawwass JF, Monsour M, Crawford S, et al. Trends and outcomes for donor oocyte cycles in the United States, 2000–2010. JAMA 2013;310:2426–34. [PubMed: 24135860]
18. Malhotra N, Gupta M, Yadav A, et al. Multivariate analysis of oocyte donor and recipient factors affecting cumulative live birth rate in oocyte donor IVF (OD-IVF) cycles. JBRA Assist Reprod 2021;25:549–56. [PubMed: 34338480]
19. Braga DPAF Setti AS, Iaconelli A Jr, Borges E Jr. Predictive factors for successful pregnancy in an egg-sharing donation program. JBRA Assist Reprod 2020;24:163–9. [PubMed: 32157861]
20. El-Habil AM. An application on multinomial logistic regression model. Pak J Stat Oper Res 2012;8:271–91.
21. Hand DJ, Till RJ. A simple generalisation of the area under the ROC curve for multiple class classification problems. Mach Learn 2001;45:171–86.
22. McLernon DJ, Steyerberg EW, Te Velde ER, Lee AJ, Bhattacharya S. Predicting the chances of a live birth after one or more complete cycles of in vitro fertilisation: population based study of linked cycle data from 113 873 women. BMJ 2016;355:i5735. [PubMed: 27852632]
23. Tal R, Seifer DB, Tal R, Granger E, Wantman E, Tal O. AMH highly correlates with cumulative live birth rate in women with diminished ovarian reserve independent of age. J Clin Endocrinol Metab 2021;106:2754–66. [PubMed: 33729496]
24. van Loendersloot LL, van Wely M, Repping S, Bossuyt PM, van der Veen F. Individualized decision-making in IVF: calculating the chances of pregnancy. Hum Reprod 2013;28:2972–80. [PubMed: 23925394]
25. Toner JP, Lanes A, Kissin DM. Chapter 18: ART surveillance in North America. In: Kissin DM, Adamson GD, Chambers GM, De Geyter C, eds. Assisted reproductive technology surveillance. Cambridge, United Kingdom of Great Britain and Northern Ireland: Cambridge University Press; 2019.
26. McLernon DJ, Raja EA, Toner JP, et al. Predicting personalized cumulative live birth following in vitro fertilization. Fertil Steril 2022;117:326–38. [PubMed: 34674824]
27. Practice Committee of the American Society for Reproductive Medicine. Smoking and infertility: a committee opinion. Fertil Steril 2018;110:611–8. [PubMed: 30196946]
28. Vyas DA, Eisenstein LG, Jones DS. Hidden in plain sight - reconsidering the use of race correction in clinical algorithms. N Engl J Med 2020;383:874–82. [PubMed: 32853499]
29. Iliodromiti S, Anderson RA, Nelson SM. Technical and performance characteristics of anti-Mullerian hormone and antral follicle count as biomarkers of ovarian response. Hum Reprod Update 2015;21:698–710. [PubMed: 25489055]

AJOG at a Glance

Why was this study conducted?

As the use of in vitro fertilization (IVF) continues to increase in the United States, models that estimate cumulative live birth rates (CLBRs) are valuable for patients and clinicians weighing treatment options. This analysis aimed to provide individualized estimates of CLBRs for individuals considering IVF using national surveillance data from 2016 to 2018 in the United States.

Key findings

In this population-based cohort of more than 200,000 patients undergoing IVF in the United States, our models had high discrimination for estimating the cumulative probability of live birth in new and return autologous (but not donor) oocyte patients.

What does this add to what is known?

Our models provide individualized estimates of the cumulative probability of a live birth to help inform patients and providers of a woman's probability of success after IVF.

