

Assisted reproductive technologies (ART), as defined by the Centers for Disease Control and Prevention (CDC), are fertility-related treatments in which eggs or embryos are manipulated. Procedures where only sperm are manipulated, such as intrauterine insemination, are not included under this definition. Additionally, procedures in which ovarian stimulation is performed without a plan for egg retrieval are also excluded by definition.

The first successful human in vitro fertilization (IVF) was performed in England in 1978—a woman had an unstimulated menstrual cycle, and physicians performed a laparoscopic retrieval of a single oocyte from the ovary. The oocyte was then fertilized in vitro and subsequently transferred as an embryo into her uterus.^[1]

Assisted Reproductive Technology (ART) — B.Sc. Zoology Notes

Exam-oriented notes suitable for a 10-mark answer on each topic

Assisted Reproductive Technology (ART) includes a group of medical techniques used to overcome infertility. In the strict definition used by the CDC, ART refers to fertility treatments in which **eggs or embryos are handled outside the body**. In a broader reproductive-biology syllabus, techniques such as artificial insemination, sperm banking, GIFT and ICSI are commonly discussed together with ART.

1. SEX SELECTION

Definition

Sex selection is the deliberate selection of the sex of an offspring before conception or before implantation of an embryo. It may involve separation of X- and Y-bearing sperm or genetic testing of embryos produced through IVF.

In humans:

- Female = XX
- Male = XY
- Ovum always carries an **X chromosome**.
- Sperm carries either **X or Y**.
- X-bearing sperm + ovum → **XX (female)**
- Y-bearing sperm + ovum → **XY (male)**

Thus, genetically, the **type of sperm fertilizing the ovum determines the chromosomal sex** of the offspring.

Basic principle

Father (XY) → X-bearing sperm or Y-bearing sperm

↓

Mother (XX) → X-bearing ovum

↓

X sperm + X ovum → XX ♀

Y sperm + X ovum → XY ♂

Methods of sex selection

A. Sperm sorting

Sperm carrying X and Y chromosomes can be enriched before fertilization. Since the X chromosome contains more DNA than the Y chromosome, techniques such as **flow cytometry** can distinguish sperm populations based on DNA content.

The selected sperm may subsequently be used for artificial insemination or IVF.

B. Preimplantation Genetic Testing (PGT)

This is a more accurate approach associated with IVF.

IVF → Embryo formation → Embryo biopsy → Genetic testing → Chromosomal analysis → Selection for a medically appropriate indication → Embryo transfer

A few cells are removed from an IVF embryo and examined genetically before embryo transfer.

Medical importance

Sex determination may have legitimate medical applications in avoiding certain **serious sex-linked genetic disorders**, particularly X-linked diseases.

Examples include:

- Haemophilia
- Duchenne muscular dystrophy
- Certain X-linked immunodeficiency disorders

Ethical and social concerns

Non-medical sex selection can contribute to:

- Gender discrimination
- Sex-ratio imbalance
- Female foeticide
- Social inequality
- Commercial misuse of reproductive technologies

Legal position in India

In India, prenatal sex determination and sex selection for non-medical purposes are prohibited under the **Pre-Conception and Pre-Natal Diagnostic Techniques (Prohibition of Sex Selection) Act, 1994 (PCPNDT Act)**.

Conclusion

Sex selection demonstrates the power of modern reproductive and genetic technology. However,

because of its profound ethical and social implications, its application requires **strict medical, ethical and legal regulation**.

2. SPERM BANKS

Definition

A **sperm bank or semen bank** is a specialized facility where semen is collected, screened, processed, cryopreserved and stored for future use in assisted reproduction.

The preserved semen may later be used for procedures such as artificial insemination, IVF or ICSI.

Principle

Sperm cells can retain their fertilizing ability for long periods when preserved at extremely low temperatures, usually in **liquid nitrogen at approximately -196°C** .

At this temperature, cellular metabolic activities are almost completely arrested.

Procedure of sperm banking

1. Semen collection

Semen is generally collected by masturbation into a sterile container after an appropriate period of abstinence.

2. Semen analysis

The sample is examined for:

- Semen volume
- Sperm concentration
- Motility
- Morphology
- Vitality

3. Screening

Depending on clinical and regulatory requirements, screening may include infectious diseases and relevant genetic/family-history assessment.

