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An Overview of Artificial Insemination: A Journey from Past to Present

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Authors' contributions

This work was carried out in collaboration among all authors. All authors read and approved the final manuscript.

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ABSTRACT

Artificial insemination (AI) has a rich history spanning centuries, beginning with early experiments in plant and animal reproduction. This article traces the development of AI from its earliest recorded instances in 1322 A.D. to modern-day advancements. Notable pioneers such as Spallanzani, Hunter, and Ivanoff contributed significantly to the evolution of AI techniques. The introduction of AI across various animal species, including cattle, horses, sheep, goats, pigs, and poultry, revolutionized breeding practices worldwide. Key milestones include the development of semen extenders, the invention of artificial vaginas for semen collection, and the advent of cryopreservation techniques. Moreover, advancements in sperm quality assessment and estrous synchronization further enhanced AI efficiency. The introduction of sexed semen technology has

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provided a means to control offspring gender, offering new avenues for genetic selection. Overall, AI has played a crucial role in improving livestock genetics, disease control, and reproductive efficiency, making significant contributions to agricultural productivity and sustainability.

Keywords: Artificial Insemination; estrous; livestock; selection; semen; extender.

1. INTRODUCTION

Before the advent of modern technologies, artificial insemination (AI) played a vital role in plant reproduction, as observed in bees and other flying insects. However, animal AI is a comparatively recent innovation of humans. Serving as one of the earliest significant biotechnologies, AI has been instrumental in enhancing farm animal reproduction and genetics. Remarkably, historical accounts from as early as 1322 A.D. recount instances of AI experimentation, such as an Arab chief stimulating a stallion with a cotton wand to facilitate mating with a prized mare. The semen was taken out and inserted into the mare with the use of a cotton wand, resulting in conception. However, in this article, we will discuss the concrete studies done by researchers to support remarkable accomplishments. Most AI research was done in the 1980s when electronic networks became readily accessible. The development of AI was based on research that led to an explosion of information in the area of animal reproduction. When artificial insemination is applied to the management of dairy cattle, it can reduce harmful genetic traits, reduce the spread of infectious diseases, increase milk production, improve efficiency in work-related tasks, and effectively manage the aforementioned conditions. These applications have resulted in significant economic benefits. In 1678, Leeuwenhoek and Hamm made history by being the first to observe sperm, which they aptly termed "animalcules." Further, according to Leeuwenhoek, these spermatozoa are called "zaaddiertjes," which are microscopic organisms that are present in human semen and have slender, flowing tails. They are about a millionth the size of a little grain of sand [2]. In 1784, Spallanzani reached a significant milestone by performing the first successful insemination on a doe. Utilizing semen maintained at body temperature, he fertilized one of the females showing estrous behavior, leading to the parturition of three kids 62 days thereafter. This groundbreaking event marked the first documented instance of artificial insemination. Through meticulous experimentation, Spallanzani discovered that only the spermatozoa remaining after semen filtration could lead to fertilization. Spallanzani's pioneering work earned him significant recognition as a key figure in the development of artificial insemination. Spallanzani's investigations uncovered a crucial finding: the freezing or chilling of stallion sperm did not lead to their demise; rather, it temporarily immobilized them until they were warmed again [3]. In 1799, Hunter employed artificial insemination to address a gentleman's hypospadias condition in England. However, it wasn't until the mid-1800s that J Marion Sims conducted a series of 55 inseminations on female humans. Regrettably, only one pregnancy ensued from his post-insemination assessments. This outcome may have been influenced by his belief that ovulation coincided with menstruation, potentially explaining the limited success. Additionally, in 1897, Heape documented isolated instances of artificial insemination employed in studies involving horses, dogs, and rabbits [1].

2. THE DEVELOPMENT OF ARTIFICIAL INSEMINATION

In 1899, Ivanoff embarked on groundbreaking efforts in Russia to establish artificial insemination (AI) as a viable procedure. By 1907, his pioneering work extended to encompass research on AI across various species, including dogs, livestock, rabbits, foxes, and poultry. Notably, Ivanoff not only conducted extensive studies but also contributed significantly to the development of AI by devising semen extenders, training personnel in the selection of superior stallions, and effectively utilizing AI to enhance their offspring [4]. In 1938, Milovanov introduced pioneering strategies for the selective breeding of ovine and bovine species. Among his notable advancements was the development of functional artificial vaginas, which continue to be employed in contemporary animal husbandry practices. This innovation represented a significant enhancement over preceding methodologies, such as the extraction of semen via female specimens.