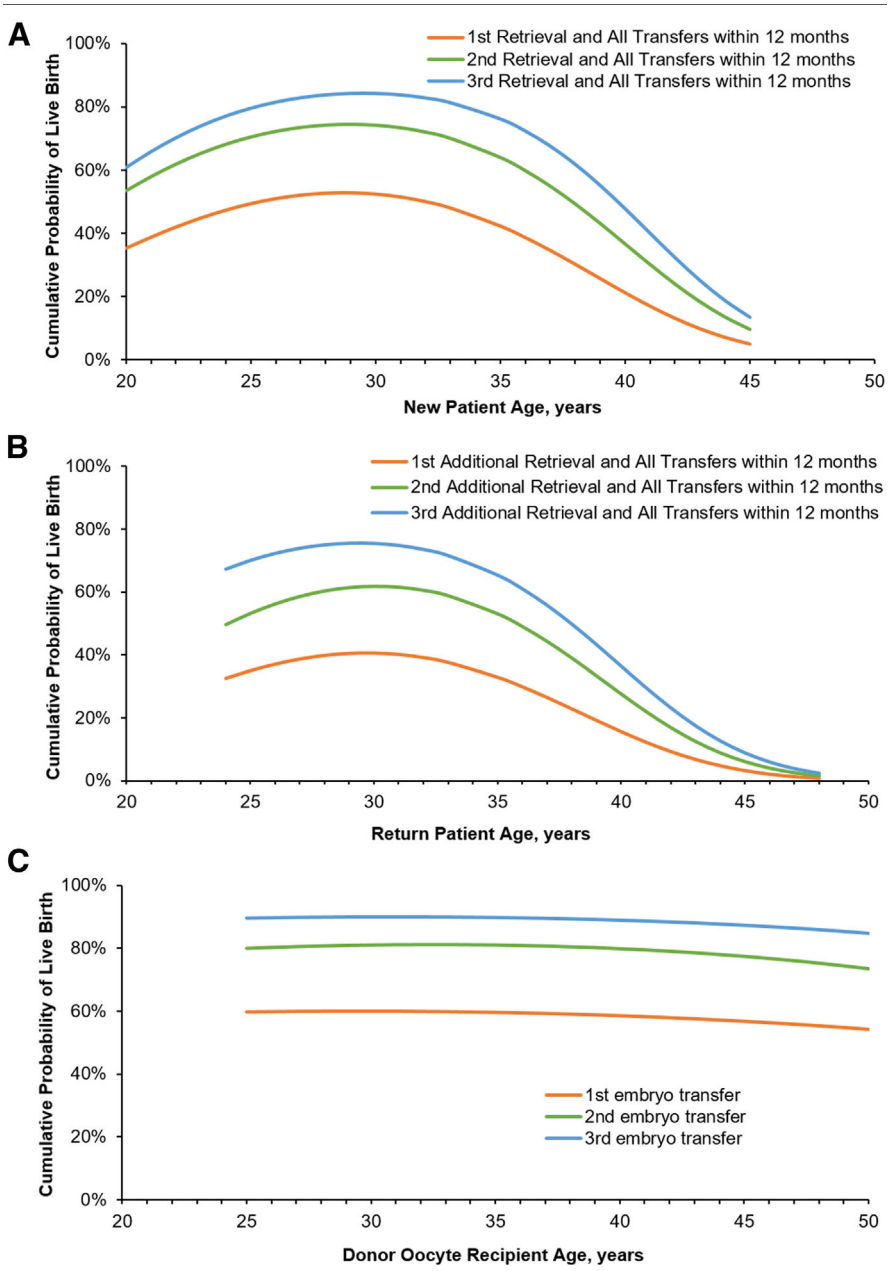

FIGURE 1. Cumulative probability of live birth according to patient age

A, New patients. **B,** Return patients. **C,** Recipient patients. Predicted cumulative probabilities of live birth are shown for a patient with a body mass index of 23 kg/m^2, unexplained infertility, and no previous pregnancy or live birth. Results are only shown for the range of ages where the model is valid (eg, 20–45 years for new patients, 24–48 years for return patients, and 25–50 years for donor oocyte recipient patients). In autologous oocyte patients, the cumulative probability of live birth was calculated for all transfers that occurred within 12 months of oocyte retrieval. In new donor oocyte patients, the cumulative probability of live birth was calculated for up to 3 transfers that occurred within 12 months of their first embryo transfer cycle.