4. Addition of cryoprotectant

A **cryoprotective medium** is mixed with semen to reduce cellular damage caused by freezing. Glycerol is a commonly used cryoprotective component.

5. Cryopreservation

The sample is divided into labelled vials or straws and cooled under controlled conditions.

6. Storage

Samples are stored in liquid nitrogen tanks at approximately **-196°C** .

7. Thawing and use

When required:

Frozen semen → Controlled thawing → Processing → Assessment → IUI/IVF/ICSI

Uses

Sperm banking is useful for:

- Donor insemination
- Fertility preservation before chemotherapy or radiotherapy
- Men undergoing surgery that may impair fertility
- Individuals at risk of future infertility
- ART procedures requiring stored sperm

Advantages

- Allows long-term fertility preservation.
- Semen can be stored before fertility-damaging treatment.
- Donor sperm can be screened and stored systematically.
- Samples may be available for future ART cycles.

Limitations

Freezing and thawing can decrease sperm motility and viability. Proper screening, identification, consent, storage and record keeping are essential.

Conclusion

Sperm banking is an important component of modern reproductive medicine and provides an effective means of **male fertility preservation and semen storage for assisted reproduction**.

3. FROZEN EMBRYOS — EMBRYO CRYOPRESERVATION

Definition

Embryo cryopreservation is the preservation of embryos produced through IVF by storing them at extremely low temperatures for future use.

Modern ART laboratories commonly use **vitrification**, an ultra-rapid freezing technique that greatly reduces ice-crystal formation.

Principle

At very low temperatures, biochemical reactions and cellular metabolism are effectively suspended, allowing viable embryos to be stored for prolonged periods.

Procedure

Ovarian stimulation

↓

Oocyte retrieval

↓

IVF/ICSI

↓

Embryo culture

↓

Embryo assessment

↓

Cryoprotectant exposure

↓

Vitrification

↓

Storage in liquid nitrogen

↓

Warming when required

↓

Embryo transfer

Methods

Slow freezing

Embryos are gradually cooled under controlled conditions. It was historically widely used but carries a greater risk of ice-crystal formation.

Vitrification

Embryos are cooled extremely rapidly in suitable cryoprotectant solutions, producing a glass-like solidification with minimal ice formation.

It has become a major method of embryo cryopreservation.

Advantages

- Surplus suitable embryos from an IVF cycle can be stored.
- Future embryo transfer may be possible without repeating ovarian stimulation and oocyte retrieval.
- Fertility may be preserved before certain medical treatments.
- Enables frozen embryo transfer at a later suitable time.
- May reduce the need to transfer multiple embryos in one cycle.

Limitations

- Not every embryo survives freezing and warming.
- Requires sophisticated laboratory facilities.
- Long-term storage involves cost and management.

- Consent and decisions regarding unused embryos raise ethical issues.

Conclusion

Embryo cryopreservation has significantly improved ART by allowing embryos to be stored safely and transferred during a later reproductive cycle.

4. IN VITRO FERTILIZATION (IVF)

Definition

In vitro fertilization (IVF) is a technique in which mature oocytes are retrieved from the ovaries and fertilized with sperm **outside the body under laboratory conditions**. The resulting embryo or embryos are cultured and subsequently transferred to the female reproductive tract.

The term *in vitro* means "**in glass**."

The birth of **Louise Brown in England in 1978** following the work of Robert Edwards and Patrick Steptoe marked the first successful birth following IVF.

Major steps of IVF

1. Controlled ovarian stimulation

Hormonal medications are administered to stimulate development of multiple ovarian follicles.

2. Monitoring

Follicular development is monitored, commonly using ultrasonography and hormonal assessment.

3. Oocyte retrieval

Mature oocytes are collected from ovarian follicles, usually by **transvaginal ultrasound-guided aspiration**.

4. Semen preparation

Semen is collected and processed to obtain suitable motile sperm.

5. Fertilization

Oocytes and sperm are brought together in culture medium.

Oocyte + sperm → Fertilization → Zygote

When severe male-factor infertility exists, **ICSI** may be used instead.

6. Embryo culture

The fertilized eggs are cultured for several days and monitored for development.

7. Embryo transfer

One or more selected embryos, according to clinical practice and guidelines, are transferred into the uterus.

8. Implantation and pregnancy

If the embryo implants successfully into the endometrium, pregnancy begins.