Table 1. Important dates in the history of Artificial Insemination [1]

Year	Description of Event
1677	Leeuwenhoek discovered spermatozoa.
1780	Spallanzani successfully inseminated a bitch
1799	Hunter used AI for a woman.
1803	Spallanzani observed that chilling sperm did not kill them.
1899	Ivanoff initiated organized AI research in Russia
1902	Sand recommended AI in Denmark, but no program was started.
1912	Ishikawa organized AI research in Japan
1914	Amantea devised the first artificial vagina for use in dogs.
1930s	Organized AI began in Denmark and the USA and quickly spread.
1937	Danish had established rectovaginal insemination, reducing sperm required
1940	Phillips developed phosphate-buffered egg yolk for preserving bull sperm
1941	Salisbury and others developed citrate-buffered egg yolk for preserving bull sperm.
1948	Almquist and Foote reported independently on the value of antibiotics in semen extenders to control microorganisms and increase fertility
1949	Polge et al. discovered that glycerol-protected sperm during freezing
1950s	Powerful tools for progeny testing were developed by Henderson and Robertson.
1954	Waterloo (Canada) was the first organization to use frozen semen 100%.
1957	American Breeders Service developed liquid nitrogen tanks and services for frozen semen.
1963	Davis et al. (Cornell) developed Tris-buffered egg yolk-glycerol for fresh and frozen sperm, used later for many species
1970	AI was used commercially for superovulated cows and embryo transfer and provided the initial framework for many breeding strategies.
1990s	Sexing bull sperm was improved with limited potential application.

Dr. Ishikawa, a scientist from Japan, received mentorship from Ivanoff. After working with Ivanoff in 1912, Dr. Ishikawa brought artificial insemination (AI) methods for domestic animal husbandry to Japan. The Japanese government started AI programs aimed at cattle and poultry in the late 1930s [6]. However, the adoption of AI progressed slower than expected, initially focusing on horses. The Ivanoff study, which was published in 1922, helped other nations learn about AI methods from Russia. Walton's seminal book on AI, released in the West in 1933, further popularized the technique. Walton achieved a milestone by successfully using ram semen to inseminate ewes, a technique later transported to Poland. Eduard Sörensen founded Denmark's first cooperative dairy AI association in 1933, motivated by the groundbreaking work in Russia. The association's efforts were fruitful, as 59% of the 1,070 cows produced calves. EJ Perry of New Jersey established the country's inaugural AI cooperation in 1938 [8]. A major turning point was reached on November 1, 1939, when the first artificially inseminated rabbit was displayed at the 12th Annual Graduate Fortnight of the New York Academy of Medicine. Gregory Pincus, an American scientist, achieved this milestone by employing in vitro fertilization techniques. He fertilized an ovum extracted from the ovarian follicles of a female rabbit using a saline solution. Subsequently, he transferred the fertilized ovum into the uterine cavity of another female rabbit, where it served as an ectopic incubation environment [1].

Through rectovaginal immobilisation of the cervix, Danish veterinarians invented a method for injecting semen deeply into the uterine body or cervix. This method offered the remarkable advantage of achieving fertilization with significantly fewer sperm, a notable breakthrough. Another significant advancement in Danish artificial insemination was the introduction of semen packaging using straws [7]. Subsequently, Cassou began commercial production of straws in 1964, and today they are widely utilized worldwide [9]. Some important landmarks regarding Artificial insemination are given in Table 1.

3. INTRODUCTION OF ARTIFICIAL INSEMINATION IN INDIA

The inaugural artificial insemination (AI) procedure in India took place in 1939 at the Palace Dairy Farm in Mysore, conducted by Sampat Kumaran. Subsequently, in 1942, a pilot experiment was initiated at the Indian Veterinary

Research Institute (IVRI) under the supervision of Dr. P. Bhattacharya to evaluate the feasibility of AI. Upon realizing the applicability of AI in Indian settings, it has since become a regular practice for cattle and buffalo breeding. In 1942, the Indian government established four regional hubs in Calcutta, Montgomery (now in Pakistan), Bangalore, and Patna to further promote AI adoption. The first AI-produced buffalo calf was successfully bred in 1943 at the Allahabad Agricultural Institute. To bolster the country's cattle and buffalo population, the Indian government established 150 significant village centers in 1951 and 1956 as part of the first five-year plan. Subsequently, the succeeding five-year plan (1956–1961) saw the incorporation of AI into 400 significant village centers, leading to a surge in AI activities.

