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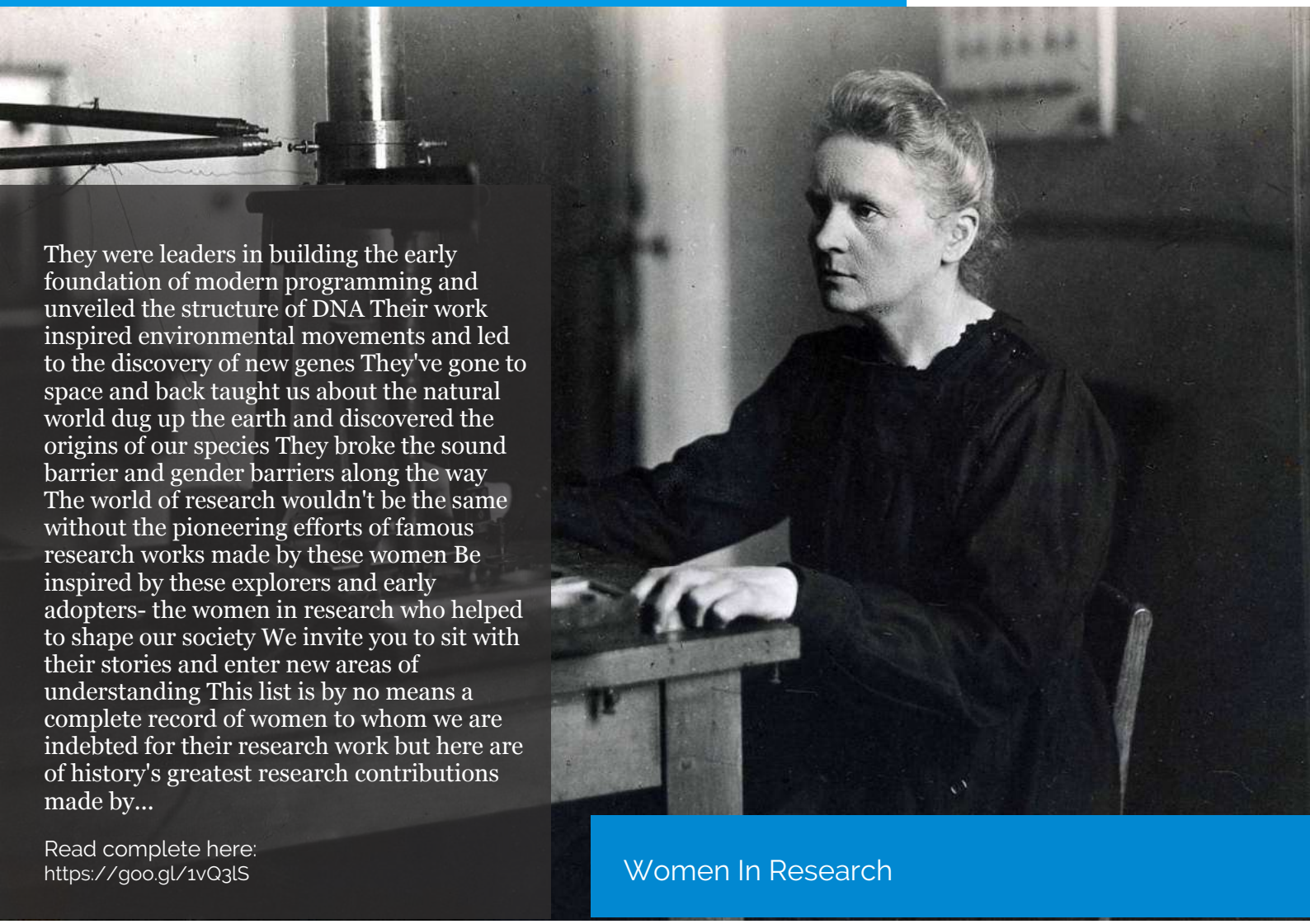

They were leaders in building the early foundation of modern programming and unveiled the structure of DNA Their work inspired environmental movements and led to the discovery of new genes They've gone to space and back taught us about the natural world dug up the earth and discovered the origins of our species They broke the sound barrier and gender barriers along the way The world of research wouldn't be the same without the pioneering efforts of famous research works made by these women Be inspired by these explorers and early adopters- the women in research who helped to shape our society We invite you to sit with their stories and enter new areas of understanding This list is by no means a complete record of women to whom we are indebted for their research work but here are of history's greatest research contributions made by...

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The Comparative Analysis of Efficacy and Safety Parameters of Insulin Degludec Versus Insulin Glargine: A Systematic Review and Meta-Analysis (2023)

Anzhelika Magomedova

University of Essex

ABSTRACT

Background and aim: Insulin glargine and degludec represent the second-generation basal insulins invented to fill in a clinical need for the insulin which matches the normal pattern of insulin secretion as closely as possible. Both insulins showed reduced rates of hypoglycaemia in real-world patients compared to the first-generation basal insulins. However, according to several studies, decludec demonstrated superiority in reaching optimal fasting plasma glucose targets without increasing risk of nocturnal hypoglycaemia. The aim of this study is to compare the efficacy and safety parameters of insulin degludec versus insulin degludec.

Keywords: major mental disorders, schizo-phrenia, neurology, psychopathology.

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Methods: This meta-analysis includes only primary investigation papers which used quantitative research methods, predominantly randomized controlled studies (RCT). PubMed, Clinicaltrials.gov, Clinicaltrialsregister.eu and Google Scholar electronic databases were used for the search of studies with the results published within 2015-2021 period. The statistical analysis for continuous variables was performed using mean differences (MD) and standard deviations (SD); the meta-analysis for dichotomous variables includes Risk Ratios.

Findings: The results of the meta-analysis demonstrate that IDeg is associated with less glycaemic variability (less overall and nocturnal hypoglycaemia episodes) in both T2D and T1D (insulin naïve and experienced) patients; IDeg is more effective in the reduction of fasting plasma glucose (FPG) levels in both T2D and T1D (naïve and experienced) patients; treatment with IDeg is associated with less weight gain IDeg versus IGlar in T2D (insulin experienced) and T1D groups; both insulins (IDeg and IGlar) provide a similar reduction of HbA1c levels.

Conclusion: In conclusion, this systematic review and meta-analysis demonstrates that insulin degludec is superior to insulin glargine in terms of four safety and efficacy variables such as change in fasting plasma glucose, body weight gain, nocturnal and overall hypoglycaemia. IDeg vs IGlar produce similar changes in HbA1c levels and the level of antibodies cross-reacting with human insulin. The most pronounced difference was detected in the number of nocturnal and overall hypoglycaemia, which confirms the fact that IDeg exhibits less glycaemic variability. Moreover, the reduced number of hypoglycaemia is accompanied with the reduction of FPG levels.

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Chapter 1: INTRODUCTION

1.1 Description of the research topic

Diabetes mellitus is a non-communicable disease which is characterized by chronic hyperglycaemia and disturbance of metabolism (Kerner, 2014)

Diabetes was known from ancient times (was first recognized around 1500 B.C.E. by Egyptians), the term was first used by the Greek physician Aretaeus (80 to 130 C.E.). Until 1921, when Frederic Banting and Charles Best discovered insulin, diabetes was a uniformly fatal disease.

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The discovery of insulin which was initially extracted from animals endowered people with a chance to survive for the long periods of time. The insulin production since has made substantial improvements switching from animal insulins with lower efficacy and higher immune reactions to the refined human analogues, closest by its chemical structure to the endogenous insulin (Polonsky, 2012).

The global prevalence of Diabetes Mellitus is estimated at 8,5% in 2014.Today, the new cases of diabetes show an upward trend globally. Moreover, the diabetes global increasing trend can be observed through decades: from 108 million in 1908 to 422 million in 2014 (WHO, 2020).

Diabetes today has become the ninth leading cause of death: from 2000 to 2019 deaths from diabetes increased by 70% worldwide; in 2019, diabetes was a direct cause of 1,5 million deaths. Moreover, diabetes has become a leading cause of disability which results in a substantial financial burden imposed on health systems globally (WHO,2020). For example, UK only spends 8,8 billion pounds annually in a direct cost, and about 13 billion in indirect costs on complicated Diabetes Type 2 (NHS,2019). Diabetes is a primary cause of blindness, myocardial infarction, stroke, kidney failure and feet amputations.

However, these complications develop in case of poor glycaemic control and persisted chronic hyperglycaemia and can be successfully prevented through a regular self-control of blood glucose, appropriate medication, diet and physical activity (Syaifuddin,2013; CINAHL, 2016; Chan, 2016; WHO,2020). Therefore, the efforts to find a better treatment option for patients with diabetes should be intensified.

Classification of diabetes includes Diabetes type 1(T1D), type 2 (T2D) and specific diabetes types (Kerner, 2014).

The two most prevalent types of diabetes requiring administration of insulin therapy are Diabetes Type 1 and Type 2. Diabetes Type 1(juvenile onset) is characterized by absolute deficiency of endogenous insulin production and insulin administration in this case is a life-saving treatment. In 2017, the estimated number of those with T1D diagnosis was nine million people. Today, the cause and measures to prevent T1D are unknown. Diabetes Type 2(adult-onset) accounts for about 95% of all diabetes cases and is mostly caused by excess body weight; T2D unlike T1D, is defined by ineffective use of endogenous insulin (WHO, 2020).

Today, about 50% of patients with Diabetes Type 2 use basal insulins as an additional treatment to oral antidiabetic drugs or basal + bolus regimes alone (Zinman et al,2012). Insulins are divided into short acting (before meal) and long-acting analogues. Long acting or basal insulins ensures a non-stop mild hypoglycaemic effect which altogether with bolus insulins allow to reach an optimal, target blood glucose levels and HbA1c <7%. However, along with multiple benefits insulin therapy has a dangerous side-effect - hypoglycaemia. Hypoglycaemia, especially severe ones can cause loss of consciousness, seizures, coma, an acute coronary syndrome, a hip fracture (Febo,2011). The generation of a basal insulin ensuring a stable hypoglycaemic effect with a minimal risk of hypoglycaemia, especially severe and nocturnal ones, is considered as a priority in the treatment of insulin-dependent patients with diabetes today (Karla, 2013).

The main purpose of this dissertation is to compare six safety and efficacy parameters of the two best available and frequently prescribed basal insulins (glargine and degludec) in order to identify the one that produces better results in terms of safety and glycaemic control in adult patients with Diabetes Type 1 and Type 2.

1.2 Background context

The dissertation considers a meta-analysis as the most appropriate strategy for the investigation of the pooled results for six variables of interest obtained from the existed high-quality trials. Insulin glargine and degludec represent the second-generation basal insulins invented to fill in a clinical need for the insulin which matches the normal pattern of insulin secretion as closely as possible (Pettus et al, 2015; Standi, 2016).

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Insulin degludec (U-100) is the newest basal insulin analogue of Novo Nordisk company, approved in 2012, while insulin glargine(U-100) is a product of Sanofi Aventis company with a longer history of clinical use (was approved by Food and Drug Administration USA in 2000) (Dedov,2015; Pettus et al, 2015). Glargine (IGlar) along with Detemir were invented as an improvement of NPH insulin, both demonstrating the lower risk of hypoglycaemia translated into the reduced rate of hospitalization for severe hypoglycemia and secondary healthcare visits in real-world patients - 9.9% lower (p = 0,022) for glargine U100 compared with NPH (Woo, 2021). However, the on-going need for the flat-profile insulin capable of reaching optimal fasting plasma glucose targets without increasing risk of nocturnal hypoglycaemia remained, and degludec (IDeg) was consequently produced to address this need (Lajara et al, 2017).

1.3 Research rationale

The dissertation is aimed at the investigation of those safety and efficacy parameters of IDeg and IGlar that demonstrated inconsistent or outdated results. A previously published reviews and meta-analyses include mostly studies conducted from 2011 to 2015, however more studies have been published since: Wysham et al, 2017 (SWITCH 2 Trial), Kawaguchi et al, 2018, Philis-Tsimikas, 2020, Kumar, 2017 (BOOST Trial), Billings et al, 2017 (DUAL VII Trial), Novo Nordisk, 2021 (SWITCH PRO Trial), Rosenstock , 2018 (BRIGHT Trial). Therefore, the inclusion of new data is needed to assess safety and efficacy parameters of IDeg and IGlar. Moreover, some reviews include studies with no direct comparison of IDeg/IGlar and are mostly focused on Diabetes Type 2 patients (Madenidou, 2018). Overall, only two systematic reviews included five studies with participants diagnosed with Diabetes Type 1. Also, there is no review measuring antibodies produced against human insulin, although this safety point accounts for the level of insulin resistance, injection-site reactions, lipodystrophies - the formation of insulin-induced hypertrophic adipose lumps or atrophic loss and further necrosis of adipose tissue (Thalange et al, 2016; Thewjitcharoen et al, 2020).

With regards to the weight gain parameter, Lingav, (2016) reported that treatment with IDeg was associated with less weight gain, while Madenidou,(2018) provides the opposite results – IGlar and Detemir are associated with weight loss, not IDeg. The results of Zhou et al,(2019) and Liu et al,(2018) demonstrate statistically insignificant difference and similar changes in body weight gain.

Similarly, the results for the overall episodes of hypoglycaemia varies across reviews and studies providing some level of inconsistency: studies of Sullivan et al(2018) and Laviola(2021) reported that a risk reduction is associated with IGlar, not IDeg. In contrast, reviews of Ratner et al (2015), Heller (2015), Liu et al(2018), Madenidou (2018), Zhang(2018) revealed the opposite results: IDeg is associated with fewer hypoglycaemia (overall, severe, nocturnal) in T2D and T1D patients; the results of Russell-Jones (2015) showed no statistically significant difference in overall episodes of hypoglycaemia IDeg/IGlar.

The results for HbA1c and fasting plasma glucose are mostly consistent with some variations between IDeg vs IGlar groups across studies.

1.4 Research question

What is the difference in terms of efficacy and safety parameters between Insulin Degludec and Insulin Glargine, in the treatment of adult (18+) patients with Diabetes Type 1 and Type 2?

Aim of study

To investigate the efficacy and safety parameters of Insulin Degludec(IDeg) compared to Insulin Glargine(IGlar) in the treatment of adult (18+) patients with +*9999Type 1 and Type 2.

Objectives

To review published papers from 2015 to 2021 in order to: -

1. Assess which of the two basalinsulins (IDeg and IGlar) is associated with less glycaemic variability (less overall and nocturnal hypoglycaemia episodes).
2. Compare the hypoglycaemic effect of IDeg and IGlar through the reduction of fasting plasma glucose (FPG) levels and HbA1c.

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3. Compare the extent of body weight gain observed during the treatment with IDeg versus IGlar.
4. Evaluate and compare the levels of antibodies cross-reacting with human insulin after the treatment with IDeg versus IGlar.

The research question and objectives will be tested through the critical literature review, quantitative analysis of secondary data. With the purpose of analyzing the existing knowledge on the research topic, the dissertation will conduct the search through Medline, Embase, Clinicaltrials.gov, Clinicaltrialsregister.eu, Google Scholar databases in the Literature Review Chapter. The Methodology chapter includes research design and strategy, research philosophy, ontology and epistemology, data collection and analysis, critical quality and ethical appraisal of the validity and reliability of the resourced studies.

The Discussion Chapter includes discussion of the main findings, analysis and interpretation of the results obtained through the statistical analysis. In addition to this, strengths and limitations of the conducted meta-analysis will be examined and discussed. Conclusion summarizes the main stages of the dissertation, its limitations and provides the final answer to the research question.

CHAPTER 2: LITERATURE REVIEW

Basal insulins glargine and degludec are the most advanced analogues of human insulin demonstrating profiles close to the normal physiological profile of endogenous insulin output. Although both insulins are claimed to produce a stable ahypoglycaemic effect during a 24 - hour period, according to some studies insulin degludec is reported (Gough, 2013; Ratner, 2015; Zang, 2018; Zhou, 2019) to produce less glycaemic variability. Insulin degludec is related to the most novel basal insulins generation with a half-life of > 25 h. Degludec is the only basal insulin that has a half-life that exceeds the dosing interval (Woo,2020).

As insulin degludec is a more expensive analogue than insulin glargine, there is a need for more evidence to demonstrate its higher levels of efficacity.

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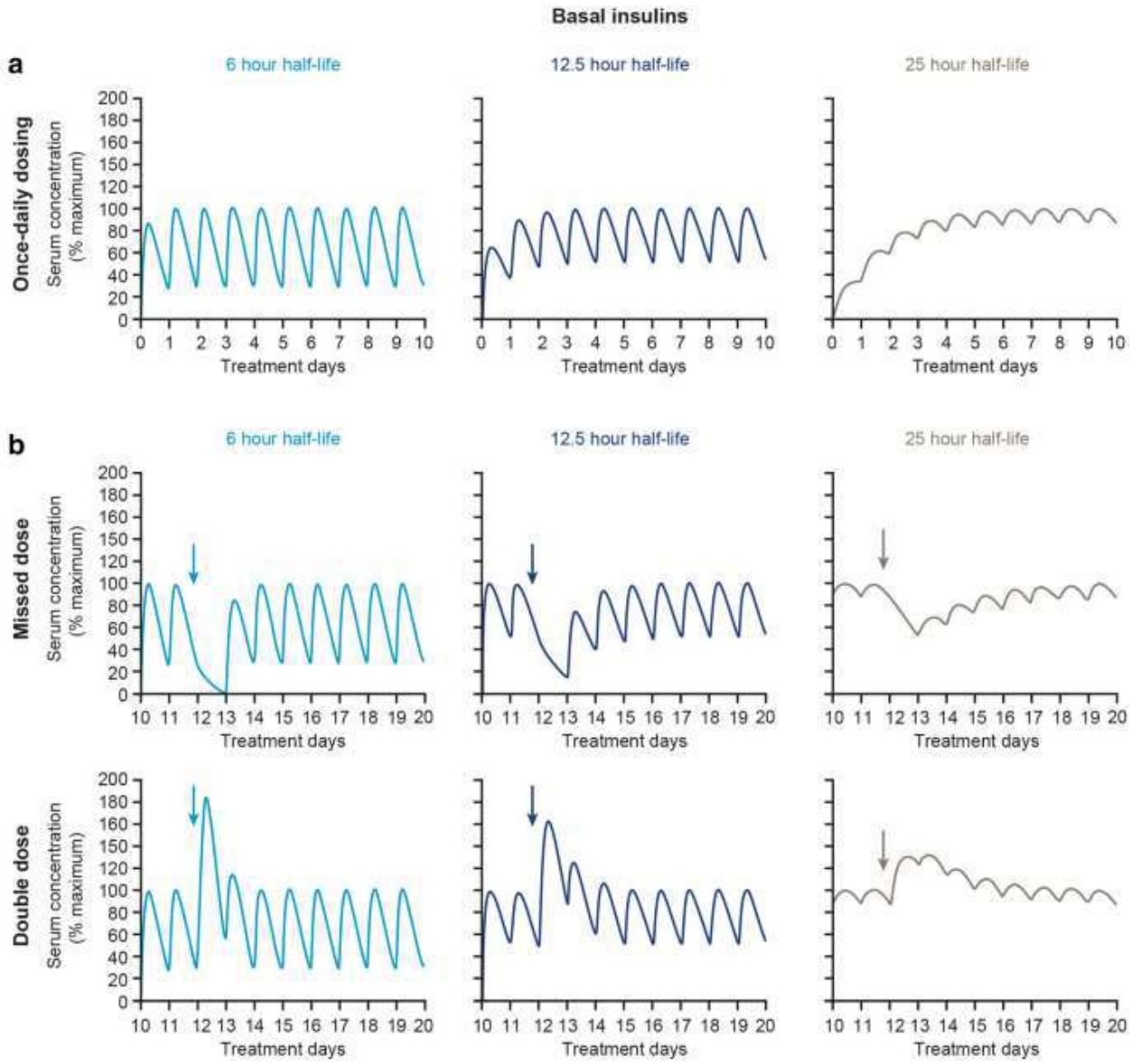

Figure 1: Glycaemic Profiles of NPL (First Vertical Row) Glargine(second Vertical Row) and Degludec (Third Vertical Row) Adjusted From Woo (2020)

There are several safety and efficacy parameters that indicates superiority of one basal insulin upon other such as: body weight gain, change in fasting plasma glucose (FPG), overall and nocturnal episodes of hypoglycaemia, change in HbA1c, cross-reacting with human insulin antibodies. The most relevant and valid information on existed research comprises of two randomized controlled trials, two retrospective cohort studies and eight systematic reviews and meta-analyses including a large number of high- and medium quality randomized controlled trials(RCTs). The results were generated from large multi-national samples which increases a statistical power and validity (Saks, 2019).

Historically, a randomized controlled trial was designed to find an answer to a very specific question. The main purpose of this trial design is to examine the effects of a particular treatment in the population where this treatment will be introduced. The inferences are based on a comparative analysis of outcomes observed in experimental and control groups (control group does not receive the intervention). A randomized controlled trial design mitigates biases that come from experimental environment and controls confounding factors by matching process. The main purpose of RCT is to minimize "confounding by indication", the phenomenon defined by the

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fact that clinicians choose treatments based on the particular characteristics of patients (Saks, 2019).

Randomization in RCTs promotes comparability and similarity of the intervention and control groups. Moreover, it serves as a basis for quantitative evaluation of the treatment effect and valid statistical inferences. The similarity of participants in both groups is essential because it ensures that other factors do not interfere with the treatment effect and influence on outcome. In addition to this, the random allocation of subjects to control and treatment groups increases generalizability and validity of the trial's results and substantially improves the quality of evidence-based studies by minimizing a selection bias (Lim, 2019).

The six variables of interest are discussed below in a separate section. The critical analysis of the literature discussed, however, will be presented separately because most reviews examined three or more variables in one review.

2.1 Body Weight Gain

Insulin therapy includes not only benefits, but several negative side effects as well, among which weight gain and hypoglycaemia are the most important ones. The issue of weight gain is particularly relevant in case of Diabetes Type 2 (T2D) which is usually observed among people who have already had excessive weight (overweight, obese). Therefore, in T2D patients, the prescription of a basal insulin demonstrating less weight gain during a long -term use will be a preferable and reasonable treatment choice.

The research examining this variable is presented by a systematic review including 15 studies with 7075 patients in the insulin glargine group (control) and 9619 patients in the insulin degludec group (experimental) (Zhou et al,2019). The review examined four main endpoints which included weight gain. The results did not identify a statistically significant difference in body weight gain between the degludec and glargine arms (WMD 0,12 [0,19 to 0,43] p = 0,46).

Another review Liu et al, (2018) including 15 high-quality RCTs revealed similar changes in body weight gain in both T1D and T2D IDeg vs IGlar groups with statistically insignificant difference (MD= 0,03 [0,11 to 0,18] p= 0,67).

The cohort study of Laviola, (2021) also reported that no statistically significant difference was observed in body weight gain between IDeg and IGlar groups of 1070 participants. This study represents a retrospective, multicentered comparative cohort study based on electronic medical records. The study involved a network of diabetes centers located in different areas of Italy. Study sample include patients with Diabetes Type 1 (T1D), aged 18+, both genders switching to either Insulin Glargine -300 or Insulin Degludec -100 from first generation basal insulins. Each cohort included 585 patients.

Although the findings of reviews on the topic reported no significant changes in body weight, the results of DUAL V randomized controlled trial (Lingvay et al,2016) revealed that insulin degludec was associated with less weight gain (1,4 kg compared to insulin glargine 1,8 kg).

In contrast to DUAL V trial's findings, the review (Madenidou, 2018) of 34 low and medium quality studies reported that weight loss was associated with basal insulin analogues detemir and glargine, and glargine demonstrated a more favourable weight profile than insulin degludec.

2.2 Episodes of hypoglycaemia (overall, nocturnal)

Episodes of hypoglycaemia is an essential safety parameter of a basal insulin relating to the overall level of glycaemic variability. The less hypoglycaemia a basal insulin produces, the better daily glycaemic control can be achieved. Hypoglycaemia influences substantially on the quality of glycaemic control, worsens an individual's productivity at school and work, increases health costs. Also, the fear and anxiety of developing hypoglycaemia negatively impacts a quality of life. The overall episodes include mild, severe and nocturnal hypoglycaemia, however nocturnal one is divided into the separate variable due to its importance (Edelman, 2014).

Nocturnal hypoglycaemia is a dangerous side effect of insulin therapy because it happens during

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a sleep and can persist a long time causing severe decrease of a blood glucose <3,1. The persisted level of blood glucose lower than 3,1 can lead to convulsions, coma and death. Moreover, frequent nocturnal hypoglycaemia worsens contrregulatory mechanisms which maintain blood glucose levels, impairs cognitive functions and awareness of hypoglycaemia (Edelman, 2014). According to several studies spontaneous nocturnal hypoglycaemia in patients with Diabetes Type 1 changes cardiac repolarization and contributes to the risk of "dead in bed" syndrome (Koivikko, 2017).

Numerous studies Zinman,(2011), Gough, (2013), Onishi, (2013) examined this variable for both glargine and degludec insulins from 2011 year; pooled results of these studies are presented in a several systematic reviews and meta-analyses (Zhou, 2019; Heller, 2015; Ratner, 2015). The findings of meta-analysis based on the results of seven BEGIN 3a phase clinical trials (completed in the period 2011-2012) including both insulin-naïve and insulin experienced patients diagnosed with T2D (5 trials) and T1D (2 trials) demonstrated that end-of -trial rates of nocturnal hypoglycaemia were lower in groups treated with insulin degludec in both patient categories – T2D and T1D, however the rates were lower for T2D patients.

The rate of overall episodes of hypoglycaemia also favours groups treated with insulin degludec. However, the difference was not statistically significant. (Russel-Jones, 2015).

The results of the meta-analysis of Zhou et al (2019) showed that a treatment with insulin degludec was associated with lower severe and nocturnal hypoglycaemia,

In terms of hypoglycaemia events, treatment with IDeg was associated with lower nocturnal and overall hypoglycaemia in patients with T2D according to the meta-analysis of Liu et al, (2018).

Finding of the retrospective cohort study revealed that incidence rates of hypoglycaemia during 6-month follow up were slightly lower in the IGlar group versus IDeg group. IGlar showed a 24% lower likelihood to experience a hypoglycaemic episode - IRR 0,76 [CI95% 0,60-0,96] (Laviola, 2021).

The review of Heller, (2015) reported that for T2D patients, the risk of nocturnal hypoglycaemia (timescale 00,01-5.59, plasma glucose ,3,1 mmol/l) was significantly lower with insulin degludec vs insulin glargine during all trial periods. For individuals with T1D, nocturnal hypoglycaemia risk was similar or lower across different definitions, trial periods and timescales. Nocturnal documented symptomatic hypoglycaemia for T2D patients during entire trial period IGlar-100,5 /IDeg 73,8 (Episodes per 100PYE).