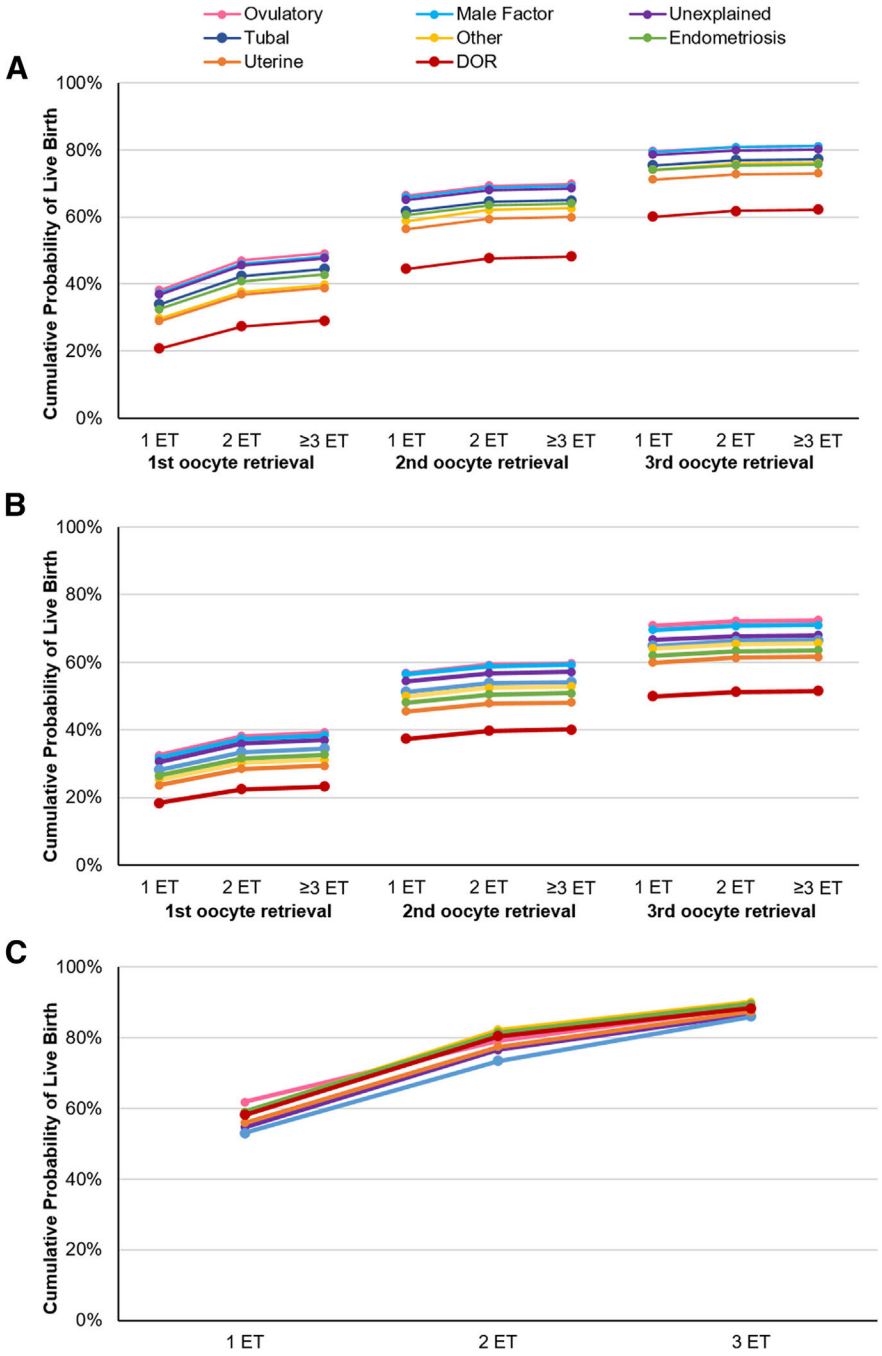

FIGURE 2. Cumulative probability of live birth according to infertility diagnosis