4. ADDITIONAL ADVANCES IN ARTIFICIAL INSEMINATION

The most popular test for sperm quality has been the determination of the proportion of normal, progressively moving sperm, as described by Anderson in 1945 [10], Maule in 1962 [11], and Salisbury in 1978 [12]. The adoption of brightfield microscopes, variable interference contrast microscopes, various stains, flow cytometry, and computer-aided sperm analysis (CASA) has increased our capacity to evaluate sperm characterisctics [12-16]. Our ability to discern the sperm's acrosomal status has enhanced as a result of Saacke and Marshall's investigation from 1968 [17]. In 1989, Barth and Oko examined the procedures for evaluating sperm morphology [18]. Ejaculate quantity and sperm concentration, which have an impact on the quantity of sperm generated, are the other two crucial elements in assessing semen. The capacity to procreate is the ultimate measure of sperm quality, although it's not always attainable. Due to this, several tests of semen quality, such as the hypoosmotic swelling test, mucous or gel penetration, DNA integrity, motility, and morphology, have been connected to fertility [13, 19, 18, 20]. Estimating sperm quantity, motility, and shape is crucial for determining fertility as they collectively assess sperm health. Sperm quantity indicates the availability of sperm for fertilization, motility determines their ability to reach the egg, and shape impacts their ability to penetrate and fertilize it. Assessing these factors helps diagnose potential fertility issues and guides appropriate treatment for improving conception chances.

Competitive fertilization with mixed sperm gives an accurate approach to evaluate a male's fertility using either in vitro fertilization tests or testing using animal insemination, according to studies by Beatty in 1960 [21], Saacke in 1981 [19], Dziuk in 1996 [22], and Foote in 1998 [16]. It is not viable to combine commercial AI and sperm, nevertheless. Cows that do not return for insemination were developed, by Thompson and Salisbury in 1947, as a key component of the AI program, and they are an appropriate technique for assessing fertility in commercial AI [23]. It provided an important brand-new way to measure breeding efficiency. Others have made strong arguments in favor of using pregnancy diagnosis. Still, it only involved a small number of cows, it happened seldom, and it didn't allow for centralized data collection and analysis. The efficacy of the non-return approach for evaluating fertility has diminished due to the availability of different semen suppliers to individual farmers and herd inseminators. The use of the light microscope and phase-contrast microscope with 20x and 40x objectives is one of the advancements in sperm motility measurement, and these are thought to produce substantially good results [24]. Recently, other techniques, including the CASA [25], flow cytometer [26], and NucleoCounter SP-100 [27], have been used to measure sperm concentration. With the aid of CASA, the morphology and concentration of sperm and its motility can be immediately assessed. Sperm concentration and membrane strength can both be determined with the NucleoCounter SP-100. The NucleoCounter SP-100 is quicker, easier, more efficient, and more accurate than the hemocytometer. Additionally, it is less expensive and easier to use than flow cytometry [27]. The first crucial method for examining the properties of sperm motility is known as computer-assisted sperm analysis. The concentrations and motility of sperm can be immediately measured. Phase-contrast microscopy cannot offer data on as many sperm kinetic properties as CASA, which is more precise and repeatable [28, 29]. In 1985, the first CASA system for application in domestic animals was made commercially accessible.

5. ADVANCEMENTS IN SEMEN PRESERVATION TECHNIQUES: A HISTORICAL PERSPECTIVE

Finding a way to preserve semen fresh long enough to ship and use it in the field presented the biggest hurdle. The first big development in the AI process occurred in 1940 with the

invention of a yolk-phosphate semen extender by Phillips and Lardy [30]. Sperm survival at 5°C allowed for the storage of sperm for up to three days, and citrate scattered the fat globules in egg yolk such that sperm were observable for microscopic examination. This semen extender was used on cattle all over the world. The bull sperm was then cryopreserved using glycerol. The next significant factor in favor of AI in dairy cattle was the 15% increase in fertility that was brought about by a better method, which at first protected sperm from cold shock as stated by Foote and Bratton in 1949 [31] and later controlled some venereal diseases by adding antibiotics [32]. Shannon enhanced the extender in the late 1950s to use liquid semen during the busy breeding season in New Zealand. By combining caproic acid, catalase, and 5% egg yolk by volume, "caprogen" was produced. Bull sperm can be preserved at room temperature by using caprogen, a helpful extender. The 1950 invention by Foote and Bratton known as the Cornell extender, which served as the industry standard for many years, contained the antibiotics penicillin, polymyxin B, and streptomycin [31]. The widespread adoption of artificial insemination (AI) within dairy farming practices, driven by the imperative to mitigate venereal infections, minimize embryonic mortality, and optimize fertility rates, has resulted in a notable surge in demand for this reproductive technology. Meeting this demand necessitated a refinement in the processing of ejaculate specimens, with a particular focus on extending their viability while concurrently reducing the sperm count per insemination event, a strategy devised to enhance efficiency without compromising fertility rates. Central to this endeavor has been the utilization of milk-based extenders, a technique refined and elucidated in various scientific publications subsequent to the seminal work of Michajilov in 1950. Through meticulous research, methodologies for milk detoxification and the judicious inclusion of glycerol for cryopreservation purposes, notably encapsulated within the framework of the milk glycerol extender, have been established as cornerstones in the advancement of semen preservation protocols within the domain of reproductive sciences [33-35]. The idea that only a few million sperm were required for each insemination was demonstrated in various publications published in 1978 by Salisbury and colleagues [12]. Cumulative investigations have conclusively elucidated that the extension duration of semen can be significantly prolonged, exceeding a factor of 25. Consequently, the total sperm count per insemination event has markedly decreased from an initial quantity exceeding 100 million to a substantially reduced figure of 4 million in instances where liquid semen is utilized for insemination procedures.