The review of Madenidou, (2018) reported pooled results of 38 randomized controlled trials where several basal insulins were analyzed in terms of weight gain, hypoglycaemia events and HbA1c. According to this review, IDeg-100 was associated with lower incidence of any hypoglycemia (confirmed, symptomatic, asymptomatic with blood glucose <3,9; 3,1) compared with Glar-100 (OR- 0,64 [0,43 to 0,96]). The data for nocturnal hypoglycaemia were reported altogether for IGlar 300 and IDeg 100, 200 showing less nocturnal hypoglycaemia compared to insulin detemir, LY2963016 and NPL.

Another review exploring this safety parameters reported that IDeg is associated with lower risk of overall and nocturnal hypoglycaemia in both Diabetes Type 2(insulin-naïve and basal-bolus) and Type 1 patients with a risk reduction variating from 24% to 40%(Woo,2020). The review examined the results of different studies and trial phases (SWITCH trial- (RR 0,94, p = 0.002, DEVOTE trial, EDITION trials, CONFIRM trial - RR 0,70, p =0.05), BRIGHT trial) and meta-analyses. Additionally, the association of the treatment with insulin degludeg with a significantly reduced risk (RR 0,60, p = 0,001) of developing severe hypoglycemia among patients with chronic kidney and cardiovascular disease was confirmed (DEVOTE trial) (Woo, 2020).

The meta-analysis of Ratner et al (2015) showed that among overall T2D population (Rate Ratio (RR) 0,83 and 0,68) and insulin-naive patients with T2D (RR-0,83 and 0,64), those using IDeg

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experienced significantly lower rates of overall confirmed and nocturnal hypoglycaemia than those using IGlar. In terms of T1D patients, during a maintenance period, a treatment with IDeg was associated with the significantly lower event rates of nocturnal confirmed hypoglycaemia as compared to IGlar (Rate Ratio 0,75). The results were statistically significant (Ratner et al, 2015).

Sullivan (2018), however, reported different results obtained from the DELIVER D+ cohort study: a considerable decrease in the incidence of hypoglycaemia was associated with IGla-300 (overall hypoglycaemia: from 15.6% to 12.7%; p = 0,006; hypoglycaemia requiring a treatment in an inpatient/emergency department: from 5.3% to 3.5%; p = 0,007). However, after the adjustment for baseline hypoglycaemia, IGlar-300 and IDeg showed similar event rates with no statistically significant difference in episodes of hypoglycaemia. At the follow-up period, the number of hypoglycaemic events was similar in both groups, but those patients who switched to IGlar-300 from IDeg demonstrated a lower inpatient/ hypoglycaemia event rate (Rate Ratio- 0,56; p = 0,016).

The review of Zhang (2018) reported results favouring insulin degludec; IDeg was associated with a reduced risk for all confirmed hypoglycaemia. The results reached a statistical significance: ERR -0,81; 95% CI – 0,72-0,92; p- 0,001), nocturnal hypoglycaemia (ERR-0,71, 95% CI – 0,63-0,80; p <0,001.

2.3 Change in HbA1c

In terms of HbA1c, the study of Sullivan, (2018) identified that the reduction in mean HbA1c levels were similar among patients from both IGlar-300 and IDeg-100 cohorts. HbA1c measurements were similar at baseline (0,63 ± 1,7% p = 0,488) and follow-up (0,58 ± 1,6% p = 0,488) periods.

Network meta-analysis of Madenidou, (2018) based on the data obtained from 37 studies showed a minimal difference in change of HbA1c level: Deg-100 (MD- 0,21% [95% CI 0,03% to 0,38%]) Deg-200 (MD 0,28% [0,04% to 0,52%]), Glar-100 (MD- 0,26% [0,11% to 0,42%]), Glar-300 (MD- 0,32% [0,13% to 0,51%]). This analysis showed that no statistically significant difference was detected in comparisons between IGlar-300, IGlar-100 vs IDeg-100, IDeg-200.

In terms of percentage of patients with HbA1c level less than 7% pooled results of 26 studies revealed that more patients treated with Glar-100 achieved an HbA1c level less than 7% than those treated with Deg-3TW – Odds Ratio 1,45 [CI95% 1,06 to 1,96].

According to the review of Zhou (2019), the sensitivity analysis which included nine trials with 13072 participants in total, revealed that insulin glargine was associated with a greater mean overall reduction in HbA1c comparing to insulin degludec. However, the difference was not statistically significant - WMD 0,03 [0,01 to 0,07] p = 0, 10. A subgroup analysis was performed for insulin-naïve and insulin-experienced groups which confirmed that the difference in the level of glycated hemoglobin was not statistically significant between IDeg and IGlar treatment groups -WMD 0,03 [0,00 to 0,07] p = 0,08.

The results of BRIGHT trial showed that from baseline to the end-of-trial period, the level of HbA1c reduced similarly from initial values in IDeg-100 treatment groups versus IGlar-300 treatment groups. The initial values of 8,7% ± 0,8% in the IDeg group and 8,6% ± 0,8% in the IGlar-300 group reduced to 7,0%± 0,8% by the week 24 in both groups. Least squares mean change in the level of HbA1c from baseline to end-of-trial period was -(-1,64 ± 0,04% [-18,0 ± 0,4] mmol/l) for IGlar group and -(-1,59 ± 0,04% (-17,4 ± 0,4 mmol/mol) for IDeg group, p < 0,0001 (Rosenstock, 2018).

The review of Liu et al, (2018) reported that the proportions of patients who achieved HbA1c < 7% from the baseline level were similar in both groups (IDeg 46,1% vs IGlar -46,9%). The overall results of HbA1c reduction were better in IGlar treatment groups. However, the difference was clinically insignificant (MD = 0,04% [0,01% to 0,07%]).

The review of Russel Jones, (2015) based on seven phase 3 clinical trials did not reveal a statistically

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significant difference in the level of HbA1c reduction between IDeg and IGlar groups, however due to the treat-to-target nature of the trials' design the difference was not expected.

The similar changes in the level of HbA1c from baseline to end-of-trial period were observed during BEGIN Basal–Bolus Type 1 and Type 2 trials which confirmed that treatments with IDeg and IGlar result in similar reduction of HbA1c levels. In T1D patient groups, glycated hemoglobin improved by 0,40% points in both insulin glargine and degludec groups during the first year (ETD –0,01 [0,14 to 0,11). Regarding the number of those who achieved a target level of HbA1c, a total of 67 (43%) participants in IGlar groups and 188 (40%) participants in IDeg groups reached the level of HbA1c < 7% (<53 mmol/l) from mean baseline values 7,7 ± 1,0%, SD (60,7 ± 11,0 mmol/mol). In T2D patient groups, the level of HbA1c reduction at first year was 1,1% in IDeg treatment groups and 1,2% in IGlar treatment groups - ETD 0,08 [0,05 to 0,21] (Hui, 2012).

The findings of Zhang, (2018) demonstrated that HbA1c concentration was higher in IDeg vs IGlar group, but the results were not clinically or statistically significant (estimated treatment difference (ETD - 0,03 [0,00 to 0,06%] p= 0,06).

2.4 Change in FPG levels.

The following authors reported the findings regarding changes in fasting plasma glucose from baseline to end-of -trial periods.

A separate analysis of four trials with T2D patients showed that those who achieved FPG target <5 was higher in IDeg group (40,9%) vs IGlar (29,4%) Also, the proportion of patients who will probably reach the FPG target without nocturnal confirmed hypoglycaemia was considerably higher in IDeg group (34,9%) vs IGlar (23,8%) (Russel-Jones, 2015).

The review of Zhang, (2018) based on eighteen trials with a total of 16791 participants reported that the FPG level was lower in the IDeg treatment groups vs IGlar ones (ETD -0,28 mmol/l [0,44 to -0,11] p= 0,001).

Zhou,et al, (2019): the analysis revealed that insulin degludec produced better FPG levels as compared to insulin glargine (weighted mean difference – 5.20 mg/dL [– 7.34, – 3.07] p < 0.0 0001).

Hui, (2012): The mean reductions in laboratory-reported FPGs were also similar between IDeg and IGlar treatment groups.

Laviola, (2021): while no statistically significant change in FPG levels were documented in the IGlar-300 group at 3 month (T3) and 6 month (T6), the IDeg-100 group demonstrated a statistically important reductions in FPG at 3 month- 15,39 mg/dl and at 6 month- 16,84 mg/dl). Between -group estimated MD- T3- 20,41 mg/dl; p-0,004; but not at T6.

The review of Liu, (2018) reported that treatment with IDeg was associated with a statistically significant reduction in FPG levels as compared to treatment with IGlar -MD = -0,41 [-0,54 to -0,28] p< 0,001, with low heterogeneity across studies- I^2- 27%.

2.5 The level of Antibodies Cross-Reacting with Human Insulin

The existed research on the level of antibodies cross-reacting with human insulin comprises of six phase 3 trials: Begin Basal Bolus Type 1 Long, Begin Flex Type 1, Begin Once Asia, Begin Flex Type 2, Begin Once Long and Begin Low Volume. The total number of participants in IDeg groups was (n =2550) and in IGlar groups (n=1184). Antibody measurements were conducted at baseline (week 0) and at weeks 12, 26, 40 and 52 depending on a treatment duration. The last measurements were performed at the end-of -trial and end of follow up periods.

The results revealed that treatment with IGlar and IDeg produce similar levels of antibodies cross-reacting with human insulin at the EOF period. The levels of IDeg- and IGlar-specific antibodies remained lower than <1% bound/total radioactivity (B/T) (Vora, 2015).

Both treatment groups demonstrated a minimal increase in mean levels of antibodies

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cross-reacting with human insulin: baseline IGlar 11,5% increased to 14,3% to end-of-follow-up period (EOF) in T1D groups. In T2D groups, baseline IGlar -0,2% grew to 6,0% to EOF. In IDeg groups, T1D patients showed 11,2% at baseline and 19,3% at EOF. In T2D groups, from baseline 0,2% the level of antibodies increased to 5,1% to EOF. Overall, an increase in the level of antibodies was higher for participants with T1D, who have already had a long-term insulin treatment experience, as compared to those with T2D (Vora, 2016).

2.6 Critical Analysis of the Research Discussed above

Laviola et al, (2021)

Strengths: the first study to compare the mid-term effectiveness and safety of second-generation basal insulins among patients with T1D.

Limitations: the main limitations are the lack of information on self-measuring blood glucose tests for a large proportion of patients and lack of possibility to perform head-to-head analysis due to considerable under-titration of both bolus and basal insulins. Also, baseline risk of hypoglycaemia was not included in the primary analysis. In addition to these, the study design itself provides limited evidence, no information about patients' selection (whether they were randomly selected or not).

Russel-Jones, (2015)

Strengths: all included studies followed a randomized controlled trial design which represents the evidence of high-quality according to the hierarchy of the evidence (Saks, 2019). In addition to this, studies included large multi-national samples (329-1030 participants) and are methodologically sound which increases the validity of their results.

Limitations: all seven studies excluded patients with severe, recurrent hypoglycaemia and therefore, the rates of recorded hypoglycaemia might be lower than in a real clinical practice. Another limitation is the open-label design of all clinical trials included in the review. As different devices were used for injection, masking in that case was not possible. The third limitation is that this meta-analysis pooled the results for Diabetes Type 1 drawing on two studies only.

Sullivan, (2018)

Strengths: DELIVER D+ study provides the first comparative evidence on clinical outcomes when switching from Gla-100/IDeg to Gla-300 or IDeg. The study provides complementary evidence obtained from a real-world clinical practice to the existed RCTs. The study has a sound methodology; propensity-score matching was performed to minimize confounding, sensitivity and subgroup analyses were conducted to analyze consistency of results.

Limitations: the study has a retrospective design, which according to Bowling,(2014) and Saks, (2019) is set in a lower layer of the hierarchy of evidence and patients' data came mostly from northwest and southern states which is not representative of the whole population of the USA. In addition to these, the study participants were mostly insulin naïve users, so their characteristics might differ from insulin experienced patients; dosage data were missing in >90% records; the findings can also be biased by the prescribing patterns depending on medical insurance coverage; the reason for switching insulins was not defined in the medical records and therefore a selection bias may not be fully excluded after propensity-score matching; short follow-up period < 6 months;

Despite the fact, that most of inpatient hypoglycaemia events might be reported in the medical records, it is likely that a considerable number of non-inpatient episodes of hypoglycaemia were not recorded.

Madenidou, (2018)

Strengths: the meta-analysis includes a large number of RCT trials (n=38), which mostly comprise of large samples thus increasing a statistical power.

Limitations: the meta-analysis has low external validity due to the inclusion of only studies that assessed a basal insulin analogue in both the intervention and comparator groups; therefore,

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the measurements of comparative efficacy of basal insulin analogues against premixed insulin regimens or NPH were limited. The comparative analysis of basal insulins' efficacy and safety parameters was limited because the conclusions were based on mostly indirect comparisons. Confidence in findings for glycemic efficacy and hypoglycemia was low due to imprecision, inconsistency and individual-study limitations.

For change in HbA1c level, approximately half of eligible studies had some concerns about bias or high risk of bias, and for nocturnal hypoglycemia almost all trials had high risk of bias. Also, the definition of any hypoglycemia varied among eligible studies, which compromises the applicability of findings in clinical practice; the dosing regimens varied across studies from once a day to twice a day.

Liu et al, (2018)

Strengths: the review included only high-quality studies following RCT design with a strong internal validity evaluated by the Jadad scale from 3 to five scores.

Limitations: this review has several limitations such as self-reporting of hypoglycaemic episodes; some of the included studies has open-label design; different definitions of hypoglycaemis across American Diabetes Association and European Medicines Agency. Also, a meta-analysis has shown a publication bias.

Zhou et al, (2019)

Strengths: first, the meta-analysis has a robust methodology, the sensitivity and subgroup analyses show consistency of the results. Second, a large number of RCTs and patients with T2D were included in this analysis.

Limitations: the main limitations are that most studies were funded by the manufacturer Novo Nordisk and has an open-label design. In addition to these, insulin concentrations (IDeg -100Units/ml, IDeg-200Units/ml, IGlar-100 Units/ml, IGlar -300Units/ml), frequency of injections (once daily or three times a week) insulin preparations and intervals between insulin injections may lead to high between- study heterogeneity. Finally, the difference in costs between insulin glargine and degludec was not taken into consideration in this analysis, however the cost is an important factor that influences a clinician's prescriptions (Zhou et al, 2019).

Zhang et al, (2018)

Strengths: the meta-analysis includes a large number of high-quality trials included (18 trials with a total of 16791 patients) which increases a statistical power; the data was extracted from original trials and adjusted for multiple baseline factors minimizing a risk of bias. A subgroup analysis was performed concerning the type of insulin degludec and duration of follow-up.

Limitations: the limitations of this meta-analysis include open-label design of the included studies; most of the studies were funded by the manufacturers; the definition of hypoglycaemia varied across studies; considerable heterogeneity observed for several outcomes (Zhang et al 2018).

Hui, (2012)

Strengths: The long duration of the included trials up to 52 weeks, an RCT design, low dropout rates, intention-to-treat analysis set in all trials.

Limitations: open-label design; different dose adjustments and injection timings for IDeg and IGlar; exclusion of patients with comorbidities and severe hypoglycaemia in anamnesis i.e. not close to a real-world clinical practice (Hui, 2012).

Rosenstock, (2018)

Strengths: the main strength of this study is a head-to-head trial design, proper insulin titration and low dropout rate. Most of participants has similar baseline characteristics.

Limitations: the main limitation is an absence of masking i.e. an open-label design which may have introduced a bias. Also, a comparatively short 24-week duration; the outcomes of a follow up period are unavailable (Rosenstock, 2018).

Ratner et al, (2015)

Strengths: this meta-analysis has two main strengths: pre-planned design and the inclusion of all phase 3 trials comparing directly insulin degludec with insulin glargine. The meta-analysis

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includes sensitivity analyses which demonstrated that baseline characteristics of the population did not influence the estimated rate ratio. Drawing on the results of sensitivity analyses it can be suggested that the findings of this meta-analysis can be applied to a wider population.

Limitations: the blinding of investigators and subjects was not possible due to the use of the different devices for the injection. Taking this absence of masking into account, a presence of a reporting bias to a certain extent can be suggested in this meta-analysis. Another limitation of the review is linked with individual study limitations: included trials excluded patients experiencing recurrent, severe hypoglycemic events from participation in the experiment (Ratner, 2015).

Lingav et al, (2016)

Strengths: the study has robust methodology, include multinational large sample IDeg (n=278), IGlar (n=279) with a proper matching of participants according to baseline characteristics.

Limitations: the trial has strict inclusion and exclusion criteria relating to body mass index, level of HbA1c and medication taken before the trial which makes its clinical applicability limited to these criteria. Also, study has a short follow-up period (1 week) and an open-label design which may introduce a reporting bias.

Woo, (2020)

Strengths: data were retrieved from studies and meta-analyses of high quality; studies contain large samples with various types of patients (insulin-naïve, insulin experienced, wide age range; some studies include participants with comorbidities (cardiovascular, chronic kidney diseases), data for both types of diabetesT2D, T1D were analyzed.

Limitations: limitations mostly relate to individual-study limitations such as open-label design and variations in definition of hypoglycaemia across studies.

Vora et al, (2015)

Strengths: the included trials followed an RCT design with high internal validity of results; the robust methodology of the review and precise measurements of antibodies used in trials.

Limitations: open-label design; at randomization, some participants had already had a long history of pretrial insulin exposure and higher levels of antibodies and others were insulin naïve (Vora, 2015).

CHAPTER 3: METHODOLOGY

3.1 Research Philosophy

This research is embedded in the paradigms of functionalism and positivism and follows hypothetico-deductive model. In the positivist paradigm, the association between study's variables are expressed quantitatively through direct or indirect effects. The dependent variable is linked with independent variable and increase in a latter one results in the increase in the dependent variable) (Park, 2020). Positivism recognizes evidence that relies on empirical experiments and methods accepted by scientific community (Bowling, 2014). The limitations of positivism relate to its context-free laws and neglect to individuality, subjectivity of human experience and specific conditions of the research (Davis, 2018).

The ontology of this dissertation draws on a rational research framework, positivism, functionalist research paradigm, objectivism. The ontology of the dissertation is aimed at the analysis and comparison of the two basal insulins (IDeg vs IGlar) in terms of safety, glycaemic variability and control. The dissertation considers that treatment effect of insulin is an objective entity which can be measured by objectivist methods for investigation of their specific aspects (efficacy and safety parameters). The limitation is that this ontology considers the existence of only one universal reality.

Epistemology of the dissertation assumes that objective facts and quantifiable data are the best tools to gain strong evidence and research findings of high validity through the quantitative analysis of numerical data (Haig, 2018).

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3.2 Study Design

This systematic review and meta-analysis include only primary investigation papers which used quantitative research methods, predominantly randomized controlled studies (RCT).

3.3 Search Strategy

Initially, the PROSPERO databases and the Cochrane Database of Systematic Reviews (CDSR) were inspected for ongoing and existing reviews. The result of this search showed that no systematic review matching the chosen research topic was found. SPIDER search strategy tools were applied in order to define the keywords. The MeSH browser and Boolean operators were used to retrieve more relevant and precise results (Aromataris, 2014).

The existing literature was searched in accordance with the Centre for Reviews and Dissemination (CRD) 2009 and Preferred Reporting Items for Systematic Reviews and Meta-Analyses (PRISMA) guidelines (CRD,2009).

PubMed, Clinicaltrials.gov, Clinicaltrialsregister.eu and Google Scholar electronic databases were used for the search of studies with the results published within 2015-2021 period. The purpose of the literature search was to detect all publications that matches the inclusion criteria and directly compare the effects of two long-acting insulins IDeg vs IGlar in patients with Diabetes Mellitus Type 1 and Type 2.

Table 1: SPIDER Search tool

S-Sample	Patients with Diabetes Type 1 or Type 2 (community based or hospital-based recruitment).
PI- Phenomenon of Interest	Overall and nocturnal hypoglycaemia, HbA1c, FPG, body weight gain, level of cross-reacting with human insulin antibodies in patients with Diabetes mellitus Type 1 and Type 2 receiving basal insulins (Insulin Degludec or Insulin Glargine)
D-Design	RCTs, cohort studies, clinical trials (primary, original research papers).
E- Evaluation (Outcome)	Overall and Nocturnal Hypoglycaemia (Number of episodes/ Rates/PYE) Change of HbA1c from baseline to the end of trial (Mean difference) Change of FPG from baseline to the end of trial (mean difference) Change in body weight from baseline to the end of trial (mean difference) The level of antibodies cross-reacting with human insulin after the treatment with IDeg/IGlar (Mean difference, % B/T=percentage bound/total radioactivity)
R-Research type	Studies with quantitative research methodology

The following search terms were used: *PubMed: "insulin glargine"* OR *"insulin degludec"* AND *"Diabetes"*- 1831 articles; *Clincaltrials.gov*- keywords: condition- *"Diabetes mellitus"*, search terms: *"insulin glargine"," insulin degludec"* - 79 trials; *Clinicaltrialsregister.eu* – keywords: *"insulin degludec", "insulin glargine"* - 41 trials; *Google Scholar:* advanced search (filter with the exact phrase) - keywords: *"insulin glargine", "insulin degludec"* - 76 articles identified.

Search limits were applied to refine the scope to studies not older than 2015 years from the publication of results, published on English language, studies including participants older than18 age, full-free text primary investigation papers or peer-reviewed articles, studies designed as clinical or randomized controlled trials.

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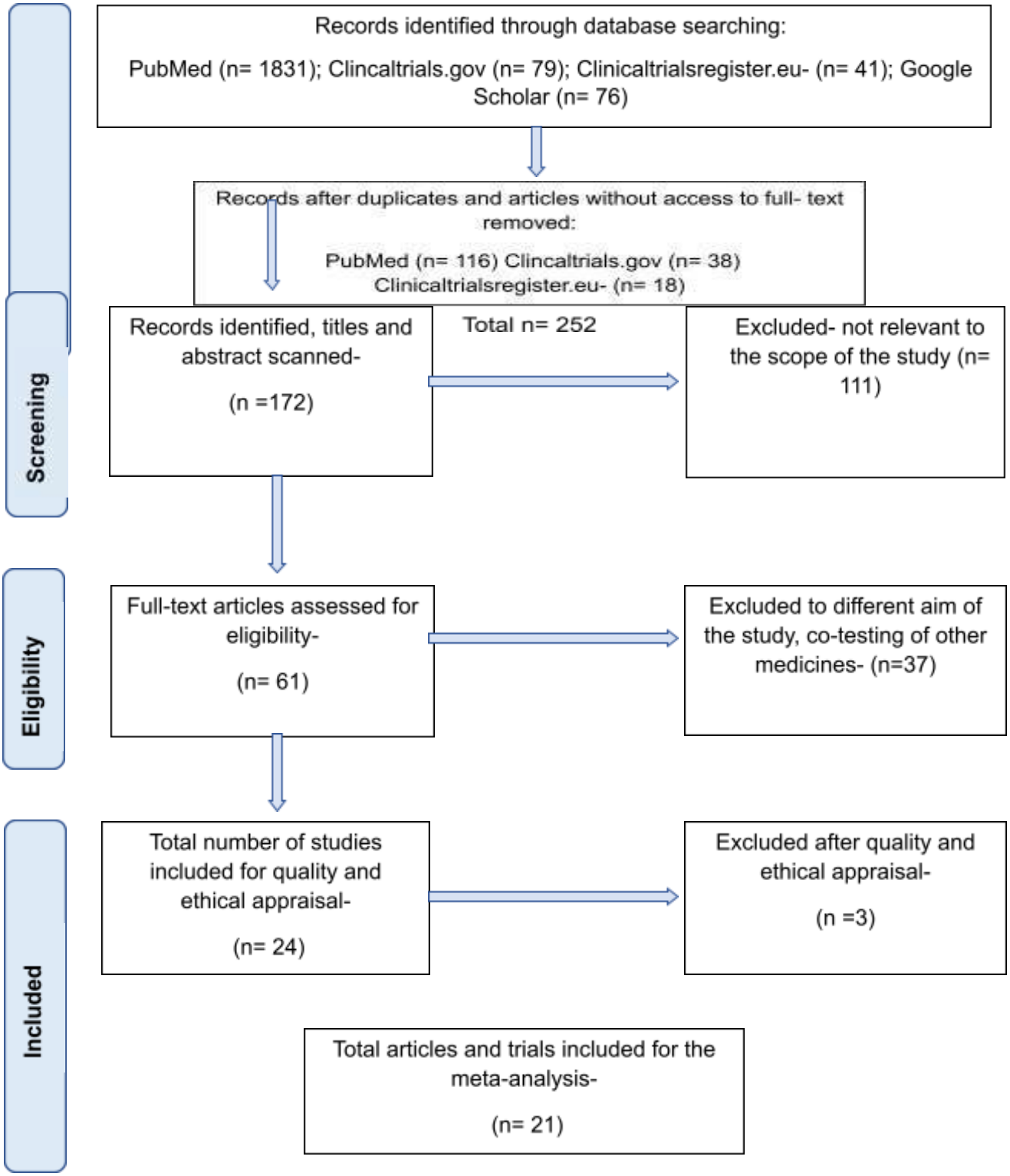

Figure 2: PRISMA Flow Diagram

3.4 Study Selection

The first stage included application of filters (free-full text, RCT, clinical trial design, publication date 2015-2021, associated data available) and screening of trials and articles resulted from filtered search for study design, titles and abstracts. The second stage involved scanning of publications and exclusion of duplicates. Studies examining safety and efficacy parameters irrelevant to the scope of this review

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were excluded. At the last stage, 61 relevant full-text articles and trials were included and scanned for data collection. 37 studies were excluded due to co-testing of other medicines along with IDeg vs IGlar to minimize confounding factors. Finally, after the application of eligibility criteria 24 studies were chosen for the quality and ethical appraisal (Table 3).