A, New patients. **B,** Return patients. **C,** Recipient patients. Predicted cumulative probabilities of live birth are shown for a patient with an age of 35 years, body mass index of 23 kg/m^2, and no previous pregnancy or live birth. In autologous oocyte patients, the cumulative probability of live birth was calculated after 1, 2, and ≥3 ETs (eg, all transfers) that occurred within 12 months of oocyte retrieval. In new donor oocyte patients, the cumulative probability of live birth was calculated after 1, 2, and 3 ETs that occurred within 12 months of their first ET cycle.

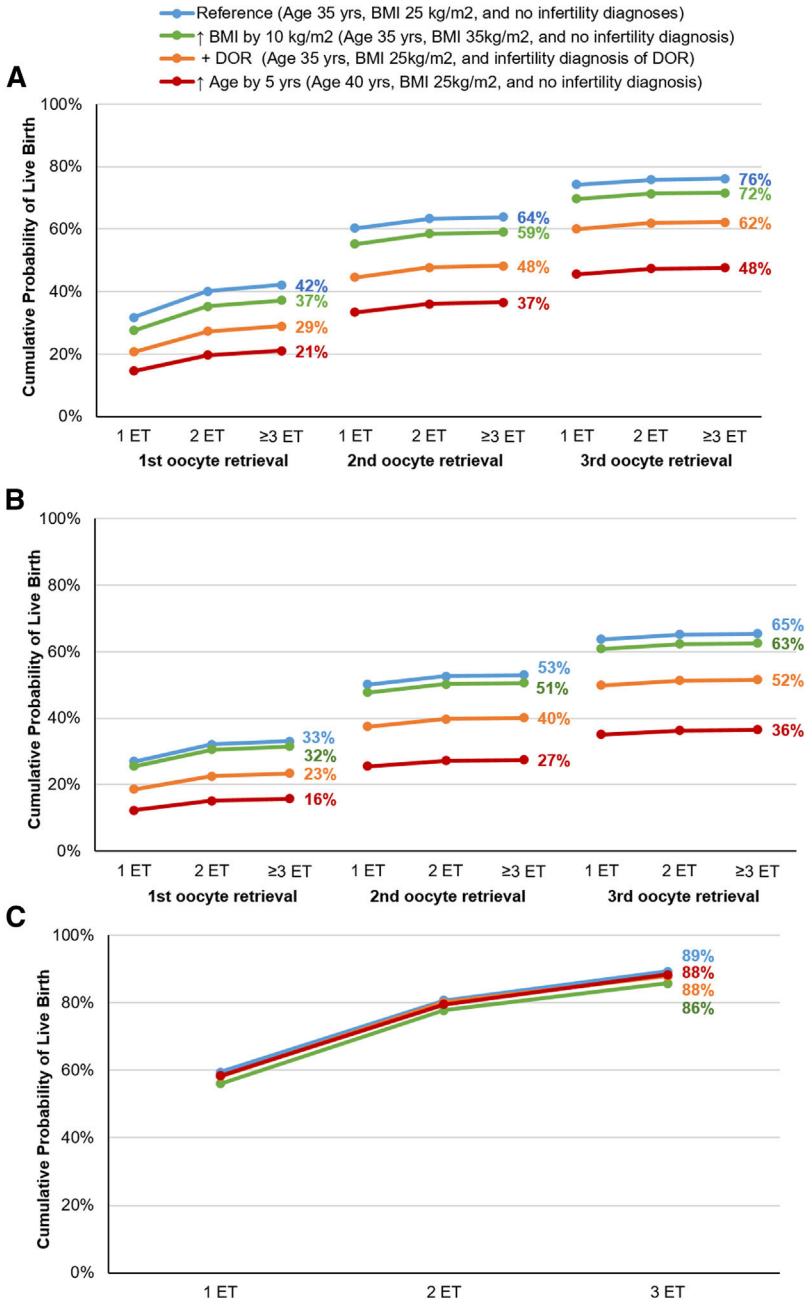

FIGURE 3. Example of predicted cumulative probabilities of live birth for patients with a BMI of 25 kg/m^2 vs 35 kg/m^2, unexplained infertility vs DOR, and aged 35 vs 40 years