The other way to increase the number of successful inseminations per bull is to take the most sperm out of each bull. In the 1950s, Bratton and colleagues did research on semen collection intensity and sexual readiness [36]. The comprehensive findings derived from the collective investigations elucidated a weekly sperm output ranging between 30 to 40 $\times 10^9$ sperm per sire, with an insemination dose yielding approximately 10×10^6 sperm. These quantifications underscored the imperative for assessing the individual sexual behaviors of bulls. Notably, this understanding facilitated the conceptualization of achieving an annual semen production capacity of up to 200,000 doses for artificial insemination, predicated upon these sperm counts. Assessment of both the quantity and quality of spermatogenesis in bulls was conducted utilizing established methodologies [37, 38], yielding insights into the interplay between testicular dimensions and sperm production. Factors to Consider in Bull Sire Evaluation [68]:

1. Semen Quality:

Semen quality is assessed by evaluating the concentration, motility, and morphology of sperm cells. Sperm motility plays a crucial role in determining a bull's breeding soundness.

2. Scrotal Circumference:

Scrotal circumference measurement reflects a bull's sperm production capability and is correlated with the onset of puberty. For yearling bulls, a minimum size of 32 centimeters is typically expected.

3. Breeding Soundness Evaluation:

This comprehensive assessment includes a physical examination, semen quality assessment, and scrotal circumference measurement. Bulls must exhibit at least 30% sperm motility, 70% normal sperm morphology, and meet minimum scrotal circumference standards based on age to pass the evaluation, indicating their suitability as potential breeders.

Table 2. Techniques for collecting semen in different animal species

Species	Semen collection methods
Boar	By using a gloved hand and an artificial vagina
Bull	By using an artificial vagina, directly from the vagina, electroejaculation, and massage technique
Dog	By using digital manipulation and artificial vagina
Ram and buck	Directly from the vagina, artificial vagina, and electroejaculation method
Stallion	Using an artificial vagina

4. Mating Ability:

A bull's mating capacity is determined by its libido and mating capability, which assess its willingness and competence to engage in successful mating with females. There are different semen collection methods acrossa varous species as mentioned in Table 2.

The selection of superior genetic traits for milk production in males stands as a primary impetus driving the adoption of artificial insemination (AI). The acceleration of population genetic shifts is facilitated by genomic selection methodologies, which augment precision while mitigating the generational gap. Historically, bull selection relied upon phenotype-based criteria, subsequently supplemented by progeny testing. Presently, emphasis is placed on utilizing genomic breeding values derived from genetic markers, enabling the identification of desirable traits in animals at remarkably early stages, sometimes immediately following birth.

In the 1950s, liquid nitrogen storage at -196°C replaced solid carbon dioxide storage at -79°C. By using glycerol, England [39] accomplished the astonishing feat of effectively freezing chicken sperm. The discovery was made in part by accident [40]. The study's primary objective, employing sugars as cryoprotectants, did not, however, provide positive outcomes. Polge tried again after spending six months at home, and this time he was successful. The container included the glycerol and protein that make up Meyers albumin, according to a chemical analysis. Chemicals had been wrongly labeled during storage. The play's central theme was serendipity. [40]. Bull sperm can be preserved in whole milk glycerol, which was developed in 1957 by Almquist and colleagues. Tris-buffered egg yolk-glycerol also offered good preservation for sperm, both frozen and unfrozen [41, 42]. Cassou improved the technology developed by Sorensen in 1940 by adding a method for securing plastic straws and an insemination pistol in 1964 [8]. The foundation for the modern cryopreservation industry was created by the development of efficient liquid nitrogen storage devices and the successful cryopreservation of sperm.