3.5 Eligibility Criteria

Table 2: Inclusion and Exclusion Criteria

	Inclusion	Exclusion
S-Sample	Samplings including participants older than 18 age. Studies which include participants diagnosed =/> six months duration, participants without severe cardiovascular and other comorbidities. Samples which do not include participants with the history of recurrent severe episodes of hypoglycaemia.	Studies including participants younger than 18 age. Studies which include newly diagnosed participants - less than six months duration, participants with severe cardiovascular and other comorbidities Samples which include participants with the history of recurrent severe episodes of hypoglycaemia.
PI- Phenomenon of Interest	Studies which include data (measurements/outcomes) of the overall, nocturnal, episodes of hypoglycaemia, the level of antibodies cross-reacting with human insulin, body weight gain, change in the HbA1c and fasting plasma glucose IDeg vs iGlar.	Studies which do not include data (measurements/outcomes) of the overall, nocturnal, episodes of hypoglycaemia, the level of antibodies cross-reacting with human insulin, body weight gain, change in the HbA1c and fasting plasma glucose IDeg vs iGlar.
D-Design	Studies relating to higher levels of hierarchy of evidence (Randomized Controlled Trials, Prospective cohort studies, Clinical trials) Trials with duration =/>12 weeks	Studies relating to lower level of hierarchy of evidence (eg. case series, case reports, case control studies, expert opinions) Trials with duration less than 12 weeks
E- Evaluation (Outcome)	Studies that provide direct comparison of efficacy and safety parameters (overall, nocturnal episodes of hypoglycaemia, the level of antibodies cross-reacting with human insulin, body weight gain, change in the HbA1c and fasting plasma glucose); active comparator is IDeg vs IGlar or IGlar vs IDeg.	Studies which co-test other new medicines along with IDeg/Glar; Studies which test short-acting insulins along with IDeg vs IGlar Isolated studies which examined only one of the insulins IDeg or IGlar.
R-Research type	Studies with results published within 7 years age range (2015-2021). Studies published in English language Primary research Studies from peer-reviewed journals Quantitative studie	Studies with results published before 2015. Languages other than English Literature other than primary research Papers from no peer-reviewed journals Qualitative, Mixed-Method studies

3.6 Data Extraction

Data extraction will be implemented in Microsoft Excel and include study design, sample size, the context of the study, limitations of the study, baseline characteristics of participants in both groups (mean age, mean weight, proportions of male/female %, diagnosis, duration of disease, treatment received prior to trial) In addition to this, data on predetermined six safety and efficacy variables of interest will be retrieved:

Safety parameters: Hypoglycaemia episodes (overall, nocturnal), the level of antibodies cross-reacting with human insulin, body weight gain.

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Efficacy parameters: Changes in fasting plasma glucose (FPG) and HbA1c levels from the baseline to the end of a trial.

3.7 Data Analysis

The statistical analysis includes the meta-analysis of continuous variables using mean differences (MD) and standard deviations (SD), Inverse Variance method, with 95% Confidence Intervals [CI 95%] p<0,05 for FPG, HbA1c, body weight gain and the level of antibodies cross-reacting with human insulin. The meta-analysis of dichotomous variables (episodes of overall and nocturnal hypoglycaemia) used Risk Ratios with [CI95%], Mantel-Haenszel method, with p< 0,05 detecting statistically significant results. The I^2 statistic was used to test heterogeneity with values of >50% representing important heterogeneity (Corcoran, 2008). The random effect model was used for all estimates. As studies applied different measurements of the same effect the random effect model was used because it incorporates study variance and heterogeneity into the weights given to individual studies (Bruce, 2017).

Effect sizes for continuous data were calculated using standardized effect sizes (*Cohen's d* formula $\theta = \frac{\mu 1 - \mu 2}{\sigma}$), $\sigma = \frac{\sqrt{(n1-1)S1^2 + (n2-1)S2^2}}{(n1+n2-2)}$ for the samples of equal size and *d Cohen's resp g Hedges* for the samples of different size with a correction of a positive bias in the pooled standard deviations. (McCabe, 2012; Lenhard, 2016). Standard Errors (SE) were calculated through the square root of Variance – $\sqrt{V}$ (see Appendix 1,2,3,4).

For dichotomous variables effect sizes were calculated through odds ratios using online formula converter (odds ratio is converted into *Cohen's d*)(Lenhard, 2016). According to Haddock, (1998) the calculation of odds ratios is the most appropriate method of defining effect size for dichotomous data.

A subgroup analysis was performed for the variables with statistically significant results to test their consistency across different patient groups:

1. Between participants with T1D and T2D,
2. Between insulin naïve and insulin experienced participants.

The subgroup analysis is needed to control the consistency of the results across all chosen variables. Examination of the publication bias was conducted through a funnel plot and the Egger's regression test for funnel plot asymmetry (Mikolajewicz, 2019; Laake, 2015).

3.8 Methodological Quality Assessment

The critical appraisal included 24 studies. The following methodological quality characteristics were evaluated: the validity of research, the reliability of results (whether the intention-to-treat analysis was performed, the presence of ethical issues or biases due to poor design, protocol violations or high drop-out rates), strengths and weaknesses (Ajetunmobi, 2002). In addition to this, a quality appraisal was implemented in order to evaluate the studies' design, methodological rigour, whether the studies provide a relevant answer to a research question and are written in a reliable way.

The Critical Appraisal Skills Programme (CASP) Checklist for Randomized Controlled Trial was used for the appraisal because all selected studies except one followed a RCT design and implemented quantitative research methods (CASP, 2019).

As a result of a quality appraisal, 21 studies were included in this systematic review and meta-analysis (Table3). Three studies out of 24 were excluded for the following reasons: Novo Nordisk, 2015 NCT00972283 trial- the available data does not contain precise names and dosages of other oral hypoglycaemic drugs which were used as additional medications along with insulin therapy. This might act as a confounding factor and produce biased results. Another trial- Novo Nordisk, 2015, NCT 01569841 was excluded because no confidence intervals and standard deviations were available for estimates, so this could affect the precision of the results. The study of Ortez-Gonzalez, 2020 possesses a low external and internal validity and contains severe methodological flaws.

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Majority of the studies included in a review consists of large, multi-ethnic and multi-national samples (more than 500 participants) recruited from general population, medical institutions, hospitals according to eligibility criteria. Trials included participants from more than 25 different countries of Asia, Africa, South and North America, Europe which increases generalizability of the results. In addition to this, large samples minimize the sampling error and allow to generate more reliable results (Bowling, 2014).

Table 3: Quality Appraisal for Quantitative Studies using CASP Checklist for Randomized Controlled Trial

Reference	Did the study address a clearly focused question?	Was the assignment of participants to intervention randomized?	Were all participants who entered the study accounted for at its conclusion?	Were the participants, investigators and assessors blinded?	Were the study groups similar at the start of the randomized controlled trial?	Apart from the experimental intervention were the study participants treated equally?	Were the effects of intervention reported comprehensively?	Was the precision of the estimate of the intervention or treatment effect (CIs)reported?	Do the benefits of the experimental intervention outweigh the harms and costs?	Can the results be applied to your local population/context?	Would the experimental intervention provide greater value to the people in your care than any of the existed interventions?
Philis-Tsimikas, 2020. CONCLUDE Trial.	+ +	+ +	++	- -	++	++	++	++	++	++	++
Gonzalez Ortiz M., 2020	+	+	-	+	+	Can't tell	-	-	-	-	-
Kawaguchi Y. et al, 2018.	+	+	+	-	+	+	+	+	Can't tell	-	Can't tell
Kumar S., 2017.	+	+	+	-	+	+	+	+	+	+	+
Wysham, K. et al, 2017 SWITCH 2	+	+	+	+	+	+	+	+	+	+	+
Lane et al, 2017 SWITCH 1	+	+	+	+	+	+	+	+	+	+	Can't tell
Novo Nordisk, 2015 NCT00612040	+	+	+	-	-	+	+	+	+	+	+
Novo Nordisk, 2015(BEGIN T1 LONG) NCT00982228	+	+	+	-	+	+	+	-	+	+	Can't tell
Novo Nordisk, 2015(BEGIN FLEX 1), NCT01079234	-	+	+	-	+	+	+	+	+	+	+
Novo Nordisk, 2015 (BEGIN: Once Long) NCT00982644	+	+	+	-	-	+	+	-	+	+	+

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Novo Nordisk, 2015 (BEGIN) NCT00972 283	-	+	+	-	-	Can't tell	+	+	+	-	-
Novo Nordisk, 2016. DUALTM V	+	+	+	-	+	+	+	+	+	+	+
Novo Nordisk, 2017. DUAL™VII	+	+	+	-	+	+	+	+	+	+	+
Novo Nordisk, 2018, NCT02906 917	+	+	+	-	+	+	+	+	+	+	+
Novo Nordisk, 2015, NCT 01006291 (BEGIN™: FLEX 2)	+	+	+	-	+	+	+	+	+	+	+
Novo Nordisk, 2015 NCT 01059799 (BEGIN: ONCE ASIA)	+	+	+	-	+	+	+	+	+	-	-
Novo Nordisk, 2015 NCT 01068665 (BEGIN: LOW VOLUME)	+	+	+	-	+	+	+	+	+	+	+
Pan C.,2016. BEGIN ONCE	+	+	+	-	+	+	+	+	+	+	+
Rosenstock J. (2018). BRIGHT Trial	+	+	+	-	+	+	+	+	+	+	+
Philis-Tsimikas et al, 2019. DUALTM IX	+	+	+	-	+	+	+	+	+	+	+
Novo Nordisk, 2015. NCT01076 647 BEGIN EASY	+	+	+	-	+	+	+	+	+	+	+
Novo Nordisk, 2016. NCT011359 92 BEGIN SIMPIFY	+	-	+	-	+	+	+	+	+	+	+

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Novo Nordisk, 2015. NCT 01569841	+	+	+	-	+	-	-	-	Can't tell	-	-
Goldenberg et al, 2021. SWITCH PRO trial	+	+	+	-	+	+	+	+	+	+	+

3.9 Baseline Characteristics of the Included Studies

Most of the selected studies examined patients with Diabetes Type 2 (17) and only four trials include participants with Diabetes Type 1. The trials' participants are predominantly middle-aged patients (45-60 years old), with BMI lower than 30 and with no severe cardiovascular or renal complications or recurrent, severe hypoglycaemia. Out of 21 studies, 8 ones include insulin naïve participants; remaining studies include mixed samples (insulin naïve + insulin experienced) and those who already used basal insulins + oral antidiabetic drugs. The duration of diabetes varied, but most samples constitute participants with long history of diabetes (diabetes duration from 9 to 23 year).

Table 4: Baseline Characteristics of the included Studies

Study, year	Participants' Diagnosis	Trial setting and duration (weeks)	Sample size		Mean Age		Gender(Female /Male %)		Mean Weight		Duration of disease (years)		Treatment received prior to trial	
			IDeg	IGlar	IDeg	IGlar	IDeg	IGlar	IDeg	IGlar	IDeg	IGlar	IDeg	IGlar
Novo Nordisk, 2015, NCT 01006291 (BEGIN™: FLEX 2)	**Diabetes Type 2**	**69 sites in 14 countries of Africa, Asia, Europe and South America. 26 weeks**	**257**	**230**	**56,5**	**56,7**	**F-45,6 51,7 M-55,4 48,3**		**Below 40kg/m2**		**T2D minimum 6 months**		**Oral Antidiabetic Drugs (OAD) alone or basal insulin alone or in combination with OAD (insulin naïve+ insulin experienced)**	**OAD only (insulin naïve)**
Novo Nordisk, 2015 NCT 01059799 (BEGIN: ONCE ASIA)	**Diabetes Type 2**	**52 sites in 6 countries: Hong Kong (1), Japan (12), Malaysia (8), South Korea (19), Thailand (6) and Taiwan (6) 26 weeks**	**289**	**146**	**58,8**	**58,1**	**F- 45,3 48,6 M -54,7 51,4**		**Below 35kg/m2**		**T2D minimum 6 months**			
Novo Nordisk, 2017 NCT 01068665 (BEGIN: LOW VOLUME)	**Diabetes Type 2**	**106 sites in 8 countries of Europe, Asia and North America. 26 weeks 166 sites in 12 countries of Europe and USA 104 weeks**	**228**	**229**	**57,8**	**57,3**	**F- 47,8 45,9 M -52,2 54,1**		**Below 45,0 kg/m2**		**T2D minimum 6 months**		**OAD only (insulin naïve)**	**OAD only (insulin naïve)**
Novo Nordisk, 2015 NCT 00982644 (BEGIN: Once Long).	**Diabetes Type 1**	**79 sites in six countries of Africa, Europe and the United States of America (USA). 104 weeks**	**773**	**257**	**59,3**	**58,7**	**F- 39,1 35,0 M -60,9 65,0**		**89,4**	**91,8**	**9,4**	**8,6**	**Treatment with any basal bolus insulin for at least 12 months**	
			472	**157**	**42,8**	**43,7**	**F- 41,1 42,7 M -58,9 57,3**		**Below 35,0 kg/m2**		**T1D minimum 12 months**			

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Novo Nordisk, 2015 NCT00982228 (BEGIN T1 LONG)	Diabetes Type 1	71/68 sites in 6 countries of Europe and USA 52 weeks		43,6 44,1	F- 40,4 46,3 M -59,6 53,7	Below or equal to 35.0 kg/m2	T1D minimum 12 months	Treatment with any basal bolus insulin for at least 12 months Treatment with insulin glargine minimum 90 days prior to screening
		75 centers in 10 countries. 26 weeks	329 164			88,3 87,3		
Novo Nordisk, 2015 NCT 01079234 (BEGIN FLEX T1)	Diabetes Type 2	89 sites in 12 countries of Europe, Asia, South and North America.		58,4 59,1	F- 48,6 50,1 M -51,4 49,1	87,2 88,2	11,64 11,33	Current treatment with IGlar at least 90 days prior to screening
Lingvay et al, 2016. DUALTM V	Diabetes Type 2	26 weeks 71 sites in 7 countries of Africa, Asia, Europe and USA	278 279 252	58,6 58,0	F- 56,3 53,9 M -43,7 46,1		13,2 13,3	Treated with any basal insulin for at least 90 days prior to the day of screening
Novo Nordisk, 2017. DUAL TM VII	Diabetes Type 2	26 weeks 230 sites in 11 countries of Europe and USA 88 weeks	254 267	58,2 59,2	F- 53,2 48,3 M -46,8 51,7	88,6 88,5	12,9 13,0	Treatment with insulin for more than 5 years Treatment with insulin and OADs
Novo Nordisk, 2018 NCT02906917.	Diabetes Type 2	Minami Osaka Hospital, Osaka, Japan 20 weeks	265	62,7 62,6	F- 41,6 46,1 M -58,4 53,9	91,6 90,7	15,0 14,8	Treatment with OADs (insulin naïve subjects)
Philis-Tsimikas, 2020. CONCLUDE trial	Diabetes Type 2	88 sites in 8 countries of Asia, USA, Europe 52 weeks	758 759	67,9 71,1	F- 33,3 46,7 M -66,7 53,3	73 70	18,1 18,5	Treatment with basal insulin with or without OADs at least 26 weeks
Kawaguchi Y. et al, 2018.	Diabetes Type 2	90 sites in 2 countries, as follows: US: 84 sites, Poland: 6 sites.	15 15 266	61,5 61,2	F- 46,9 46,9 M -53,1 53,1	90,8 92,6	14,2 13,9	Current treatment with a basal–bolus regimen or CSII (with rapid acting insulin) for ≥ 26 weeks prior to Visit 1
Kumar S., 2017. BOOST Trial. NCT01045707	Diabetes Type 1	64 weeks 158 study centers across 16 countries	264 360	45,4 46,4	F- 49,4 46,3 M -50,6 53,7	82,1 78,9	23,2 23,6	OADs only (insulin naïve)
Wysham, K. et al, 2017. SWITCH 2 Trial		24 weeks	360					Treated with insulin for at least six months - any regimen
Lane, W. et al, 2017. SWITCH 1 Trial.	Diabetes Type 2	28 centres in Australia, USA and Europe 16 weeks	249 252	60,5 60,6	F- 45,6 47,0 M -54,4 53,0	91,5 90,5	10,7 10,5	Treatment with AODs (insulin naïve)
	Diabetes Type 1	74 sites in 11 countries of Soth America, Asia, USA and Europe. 26 weeks		45,1 47,2	F- 63,0 54,0 M -37,0 46,0	80,6 77,7	21,8 19,1	Current treatment with

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Rosenstock J. (2018). BRIGHT Trial	Diabetes Type 2	27 sites in the USA 16 weeks	463 466	56,1 57,2	F- 42,4 40,0 M -57,6 60,0	89,3 87,2	9,8 9,3	basal-oral therapy (BOT)at least three months with insulin glargine once daily
Novo Nordisk, 2015. NCT00612040	Diabetes Type 2	94 sites in 7 countries of Africa, Asia, Europe and USA, Canada 26 weeks	119 59	58,7 58,7	F- 33,3 33,3 M -66,7 66,7	99,3 99,3	T2D for at least 6 months	Treatment with OADs (insulin naïve)
Philis-Tsimikas et al, 2019. DUALTM IX.	Diabetes Type 2	68 sites in six countriesof South America, Africa, Asia, North America, Europe 26 weeks	210 210	57,3 57,5	F- 45,9 40,4 M -54,1 59,6	Below or equal to 45.0 kg/m2	Clinically diagnosed T2D	Current treatment with OADs only (insulin naïve)
Novo Nordisk, 2016. NCT01135992 BEGIN SIMPIFY	Diabetes Type 2	56 sites in Canada, Poland, Slovakia, South Africa, USA.	142 142	55,9 56,6	F- 46,1 52,5 M -53,9 47,5	75,5 73,8	7,55 8,26	Treated with insulin for more than 5 years
Novo Nordisk, 2015. NCT01076647 BEGIN EASY	Diabetes Type 2		233 234	62,9 62,7	F- 52,6 51,4 M- 47,4 48,6	Below or equal to 45 kg/m2	14,5 15,6	
Pan C.,2016. BEGIN ONCE.			555 278					
Goldenberg et al, 2021. SWITCH PRO trial. NCT03687827			249 249					

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Table 5: Data on Six Safety and Efficacy Parameters Retrieved from Studies Included in Meta-Analysis

Study, year	Cross-reacting antibodies to insulin %B/T* mean (SD)		Body weight gain (after treatment) kg		Change from baseline fasting plasma glucose (FPG) mean (SD)mmol/l		Episodes of nocturnal hypoglycaemia (PYE) and Rate Ratio		Overall episodes of hypoglycaemia (PYE) and Rate Ratio		HbA1c (Mean difference /Standard Deviation) mmol/l	
	IDeg	IGlar	IDeg	IGlar	IDeg	IGlar	IDeg	IGlar	IDeg	IGlar	IDeg	IGlar
					-3,2	-2,8			36,3	34,8	-1,28	-1.26
Novo Nordisk, 2015, NCT 01006291 (BEGIN™: FLEX 2)	BSL 3,9 (10,9) EOT 5,1 (13.6)	BSL 3,3 (9,5) EOT 5,0 (12,4)	RR [−0.53 to 0.52], *P* = NS).		ETD −0.42 mm [−0.82 to −0.02], p = 0.04)		56 RR 0.77 [0.44−1.35], *P* = NS	75	RR1.03 [0.75−1.40], *P* = NS		(1,00) (0.87) ETD -0.04% [-0.12 to 0.20]	(1.07)
Novo Nordisk, 2015 NCT 01059799 (BEGIN: ONCE ASIA)	BSL 0,2 (1,2) EOT 0,5 (2,3)	BSL 0,9 (6,7) EOT 6,0 (15,0)	ETD−0.17 [95% CI −0.59 to 0.26], P = 0.44, NS		-1,6 ETD -0,09[]-0,41;0.23] RR 0.89 [95% CI 0.80 to 0.99], *P* = 0.013)	-1,8	78 RR 0.52, 95% CI 0.27 to 1.00, P = 0.05) NS	124	29,8 RR 0.63, 95% CI [0.42 to 0.94] P = 0.02)	37,0	-1.24 (0.87) ETD -0.11% [95% CI −0.03 to 0.24]	-1,35 (0.87)
Novo Nordisk, 2015 NCT 01068665 (BEGIN: LOW VOLUME)	BSL 0,4 (5,1) EOT 0,6 (3,0)	BSL 2,2 (1,3) EOT 2,4 (8,5)	(ETD 0.44 [95% CI −0.20 to 1.08], *P* = NS)		-3.70 (3.06) ETD −0.42 [95% CI −0.78 to −0.06]	-3,38 (2.96)	27 RR 0.64 [0.30−1.37], *P* = 0.25) NS	46	17,2 RR 0.86 [0.58−1.28], *P* = 0.46) NS	20,5	-1,30 (1,04) ETD 0.04 (95% CI −0.11 to 0.19)	-1,32 (0,98)
Novo Nordisk, 2015 NCT 00982644 (BEGIN: Once Long).	BSL 0,4 (3,4) EOT 1,1 (5,5)	BSL 0,2 (1,8) EOT 2,5 (7,8)			-4,17 (1.82) ETD -0,43 [-0,74;-0,13]	-3,56 (1.69)	172 RR0,84[0,68-1,04] NS	206	27,0 RR0.57 (0.40−0.81) p=0.002	42,0	-1.06 (1.01) ETD 0.07% (95% CI −0.07 to 0.22), *P* = 0.339 NS	-1,19 (0.97)
Novo Nordisk, 2015 NCT00982228 (BEGIN T1 LONG)	BSL 13,5 (17,2) EOT 15.8 (18,0)	BSL 12,4 (15,4) EOT 13,0 (16,9)			-1,8 (0,17) ETD -,033 [-1,03; -0,36]	-1,4 (0,34)	39,1 RR 0.73 [0.56; 0.96]	52,2	37,5 RR1,07 [0,89 to 1,28]; p=0,48) (NS)	37,4	-0,27 (0,75) ETD-0,01 [95% CI -0,14 to 0,11]; p<0,0001	-0,24 (0,86)
Novo Nordisk, 2015 NCT 01079234 (BEGIN FLEX T1)	BSL 12,2 (14,7) EOT 19.3 (20.8)	BSL 11,5 (13,6) EOT 14,3 (15,9)	1.3 (3.6) ETD −0.51 [−1.24; 0.22]	1.9 (4,5)	-1,73 (5,32) ETD −0,97 mmol/L (−1.74; −0.20) P =0 .005]	-0,61 (5,23)	64,0 RR0.75 [0.58; 0.97]	84,8	68,1 RR 1.02 [0.84; 1.24] (NS)	63,4	−0,13 (0,67) ETD 0.07 [−0.05 to 0.19]	-0,21 (0,73)
Novo Nordisk, 2017. DUALTM VII					-2,4 ETD -0,57[0,31 to 0,83] p= 0,0001	-1,9	13 RR0,25 [0,13 to 0,45] p= 0,0001	16,6	10,7 RR 0,11 [0,08 to 0,17] p=0,0001	81,7	-1,48 (0,05) ETD -0,02(-0,16 to 0,12) p-0,0001	-1,46 (0,05)
Novo Nordisk, 2016. DUAL TM V			-1,4 (3,5) ETD -3,20 -3,77 to -2,64)	1,8 (3,6)	NS		22 RR0,17(95%CI 0,10 to 0,31), p= 0,001	123	22,3 RR -0,44(0,31 to 0,63) p=0,001	50,5	-1,81 (1,08) ETD -0,66% (-0,80 to -0,52) p=0,001	-1,13 (0,98)
Novo Nordisk, 2018 NCT02906917.			2,5 (3,8)	2,4 (3,2)	-2,7 (3,0)	-2,3 (3,1)	113 RR0.61 [95% CI: 0.40; 0.93]	189	53,7 RR 0,86(0,65 to 1,14) NS	64,0	-1,2 (0.9) ETD 0.07% (95% i [CI -0.06- 0.21]	-1,2 (0.9)
Philis-Tsimikas, 2020. CONCLUDE trial					-1,97 (2,74) ETD−0.62 (−0.80, −0.44)	-1,43 (3,1)	62 RR 0.63 (0.49, 0.81)	94	138 RR0.82 (0.67, 1.00) NS	164	-0,54 (0,91) ETD−1.05 (−1.89, −0.21)	-0,46 (0,90)
Kawaguchi Y. et al, 2018.					-1,7 [ETD 0.33 mmol/l; 95% CI −0.11, 0.77] P=0,05	-1,8			5,5	1,3	-1.65 (1.28) ETD−0.03% (95% CI −0.20, 0.14]	-1.72 (1,17)
Kumar S., 2017. BOOST Trial.			ETD0.33 kg; 95% CI −0.17, 0.83; NS		-1,8 (2,3)	-1,6 (2,2)	19 RR0.80, [95% CI 0.49,1.30] NS	53	41,9 RR 1.43, 95% CI 1.07, 1.92; *P* < 0.05	21,1	-0.49 (0.99) [ETD], 0.09% [95% CI, −0.04% to 0.23%]; *P* < .001	-0.58 (1,02)

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		1.5 [4.4] 1,8 [4.3]		55 93 RR= 0.58 [95% CI, 0.46 to 0.74]; *P* < .001	18,5 26,5 RR = 0.70 [95% CI, 0.61 to 0.80] p< 0,001	-0.73 -0,66 (0.89) (0,76)
Wysham, K. et al, 2017. SWITCH 2 Trial			-1,95 -1,58 (3,57) (3,56)			ETD -0,03 [-0.10 to 0.15]
		2.6 2.7 ETD -0.25 [−0.99 to 0.49] p = 0.51) NS	-3.95 -3.52 (0.109) (0,110)	28,1 37,2 RR0.75 (95% CI, 0.68-0.83: *P* < .001)	20,4 21,7 RR0.94 (0.91-0.98) *P* < .002	-1.59 -1,64 (0.037) (0,037) ETD -0,05 [-0,15 to 0,05]
Lane, W. et al, 2017. SWITCH 1 Trial.		2.0 2,3 (3.8) (3,6)		183 226 RR0,81 [0,58 to 1,12) NS		
			-1.60 -0,54 (4.66) (4,36)		93,4 108,3 RR 0,86 [0,71 to 1,04) NS	-0.57 - 0.62 (0.76) (0,68) ETD -0.10 %-point [−0.14 to 0.34]
Rosenstock J. (2018). BRIGHT Trial		0,1 0.7 2,5) (1,6)	ETD −0.76 mmol/L [−2.04 to 0.52]	5,1 12,3 RR: 0.42 [0.25–0.69]		
			-3.72 -3,50 (2.89) (2,43)		5,95 6,62 (RR: 0.72 [0.52–1.00] NS	-1.94 -1,68 (0.95) (1,05) ETD -0,34 [95%;-0,48 to -0,20]
Novo Nordisk, 2015. NCT00612040		0,0 2,0 (3,8) (3,9) ETD-1,92-2.64 to -1.19	ETD−0.33 mmol/L [95%CI −0.64, −0.01] *P* = 0.04			
			-0,7 0,0 (2,2) (2,3)		37,0 90,0 RR 0,42 [CI95%;0.23 to 0.75]	
Philis-Tsimikas et al, 2019. DUALTM IX		0,1 0,6 (0,4) (2,2)		8,3 11,1		-1,05 -1,36 (0,94) (0,95) -0,26% [95% CI -0,11 to 0,41]
					45,3 42,4	
Novo Nordisk, 2016. NCT01135992 BEGIN SIMPIFY		0,8 1,0 (3,9) (3,7)		RR 0.60, [0.21-1.69] NS		−1.3 -1,2 (1.1) (1.0) ETD−0.05 % [−0.18 to 0.08]
			-3.35 -3,14 (2.91) (2,71)		10,0 16,0 RR 1.04, [95% CI 0.69-1.55] NS	
Novo Nordisk, 2015. NCT01076647 BEGIN EASY	BSL 2.0 1,6 (8.7) (7,5)	ETD [95 % CI] 0.34 [−0.09 to 0.78]	ETD −0.26 [−0.53 to 0.02]	22 24 RR0.77 [0.43 to 1.37] NS		
					85,0 97,0 RR0.80 [0.59 to 1.10] NS	
Pan C.,2016. BEGIN ONCE.	EOT 3.2 4,9 (11.1) (12,5)					-0,50 -0,40 (0,42) (0,42) ETD-0,06% [95%CI -0,11 to -0,01]
				31,1 40,9 RR 0,76[95%CI 0,65 to 0,90]		
					55,8 64,1 RR 0,87[0,75 to 1,00] NS	
Goldenberg et al, 2021. SWITCH PRO trial						

% B/T=percentage bound/total radioactivity, NA- not applicable, ETD- estimated treatment difference, NS- non-significant, BSL- baseline period, EOT- end of trial period.