A, New patients. **B,** Return patients. **C,** Recipient patients. Predicted cumulative probabilities of live birth are shown for a patient with an age of 35 years, BMI of 25 kg/m^2, unexplained infertility, and no previous pregnancy or live birth, unless otherwise indicated. In autologous oocyte patients, the cumulative probability of live birth was calculated after 1, 2, and ≥3 ETs (eg, all transfers) that occurred within 12 months of oocyte retrieval. In new donor oocyte patients, the cumulative probability of live birth was calculated after 1, 2, and 3 ETs that occurred within 12 months of their first ET cycle.

Am J Obstet Gynecol. Author manuscript; available in PMC 2024 April 29.

TABLE 1

Characteristics of women who underwent autologous ART at their first intended oocyte retrieval and women using donor oocytes at their first transfer

Variable	Women undergoing autologous ART	Women undergoing donor oocyte ART
Number of women	196,916	25,831
Age (y)		
18–29	22,749 (11.6)	918 (3.6)
30–34	63,086 (32.0)	2694 (10.4)
35–37	43,995 (22.3)	2882 (11.2)
38–40	37,729 (19.2)	4030 (15.6)
41–43	22,235 (11.3)	6077 (23.5)
44–59	7122 (3.6)	9230 (35.7)
BMI (kg/m^2)[a]		
<18.5	7994 (4.1)	1427 (5.5)
18.5–24.9	95,169 (48.3)	11,577 (44.8)
25.0–29.9	51,398 (26.1)	7261 (28.1)
30.0–34.9	25,540 (13.0)	3582 (13.9)
≥35.0	16,815 (8.5)	1983 (7.7)
Race and ethnicity[a]		
Non-Hispanic White	125,892 (63.9)	15,705 (60.8)
Non-Hispanic Black	14,719 (7.5)	2005 (7.8)
Asian	37,315 (18.9)	5598 (21.7)
Hispanic	16,488 (8.4)	2174 (8.4)
Other[b]	2502 (1.3)	349 (1.4)
Number of previous pregnancies		
0	98,156 (49.8)	12,441 (48.2)
1	45,280 (23.0)	5411 (20.9)
≥2	53,480 (27.2)	7979 (30.9)
Number of previous live births		
0	143,523 (72.9)	19,296 (74.7)

Variable	Women undergoing autologous ART	Women undergoing donor oocyte ART
1	38,503 (19.6)	4356 (16.9)
≥2	14,890 (7.6)	2179 (8.4)
Previous IVF treatments		
0	152,426 (77.4)	8371 (32.4)
1	16,574 (8.4)	5771 (22.3)
2	11,335 (5.8)	3366 (12.0)
≥3	16,581 (8.4)	6405 (24.8)
Infertility diagnosis or reason for IVF[c]		
Male factor	62,406 (31.7)	4199 (16.3)
Endometriosis	14,687 (7.5)	1213 (4.7)
Tubal factor	24,659 (12.5)	1493 (5.8)
Ovulatory disorder	29,541 (15.0)	1451 (5.6)
Diminished ovarian reserve	54,935 (27.9)	17,227 (66.7)
Uterine factor	11,159 (5.7)	1521 (5.9)
Other reason	40,029 (20.3)	6303 (24.4)
Unexplained	25,906 (13.2)	1151 (4.5)
Sperm source		
Donor	12,432 (6.3)	2987 (11.6)
Male partner	184,139 (93.5)	22,189 (85.9)
Combination	42 (<0.1)	383 (1.5)
Unknown	303 (0.2)	272 (1.1)
Paternal age (y)[d]		
<25	643 (0.3)	31 (0.1)
25–30	15,966 (8.7)	773 (3.5)
31–33	27,958 (15.2)	1482 (6.7)
34–36	37,657 (20.5)	2606 (11.7)
37–39	34,757 (18.9)	3284 (14.8)
40–45	44,249 (24.0)	7554 (34.0)
46–50	12,994 (7.1)	3490 (15.7)