Flow diagram

Ovarian stimulation

↓

Follicular maturation

↓

Oocyte retrieval

↓

Sperm preparation

↓

Fertilization in laboratory

↓

Zygote

↓

Embryo culture

↓

Embryo transfer

↓

Implantation → Pregnancy

Indications

IVF may be used in:

- Blocked or severely damaged fallopian tubes
- Endometriosis-associated infertility
- Certain male-factor infertility cases
- Unexplained infertility
- Failure of simpler fertility treatments
- Fertility treatment involving donor gametes
- Some cases requiring genetic testing of embryos

Advantages

IVF enables fertilization to occur even when natural interaction between sperm and oocyte in the fallopian tube is difficult or impossible.

Limitations

- Expensive and technically demanding
- Ovarian stimulation may produce adverse effects

- Procedures can be physically and emotionally demanding
- Success is not guaranteed
- Multiple pregnancy risk increases when multiple embryos are transferred

Conclusion

IVF is one of the most important advances in reproductive medicine and forms the basis for several modern ART techniques.

5. EMBRYO TRANSFER (ET)

Definition

Embryo transfer (ET) is the placement of an embryo produced through assisted fertilization into the female reproductive tract with the aim of achieving implantation and pregnancy.

It represents the final essential stage of an IVF treatment cycle.

Types

Depending on the developmental stage and site of transfer, older textbook classifications include:

Zygote/early embryo → Fallopian tube → ZIFT

Later cleavage-stage embryo/blastocyst → Uterus → uterine embryo transfer

Modern IVF practice most commonly involves transfer into the uterus.

Procedure

Embryo culture

↓

Selection of suitable embryo(s)

↓

Loading into a soft transfer catheter

↓

Catheter passed through cervix

↓

Embryo deposited within uterine cavity

↓

Catheter withdrawn

↓

Implantation may occur

Embryo transfer is usually performed without general anaesthesia and is often guided by ultrasound.

Factors affecting success

- Maternal age
- Embryo quality
- Endometrial receptivity
- Uterine condition
- Embryo developmental stage
- Number of embryos transferred
- Laboratory and clinical expertise

Complications

Transferring multiple embryos can increase the risk of **multiple pregnancy**, so contemporary practice often aims to limit the number transferred when appropriate.

Conclusion

Embryo transfer is a crucial step in ART because successful fertilization alone does not establish pregnancy; the embryo must subsequently reach a receptive uterus and implant.

6. IUT — INTRAUTERINE TRANSFER

Definition

In standard NCERT-style ART terminology, **intrauterine transfer (IUT)** refers to the transfer of an **in-vitro-produced embryo with more than 8 blastomeres into the uterus** for further development and implantation.

Do not confuse IUT with IUI.

IUT = embryo transfer into uterus

IUI = sperm/semen introduced into uterus

Principle

An embryo produced outside the body is placed into the uterus, where subsequent development and implantation can occur.

Procedure

Oocyte retrieval

↓

Fertilization in vitro

↓

Embryonic cleavage

↓

Embryo develops beyond early cleavage stage

↓

Transfer into uterus

↓

Implantation

↓

Pregnancy

Importance

IUT:

- Bypasses certain causes of infertility.
- Allows laboratory fertilization and early embryo culture.
- Places the embryo directly into the uterus for implantation.
- Forms part of IVF-embryo transfer procedures.

IUT vs IUI

IUT	IUI
Embryo is transferred	Sperm is introduced
Fertilization has already occurred	Fertilization occurs inside female tract
Associated with IVF	Artificial insemination technique
Embryo enters uterus	Processed semen enters uterus

Conclusion

IUT is essentially an embryo-transfer technique in which an embryo produced by IVF is introduced into the uterus to permit implantation and further development.

7. ZIFT — ZYGOTE INTRAFALLOPIAN TRANSFER

Definition

Zygote intrafallopian transfer (ZIFT) is an ART procedure in which fertilization occurs **in vitro**, after which the resulting zygote or early embryo is transferred into a fallopian tube.

In conventional textbook terminology, an embryo with **up to about 8 blastomeres** may be transferred into the fallopian tube.

Procedure

Ovarian stimulation

↓

Oocyte retrieval

↓

Sperm collection



In-vitro fertilization



Zygote/early embryo formation



Transfer into fallopian tube



Further development



Movement towards uterus



Implantation

Requirement

At least one fallopian tube should generally be functional because the zygote/early embryo is transferred into the tube.