3.9 Ethical Appraisal

The trials selected for this review are ethically sound and carried out in compliance with the Declaration of Helsinki, 2008. All selected trials obtained approvals from different independent ethical committees and have written consent forms from participants. Although, no participants will be recruited for this study; ethical approval from the University of Essex will be applied for prior to conducting the study.

CHAPTER 4: RESULTS

The results of the meta-analysis demonstrate that:

1. IDeg is associated with less glycaemic variability (less overall and nocturnal hypoglycaemia episodes) in both T2D and T1D (insulin naïve and experienced) patients.
2. IDeg is more effective in the reduction of fasting plasma glucose (FPG) levels in both T2D and T1D (naïve and experienced) patients.

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3. Treatment with IDeg is associated with less weight gain IDeg versus IGlar in T2D (insulin experienced) and T1D groups.
4. Both insulins (IDeg and IGlar) provide a similar reduction of HbA1c levels
5. The difference in the level of antibodies cross-reacting with human insulin after the treatment with IDeg vs IGlar is not statistically significant.

The aim of the study was to investigate and compare the efficacy and safety parameters of insulin degludec versus insulin glargine in the treatment of adult (18+) patients with Diabetes Type 1 and Type 2.

4.1 Efficacy Parameters

Change in HbA1c level

For the analysis of HbA1c estimates, nineteen out of 21 studies were selected with a total number of participants in IDeg groups (n=6607) and in IGlar groups (n=5112). The pooled estimates of 19 studies with available data on the levels of HbA1c showed that the result is numerically lower for IDeg, but the overall difference is not statistically significant; the overall effect Z= 0,49; p = 0,62 (see Figure 3 below). In addition to this, a high between-study heterogeneity was detected (I^2-85%). A funnel plot revealed gaps in the bottom areas, however this can be explained by high heterogeneity (see Figure 4). The plot was not examined for funnel plot asymmetry (publication bias) because the result is not statistically significant.

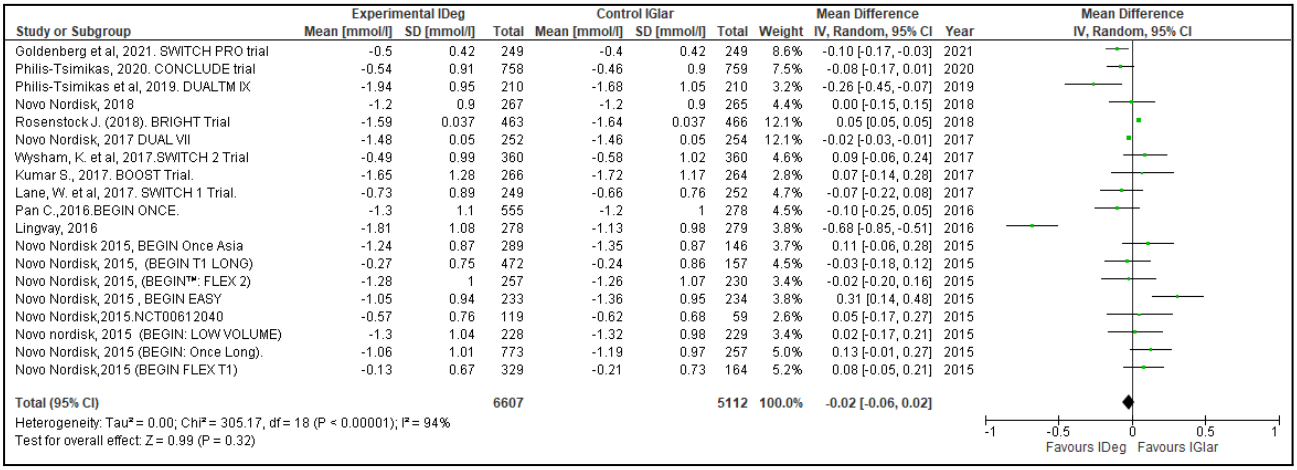

Figure 3: Forest Plot for Change in HbA1c Levez

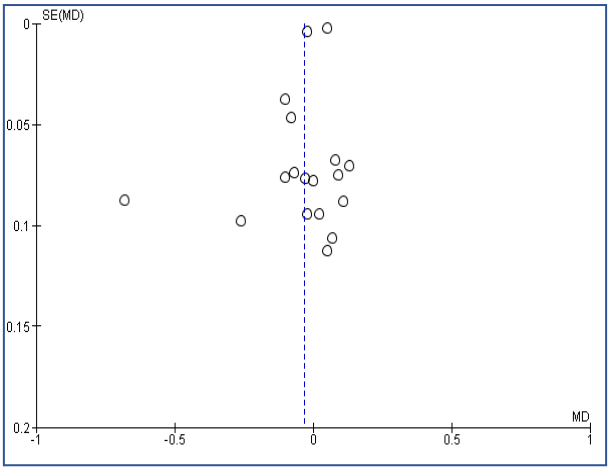

Figure 4: Funnel Plot for HbA1c

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4.2 Change in Fasting Plasma Glucose (FPG) level

In terms of FPG, not all studies included in this review contained standard deviations and therefore the meta-analysis was performed drawing on the data which contain means and standard deviations. As a result, fifteen out of 21 studies were selected for this analysis with a total number of participants in IDeg groups (n=5448) and in IGlar groups (n=4092). No significant between-study heterogeneity was detected, I^2– 39% (lower than 50%). In addition to this, the results obtained showed high significance (Z=11,82; p< 0, 00001) (see Figure 5). The estimated pooled mean difference shows that IDeg is more effective in the reduction of fasting blood glucose levels as compared to IGlar (MD = -0,40[-0,47 to-0,34]).

This result is consistent across all subgroups: T1D subgroup MD = -0,40[-0,46 to-0,35] p<0000,1, I^2 – 0%; T2D subgroup MD = -0,37 [-0,50 to -0,24] p<0,00001, I^2 – 49%; subgroup experienced MD = -0,41 [-0,45 to -0,35] p<0,00001, I^2- 0%; subgroup naïve MD = -0,32 [-0,51 to -0,13] p<0,00001, I^2- 65% (see Figure 6,7,8,9). A funnel plot was examined for asymmetry using the Egger's regression test. The Egger's test did not detect a true asymmetry (publication bias) as p= 0, 332 (See Table 6, Figure 10,11). The result of this test can be considered as a reliable one as more than 10 studies were included in the analysis (BMJ).

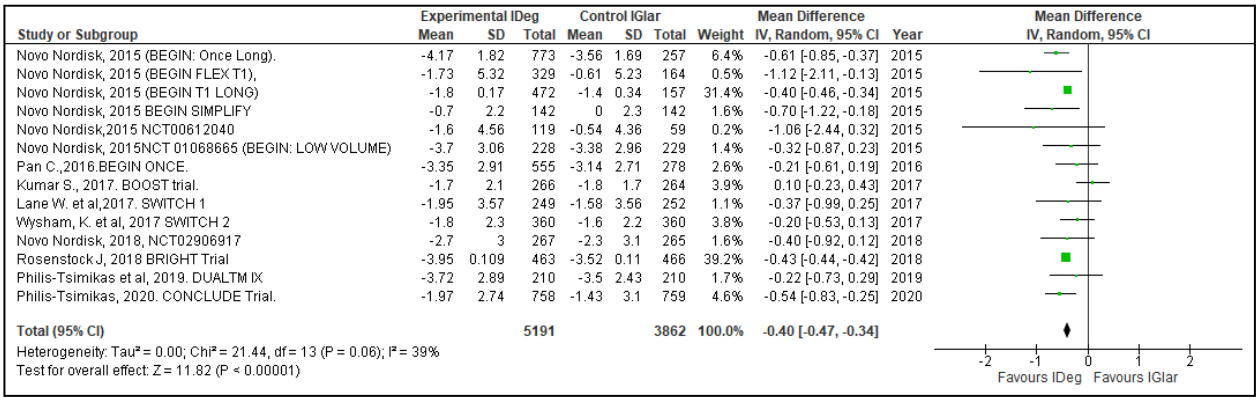

Figure 5: Forest Plot for FPG

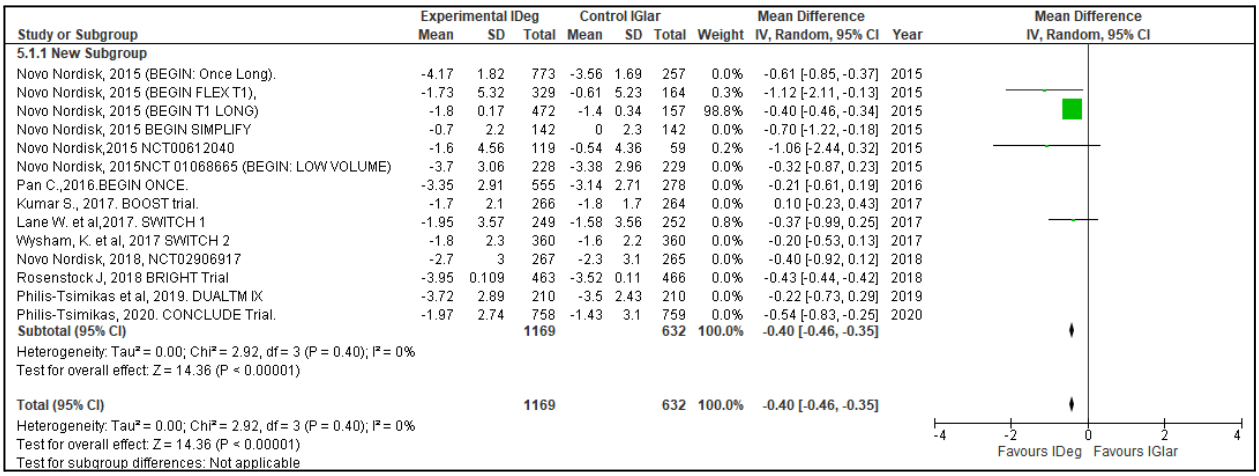

Figure 6: Subgroup T1D

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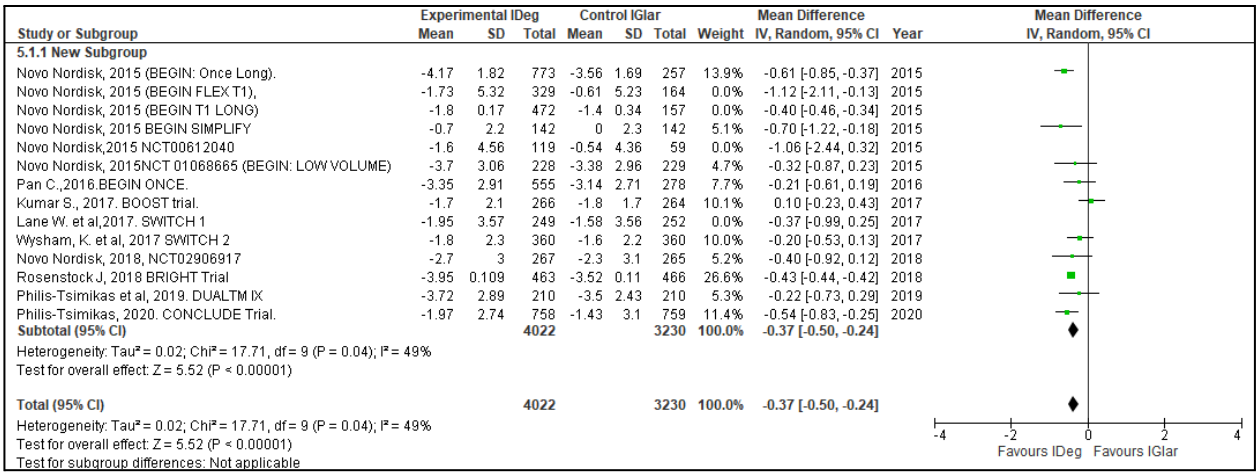

Figure 7: Subgroup T2D

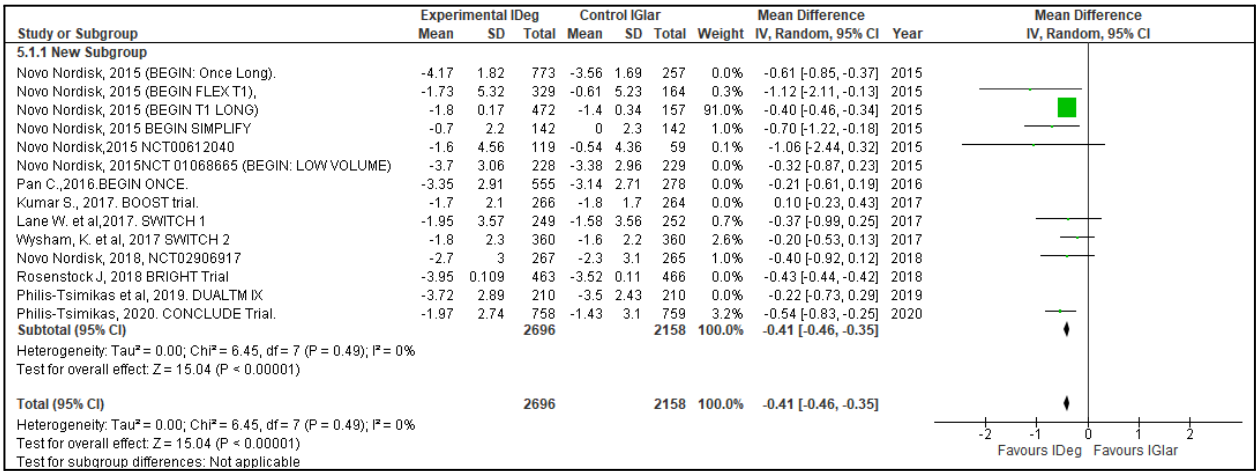

Figure 8: Subgroup Experienced

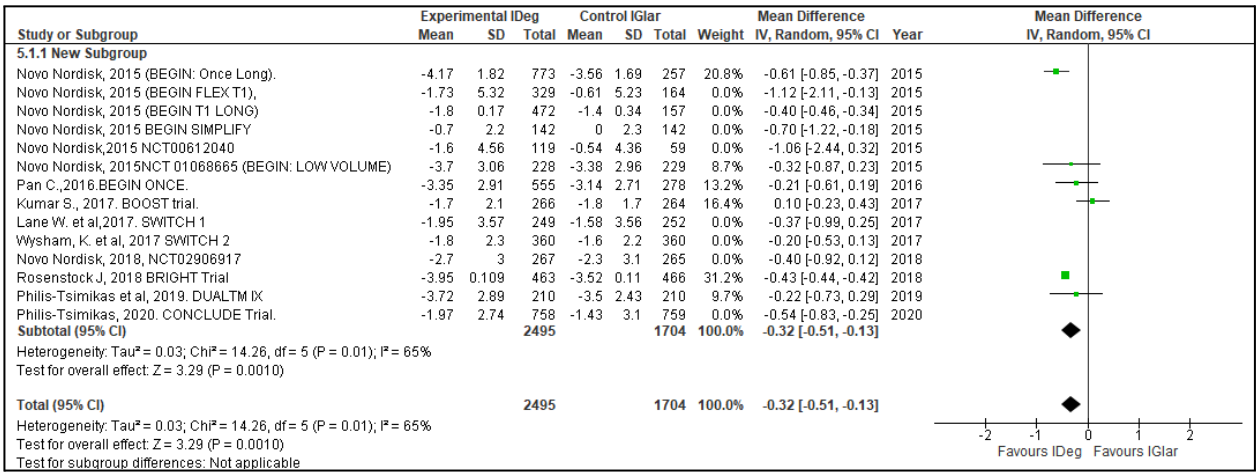

Figure 9: Subgroup Naïve

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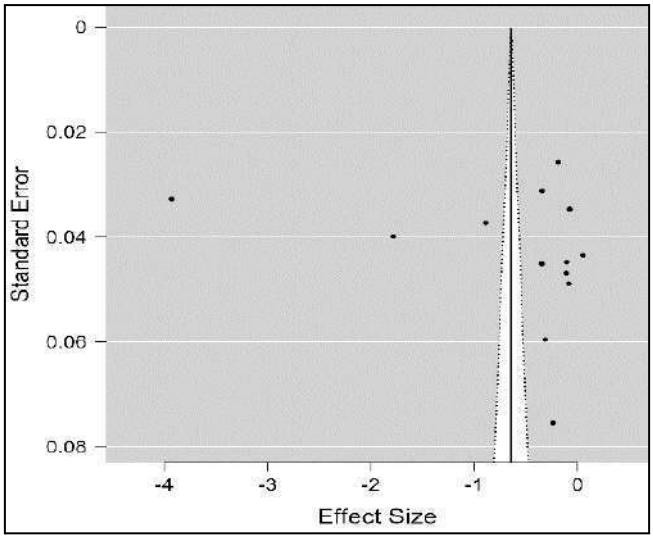

Figure 10: Funnel Plot for FPG Performed on JASP

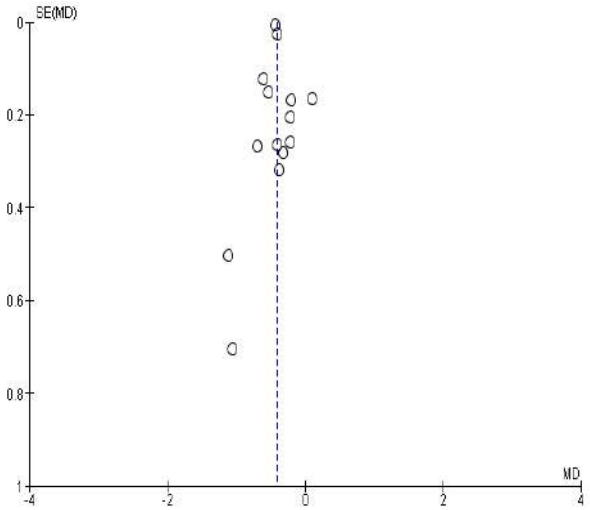

Figure 11: Funnel plot for FPG performed on RevMan 5.4

Table 6: Egger's Test

Regression test for Funnel plot asymmetry ("Egger's test")		
	z	P
sei	0.969	0.332

4.3 Safety Parameters

Body Weight Gain

Nine out of 21 studies which contained standard deviations of the mean were selected for this analysis with a total number of 2401 participants in IDeg groups and 2179 in IGlar groups. The analysis detected considerable between-studies heterogeneity I^2 – 92%. After the exclusion of the study - Lingvay, 2016 DUAL TM V heterogeneity fell to 68% (see Figure 12,13). The results revealed that a treatment with IDeg is associated with less weight gain and the difference is statistically significant with MD -0,84kg [95% -1,50 to -0,18], Z=2,50 and p= 0,01 (see Figure 12). The analyses of subgroups showed that all subgroups (T2D,T1D, insulin experienced), except the insulin naïve group, demonstrate a statistically significant reduction in weight gain associated with insulin degludec: T2D subgroup = -0,91(-1,73 to -0,08) p=0,03, Z= 2,16, I^2- 94%; T1D subgroup = -0,60(-1,08 to -0,12) p=0,01, Z=2,44, I^2= 0%; subgroup experienced- -1,19(-2,11 to -0,28) p=

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0,01, Z=2,55, I^2– 93% (See Figure 14,15,17). The reduction ranges from -0,60 to -1,19kg. Subgroup which consisted of insulin naïve patients lacks statistical significance- -0,16[-0,48 to 0,17) p=0,35, I^2-0% (See Figure 16).

The funnel plot was examined for asymmetry and no publication bias was detected – Egger's test p =0,797(see Table 7, Figure 18,19). However, the number of studies examined was lower than 10, so this may weaken the validity of the test (BMJ).

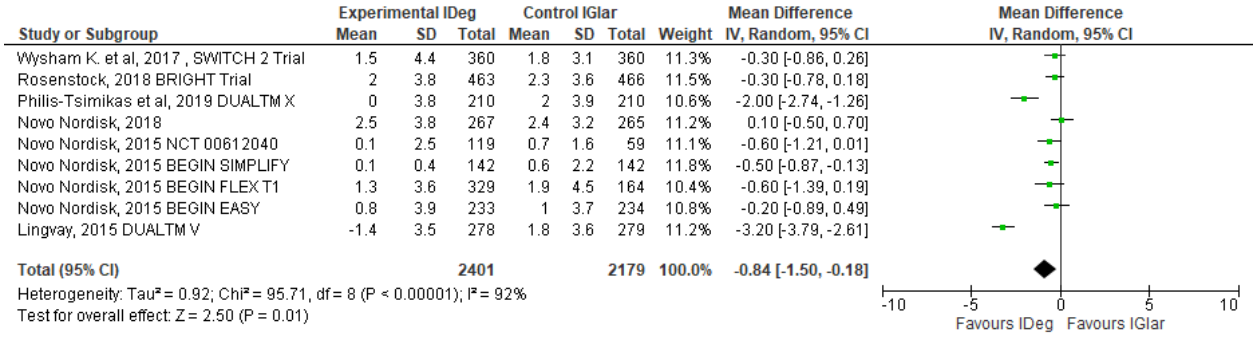

Figure 12: Forest Plot for Body Weight Gain

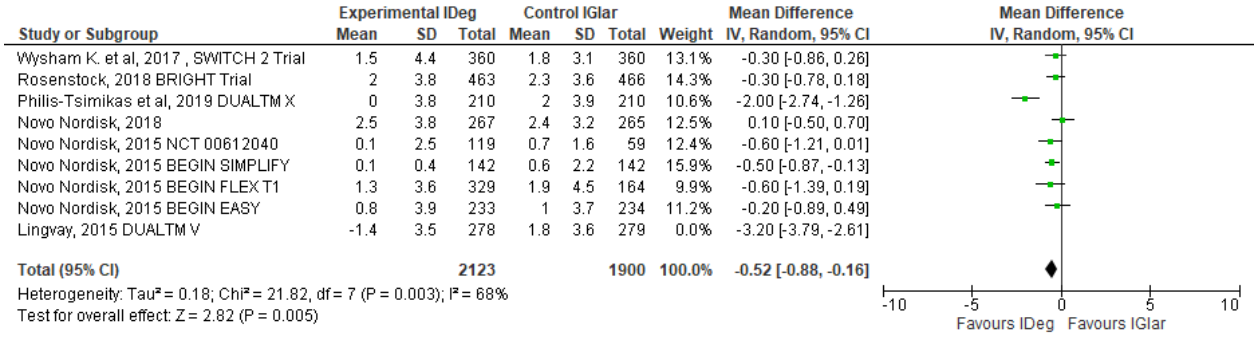

Figure 13: Lingvay, 2016 DUAL TM V Excluded (source of heterogeneity)

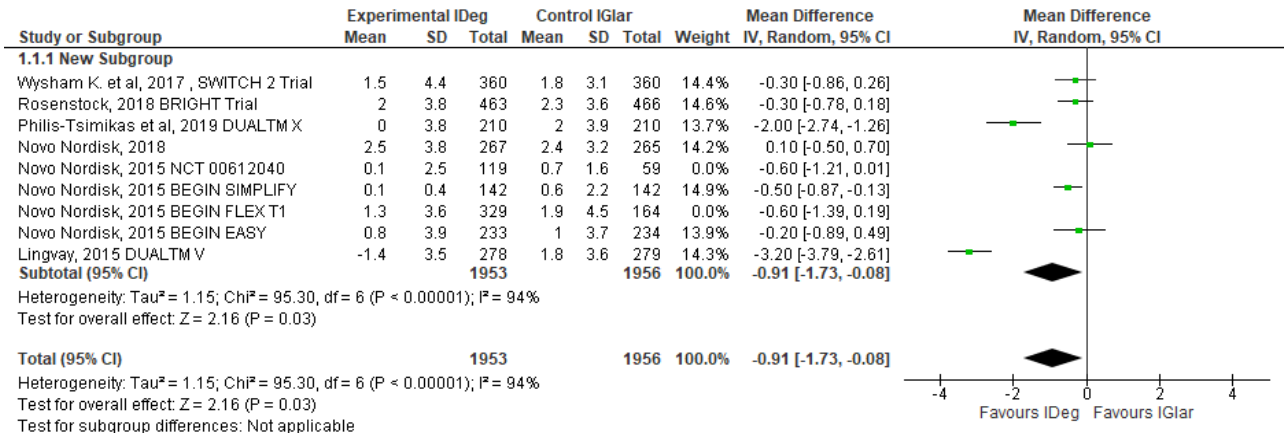

Figure 14: Subgroup T2D

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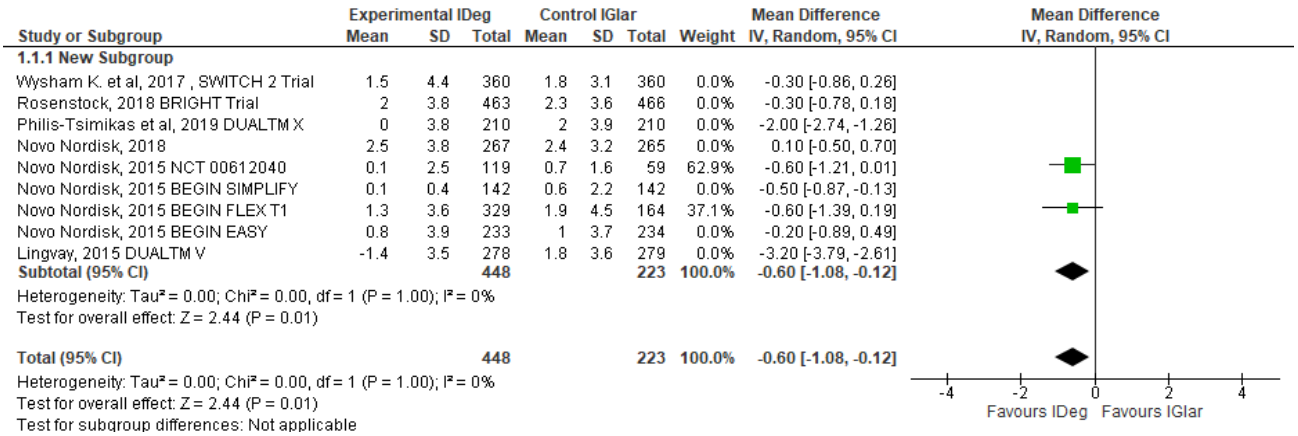