For success in the field, accurate estrous identification and skilled insemination were necessary. In 1948, Trimberger created the A.M. to P.M. and P.M. to A.M. scheme, a traditional insemination norm [43]. It was based on observation, ovary palpation, and data from breeding. This rule states that for the best fertility, cows first discovered in estrous in the morning should be inseminated in the afternoon. Cows that first enter estrous in the evening ought to be sexing by noon the next day. Estrous synchronization, which was created by Hansel and Convey in 1983 [44], enables insemination at a predetermined time without estrous detection but frequently results in lower fertility. In 1971, Rowson predicted that combining artificial insemination with superovulation, estrous synchronization, and embryo alteration would lead to huge increases in animal productivity that would go beyond the use of AI alone [45].

Semen sexing: One of the most dramatic advances in technology in recent years is the sexing of sperm by DNA quantification utilizing flow cytometry technology developed at Livermore Laboratories [46]. The main advancement was the development of an in situ probe that was able to segregate sperm while maintaining their structural integrity and producing a fluorescent signal [47]. The use of this method to deliver a live rabbit was then shown. It is astounding that the Hoechst 33342 dye preferentially binds to DNA, easily traverses cell membranes, and quantitatively distinguishes X and Y-sperm without appearing to be harmful to cells or compromising sperm function [48-50]. Another reproductive innovation called sexed semen aims to change the progeny's sex ratio to the chosen gender. It was discovered that this technology has a 90% effectiveness rate, meaning that 90% of the offspring will be female. The sexed semen technology is built on the distinctions between X and Y spermatozoa [51].

The fundamental and only characteristic that still distinguishes X- and Y-sperm is the differential in DNA content [50]. Other alternatives to this have been investigated and developed due to these drawbacks.

AI in other species:

- Swine

Ivanoff created the first swine AI system in Russia at the beginning of the 20th century. Inquiries were conducted in more depth in the 1930s. Early studies were conducted in Western Europe, Japan, and the United States. Artificial vaginas built for collecting boar semen were developed to provide pressure to the glans penis [52–54]. An alternative is to use a gloved hand. The concentration of electrolytes was maintained at low levels by Milovanov in 1938 [5], Anderson in 1945 [10], Polge in 1956 [54], and Maule in 1962 [11] using a glucose solution containing sodium sulphate or potassium tartrate and peptone. The yolk phosphate, yolk citrate, and milk extenders were modified for use with boar semen [11, 54]. After employing frozen bull sperm with success, attempts were made to freeze swine semen as well. Fresh or extended liquid semen is frequently used for artificial insemination (AI) in pigs, with a typical dosage of 3 109 sperm in 80 mL [6, 13, 55]. Later, post-cervical AI (PCAI), often referred to as intrauterine AI, began to be used on farms [56]. With this method, a catheter inner tube or cannula that reaches 15-20 cm deeper than Cervical AI is used to deposit the semen dosage into the uterine body.

- Horses

In 1899, Russia started researching artificial insemination (AI) for horses, and in 1912, Ishikawa started testing the technology in Japan. The collecting, processing, and artificial insemination of stallion and jack semen were initially studied in the United States by McKenzie *et al.* in 1939 [57] and Berliner in 1942 [58]. Prior to the invention of the artificial vagina, an estrous mare's vagina was used to insert a rubber semen collection bag in order to gather semen. Numerous artificial vagina kinds were created in the 1930s and 1940s, and since then, they have undergone modifications. The methods for analysing semen are similar to those for analysing semen from bulls.

Interest in cryopreserving horse sperm was spurred by the development of techniques for preserving bovine sperm. Within 48 hours of collection, chilled, extended semen is usually used in equine artificial insemination (AI).

- Sheep and Goats

The season has an impact on the quality and effectiveness of the semen, and Gunn's invention of electroejaculation in 1936 is a practical way to gather semen from a lot of rams in the field [59]. Numerous advancements have been made to the methods and media for freezing semen, including those that use egg yolk-trisglycerol [60-63], as a result of the procedures developed for bull sperm [41].

- Poultry

The practice of artificial insemination in chickens is common. Burrows and Quinn created the method of abdominal massage and pressure to collect semen in 1937 [64]. The collection, processing, and AI of sperm were explored by Sexton in 1979, Lake in 1986, and most recently Donoghue and Wishart in 2000 [65-67].