Variable	Women undergoing autologous ART	Women undergoing donor oocyte ART
>50	9915 (5.4)	2970 (13.4)

Data are presented as number (percentage), unless otherwise specified.

ART, assisted reproductive technology; *BMI*, body mass index; *IVF*, in vitro fertilization.

[a] Amount of missing data that were imputed: 18% for BMI, 36% for race and ethnicity, and 14% for sperm source

[b] Other races included Native Hawaiian or Other Pacific Islander, American Indian or Alaska Native, and ≥2 races

[c] Infertility diagnoses are not mutually exclusive

[d] Paternal age was only reported among women using sperm from their male partner.

TABLE 2

Characteristics of ART treatment cycles included in the analysis (2016–2018)

Variable	Autologous cycles	Donor oocyte cycles
Number of intended retrievals	253,343	NA
Number of transfers	207,766	36,909
Number of oocytes retrieved, median (IQR)[a]	11 (6–17)	NA
Fertilization method[b]		
IVF	35,514 (14.0)	2789 (7.6)
ICSI	190,276 (75.1)	25,054 (67.9)
Unknown	27,553 (10.9)	9066 (24.6)
Use of PGT[a,b]		
No	157,429 (62.1)	26,893 (72.9)
Yes	95,914 (37.9)	10,016 (27.1)
Type of ET		
Fresh	81,251 (39.1)	16,564 (44.9)
Frozen	124,309 (59.8)	16,952 (45.9)
Unknown	2206 (1.1)	3393 (9.2)
Number of embryos transferred		
1	121,661 (58.6)	24,106 (65.3)
2	74,422 (35.8)	12,346 (33.4)
≥3	11,683 (5.6)	446 (1.2)
Stage of ET[c]		
Cleavage (2–3 d)	23,347 (28.7)	649 (3.9)
Blastocyst (5–6 d)	53,059 (65.3)	8613 (52.0)
Other	4845 (6.0)	220 (1.3)
Unknown[d]	—	7082 (42.8)
Outcome of ET		
Not pregnant	76,785 (37.0)	11,348 (30.7)
Biochemical pregnancy loss	19,749 (9.5)	3515 (9.5)

Am J Obstet Gynecol. Author manuscript; available in PMC 2024 April 29.

Variable	Autologous cycles	Donor oocyte cycles
Spontaneous abortion	17,445 (8.4)	3409 (9.2)
Ectopic pregnancy	1343 (0.6)	199 (0.5)
Therapeutic abortion	832 (0.4)	144 (0.4)
Stillbirth	569 (0.3)	129 (0.3)
Maternal death before birth	17 (<0.1)	<5 (<0.1)
Live birth	89,896 (43.3)	17,900 (48.5)
Unknown	1130 (0.5)	248 (0.7)

Data are presented as number (percentage), unless otherwise specified. The denominator for percentages is number of transfers, unless otherwise specified.

ART, assisted reproductive technology; *ET*, embryo transfer; *ICSI*, intracytoplasmic sperm injection; *IQR*, interquartile range; *IVF*, in vitro fertilization; *NA*, not applicable; *PGT*, preimplantation genetic testing.

[a] Amount of missing data that were imputed: 8.6% for number of oocytes retrieved and 10.9% for use of PGT

[b] Denominator for percentage is number of intended retrievals

[c] Only available among fresh ETs

[d] Stage was unknown because oocyte retrieval date was not available.