Figure 15: Subgroup T1D

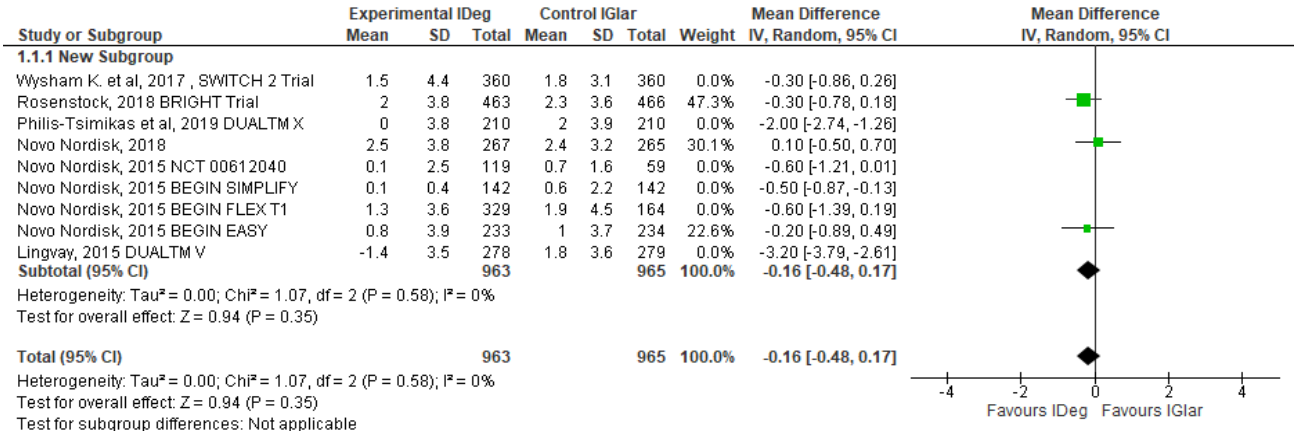

Figure 16: Subgroup Naïve

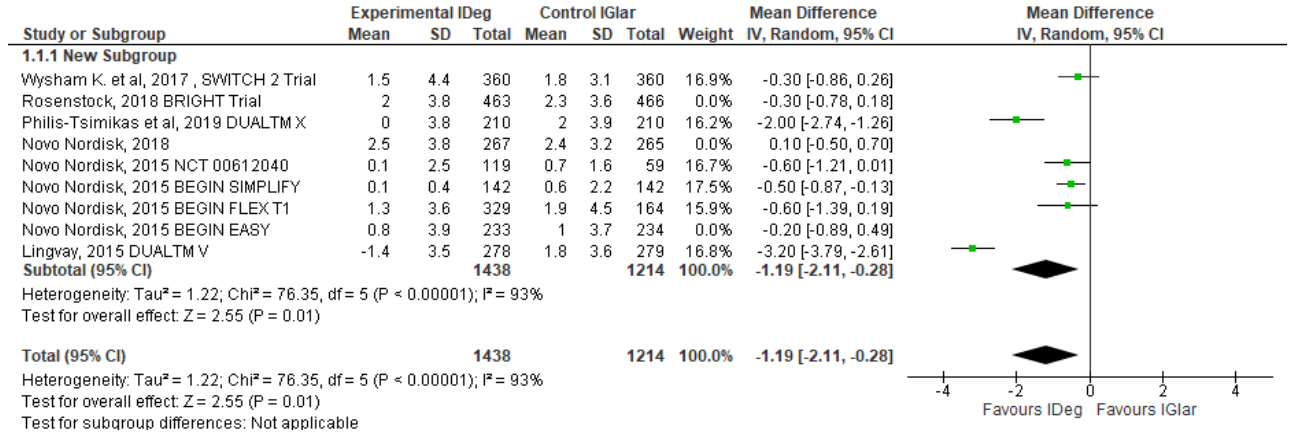

Figure 17: Subgroup Experienced

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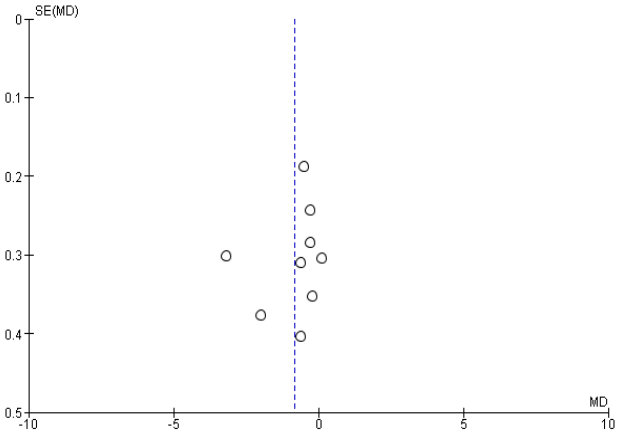

Figure 18: Funnel Plot for Body Weight Gain Performed on RevMan 5.4

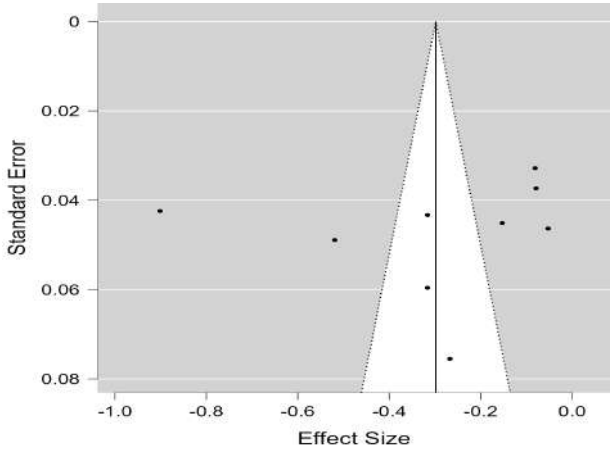

Figure 19: Funnel Plot for Body Weight Gain Performed on JASP

Table 7: Egger's Test

Regression Test for Funnel Plot Asymmetry ("Egger's Test")		
	z	p
sei	-0.257	0.797

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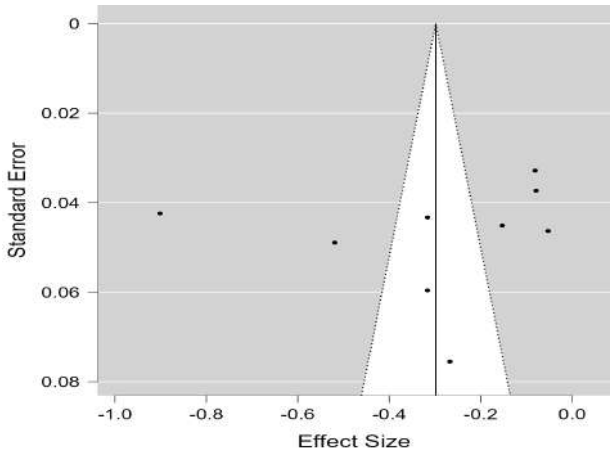

Figure 19: Funnel Plot for Body Weight Gain Performed on JASP

Table 7: Egger's Test

Regression Test for Funnel Plot Asymmetry ("Egger's Test")		
	z	p
sei	-0.257	0.797

4.4 Overall Episodes of Hypoglycaemia

21 studies were selected for the analysis of the overall episodes of hypoglycaemia with a total number of 6764 participants in IDeg groups and 5269 in IGlar groups. The results showed that treatment with IDeg is associated with considerable reduction in overall episodes of hypoglycaemia - RR- 0,61[95% 0,47 to 0,77] which can be interpreted as 39% lower risk of hypoglycaemia. The result has a high statistical power Z= 4,20; p<0,0001 (see Figure 20).

However, a considerable heterogeneity was detected (I^2- 85%). The subgroup analysis showed reduced heterogeneity in T1D groups I^2 -62% (see Figure 21), but in other subgroups (naïve, experienced, T2D) heterogeneity remained high I^2 - 82-87% (see Figure 22, 23, 24). The subgroup analyses confirmed the consistency of the results favouring IDeg across all subgroups: subgroup insulin naïve- RR 0,58 [0,38 to 0,88] p= 0,01; subgroup insulin experienced- RR 0,64 [0,48 to 0,84] p= 0,001; subgroup T1D -RR 0,52 [0,33 to 0,72] p=0,001; subgroup T2D- RR 0,63 [0,49 to 0,82] p=0,0007 (See Figure 22, 23, 24). The subgroup analysis identified that T1D and insulin naïve groups showed the highest numbers for risk reduction 42% and 48%, respectively (see Figure 21, 24).

A funnel plot was examined for asymmetry using the Egger's regression test. The Egger's test which included 21 studies detected a statistically significant funnel plot asymmetry (publication bias) p= 0,002 (see Table 8, Figure 25,26). The second Egger's test was performed including only those studies which showed statistically significant results. The second test indicated no true asymmetry p=0,651 (see Table 9, Figure 27). Therefore, the detected asymmetry can be explained by high between-studies heterogeneity and inclusion of studies with statistically insignificant results.

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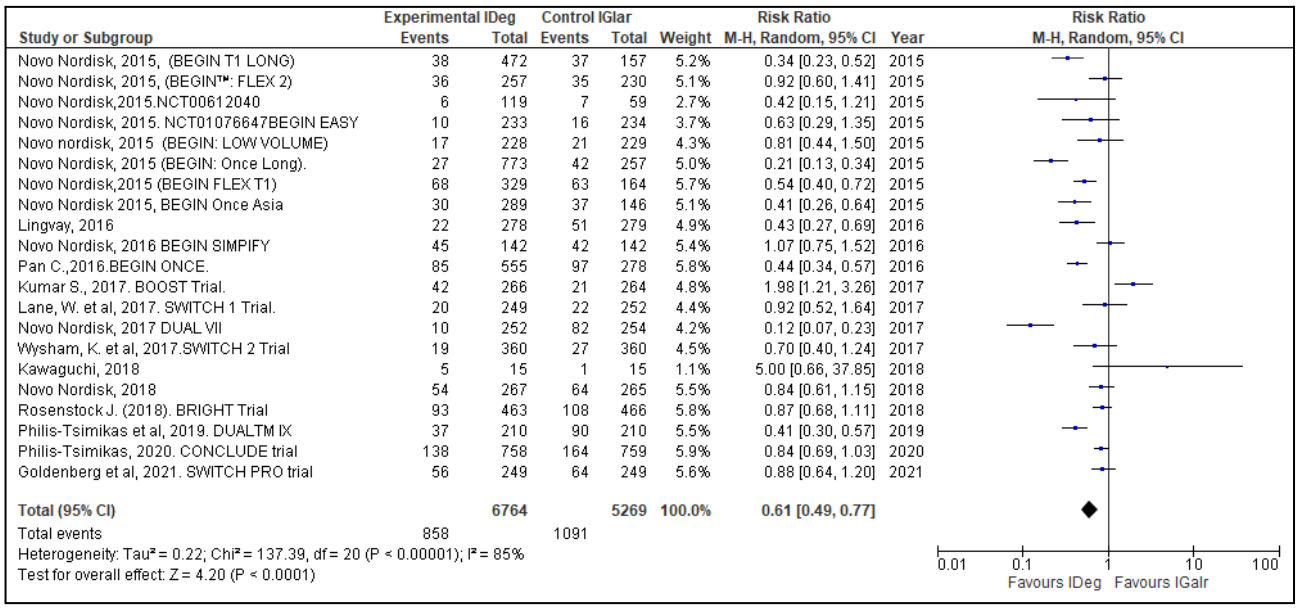

Figure 20: Forest Plot for the Overall Episodes of Hypoglycaemia (OEH)

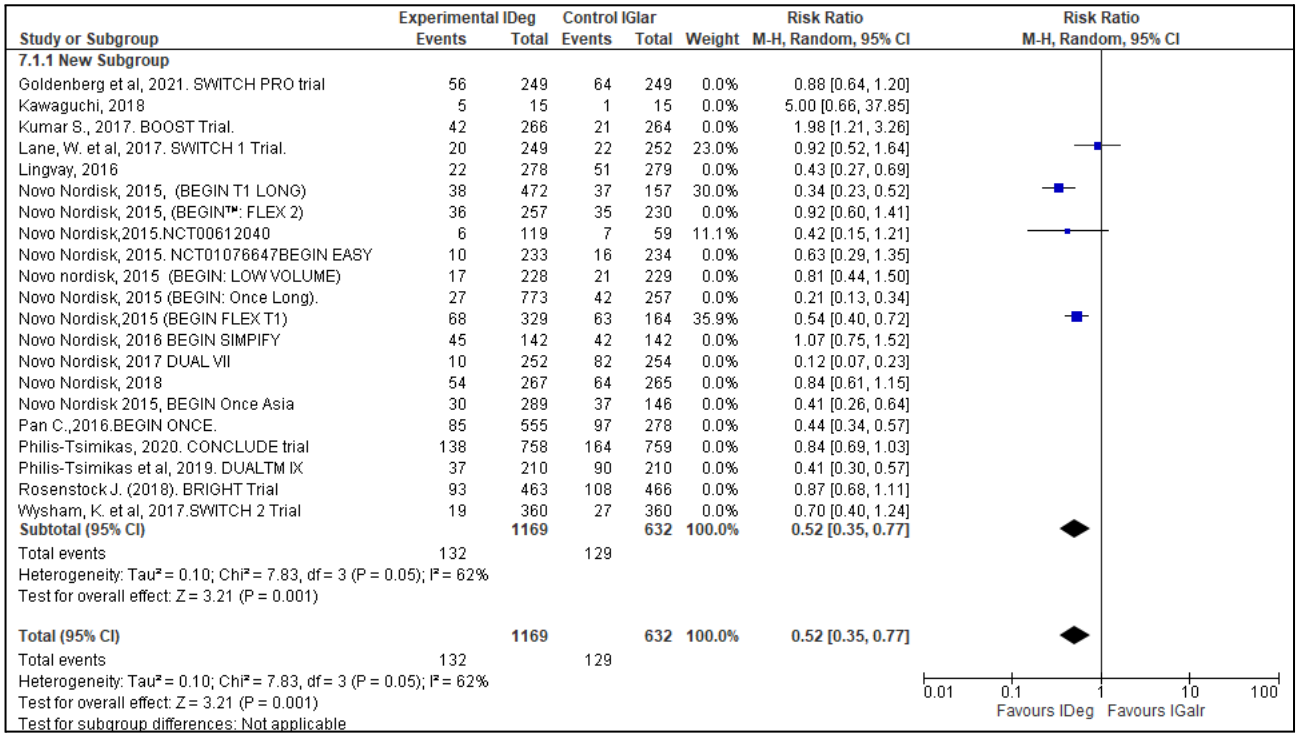

Figure 21: Subgroup T1D

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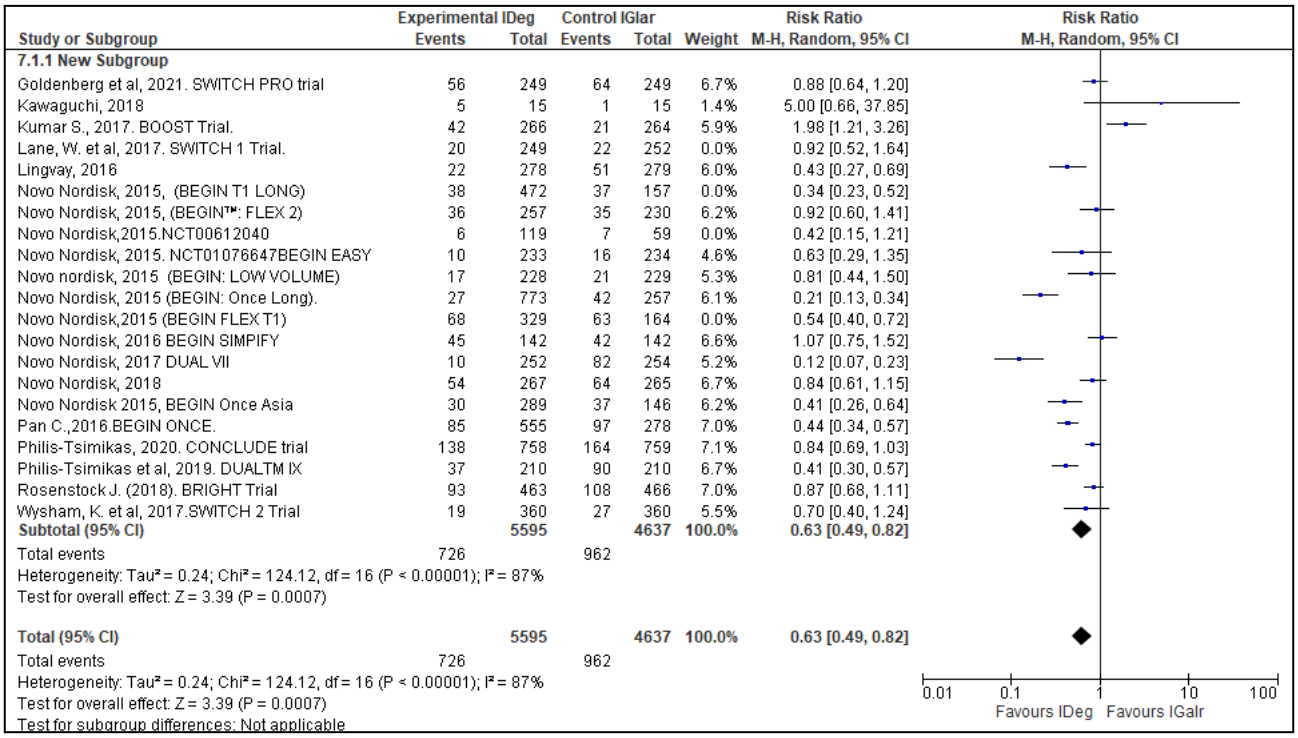

Figure 22: Subgroup T2D

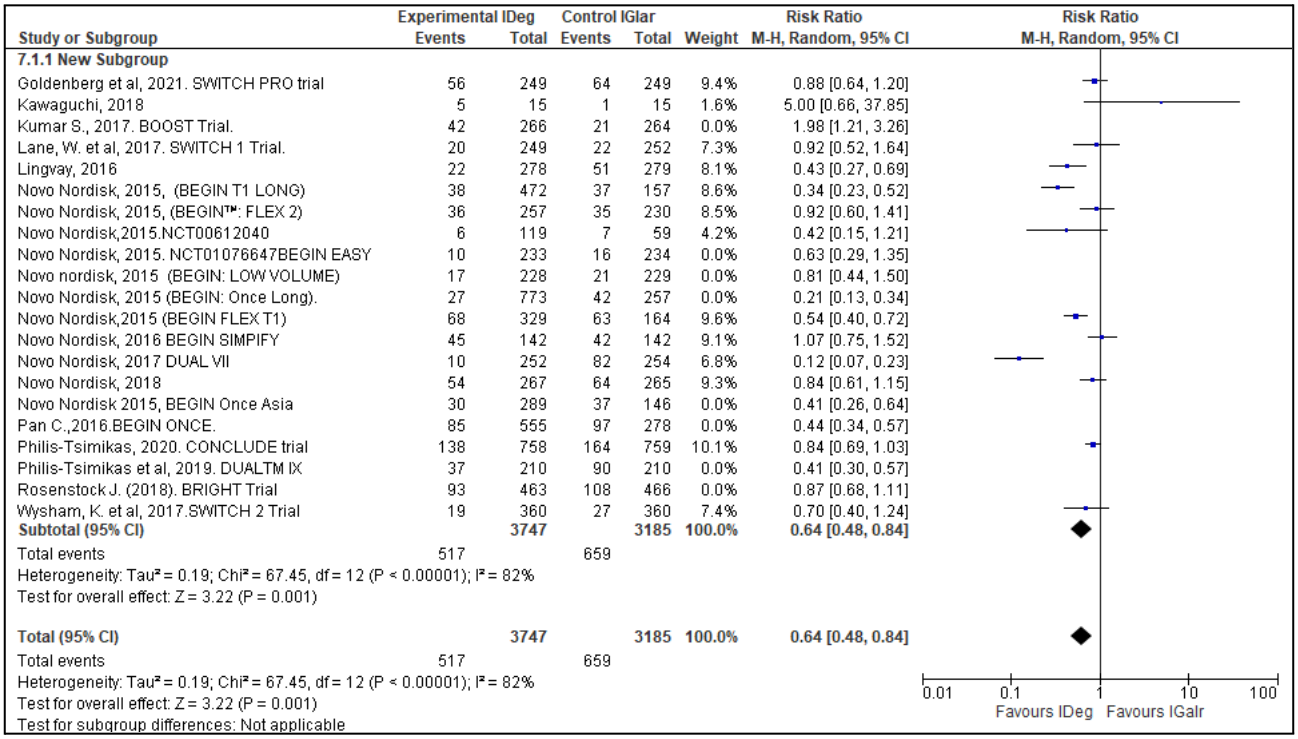

Figure 23. Subgroup Experienced

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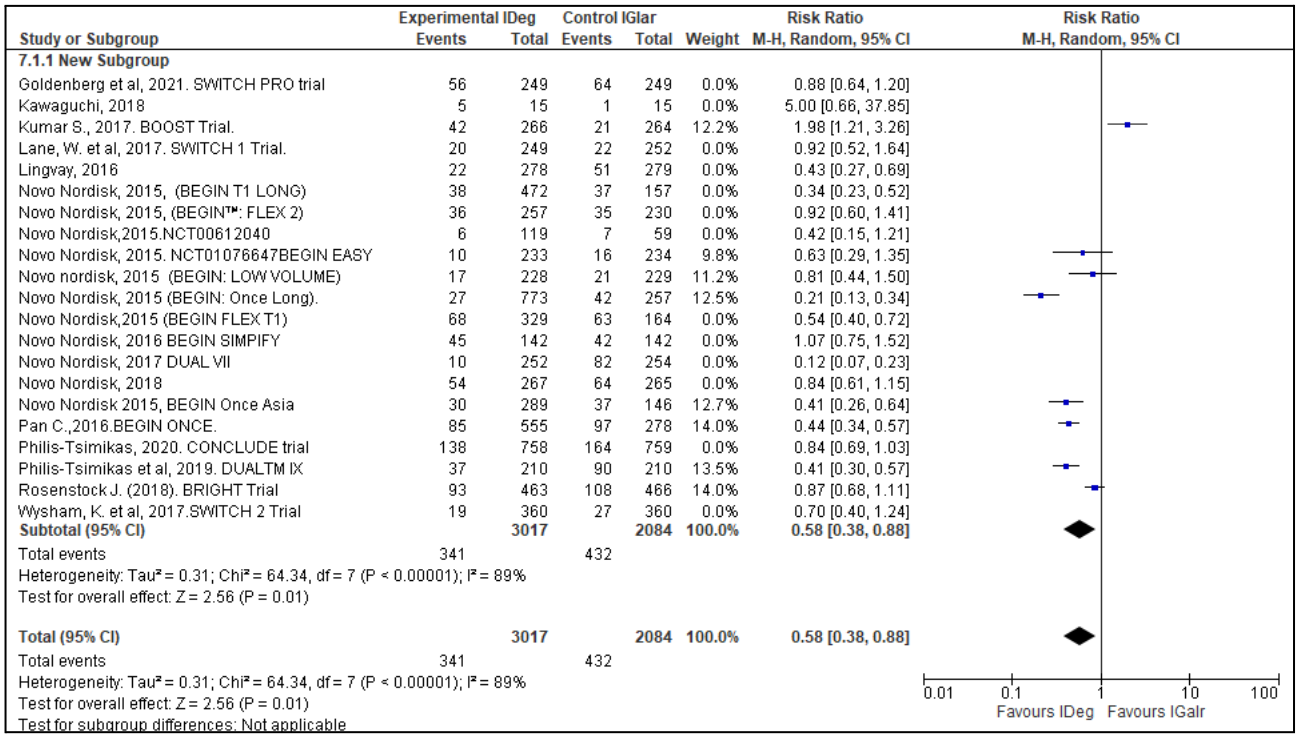

Figure 24: Subgroup Naïve

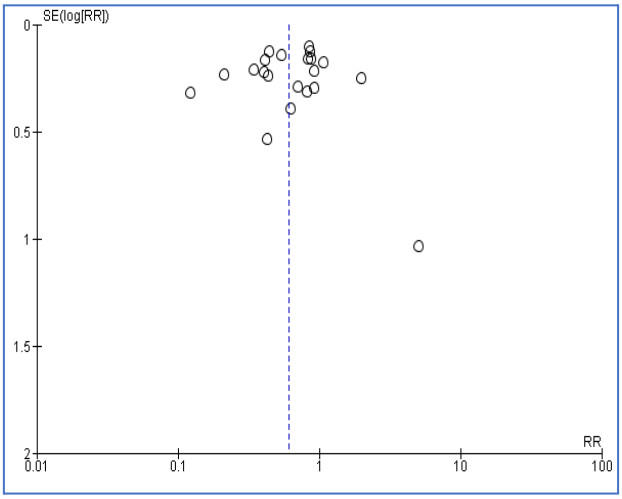

Figure 25: Funnel Plot the OEH Performed on RevMan 5,4

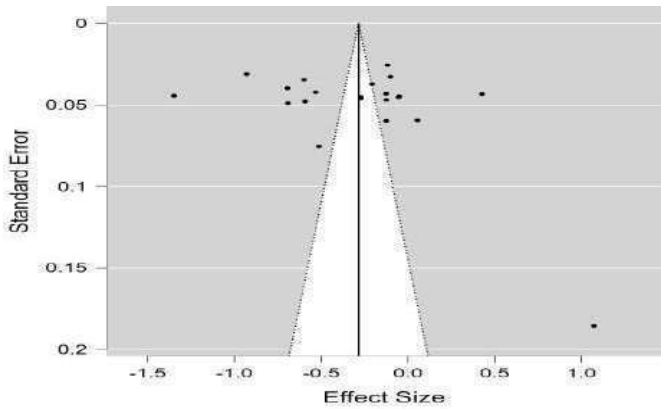

Figure 26: Funnel Plot for OEH Performed on JA

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Table 8: Egger's test

Regression test for Funnel plot asymmetry ("Egger's test")		
	z	p
sei	3.049	0.002

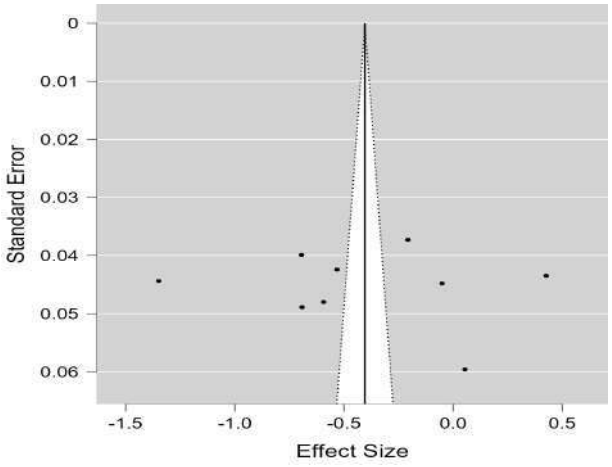

Figure 27: Funnel Plot for OEH (studies with insignificant results excluded)

Table 9: Egger's test

Regression test for Funnel plot asymmetry ("Egger's test")		
	z	p
sei	0.453	0.651

4.5 Episodes of Nocturnal Hypoglycaemia

Eighteen out of 21 studies were selected for this analysis with a total number of 6306 participants in IDeg groups and 4810 in IGlar groups. The results showed that treatment with IDeg is associated with a statistically significant reduction in episodes of nocturnal hypoglycaemia RR 0,48 [95%0,38 to 0,60] p<0,00001 (see Figure 28). The result can be interpreted as a treatment with IDeg is associated with 52% lower risk of nocturnal hypoglycaemia, which is twofold risk reduction compared to IGlar. The analysis detected high between-studies heterogeneity I^2- 92%. The subgroup analyses did not considerably reduce heterogeneity I^2- 80-95% (see Figure 29, 30, 31, 32).