6. IMPLICATIONS

Initially attempts to develop AI were faced with several obstacles such as the fear that AI would lead to abnormalities. However, the field-tested research that accompanied AI proved to the agricultural community that the technology could identify superior production bulls free from lethal genes, would control venereal diseases, and did result in healthy calves. The knowledge gained from AI was extremely helpful in the stepwise development of each successive reproductive technology, such as frozen semen, superovulation, embryo transfer, and cloning.

7. CONCLUSION

The journey of artificial insemination (AI) is a testament to human ingenuity and our relentless pursuit of improving agricultural practices. From its humble beginnings in ancient Arabia to the groundbreaking research of Spallanzani and Ivanoff, AI has evolved into a sophisticated biotechnological tool that has revolutionized animal breeding. Early pioneers like Leeuwenhoek and Spallanzani laid the foundation for AI by unraveling the mysteries of spermatozoa and demonstrating its potential for fertilization. Ivanoff's systematic research in Russia and the subsequent spread of AI to countries like Japan and Denmark marked significant milestones in its development. The

introduction of AI in India in the 1940s ushered in a new era of livestock breeding, leading to increased productivity and improved animal genetics. Over the years, advancements in semen preservation techniques, sperm quality evaluation, and estrous synchronization have further enhanced the effectiveness of AI. The advent of sexed semen technology has added a new dimension to AI, allowing for precise control over the gender ratio of offspring. This innovation has far-reaching implications for livestock production and genetic selection strategies. Moreover, AI has not only transformed cattle breeding but has also found applications in other species like swine, horses, sheep, goats, and poultry. Each adaptation has brought about its own set of challenges and innovations, contributing to the continuous evolution of AI technology. Despite initial skepticism and challenges, AI has emerged as a cornerstone of modern animal husbandry, offering solutions to issues like genetic disorders, venereal diseases, and low fertility rates. The cumulative knowledge gained from AI research has paved the way for further advancements in reproductive technologies such as embryo transfer and cloning. In conclusion, the journey of artificial insemination from ancient practices to modern biotechnology exemplifies the power of human innovation in reshaping agriculture and ensuring food security for generations to come. As we continue to push the boundaries of scientific discovery, AI will undoubtedly remain a vital tool in the arsenal of farmers and breeders worldwide.

COMPETING INTERESTS

Authors have declared that no competing interests exist.

REFERENCES

1. Foote RH. The history of artificial insemination: Selected notes and notables1. J Anim Sci. 2002;80:1-10.
2. Leeuwenhoek AV. De natis esemine genitali animalculis. Philosophical Transactions of the Royal Society, 1678; 12:1040-1043.
3. Spallanzani L. Dissertations relative to the natural history of animals and vegetables Vol.2. J. Murray, London; 1784.
4. Ivanoff, EI. On the use of artificial insemination for zootechnical purposes in Russia. J Agri Sci. 1922;12(3):244-256.
5. Milovanov VK. Artificial Insemination of Livestock in the U.S.S.R. Trans. By Birron A and Cole ZS. Washington, DC: S Monson, Jerusalem Tech. Services, , US Dept Commerce; 1964.
6. Nishikawa Y. Semen properties and artificial insemination in horses. Studies on Reproduction in Horses. Kyoto Japan: Koei. 1959;208.
7. Sørensen E. Insemination with gelatinized semen in paraffined cellophane tubes. Medlernsbl. Danske Dyrlaegeforen. 1940; 23:166-169.
8. Ombelet WJ, Robays V. Artificial insemination history: hurdles and milestones. Facts, views & vision in ObGyn. 2015;7(2):137.
9. Cassou R. La méthode des paillettes en plastique adaptée a la généralisation de la congélation. In Fifth International Congress on Animal Reproduction and Artificial Insemination, 1964;4:540-546.
10. Anderson J. The Semen of Animals and its Use for Artificial Insemination. Tech. Comm. Imperial Bureau of Animal Breeding Genetics, Edinburgh; 1945.
11. Maule MJ. The Semen of Animals and Artificial Insemination. Commonwealth Agricultural Bureaux, Farnham Royal, U.K; 1962.
12. Salisbury GW, VanDemark NL, Lodge JR. Physiology of reproduction and artificial insemination of cattle. 2nd ed. San Francisco: WH Freeman and Co; 1978.
13. Graham EF. Fundamentals of the preservation of spermatozoa. In: The Integrity of Frozen Spermatozoa. Proc Conf Natl Acad Sci. 1978;4-44.
14. Pace MM, Sullivan JJ, Elliott FI, Graham EF, Coulter GH. Effects of thawing temperature, number of spermatozoa, and spermatozoal quality on fertility of bovine spermatozoa packaged in .5 ml French straws. J Anim Sci. 1981;53:693-701.
15. Garner DL, Thomas CA, Joerg HW, DeJarnett JM, Marshall CE. Fluorometric assessments of mitochondrial function and viability in cryopreserved bovine spermatozoa. Biol Reprod. 1997;57:1401-1406.
16. Foote RH. Artificial Insemination to Cloning: Tracing 50 Years of Research. Published by the author, Ithaca, New York; 1998.
17. Saacke RG, Marshall CE. Observations on the acrosomal cap of fixed and unfixed