ZIFT versus IVF with uterine embryo transfer

ZIFT	IVF with uterine ET
Fertilization occurs in vitro	Fertilization occurs in vitro
Zygote/early embryo placed in tube	Embryo placed in uterus
Requires usable fallopian tube	Can bypass fallopian tubes
More invasive	Uterine transfer is less invasive

Advantages

The early embryo undergoes part of its development within the environment of the fallopian tube.

Limitations

ZIFT is invasive compared with standard uterine embryo transfer and is now much less commonly performed.

Conclusion

ZIFT combines **in-vitro fertilization with intrafallopian transfer** of the resulting zygote or early embryo.

8. GIFT — GAMETE INTRAFALLOPIAN TRANSFER

Definition

Gamete intrafallopian transfer (GIFT) is a technique in which oocytes and sperm are introduced together into the fallopian tube so that **fertilization occurs inside the female body**.

This is the most important distinction between GIFT and ZIFT.

Procedure

Ovarian stimulation

↓

Oocyte retrieval

↓

Sperm collection and preparation

↓

Oocytes + sperm placed into fallopian tube

↓

Fertilization occurs in vivo

↓

Zygote develops naturally

↓

Embryo reaches uterus

↓

Implantation

Requirements

At least one fallopian tube must be patent and functional.

Advantages

- Fertilization occurs within the natural tubal environment.
- Gametes spend less time under laboratory fertilization conditions.

Limitations

- Requires functional fallopian tube.
- More invasive than standard uterine embryo transfer.
- Fertilization cannot be directly confirmed before transfer.
- It has largely been replaced by IVF/ICSI in modern practice.

GIFT vs ZIFT

Feature	GIFT	ZIFT
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Material transferred	Sperm + oocyte	Zygote/early embryo
Fertilization	Inside body	Laboratory
Site of transfer	Fallopian tube	Fallopian tube
Fertilization confirmed beforehand?	No	Yes

Memory trick

GIFT = Gametes are Given Into Fallopian Tube.

ZIFT = Zygote is Introduced into Fallopian Tube.

Conclusion

GIFT differs fundamentally from IVF and ZIFT because the **actual fertilization event occurs within the fallopian tube rather than in the laboratory.**

9. ICSI — INTRACYTOPLASMIC SPERM INJECTION

Definition

Intracytoplasmic sperm injection (ICSI) is an advanced micromanipulation technique in which a **single spermatozoon is injected directly into the cytoplasm of a mature oocyte** to facilitate fertilization.

It is particularly important for severe male-factor infertility.

Principle

Normally, sperm must penetrate the coverings of the oocyte by itself. In ICSI, this penetration step is bypassed by introducing one sperm directly into the oocyte.

Procedure

Ovarian stimulation

↓

Oocyte retrieval

↓

Removal of surrounding cumulus cells and assessment of maturity

↓

Selection of sperm

↓

Immobilization of sperm

↓

Oocyte held with holding pipette

↓

Fine injection pipette enters oocyte

↓

Single sperm injected into cytoplasm

↓

Fertilization assessment

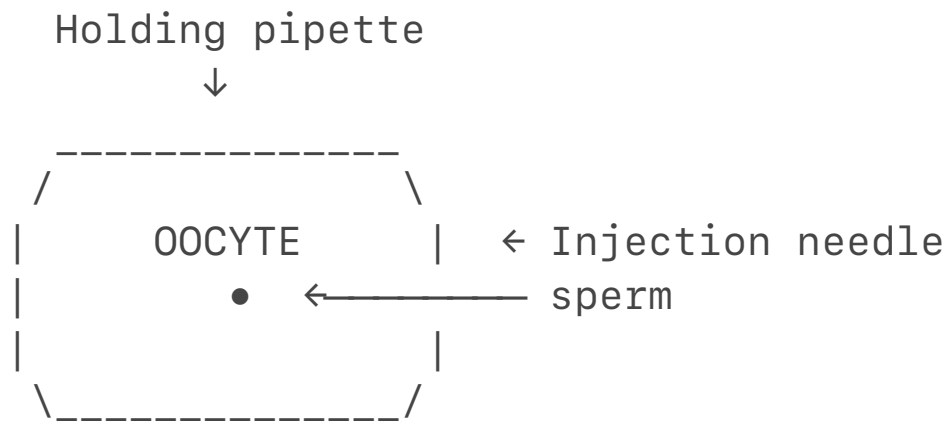
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Embryo culture