The subgroup analyses confirmed the consistency of the results favouring IDeg across all subgroups: subgroup insulin naïve- RR 0,43 [0,28 to 0,64] p< 0,00001; subgroup insulin experienced- RR 0,52 [0,41 to 0,68] , Z= 6,29 and p< 0,00001; subgroup T1D - RR 0,37 [0,23 to 0,61] p<0,00001; subgroup T2D- RR 0,51 [0,40 to 0,66] p< 0,00001(see Figure 29, 30, 31, 32). Similar to the results for the overall episodes of hypoglycaemia, this subgroup analysis also revealed that T1D and insulin naïve groups benefit most from a treatment with IDeg, demonstrating a considerable risk reduction of 63% and 57%, respectively (see Figure 29, 32).

A funnel plot has visible gaps at the bottom areas and therefore the funnel plot asymmetry was examined using the Egger's regression test (see Figure 33, 34). The Egger's test did not detect a true asymmetry (publication bias) as p= 0, 948 (see Table 10). Therefore, the visible asymmetry on a funnel plot can be explained by high between-studies heterogeneity and inclusion of studies with insignificant results.

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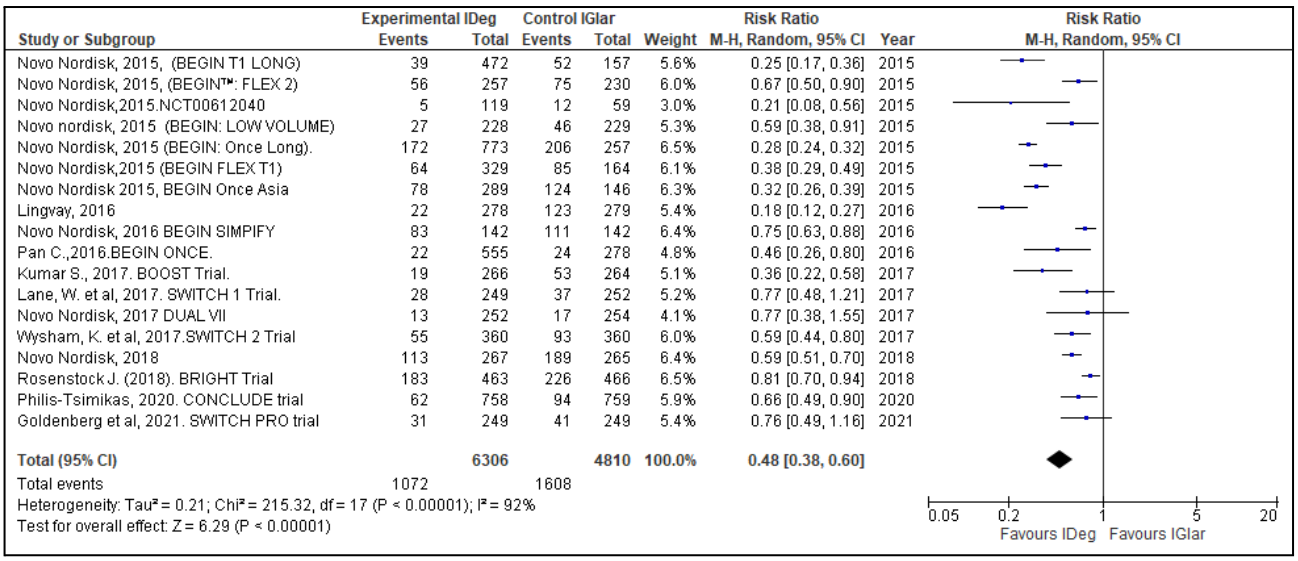

Figure 28: Forest Plot for Episodes of Nocturnal Hypoglycaemia (enh)

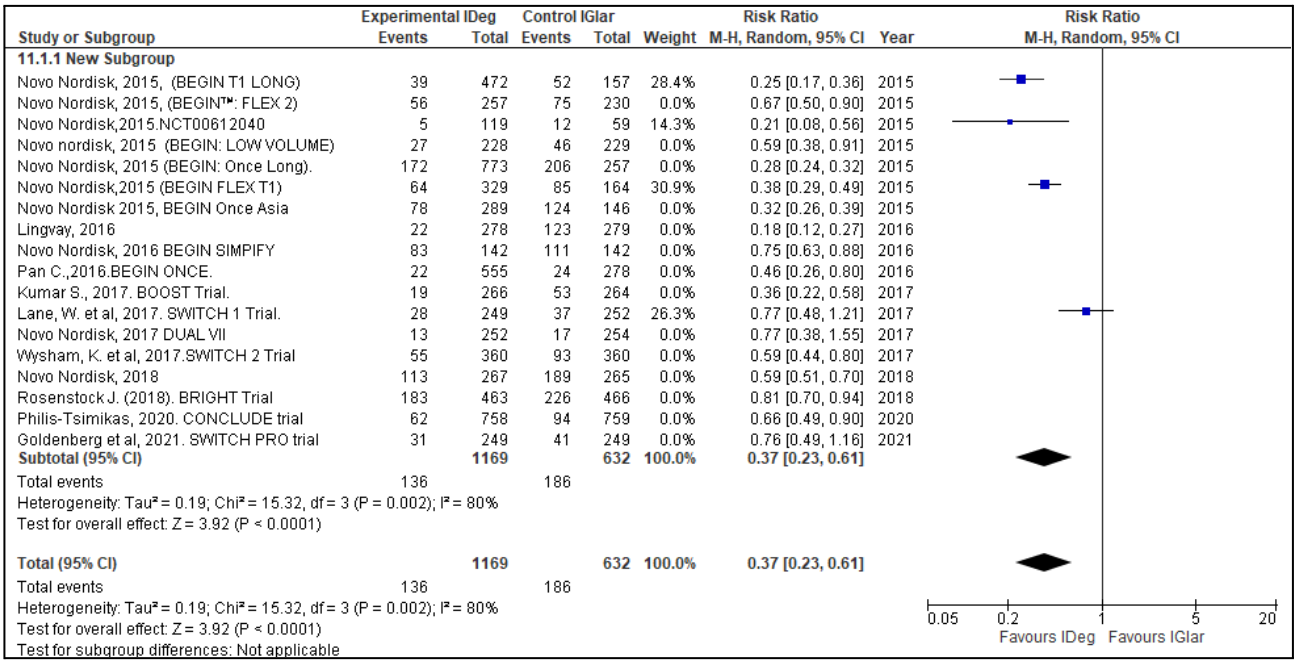

Figure 29: Subgroup T1D

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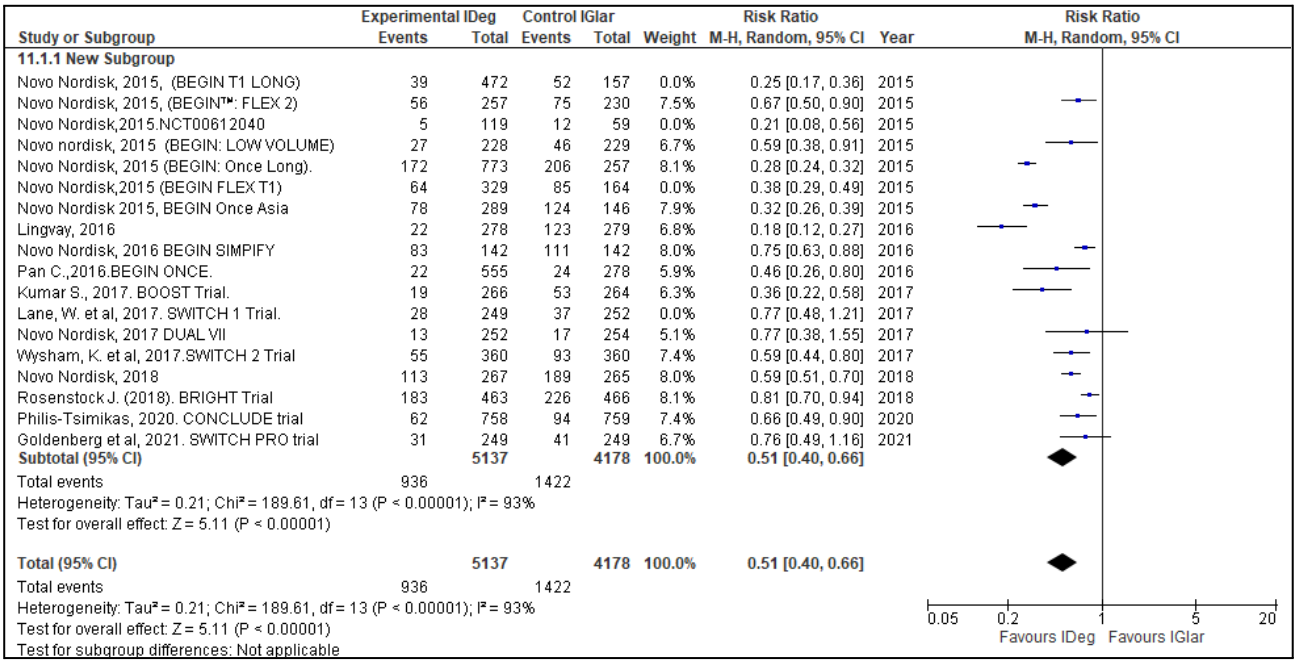

Figure 30: Subgroup T2D

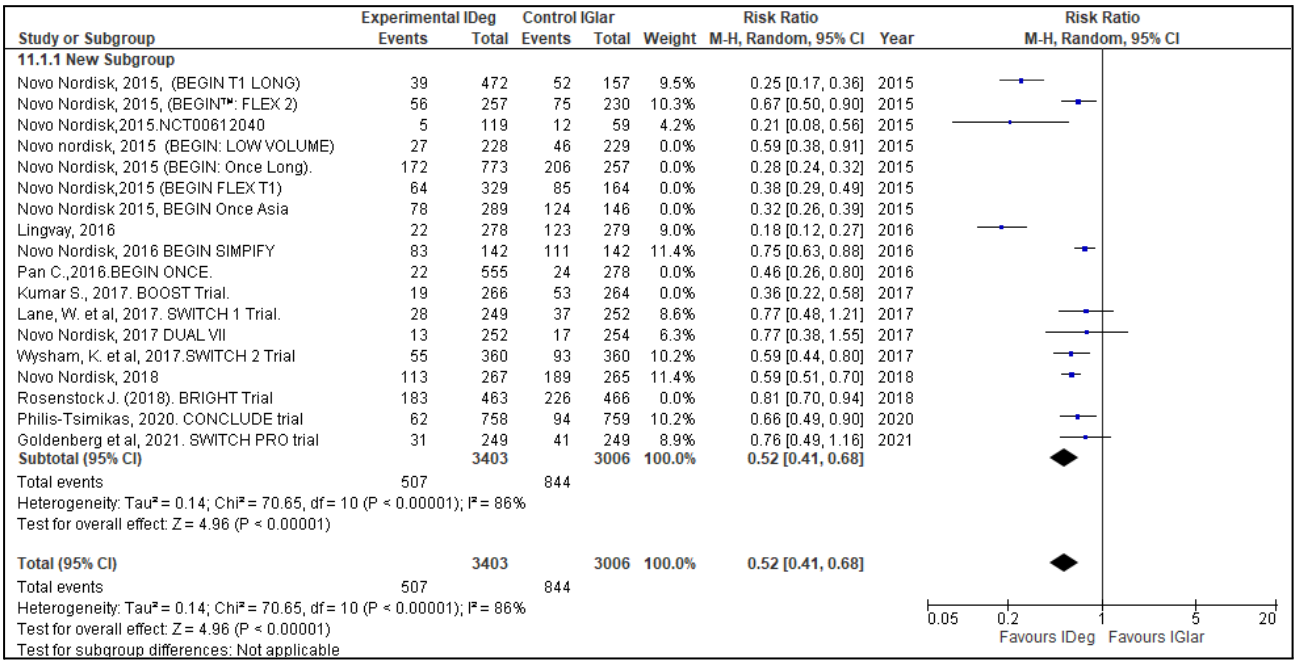

Figure 31: Subgroup experienced

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Study or Subgroup	Experimental IDeg Events	Total	Control IGlar Events	Total	Weight	Risk Ratio M-H, Random, 95% CI	Year
11.1.1 New Subgroup							
Novo Nordisk, 2015, (BEGIN T1 LONG)	39	472	52	157	0.0%	0.25 [0.17, 0.36]	2015
Novo Nordisk, 2015, (BEGIN™: FLEX 2)	56	257	75	230	0.0%	0.67 [0.50, 0.90]	2015
Novo Nordisk,2015.NCT00612040	5	119	12	59	0.0%	0.21 [0.08, 0.56]	2015
Novo nordisk, 2015 (BEGIN: LOW VOLUME)	27	228	46	229	13.5%	0.59 [0.38, 0.91]	2015
Novo Nordisk, 2015 (BEGIN: Once Long).	172	773	206	257	15.6%	0.28 [0.24, 0.32]	2015
Novo Nordisk,2015 (BEGIN FLEX T1)	64	329	85	164	14.9%	0.38 [0.29, 0.49]	2015
Novo Nordisk 2015, BEGIN Once Asia	78	289	124	146	15.3%	0.32 [0.26, 0.39]	2015
Lingvay, 2016	22	278	123	279	0.0%	0.18 [0.12, 0.27]	2016
Novo Nordisk, 2016 BEGIN SIMPIFY	83	142	111	142	0.0%	0.75 [0.63, 0.88]	2016
Pan C.,2016.BEGIN ONCE.	22	555	24	278	12.3%	0.46 [0.26, 0.80]	2016
Kumar S., 2017. BOOST Trial.	19	266	53	264	12.9%	0.36 [0.22, 0.58]	2017
Lane, W. et al, 2017. SWITCH 1 Trial.	28	249	37	252	0.0%	0.77 [0.48, 1.21]	2017
Novo Nordisk, 2017 DUAL VII	13	252	17	254	0.0%	0.77 [0.38, 1.55]	2017
Wysham, K. et al, 2017.SWITCH 2 Trial	55	360	93	360	0.0%	0.59 [0.44, 0.80]	2017
Novo Nordisk, 2018	113	267	189	265	0.0%	0.59 [0.51, 0.70]	2018
Rosenstock J. (2018). BRIGHT Trial	183	463	226	466	15.6%	0.81 [0.70, 0.94]	2018
Philis-Tsimikas, 2020. CONCLUDE trial	62	758	94	759	0.0%	0.66 [0.49, 0.90]	2020
Goldenberg et al, 2021. SWITCH PRO trial	31	249	41	249	0.0%	0.76 [0.49, 1.16]	2021
Subtotal (95% CI)		**2903**		**1804**	**100.0%**	**0.43 [0.28, 0.64]**	
Total events	565		764				
Heterogeneity: Tau² = 0.28; Chi² = 121.34, df = 6 (P < 0.00001); I² = 95%							
Test for overall effect: Z = 4.08 (P < 0.0001)							
Total (95% CI)		**2903**		**1804**	**100.0%**	**0.43 [0.28, 0.64]**	
Total events	565		764				
Heterogeneity: Tau² = 0.28; Chi² = 121.34, df = 6 (P < 0.00001); I² = 95%							
Test for overall effect: Z = 4.08 (P < 0.0001)							
Test for subgroup differences: Not applicable							

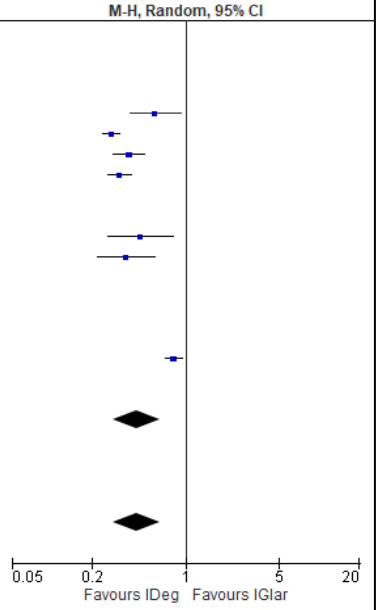

Figure 32. Subgroup naïve

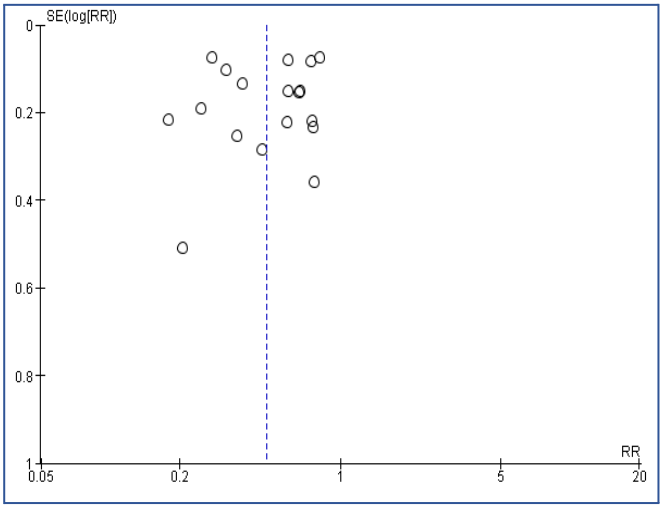

Figure 33: Funnel Plot for ENH Performed on RevMan 5.4

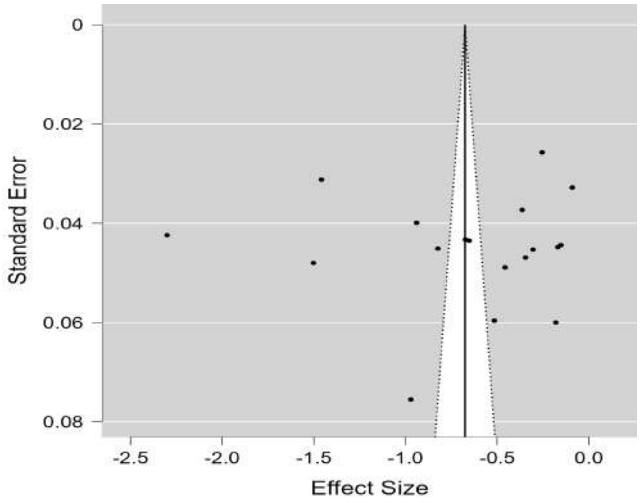

Figure 34: Funnel Plot for ENH Performed on JASP

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Table 10: Egger's test

Regression test for Funnel plot asymmetry ("Egger's test")		
	z	p
sei	-0.066	0.948

4.6 The Level of Antibodies Cross-Reacting with Human Insulin

Seven out of 21 studies were selected for this analysis with a total number of 2903 participants in IDeg groups and 1461 in IGlar groups. The result of meta-analysis indicates numerically lower levels of antibodies cross-reacting with human insulin in IDeg groups MD -0,69 [-2,35 to 0,98], but the difference is not statistically significant p = 0,42 (see Figure 35). The funnel plot revealed a gap in the left bottom area but was not examined on asymmetry as the result is not statistically significant (see Figure 36).

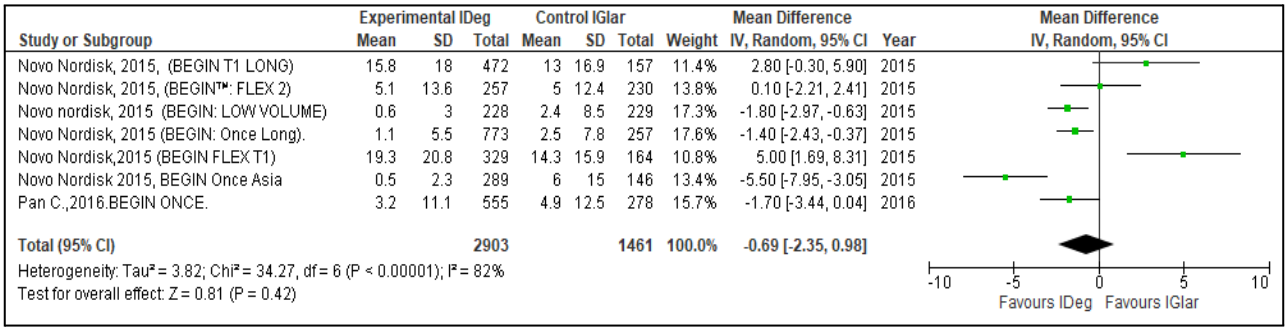

Figure 35: Forest Plot for End-of_trial Periods IDeg vs IGlar Groups

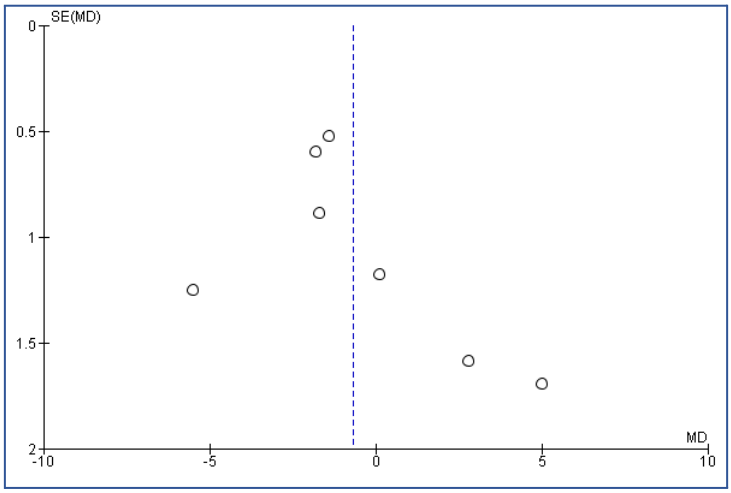

Figure 36: Funnel Plot for Cross-Reacting Antibodies

CHAPTER 5: DISCUSSION

This analysis shows that insulin degludec is associated with less glycaemic variability, a greater reduction in FPG levels, reduced weight gain and less overall and nocturnal hypoglycaemia across all T1D, T2D, insulin naïve and experienced groups. No significant difference was detected in the levels of HbA1c and the level of antibodies cross-reacting with human insulin between treatments with IDeg vs IGlar.

With regards to *HbA1c levels,* no significant difference was detected by this meta-analysis including T1D, T2D, insulin naïve and experienced groups. From one side, this indicates that generally, insulin glargine is not inferior to insulin degludec and possesses the ability to reach

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the same level of HbA1c and provide the similar level of glycaemic control. On the other side, the majority of included studies followed treat-to-target design and set non-inferiority of IDeg vs IGlar as the primary endpoint of the study. In this case, the difference between IDeg and IGlar was not expected. The longer observational or RCT studies without treat-to-target treatment strategy may clarify a reliability of the results reported.

This analysis revealed similar findings to most authors who performed meta-analyses on a change of HbA1c level- Madenidou,(2018), Zhang, (2018), Russel-Jones, (2015), and Zhou, (2019). The opposite result was reported in the review of Liu, (2018) where insulin glargine showed superiority in HbA1c reduction. However, this difference was not clinically relevant- MD = 0,04% [0.01% to 0,07%].

HbA1c is one of the most important diagnostic markers of diabetes management. This marker is directly linked with mean blood glucose concentrations and long-term complications caused by diabetes. This indicator reflects the mean blood glucose level that a patient has had during the previous three or four weeks.

Glycaemic control among diabetics is primarily guided by the systematic assessment of glycated hemoglobin. The recommended by American Diabetes Association and World Health Organisation level is set to be lower or equal to 7,0%. This level of HbA1c has been associated with a reduced risk of developing microvascular complications, retinopathy, neuropathy and nephropathy (Rezende, 2020; Dedov, 2021)

The analysis of pooled results of nine studies examining *change in body weight* demonstrates that IDeg is associated with less weight gain in comparison with IGlar. The difference is statistically significant across T2D, T1D and insulin experienced groups, but not for insulin naïve group. The analysis showed high heterogeneity in T2D and insulin experienced subgroups (up to 94%) and absence of heterogeneity in T1D group. This subgroup included only two studies, so the results may lack validity. Generally, the difference in weight gain -0,84 kg observed between IDeg and IGlar has a minimal effect in a clinical practice. However, the observations were made during a 24-week study duration, taking into account that most patients with diabetes use insulin for a lifetime, the difference might be larger. The absence of standard deviations (SD) and available dataset of study participants that is needed for SD calculations limited the number of studies included in the meta-analysis.

Generally, treatments with both insulins during the trial period (12 weeks in average) are associated with weight gain: in 5 studies it was minimal, ranging from 0,1 to 0,8 and in the remaining 3 studies, except Lingvay,2016, weight gain ranged from 1,8 to 2,5 kg (See Figure 12).