bovine spermatozoa. J Reprod Fertil. 1968;16:511-514.
18. Barth AD, Oko RJ. Abnormal morphology of bovine spermatozoa. Iowa State University Press, Ames; 1989
19. Saacke RG. Components of semen quality. J Anim Sci. 1981;55:1-13.
20. Foote RH. Artificial insemination from its origins up to today. In: V. Russo, S. Dall 'Olio, and L. Fontanesi (ed.) Proc. of the Spallanzani Int. Symp., Reggio Emilia, Italy. 1999;23–67.
21. Beatty BA. Fertility of mixed semen from different rabbits. J Reprod Fertil. 1960;1: 52-60.
22. Dziuk PJ. Review: Factors that influence the proportion of offspring sired by a male following heterospermic insemination. Anim Reprod Sci. 1996; 43:65-88.
23. Thompson AW, Salisbury GW. A suggested procedure for the establishment of standard and comparable breeding efficiency reports in artificial breeding. Mimeo. Pub. 1, Cornell University, Ithaca, NY; 1947.
24. Cuche E, Marquet P, Depeursinge C. Simultaneous amplitude-contrast and quantitative phase-contrast microscopy by numerical reconstruction of Fresnel off-axis holograms. Applied optics. 1999;38(34): 6994-7001.
25. Kuster C. Sperm concentration determination between hemacytometric and CASA systems: Why they can be different. Theriogenology. 2005;64(3):614-617.
26. Christensen P, Hansen C, Liboriussen T, Lehn-Jensen H. Implementation of flow cytometry for quality control in four Danish bull studs. Anim Reprod Sci. 2005;85(3-4):201-208.
27. Anzar M, Kroetsch M, Buhr MM. Comparison of different methods for assessment of sperm concentration and membrane integrity with bull semen. J Androl. 2009;30(6):661-668.
28. Vantman D, Banks SM, Koukoulis G, Dennison L, Sherins RJ. Assessment of sperm motion characteristics from fertile and infertile men using a fully automated computer-assisted semen analyzer. Fertility and sterility. 1989;51(1):156-161.
29. Günzel-Apel AR, Günther C, Terhaer P, Bader H. Computer-assisted analysis of motility, velocity and linearity of dog spermatozoa. J Reprod fert Supp. 1993; 47:271-278.
30. Phillips PH, and Lardy HA. A yolk-buffer pabulum for the preservation of bull semen. J Dairy Sci. 1940;23:399-404.
31. Foote RH, Bratton RW. The fertility of bovine semen cooled with and without the addition of citrate-sulfanilamide yolk extender. J Dairy Sci. 1949;32:856-861.
32. Almquist RH, Glantz PJ, Shaffer HE. The effect of a combination of penicillin and streptomycin upon the livability and bacterial content of bovine semen. J Dairy Sci. 1949;32:183-190.
33. Thacker DL, Almquist JO. Diluters for bovine semen. I. Fertility and motility of bovine spermatozoa in boiled milk. J Dairy Sci. 1953;36(2):173-180.
34. O'dell WT, Almquist JO. Freezing bovine semen. I. Techniques for freezing bovine spermatozoa in milk diluents. J Dairy Sci. 1957;40(12):1534-1541.
35. Almquist JO, Wickersham EW. Diluents for bovine semen. XII. Fertility and motility of spermatozoa in skim milk with various levels of glycerol and methods of glycerolization. J Dairy Sci. 1962;45:782-787.
36. Musgrave RWD, Dunn HO, Foote RH. Causes and prevention of reproductive failures in dairy cattle. II. Influence of underfeeding and overfeeding from birth to 80 weeks of age on growth, sexual development, and semen production of Holstein bulls. Cornell Univ. Agric Exp Sta Bull. 940, Ithaca. 1959;1–45.
37. Foote RH. Research techniques to study reproductive physiology in the male. Techniques and Procedures in Animal Science Research. Am Soc Anim Prod. Albany, New York; 1969;81-110.
38. Amann RP. Sperm production rates. In: A. D. Johnson, W. R. Gomes, and N. L. Van Demark (ed.) The Testis. 1970;1:443-482.
39. Polge C, Smith AU, Parkes AS. Revival of spermatozoa after vitrification and dehydration at low temperatures. Nature, London; 1949;164:666.
40. Polge C. Frozen semen and the AI Programme in Great Britain. In Proc. 2nd Tech. Conf. Artif Insem Reprod. NAAB, Columbia; 1968;46-51.
41. Davis IS, Bratton RW, Foote RH. Livability of bovine spermatozoa at 5, −25, and −85°C in tris-buffered and citrate buffered yolk-glycerol extenders. J Dairy Sci. 1963; 46:333-336.
42. Foote RH. Artificial Insemination to Cloning: Tracing 50 Years of Research.