↓

Embryo transfer

Simple diagram



Indications

ICSI is particularly useful in:

- Severe oligozoospermia — very low sperm count
- Severe asthenozoospermia — poor sperm motility
- Severe teratozoospermia — abnormal sperm morphology
- Surgically retrieved sperm
- Certain cases of previous fertilization failure with conventional IVF

Advantages

- Only one sperm is required for injection into each mature oocyte.
- Bypasses several barriers to sperm-oocyte interaction.
- Extremely useful in severe male-factor infertility.
- Can be combined with IVF and embryo cryopreservation.

Limitations

ICSI requires specialized equipment and highly trained embryologists. It does not guarantee fertilization, embryo development, implantation or pregnancy.

IVF vs ICSI

Conventional IVF: many sperm are placed around an oocyte → one penetrates naturally.

ICSI: embryologist selects one sperm → injects it directly into the oocyte.

Conclusion

ICSI revolutionized the treatment of **severe male-factor infertility** by allowing fertilization even when sperm cannot efficiently penetrate an oocyte on their own.

10. PROST — PRONUCLEAR STAGE TUBAL TRANSFER

Definition

Pronuclear stage tubal transfer (PROST) is an assisted reproductive technique in which oocytes are fertilized **in vitro** and transferred into the fallopian tube at the **pronuclear stage**, before the first cleavage division.

It is closely related to ZIFT.

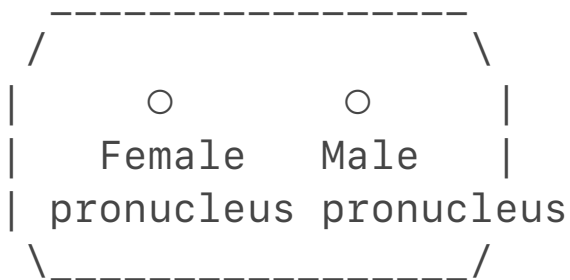
What is the pronuclear stage?

Following fertilization, the genetic material of sperm and ovum initially exists as two separate pronuclei:

- Male pronucleus
- Female pronucleus

Their presence is an important indication of normal fertilization.

Fertilized oocyte



Procedure

Ovarian stimulation

↓

Oocyte retrieval

↓

In-vitro fertilization

↓

Formation of male and female pronuclei

↓

Selection at pronuclear stage



Transfer into fallopian tube



Cleavage and embryo development



Movement towards uterus



Implantation

Difference between PROST and ZIFT

The terminology may overlap historically, but the distinction is mainly based on the developmental stage at transfer.

PROST	ZIFT
Transfer specifically at pronuclear stage	Transfer of zygote/early cleavage embryo
Before first cleavage	May include early cleavage stages
Transfer into fallopian tube	Transfer into fallopian tube
Fertilization occurs in vitro	Fertilization occurs in vitro

Advantages

- Fertilization can be confirmed before transfer.
- Early development subsequently occurs within the fallopian tube.

Limitations

- Requires a functional fallopian tube.
- More invasive than routine uterine embryo transfer.
- Rarely used today because modern IVF with uterine embryo transfer is simpler and less invasive.

Conclusion

PROST is a specialized historical ART technique involving the **transfer of a fertilized oocyte at the pronuclear stage into the fallopian tube.**

★ Most Important Comparison for Examination

Technique	What is transferred?	Fertilization occurs	Transfer site
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GIFT	Sperm + oocyte	Inside body	Fallopian tube
ZIFT	Zygote/early embryo	In vitro	Fallopian tube
PROST	Pronuclear-stage fertilized oocyte	In vitro	Fallopian tube
IUT	Embryo	In vitro	Uterus
IVF-ET	Cultured embryo after IVF	In vitro	Usually uterus
ICSI	Sperm injected into oocyte	In vitro	Embryo later transferred to uterus

One-line memory sequence

GIFT → Gametes

PROST → Pronuclei

ZIFT → Zygote/early embryo

IUT → Embryo into uterus

ICSI → One sperm injected into one oocyte

For a 10-mark B.Sc. answer, the best structure is: **Definition → Principle → Procedure/flowchart → Indications → Advantages → Limitations → Conclusion**. This format makes the answer organized, diagram-friendly and easy to score.