The findings of other authors varied. The review of Liu, (2018) including 15 studies revealed similar changes in body weight gain IDeg/IGlar -MD = 0,03 [0,11 to 0,18] p=0,67, while the review of Madenidou,(2018) including 36 studies reported that insulin glargine showed more favourable results compared to IDeg100, IDeg200 -MD = 0,75 kg [CI, 1,24 to 0,26 kg]. The review of Zhou, (2019) included six studies out of 15 in the meta-analysis of change in body weight gain- this analysis did not reveal statistically significant difference IDeg/IGlar -MD 0,23 [0.14 to 0,61] p = 0.22). Zhang, (2018) reported a minimal difference in favour of IDeg ETD – 0.09 kg [– 0,19 to 0,37] which is not clinically relevant.

Weight gain is one of the most common side effects of insulin therapy. The number of T2D patients who needs the administration of insulin in order to achieve adequate glycaemic control have been increasing in recent years. As most T2D patients have already had an excess body weight and cardiovascular complications this disadvantage of insulin therapy is particularly relevant in this group. According to DIGAMI 2 study including 865 survivors, the initiation of insulin treatment after myocardial infarction was closely associated with a weight gain and considerable increase in the incidence of

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reinfarction. The inferences were made based on the comparison of groups receiving only oral hypoglycaemic drugs or without any glucose lowering therapy and those who initiated treatment with insulin (Aas, 2009).

It has been estimated that during the first year of insulin therapy, the average weight gain ranges from 2 to 6 kilograms, However, this parameter demonstrates large differences depending on an individual; some patients experience moderate weight gain or even lose weight, while others suffer from substantial insulin-associated weight gain (Jansen, 2014).

According to several longitudinal observational studies elevated levels of HbA1c during long periods significantly increase the risk of developing cardiovascular and multivessel coronary artery disease in patients with Diabetes Type 2 (Rezende,2020; Dedov, 2019). Chronic hyperglycemia causes systemic inflammation through advanced glycation end products and reactive oxygen species. This chronic inflammation may result in vascular damage (Rezende, 2020).

In terms of *overall and nocturnal hypoglycaemia,* the groups receiving treatment with IDeg showed the lower rates of hypoglycaemic events. The rates were lower with IDeg during different study periods (titration and maintenance), however, the lowest rates of overall and nocturnal hypoglycaemia were reported during maintenance treatment periods in all populations.

The results of other researchers report similar findings with statistically significant reduction in overall episodes of hypoglycaemia associated with IDeg in T1D and T2D patients: Liu, (2018) RR - 0,88 [0,81 to 0,96], subgroup analysis revealed that reduction was true only for T2D patients; Zhang, (2018) ERR 0,81 [0,72 to 0,92]; Ratner, (2015) overall T1D, T2D- RR 0,83 [0,74 to 0,94], T2D naïve -RR 0,83 [0,70to 0,98]; Madenidou,(2018) overall -OR 0,64 [0,43 to 0,96]. Among the existed reviews, the one of Zhou, (2019) did not reveal statistically significant difference in overall hypoglycaemia IDeg vs IGlar RR 0,98 [0,93 to 1,03] p = 0,43.

Regarding *nocturnal hypoglycaemia*,10 out of 18 individual trials showed a significant reduction in hypoglycaemia rates and remaining 8 showed non-significant difference. The meta-analysis of the pooled populations T1D+T2D, pooled T1D, pooled T2D demonstrates statistically significant reduction in nocturnal hypoglycaemia rates associated with insulin degludec.

Moreover, the reduction in hypoglycaemic episodes is accompanied with more physiological FPG levels as compared to IGlar. The meta-analysis of pooled estimates of 14 studies revealed that IDeg is associated with the greater reduction of *fasting plasma glucose* levels. The reduction was moderate but significant across all T1D, T2D, insulin experienced and naïve subgroups with absent or low heterogeneity except naïve group which showed considerable heterogeneity (I^2- 65%). This suggests that IDeg is more effective in achieving FPG target levels without nocturnal hypoglycaemia in comparison with IGlar. In previous treatments with other basal insulins, it was rather problematic to reach FPG target without significant increase in risk of nocturnal hypoglycaemia. This fear of nocturnal hypoglycaemia prevented patients with diabetes from attempts to reach target FPG levels (Russel-Jones,2015). The IDeg showed the ability to solve this long -lasting problem of insulin therapy.

The findings of other authors examining nocturnal hypoglycaemia are quite consistent and similar to the results of this current meta-analysis. The meta-analysis of Heller, (2016) showed a considerable reduction in episodes of hypoglycaemia measured between 00.01-05.59 in subgroups T2D naïve- 0,64 [0,48 to 0,86], T2D basal-bolus group -0,77 [0,60 to 0,97]. All existed meta-analyses report significant a reduction of nocturnal hypoglycaemia in all T2D insulin naïve and experienced groups, and in most of T1D groups: Ratner,(2015)- overall T2D population RR- 0,83, T2D naïve- 0,64, T1D RR 0,75 [0,60 to 0,94]; Zhang, (2018) ERR-0,71 [0,63 too,80]; Zhou,(2019) RR 0,81 [0,75 to 0,88] p< 0.0001; Liu, (2018) overall nocturnal RR = 0,74 [0,69 to 0,79], T1D RR - 0,74 [0,68 to 0,81], T2D RR - 0,74 [0,66 to 0,82] p<0,001.

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Concerning FPG levels, the result obtained from the current study correlates with the findings of previous reviews: Russel-Jones, (2015); Zhang, (2018)- [ETD – 0.28 mmol/L (– 0.44; – 0.11)]; the meta-analysis of Liu, (2018) found almost the same results for a change in FPG - MD = –0.41[–0.54 to –0.28].

The analysis of FPG has remained as the one of the most precise diagnostic markers of glycemic control used in clinical practice. Along with the level of HbA1c, FPG is also a significant predictor of cardiovascular and other microvascular implications in patients with diabetes (Lu, 2019; Zhou, 2021).

Concerning the *overall episodes of hypoglycaemia*, this meta-analysis of pooled estimates revealed a statistically significant reduction in the risk of developing hypoglycaemia associated with insulin degludec. However, the analysis includes individual studies with non-significant differences in hypoglycaemia rates; 11 studies out of 21 have results which are not statistically significant.

Additionally, the remaining studies include three studies which showed the opposite results (IGlar's superiority in terms of event rate). All three studies have several limitations, for example the study of Kawaguchi, 2018- after switching to insulin degludec the dosage was not changed during the treatment periods and this led to the higher incidence of hypoglycaemia. The insulin requirement to achieve the same level of glycaemic control with IDeg is lower than with IGlar. This fact was confirmed by the researcher when the rates of hypoglycaemia dropped after the reduction in the dosage of IDeg. In addition to this, IGlar was used in concentration 300U/l which can affect the results, as a novel high-concentrated glargine may produce effect different from 100U/I (Reid, 2017). Also, the sample was small (consisted of 30 participants), which reduces generalizability and validity of the research.

The study of Kumar, (2017) showed 43% increase in hypoglycaemia events in IDeg groups, which the author explained by several flaws in

The study of Kumar, (2017) showed 43% increase in hypoglycaemia events in IDeg groups, which the author explained by several flaws in administration of IDeg and IGlar. IDeg and IGlar was administered at different times of the day and vary among patients depending on their lifestyle.

Also, patients in the IDeg group had the same time for bolus and IDeg injections which could trigger an increase in daytime postprandial hypoglycaemia, the daytime effects of the bolus component overlapped the effect of basal insulin (Kumar, 2017). The study BEGIN SIMPIFY had the similar to Kawaguchi,2018 limitations (Novo Nordisk, 2015).

According to this analysis, IDeg demonstrates superiority in achieving normoglycaemia without nocturnal and overall confirmed hypoglycaemia. This aspect is particularly important as both hypergycaemia and hypoglycaemia can lead to adverse cardiovascular consequences. The main problem of insulin therapy is the difficulty to reach stable glucose control within the recommended target levels (FPG <6,1mmol/l, after meal < 7,8 mmol/l, HbA1c <7,0%) (Dedov, 2019; Dedov, 2021). Insulin degludec produces less hypoglycaemia and glycaemic variability and therefore ensures a more physiological glycaemic control. Variability in glucose control may increase risk of cardiovascular pathology in diabetics even when a patient has an acceptable HbA1c level (Rezende, 2020).

The meta-analysis of seven trials examining *the level of cross-reacting antibodies against human insulins* showed that treatments with insulin degludec versus insulin glargine did not reach a statistically significant difference and demonstrate similarity in this safety characteristic. This is the first meta-analysis examining the level of antibodies cross-reacting with human insulin produced after the treatment with IDeg vs IGlar, and therefore no valid comparison with other reviews can be conducted.

According to Vora, (2016), the author who compared the levels of antibodies cross-reacting with human insulin measured as mean differences, IDeg and IGlar produced a similar

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increase in antibodies' formation. Generally, antibodies produced during the treatment with both insulins remained low T1D (<20% B/T) and T2D (<6% B/T). In addition to this, antibody formation was not associated with change in HbA1c, insulin dose or rates of adverse events (Vora, 2016). The result of this meta-analysis confirms the findings of Vora, (2016).

5.1 Strengths of the Current Study

Systematic reviews and meta-analysis are ranked at the top of the hierarchy of evidence-based medicine and present the most valid and comprehensive quantitative evidence on the topic. Moreover, meta-analysis identifies lack of adequate evidence and reveals areas where additional research is needed. Meta-analysis strengthens evidence generated through the systematic review. Meta-analysis provides an opportunity to summarize findings of a large number of studies and surfaces associations that were not previously detected. Systematic review and meta-analysis provide a transparency which cannot be offered by a traditional, narrative synthesis of research findings. This characteristic helps to conduct a more objective evaluation of the evidence and resolve uncertainty when original research, reviews and editorials disagree (Littell, 2008; Egger, 2001).

A systematic approach ensures that this transparency is combined with discipline, thus minimizing bias. Additionally, meta-analysis can enhance the precision of treatment effects, reduce the probability of false negative results and eventually, speed up the introduction of effective treatments to population. The subgroup analysis, usually performed in meta-analysis, may reveal the patient groups who respond particularly well to the intervention (Egger, 2001).

The meta-analysis including high-quality RCT trials today offers the best available evidence in quantitative research. This meta-analysis includes 21 studies designed as randomized controlled trials which are recognized as a "gold standard" for research, best suited for the experimental interventions including testing of new drugs. RCT design provides a high internal validity of results and is positioned on higher levels of hierarchy of evidence (Ingham-Bromfield, 2016; Saks,2019).

Generally, studies included in this meta-analysis are of high methodological quality: study participants had similar baseline characteristics and were properly matched, incompletion and withdrawal rates are low, the number of participants who failed to complete the trial was similar in control (IGlar) and experimental (IDeg) groups; all studies include sensitivity analysis. The ITT (intention-to-treat analysis) was performed in studies where higher numbers of drop-out rates were present with the purpose of minimizing an attrition bias (Wysham,2017; CRD,2009). Most of studies are long-term >12 weeks with extensions and follow-ups; in studies with crossover designs wash-out periods were applied to address a possible carryover effect. Despite the fact, that most of the studies were funded by the manufacturer (Novo Nordisk AS), principal investigators were independent researchers, not employed by this company. This is the first systematic review assessing the parameter- the level of antibodies cross-reacting with human insulin produced after the treatment with IDeg vs IGlar. Also, this meta-analysis includes 21 studies ranging from 2015 to 2020, representing the most novel and comprehensive evidence on the chosen topic. The analysis includes early trials as well as the most up-to-date studies.

This meta-analysis used robust methodology, includes subgroup analyses and tests a publication bias in all variables using the Egger's regression test.

5.2 Limitations

This meta-analysis has several limitations such as a high heterogeneity of the results for the hypoglycaemia and body weight gain parameters as well as low external validity. Likewise many forms of research, results of the meta-analysis lack generalizability and work best in contexts similar to those, where the intervention took place. This limitation can also be referred to randomized controlled trials which usually constitute meta-analysis. As a rule, the trials are conducted in "ideal" environments characterized

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by intensive training of specialists, homogenous samples, a single problem focus and higher methodological rigor which is usually not possible to replicate in a real-world clinical practice. In typical clinical settings, the lack of training and supervision of therapists is present, and patients are more diverse, with multiple health problems (Littell, 2008).

Another limitation is time lag bias which appears due to the fact, that trials with positive, statistically significant results are published faster (median time to publication 2-4 years) while studies with negative results wait up to 6 years before the publication; studies with positive results dominates literature. This means that although most of conducted studies will be eventually published, some of them may not appear in the meta-analysis (Egger, 2001). Also, a language bias may be present, as the search was limited to studies published in English (CRD,2009). Also, the meta-regression was not performed in this analysis.

In this meta-analysis out of 21 selected studies, only three were designed as randomized double-blinded trials. The remaining 18 trials followed open-label design and excluded patients with recurrent, severe hypoglycaemia. Absence of masking can lead to participants/observer bias (Saks, 2019). Additionally, in spite of the fact, that all studies set 18+ years of age as inclusion criteria, most samples represent middle-aged participants (45-60 years), patients younger than 45 years and older than 75 years were underrepresented, which reduces generalizability of results to these two age groups.

This meta-analysis includes studies which used different concentrations of insulin glargine, most studies used treatment with IGlar-100U/ml, but some trials utilize IGlar-300U/ml. For example, two trials BRIGHT Trial and Kawaguchi, 2018 revealed that insulin glargine in concentration of 300U/ml showed similar or opposite to insulin degludec results in terms of reduced overall and nocturnal hypoglycaemia.

The similar inferences were made in a prospective cohort study conducted in Serbia by Velojic-Golubovic et al, (2021), where a novel formulation of high-concentrated insulin glargine 300U/ml showed a significantly slower absorption after a subcutaneous injection in comparison with insulin glargine 100U/ml. The more prolonged absorption resulted in a more even profile, better glycaemic control and longer duration of action. This cohort included a total of 350 patients with Diabetes Type 2 which were recruited by local physicians from general hospitals and regional medical centers.

Another retrospective cohort study conducted in Japan compared IGlar-100U/ml, IGlar-300U/ml and IDeg-100U/ml using parameters like weight gain and HbA1c levels. The study included a total of 294 patients with Diabetes Type 2 and 307 patients with Diabetes Type 1; both groups had elevated levels of HbA1c >7.0% prior to study. The results showed that IGlar-300U/ml and IDeg-100U/ml produced a similar reduction of HbA1c levels and weight gain. However, the selection of IDeg was associated with the reduced total insulin dosage i.e. IDeg can reach the same targets at lower total daily dosage in comparison to iGlar (Oya, 2021).

5.3 The reasons for high heterogeneity in the overall, nocturnal episodes of hypoglycaemia and body weight gain parameters

The analysis for the episodes of overall and nocturnal hypoglycaemia were based on a large number of studies 21 and 18, respectively. The included studies consist of various participants of different age group, weight, baseline HbA1c, ethnicity. Studies contain multi-national samples and some of them included participants with comorbidities (cardiovascular or kidney diseases) which can affect results. Also, definitions of hypoglycaemia differ across studies (some studies define confirmed hypoglycaemia with blood glucose level of 3,1 mmol/l and others 3,9 mmol/l). Additionally, some studies measure blood glucose levels in mmol/l and others in mg/dl (Zhou, 2019; Zhang, 2018).

5.4 Publication bias

The publication bias was not revealed by this meta-analysis, however, the analysis of body

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weight gain variable included 9 studies, which is lower than recommended 10 studies for the Egger's test. The Egger's test requires at least 10 studies to produce valid and precise results, so the precision of the test decreases with a smaller number of studies (Sterne, 2011). According to the Egger's test, true asymmetry and the presence of publication bias is confirmed if p -value equates or is less than 0,05 (Bruce, 2017). Publication bias is particularly problematic in RCT studies and can negatively affect the overall treatment effect because small studies with negative results are underrepresented in the meta-analysis (Laake, 2015). However, a funnel plot asymmetry can be the result of between-studies heterogeneity and inclusion of studies with statistically insignificant results (Egger, 1997).

5.5 Application of this Study

The results of this study can be transferred into clinical practice, and inferences of this study can be applied to T1D and T2D patients to optimize a diabetes treatment and glycaemic control of this groups. The prescription of IDeg is particularly relevant in the treatment of T1D and T2D insulin naïve patients starting insulin therapy in primary care. As it comes to weight gain parameter, additional research is needed with a full access to patient's data, as the inclusion of more studies can reveal a wider difference between IDeg and IGlar. In this case, IDeg can be used as a better option for the treatment of overweight and obese patients with Diabetes Type 2.

With regards to hypoglycaemia, IDeg can be safely used as an alternative to other basal insulins of first and second generation as the most pronounced superiority was revealed in the reduction of nocturnal and overall hypoglycaemia in all subgroups. This is especially recommended to patients with T1D and T2D on basal-bolus regimes with frequent nocturnal and overall hypoglycaemia.

This analysis indicated that T1D patients and T2D patients using basal-bolus regime experienced higher number of hypoglycaemic events. The samples which used only basal insulin or naïve patients have fewer events due to the absence of bolus insulin's effect (insulin Aspart was used in basal-bolus regimes in all trials). In case of T1D patients, the use of both insulins increases the risk of hypoglycaemia. Therefore, as analysis confirmed that T1D group benefits the most from IDeg therapy in terms of risk of developing hypoglycaemia, this basal insulin can be used in the treatment of newly diagnosed T1D patients as well as those with long history of diabetes.

However, approach should be individual, as the conditions of randomized controlled trial design may differ from a real clinical practice where the number of hypoglycaemic episodes is usually higher (Russel-Jones, 2015). Also, according to Russel-Jones, (2015) real practice includes patients with BMI higher than 30 years old, and patients with severe and recurrent hypoglycaemia – groups which were not included in the experiment. So, the results should be generalized with cautions.

5.6 Recommendations for Future Research

This analysis and review of the newest literature revealed that studies which used IGlar 300U/ml showed similar to IDeg100U/ml results, and for this reason it can be assumed that IGlar -300U/ml may have a more stable and flat activity profile than IGlar-100U/ml, and further investigation is needed to implement a direct comparison between IGlar-300U/ml and IDeg-100U/ml. Concerning body weight gain parameter, the publication bias cannot be fully excluded, so additional research is needed with a full access to patients' dataset, as most studies did not include standard deviations. Additionally, the future reviews could implement analysis including studies with samples using isolated basal regimes + oral hypoglycaemic drugs and basal-bolus regimes, so that the hypoglycaemic effect of bolus insulin would not interfere during the testing of basal insulins (Kumar, 2017). This is particularly relevant in insulin naïve patients with T2D.

Also, mean age of all samples ranged between 40-60 years with a few 65+ participants and future research could expand age limits and recruit more elderly people 65+. Another point to consider in the future investigation is the inclusion of people with diabetes complications,

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obesity (BMI more than 30) and severe hypoglycaemia.

5.6 Conclusion

In conclusion, this systematic review and meta-analysis demonstrates that insulin degludec is superior to insulin glargine in terms of four safety and efficacy variables such as change in fasting plasma glucose, body weight gain, nocturnal and overall hypoglycaemia. IDeg vs IGlar produce similar changes in HbA1c levels and the level of antibodies cross-reacting with human insulin. The most pronounced difference was detected in the number of nocturnal and overall hypoglycaemia, which confirms the fact that IDeg exhibits less glycaemic variability and ensures a more flat activity profile. Moreover, the reduced number of hypoglycaemia is accompanied with the reduction of FPG levels. Insulin treatment that achieves near normoglycemia without increasing the risk of hypoglycemia provides an opportunity of reaching glycaemic control which is close to physiological human insulin production (Gelhorn, 2020). This characteristic would be beneficial to T1D as well as T2D naïve and experienced patients because IDeg possesses the ability to ensure a similar to IGlar level of HbA1c along with lower rates of hypoglycaemia, better FPG levels and less weight gain. The additional benefit of better glycaemic control is the reduction in emotional and physiological distress (Gelhorn, 2020).

The findings of this meta-analysis on overall and nocturnal hypoglycaemia, FPG and HbA1c are similar to most existed reviews conducted from 2015 to 2019: Liu,(2018); Zhou,(2019), Ratner, 2015; Heller, (2016); Russel-Jones, (2015). The results on weight gain parameters are similar to Zhang,(2018) and opposite to Madenidou, (2018) and Zhou,(2019). This analysis adds value and evidence to the existed reviews on the topic.

The general inference based on the current analysis is that the basal insulin analogue degludec in comparison with glargine provides a better option for patients with Diabetes Type 1 and Diabetes Type 2. This study adds evidence for health practitioners and managers considering administration of a basal insulin to patients with T1D and T2D in favour of IDeg. As the cost of IDeg on the market is higher that IGlar's the robust evidence is needed to justify the administration of IDeg for a wider use (Karla, 2013).

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Appendix 1: Body Weight gain Standard Errors, Effect Sizes and Pooled Standard deviations (SD)

Study ID	Pooled SD	Effect size (Cohen's d)	Standard error
BEGIN Easy	3,801	-0,0526	0,0463
Novo Nordisk, 2015 NCT00612040	2,244	-0,2673	0,0755
BEGIN FLEX T1	3,922	-0,1529	0,0451
BEGIN SIMPLIFY	1,581	-0,3162	0,0596
Lingvay, 2016 DUAL V	3,55	-0,9014	0,0424
Wysham K. et al, 2017, SWITCH 2	3,806	-0,0788	0,0373
Novo Nordisk,2018	3,514	0,0284	0,0433
Rosenstock, 2018 BRIGHT Trial	3,701	-0,081	0,0328
Philis -Tsimikas et al, 2019 DUALTM IX	3,85	-0,5194	0,0489

Appendix 2: FPG Standard Errors, Effect Sizes and Pooled Standard Deviations

Study ID	Standard Error	Effect size (Cohen's d)	Pooled SD
BEGIN FLEX T1	0,0451	-0,3443	3,2527
BEGIN T1 LONG	0,0399	-1,7809	0,2246
Novo Nordisk, 2015 NCT00612040	0,0755	-0,2358	4,4950
BEGIN Once Long	0,0312	-0,3410	1,7885
BEGIN SIMPLIFY	0,0596	-0,3110	2,2505
Pan C., 2016. BEGIN ONCE	0,0347	-0,0738	2,8448
Wysham, K. et al, 2017. SWITCH 2 Trial	0,0373	-0,0888	2,2505
Kumar S., 2017. BOOST Trial	0,0435	0,0523	1,9112
Rosenstock, 2018 Bright Trial	0,0328	-3,9269	0,1095

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ABSTRACT

In 1976 Edward Evarts "The languages of the brain introduction to neuropsychology" studied the behavior of certain neural mechanisms which are activated in the motor cortex and provide a mirror image of the force field external (orthostatism, variations of inertia in the actions). This type of neuron acts during muscle contraction. The confirmation came from the experiences made with monkeys who were trained to manipulate levers to which various weights were connected which opposed the pressure action. The recordings show that these brain areas are activated before the lever is pressed and that the electrical activity (electromyography) is proportional to the amount of force, pressure, necessary to overcome the resistance which, in the containers with the food, was greater.

Keywords: pressure, vessel, neurofunctional.

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Orthostatic Pressure, Vessel Pressure and Neurofunctional Changes: A Correlation Study

Roberto Piga[α], Nikos Makris[σ], Stefano Pallanti[ρ], Renato Palma[ↀ], Andrea Castellani[¥], Simone Palmieri[§], Marco Guasparri[χ], Paolo Piga[ν] & Matteo Bucalossi[Θ]

ABSTRACT

In 1976 Edward Evarts "The languages of the brain introduction to neuropsychology" studied the behavior of certain neural mechanisms which are activated in the motor cortex and provide a mirror image of the force field external (orthostatism, variations of inertia in the actions). This type of neuron acts during muscle contraction. The confirmation came from the experiences made with monkeys who were trained to manipulate levers to which various weights were connected which opposed the pressure action. The recordings show that these brain areas are activated before the lever is pressed and that the electrical activity (electromyography) is proportional to the amount of force, pressure, necessary to overcome the resistance which, in the containers with the food, was greater.

The information on the pressure to be exerted (choice of the task and execution) is provided by the tension that arises from the adjustment, a kind of pre-regulation, which takes place in the agonist and antagonist muscles before the gesture (reaction), determining a state of cocontraction for effect of the Feed-forward control mechanism (in this phase the system oscillates like the needle of the balance, which subsequently stops on the exact weight). The aim is to contrast the weight with an adequate stiffness (consistency of the contractile structures) in times of the order of 0 milliseconds, to compensate for the delay of the proprioceptive feed-backs. It is probable, as Prof. Nikos Makris, that a kind of resonance is created between the oscillation frequencies of the peripheral structures with those of the brain areas.

From our study it emerges that a different approach to fatigue, considered as a signal, and not a value, has allowed us to modulate the work proposal, both at a sporting and rehabilitation level, in order to choose what to suggest, depending on a measurable and objective data obtained on resilience. This data allows you to choose whether to increase the load or reduce the tension, in order to reduce the entropy of the system, and therefore reduce energy expenditure in both the athlete and the neurological patient.

Keyword: pressure, vessel, neurofunctional.

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I. INTRODUCTION

If our stomachs were distant from the heart pump, we would be subjected to particularly intense activity every day to get the blood necessary for digesting food and we might not have the resources to maintain 'service needs', such as getting blood to the brain. The brain immediately sends out alarm signals if it is forced to work below threshold. Certain areas of the body need more oxygen exchange in order to function. Chemical and physical factors come into play, such as carbon dioxide pressure, osmotic pressure and others. This is referred to as resilience, change of state. In our study, we evaluated the phenomenon of blood flow reflux and its

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consequences. Skeletal muscle blood flow is linked to contractile activity, and is controlled by nervous factors. From a muscular standpoint, many local factors need to be taken in account, related to blood pressure, tissue pressure, blood viscosity and muscle fibre type. In some cases, there can be an increase in flow of up to 15 to 20 times the normal value. [6] The local mechanism follows this pattern: following repeated contraction, there is a compression effect exerted by the muscle on the blood vessels in a continuous and progressive manner. During each contraction, usually intermittent, arterial flow is reduced and venous drainage may also stop. If the contractions are intense and prolonged, the vascular area is compressed and blood flow may temporarily stop.