Published by the author, Ithaca, New York. 1988.
43. Trimberger GW. Breeding efficiency in dairy cattle from artificial insemination at various intervals before and after ovulation. Nebraska Agric Exp Sta Bull Lincoln. 1948;153:26.
44. Hansel W, Convey EM. Physiology of the estrous cycle. J Anim Sci. 1983; 57(2):404-424.
45. Rowson LEA. The role of reproductive research in animal production. J Reprod Fertil. 1971;26:113-126.
46. Gledhill BL. Cytometry of mammalian sperm. Gamete Res. 1985;12:423-438.
47. Johnson LA, Flook JP, Hawk HW. Sex preselection in rabbits: live births from X and Y sperm separated by DNA and cell sorting. Biol Reprod. 1989;41(2):199-203.
48. Penfold LM, Holt C, Holt WV, Welh GL, Cran DG, Johnson LA. Comparative motility of X and Y chromosome–bearing bovine sperm separated on the basis of DNA content by flow sorting. Mol Reprod Dev. 1998;50(3):323-327.
49. Garner DL, Seidel GE. History of commercializing sexed semen for cattle. Theriogenology. 2008;69(7):886-895.
50. Garner DL. Hoechst 33342: the dye that enabled differentiation of living X-and Y-chromosome bearing mammalian sperm. Theriogenology. 2009;71(1):11-21.
51. Sharma P, Hadiya KK. Technologies for Separation of 'X' and 'Y' Spermatozoa in Bovines: An Overview. Ind J Vet Sci Biotech. 2023;19(5):1-10.
52. McKenzie FF. A method for collection of boar semen. J Anim Vet Med Assoc. 1931; 78:244-246.
53. Ito T, Niwa T, Kudo A. Studies on artificial insemination in swine. Zootech Exp Sta Res Bull. 1948;55:1-74.
54. Polge, C. The development of artificial insemination service for pigs. In Anim. Breed Abstr. 1956;24:209-217.
55. Iritani A. Problems of freezing spermatozoa of different species. In: Proc. 9th Int. Congr. Anim Reprod Artif Insemin. Madrid, Spain. 1980;1:115-131.
56. Watson PF, Behan, JR. Intrauterine insemination of sows with reduced sperm numbers: results of a commercially based field trial. Theriogenology. 2002;57(6): 1683-1693.
57. McKenzie FF, Lasley JF, Phillips RW. The storage of horse and swine semen. Anim Sci J. 1939;(1):222-225.
58. Berliner VR. Dilutors for stallion and jack semen. J. Ani. Sci. 1942;1(4):314-319.
59. Gunn RMC. Fertility in Sheep. CSIRO Bull. 1936; 94, Melbourne, Australia.
60. Corteel JM. Collection, processing and artificial insemination of goat semen. Goat Prod. 1981;171-191.
61. Salamon S, Maxwell WMC. Frozen storage of ram semen II. Causes of low fertility after cervical insemination and methods of improvement. Anim Reprod Sci. 1995; 38(1-2):1-36.
62. Maxwell WMC, Watson PF. Recent progress in the preservation of ram semen. Anim Reprod Sci. 1996;42(1-4):55-65.
63. Amoah EA, Gelaye S. Biotechnological advances in goat reproduction. J Anim Sci. 1997;75(2):578-585.
64. Burrows WH, Quinn JP. The collection of spermatozoa from domestic fowl and turkey. Poult Sci. 1937;16(1):19-24.
65. Sexton TJ. Preservation of poultry semen-a review. Anim Reprod. 1979;159-170.
66. Lake PE. The history and future of the cryopreservation of avian germ plasm. Poult Sci. 1986;65(1):1-15.
67. Donoghue AM, Wishart GJ. Storage of poultry semen. Anim Reprod Sci. 2000; 62(1-3):213-232.
68. Perry GA, Patterson D. Determining reproductive fertility in herd bulls. University Extension, University of Missouri--Columbia; 2001.

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