Diabetes mellitus is a chronic disease with pandemic proportions. It has been estimated that 451 million people were diabetic in 2017 and recent statistics suggest that a worrisome 693 million people will suffer from diabetes in 2045 [1]. This metabolic disease is defined by impaired plasma glucose levels [2], which is due to insufficient insulin secretion or/and insulin resistance [3]. Thus, diminished insulin bioactivity causes a dysregulation on glucose metabolism in multiple tissues and, if not properly treated, hyperglycaemia and low insulin levels can evolve to other conditions and co-morbidities of distinct nature [4]. Pharmacological agents with antidiabetic activity have the ability to balance the dysregulated glycolytic flux on diabetes. Multiple drugs have this regulatory effect, among which metformin stands out as one of the most prescribed antidiabetic drugs. In fact, metformin was one of the first antidiabetic drugs discovered and is widely used. This biguanide is able to inhibit liver gluconeogenesis [5] which is the main antidiabetic property of this compound. However, this drug also stimulates glucose transporters, promoting glucose internalization [6], and reducing glycaemia levels.

Pharmacological treatment and lifestyle changes are crucial for minimizing the impact of diabetes mellitus on the metabolism of multiple organs. One of the most neglected systems affected by this pathology is the male reproductive system [7]. It has been reported that the diabetic condition dysregulates spermatogenesis [8] and can cause erectile dysfunction [9], among others. Both factors impair male fertility and impact life quality of male diabetic patients. Interestingly, studies on metformin treatment made in healthy rats showed a negative impact on male fertility [10]. Treatment with 30 mg/kg of metformin during 21 days showed to decrease testosterone and sperm count levels. On the other hand, treatment of diabetic rats with doses of 100 mg/kg of this biguanide for 4 weeks was able to reverse the negative effects of diabetes on fertility by restoring testosterone levels and seminiferous tubules physiology [11]. An overview of this subject has been published by Meneses and colleagues, in 2015. The authors presented and discussed the available data regarding the effects of metformin on male reproductive function [12]. Herein, we will update this subject based on literature published since then and by discussing the new results available.

Spermatogenesis is regulated by the hypothalamus-pituitary-testes axis, via the secretion of two major pituitary hormones: the luteinizing hormone (LH) and follicle-stimulating hormone (FSH). LH acts in Leydig cells, activating the synthesis of androgens that are a critical element for spermatogenesis development [13]. Metformin decreases testosterone levels in healthy male rats, however this biguanide restores testosterone secretion in diabetic rats to levels near those seen on healthy individuals [14]. A recent study, associated these effects with the modulation of testicular proteins responsible for steroidogenesis (StAR and CYP11A1). The mRNA transcripts levels of these proteins were increased when streptozotocin-induced diabetic rats were treated with 300 mg/kg of metformin for 4 weeks [14], which resulted in augmented levels of testosterone. On the other side, FSH is equally important for male fertility, since it has an important role on Sertoli cell proliferation [13], through the stimulation of cyclin expression [15]. In an experiment with rat Sertoli cells, 24 hours treatment with 10 mM of metformin showed to decrease mRNA levels of cyclin D1 and D2, which led to a decrease in Sertoli cell population, when compared with non-treated animals [15]. The authors hypothesized that metformin...
seemed to have an opposite effect to FSH on the proliferation of Sertoli cells on non-diabetic individuals. In fact, metformin is known for decreasing cell proliferation and having application on cancer cells containment [16]. However, despite 10 mM of metformin for 24h decreased Sertoli cell number, this treatment did not affect remaining testicular cells [13] or sperm viability [17]. In a similar study, using prepubertal chicken Sertoli cells, metformin induced a similar decrease in Sertoli cells number, without affecting apoptosis rate or cell viability. The authors also suggested that metformin seemed to delay the development of germ cells [18], based on the alterations detected on seminiferous tubules physiology, which can be considered as a red flag for male reproductive function impairment. These negative results are seemingly caused by the fact that the experiment was performed in non-diabetic animal models. With this in mind, Tertti and co-workers designed an experiment where they studied if treatment with 1500 mg/day of metformin during pregnancy in humans with gestational diabetes could affect the male offspring fertility [19]. The trial was performed in pregnant women with 22 to 34 weeks of gestation and the testicular size of male offspring, with ages between 33 to 85 months, was measured. This study did not detect any difference in testicular size between the offspring of moms treated with metformin, and treated with insulin. However, in a similar study performed in rats, the male offspring of treated mothers between the first gestation day and the twenty-first lactation day with metformin 300 mg/kg/day showed a decrease in sperm count [20]. In addition, the sexual behaviour of offspring from rats treated and not treated with metformin were distinct. The offspring of treated rats recorded a larger number of interruptions necessary to ejaculation and a smaller latency to the first intromission. The author hypothesised that the observed results on sexual behaviour caused by metformin, could be mediated by the ability to impair sex hormone-binding globulin secretion levels and the fact that metformin can act as an aromatase inhibitor [20]. Both factors resulted in lower testosterone bioactivity, which led to lower sexual appetite. It is worth to highlight, like in the experiment made in humans, the authors did not found any difference on testicular weight between the two experimental groups.

Ghasemnejad-Berenji and co-workers performed a study where a protective effect of metformin on rats that were physically damaged by torsion and detorsion of the testes was accessed. Metformin showed to be relevant to maintain a well-organized structure of seminiferous tubules, while intratubular necrosis and a lower number of germ cells were observed in non-treated rats [21]. Metformin treatment resulted in increased epididymal sperm concentration and sperm motility, mainly by the reduction of oxidative stress and apoptosis of germ cells. From these novel studies we can conclude that metformin has a protective effect not only on sperm but also on testicular cells, especially on intratubular tissue, which leads to a normalization of spermatogenesis.

Altogether, the available data on the effects of metformin on male fertility highlights an enhanced reproductive function when compared with non-diabetic animal models. In fact, metformin showed to be relevant to maintain a well-organized testicular structure, which can be considered as a red flag for male reproductive function impairment. These negative results are seemingly caused by the fact that the experiment was performed in non-diabetic animal models. With this in mind, Tertti and co-workers designed an experiment where they studied if treatment with 1500 mg/day of metformin during pregnancy in humans with gestational diabetes could affect the male offspring fertility [19]. The trial was performed in pregnant women with 22 to 34 weeks of gestation and the testicular size of male offspring, with ages between 33 to 85 months, was measured. This study did not detect any difference in testicular size between the offspring of moms treated with metformin, and treated with insulin. However, in a similar study performed in rats, the male offspring of treated mothers between the first gestation day and the twenty-first lactation day with metformin 300 mg/kg/day showed a decrease in sperm count [20]. In addition, the sexual behaviour of offspring from rats treated and not treated with metformin were distinct. The offspring of treated rats recorded a larger number of interruptions necessary to ejaculation and a smaller latency to the first intromission. The author hypothesised that the observed results on sexual behaviour caused by metformin, could be mediated by the ability to impair sex hormone-binding globulin secretion levels and the fact that metformin can act as an aromatase inhibitor [20]. Both factors resulted in lower testosterone bioactivity, which led to lower sexual appetite. It is worth to highlight, like in the experiment made in humans, the authors did not found any difference on testicular weight between the two experimental groups.

**References**