In the upright position, at rest, the venous valves are open and promote antigravity blood outflow. When the leg muscles (e.g., gastrocnemius) contract, they compress the vein and the pressure increment inside pushes the blood upwards through the upper valve, while the lower one closes. After the contraction, the muscle loosens its tension (pressure/tension mechanism) and the resulting drop in pressure allows the upper valve to close and the lower valve to open, so that the muscle segment once again is filled with blood. [15-16] This mechanism is typical in conditions where muscle tone is maintained (at rest in an upright position) or in the presence of moderate activity (walking on level ground). In these conditions, the sympathetic intervention is also superimposed, which requires a vasoconstrictive effect starting from a low frequency (1-2 impulses/second) up to a maximum of vasoconstriction, which is achieved with frequencies of 8-10 impulses/second. This is followed by the release of adrenalin at the nerve endings, which produces a vasodilatory effect at low doses. During skeletal muscle contraction, from a biochemical point of view, potassium and phosphates are released, osmolarity increases and contributes to active hyperaemia. Consequently, a temporary vasorelaxation is observed. Also, other critical mediators of vasodilation are lactic acid, carbon dioxide and hydrogen ions. [8] This rapid and incomplete examination of the mechanisms underlying vasodilator and vasoconstrictor phenomena, which alternate depending on certain balance and situations, has led us to reflect on fatigue through the concept of resilience. There is intent about the usefulness of looking at the various sciences as a whole, in order to provide a general framework that informs indistinctly the various fields of knowledge. As sport scientists, we investigate the movement in all its form, and in order to achieve our aim, we utilize every means and method. With this promises we planned and realized the SLED device. The SLED (Ergo-active Energy Tensor Chair) is an orthostatic tension simulator that creates different inertial moments.

The seating posture of this revolutionary chair tends to eliminate the drawbacks of a horizontal seating surface that induces a kyphotic posture. The purpose of this device is to encourage a body position with a theoretical lordosis. Through the inclination of the seating surface towards the feet, it's required a constant activation of the lower limbs to brake and prevent the body from sliding forwards and downward. This instrumental approach guaranteed a movement experience that takes into account variations in moments of inertia in a stable semi-orthostatic setting, and allows exercises such as stretching and core exercises to be performed in real life conditions. [2] The SLED is the magnifying glass through which we investigate how the human body creates muscular tension and manages loads. Thinking the human body as a spring, we could note that it is continuously deformed. In fact, the moments of inertia generated from the body position and the forces that act on it causes a continuous deformation to whom the musculoskeletal system reacts modulating the energy delivery in order to find a balance. Blood pressure represent the force exerted by the heart to pump blood through the cardiovascular system. The balance between diastole and systole determines a person's blood pressure. Specifically, systolic pressure is the maximum pressure exerted by the cardiac pump during systole, while diastolic pressure represents the minimum pressure in the arteries during diastole. The systolic pressure value minus the diastolic pressure is called pulse pressure and provides useful information about the blood vessels conditions. [7] Tension and pressure are

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both measured in Pascal (Pa) and are closely related. The study of vascular dynamics shows that a vessel that expands exerts pressure on the walls; conversely, when it narrows, it exerts pressure on the capillary vessels, actually increasing capillarisation, with all the associated benefits. Pulse pressure quantitatively denounces the blood volume that is created between systolic and diastolic pressure. Lowering the diastolic pressure has various benefits, not only increased capillarisation, but also improved lymphatic activity, increased fluid drainage and elimination of waste substances. [9] In order to investigate the peripheric vascular behaviours under load, we have defined as resilience, the relationship between the pulse and the diastolic pressure, measured both before and after inertial load changes. The level of resilience is representative of how the biomechanical system reacts to certain stimuli. The peculiarity of this model of investigation concerns the reduced influence of the subject's mental and motivational mechanisms, which are usually included in tests measuring physical condition as a function of strength, endurance or speed.

II. MATERIAL AND METHODS

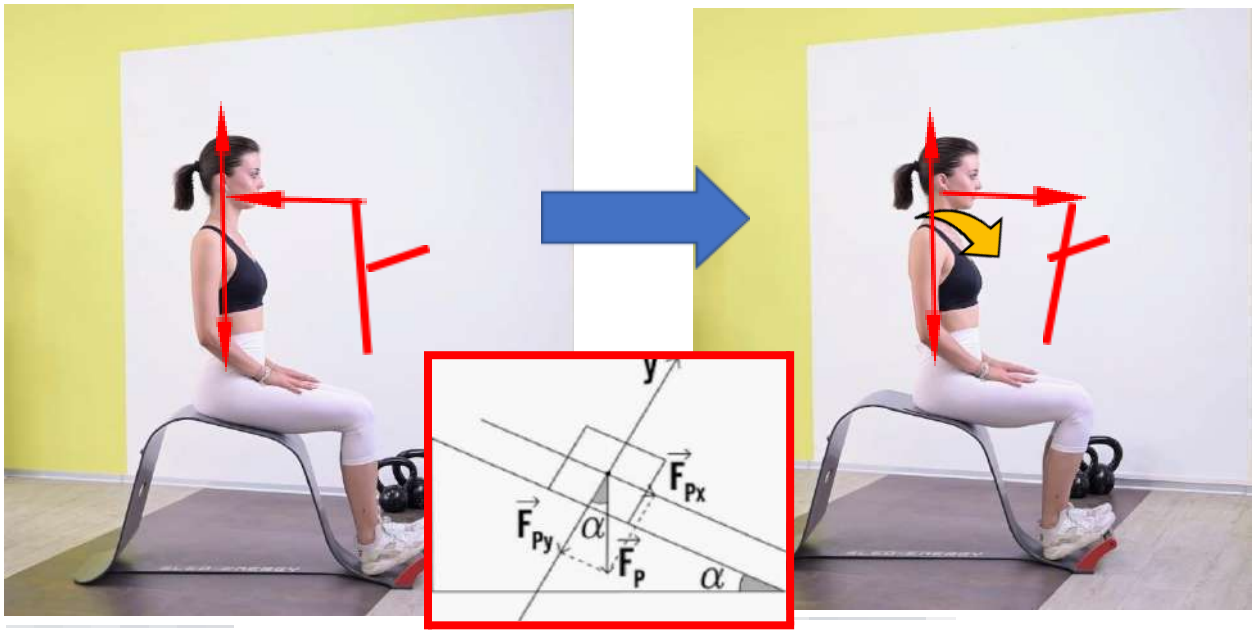
2.1 Participants

During everyday clinical practice or specific intervention, every test here reported was carried out. The following were the different populations of subjects that were observed: subject over 45 years old with some physical impairment (brain stroke, Parkinson's disease, multiple sclerosis) and sport athletes. The latter were divided in tennis professional young athletes and other sport athletes. These two groups were necessary to compare different type of training. In fact, tennis players were tested before and after a tennis session, while other sport athletes performed a band resisted strength training (hypertensor training).

2.2 Study design

To study the phenomenon of blood flow in relation to the contractile behaviour of muscles, we located a sphygmomanometer on the gastrocnemius of the subjects. Asking the subjects to gently slide down and forward on the sled, we recreated a variation of the angular moments of inertia of the limbs, effectively reproducing in the laboratory a functional motor situation that resemble the gesture of standing up from a chair.

We used a simulator, which we called Sled, which allows the body to slide downwards, creating tension against gravity.



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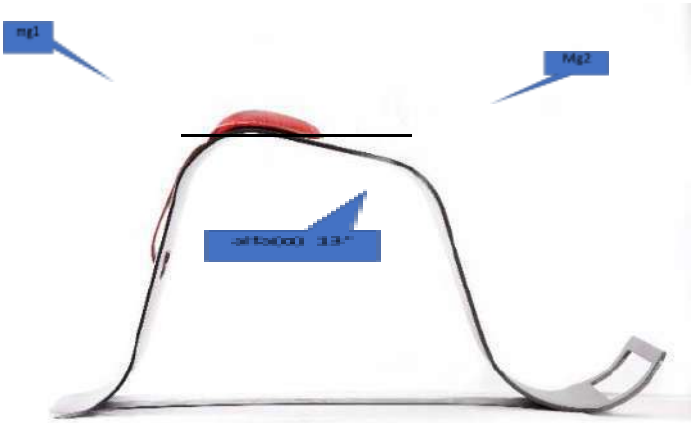
2.3 Equipment

Following, the material we used to configurate the test.

1. Sled Device



2. Beurer precision electronic scale (digital measurement). To measure body weight of the subjects.

3. Omron digital blood pressure monitor with clinical validation. To measure blood pression on the gastrocnemius site.

2.4 Test procedure

Following careful explanation of the procedure and anthropometric measurements, the subject was asked to seat on the tensor sled device (SLED). While seated on the top of the device (no sliding) the first digital blood pressure measurement was taken. Following, the subject was asked to gently slide forward until balance.

Here the tester had to express the subjective amount of force to the ground to prevent excessive sliding. As soon as the subject stopped his body and showed balance while constantly pressing against gravity, the second blood pressure measurement was detected.

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2.5 Measurement Outcomes

From the digital blood pressure analyses, we looked at systolic pressure and diastolic pressure. The difference of the two is defined pulse pressure. Data were compared in various way. First, for every subject we compared measurements "at rest" versus "active", to observe how the body modulates blood pressure in response to a change of inertia and therefore tension.

Among athletes, we compared tests before and after sports performance. Last, studying subjects with motor disturbances, we tried to investigate whether differences could be identified in the analysis between the lower limbs. Thus, we were able to assess the reliability of the test to monitor imbalances and track training progress over time.

III. RESULTS

In the graph we utilize the term rest for the static position seated on the sled, and active to identify the loading phase.

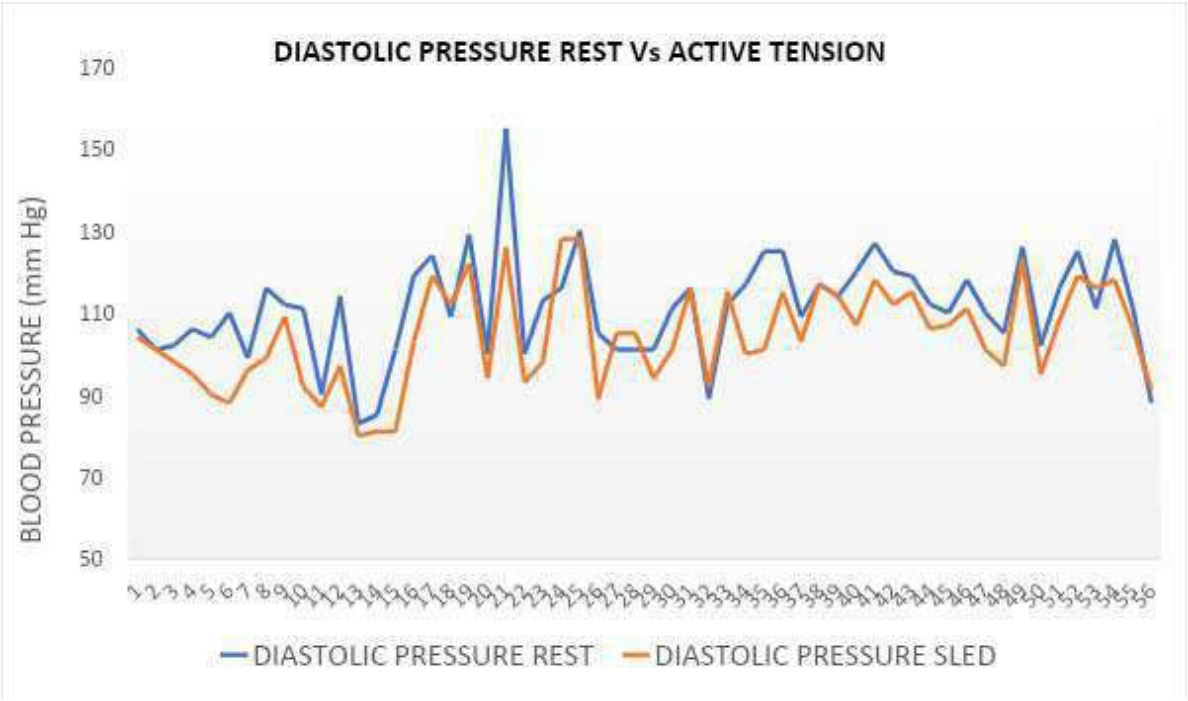
3.1 Rest vs Active

A total of 55 subjects (sport + pathologic) executed the test, two measurements of the blood pressure were taken for each participant, one at rest and one during the active phase. Within group analyses was performed for diastolic pressure, systolic pressure and resilience (pulse pressure/diastolic pressure).

Diastolic pressure

- The diastolic pressure is lower in the active position.
- The medium average decrease is 6%.

Table 1: Diastolic Pressure: Rest vs Active



Systolic Pressure

- No significant change between the two measurements.
- An average decrease is observed; however, this corresponds to a tiny percentage (0.7%).

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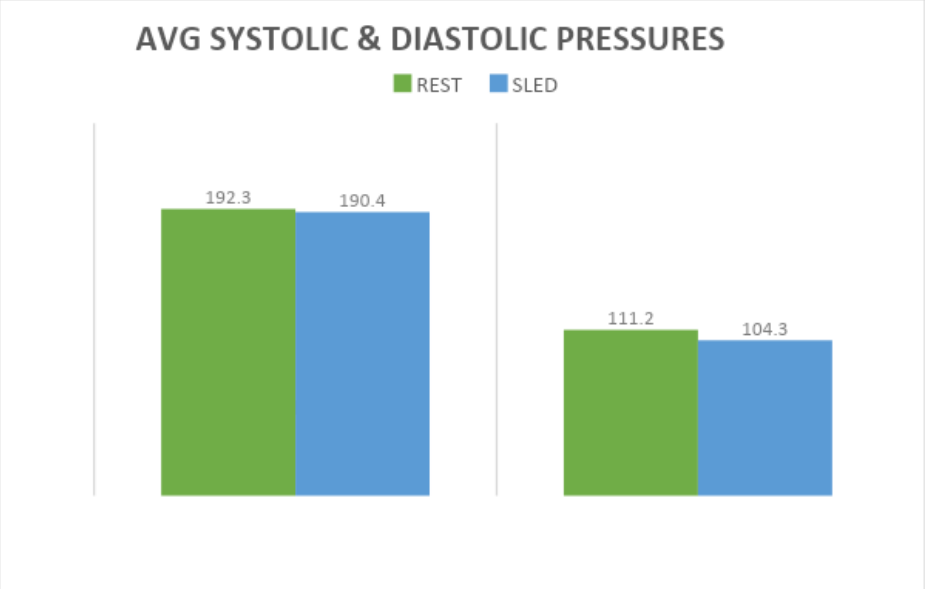
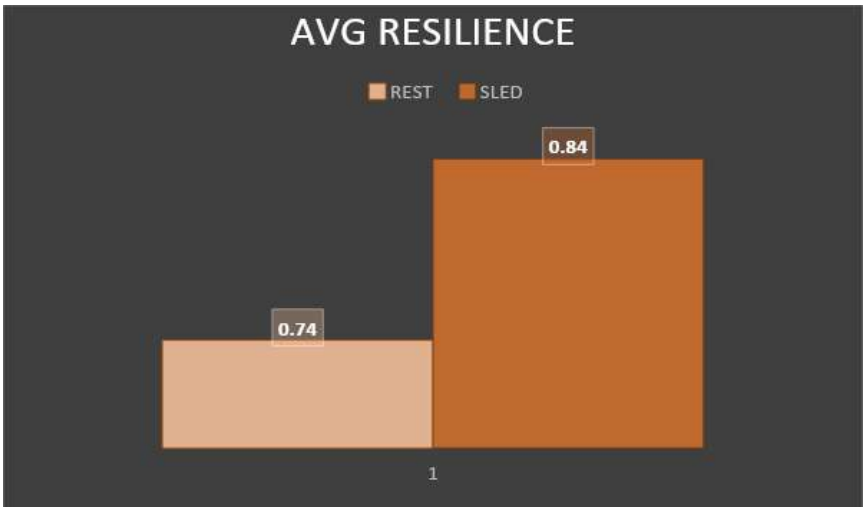
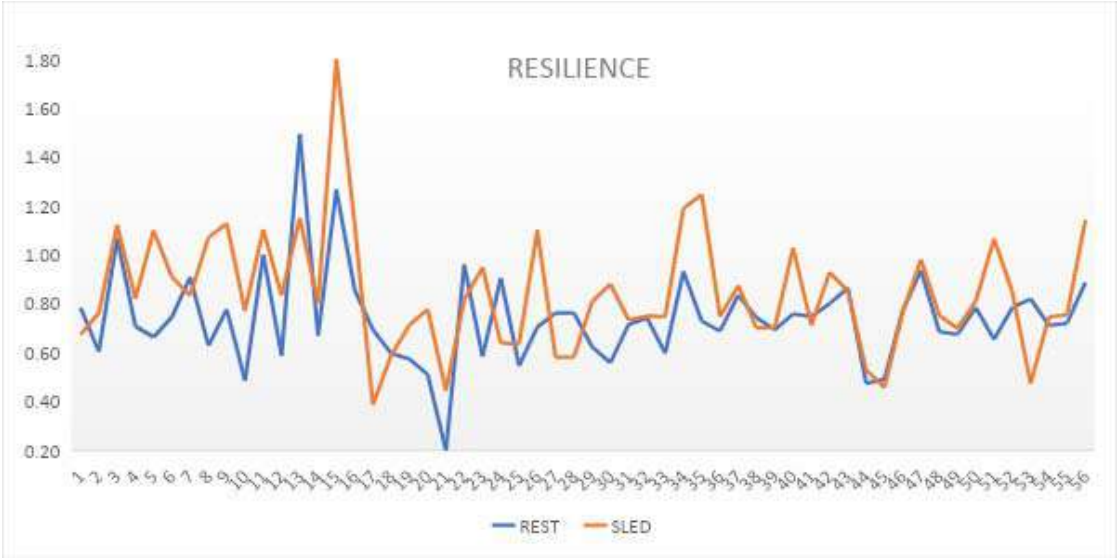


Table 3: Avg. Resilience Rest Vs Active





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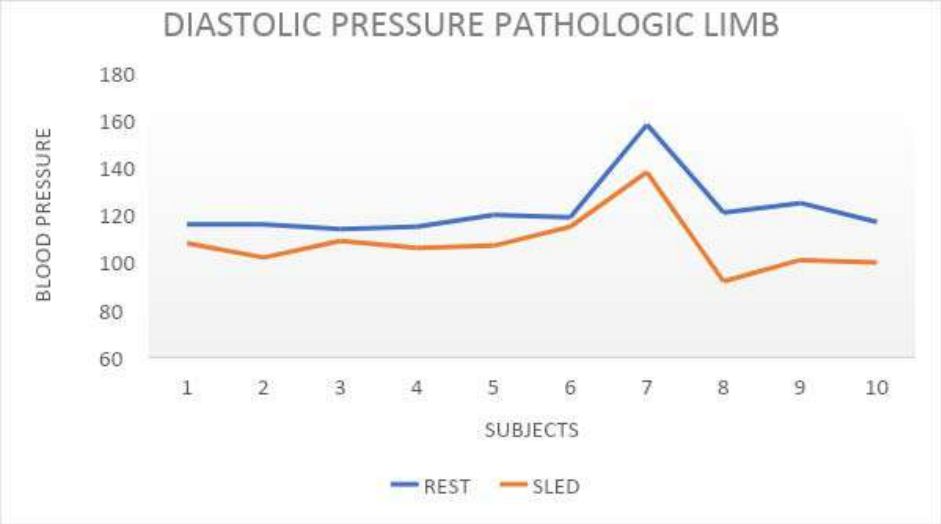
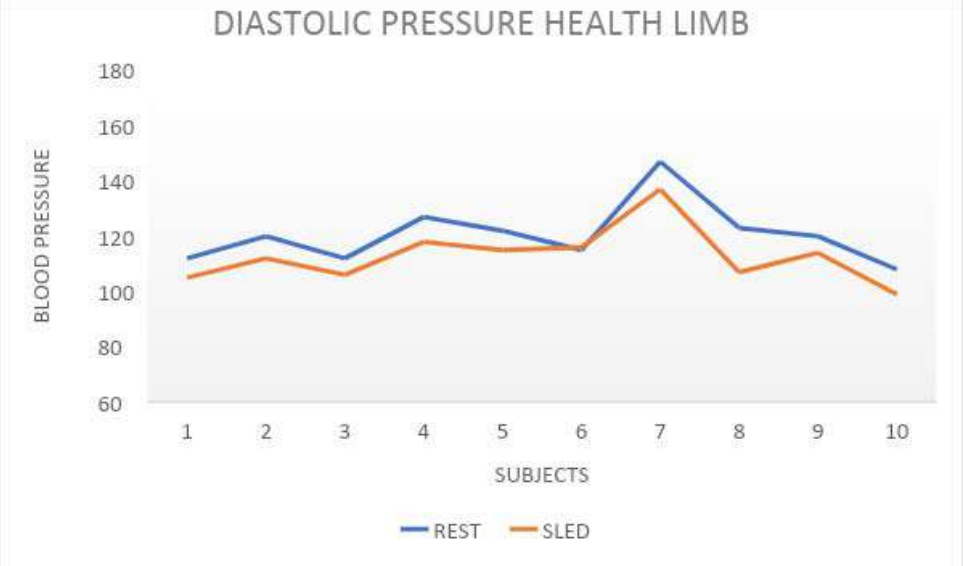
3.2 Pathologic vs Healthy Limb

A total of 10 subject (> 45 yrs.) with different motor disturbances were examined in to identify lower limb imbalances. Indeed, all patients showed one healthy leg and one problematic leg, on which the various pathologies had a more obvious influence.

Diastolic Pressure

- On the pathological leg the diastolic pressure is higher at rest than on the Sled, on the healthy leg there is the same trend although the difference between the two is smaller.
- Comparing the two legs: on the Sled, the healthy leg shows a higher diastolic pressure than the pathological leg. At rest, however, the situation does not differ significantly between the two limbs.





Systolic Pressure

- The sick leg has on average higher systolic pressures than the sane one.
- Comparing the same leg between the position at rest and on sled, it can be seen that in both legs the systolic pressure drops by about 3% on sled and is higher at rest.

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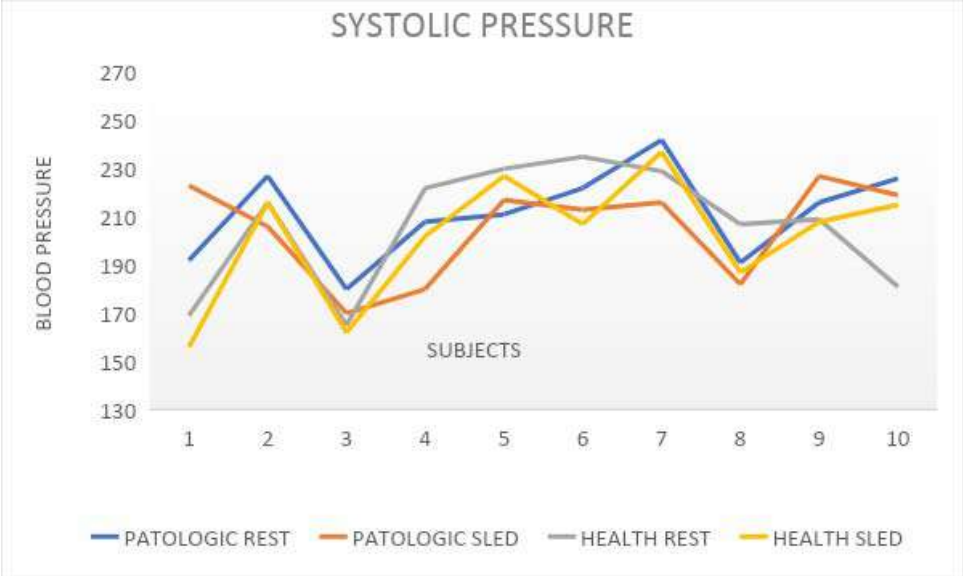

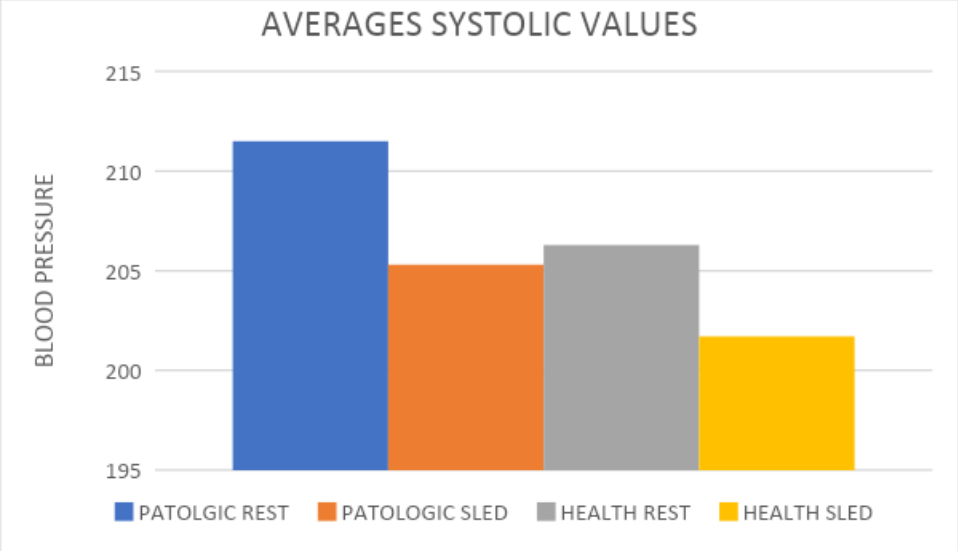

3.3 Athletes on Sled Pre vs Post Sport Performance Athletes on Sled Pre vs Post Sport Performance

Two different type of sport performance: Tennis session (90 min) and hypertensorial session (15 min).

The analysis was carried out by comparing only the measurements taken on SLED, before and after the activity.

Diastolic pressure

- Average diastolic pressure remains constant between pre and post tensor training, while it increases post tennis activity.

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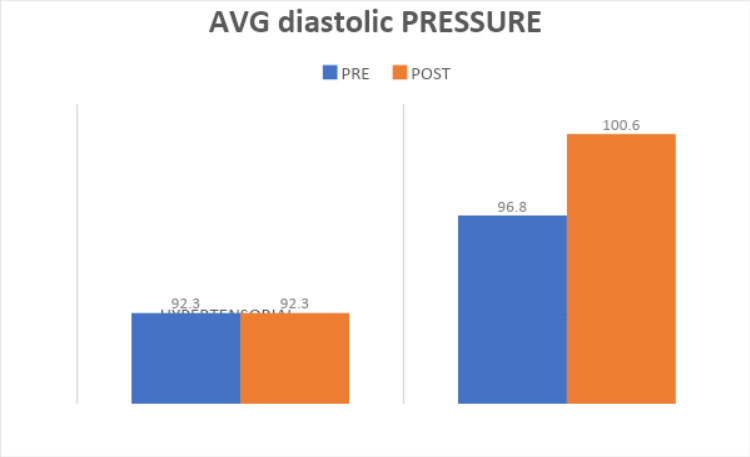
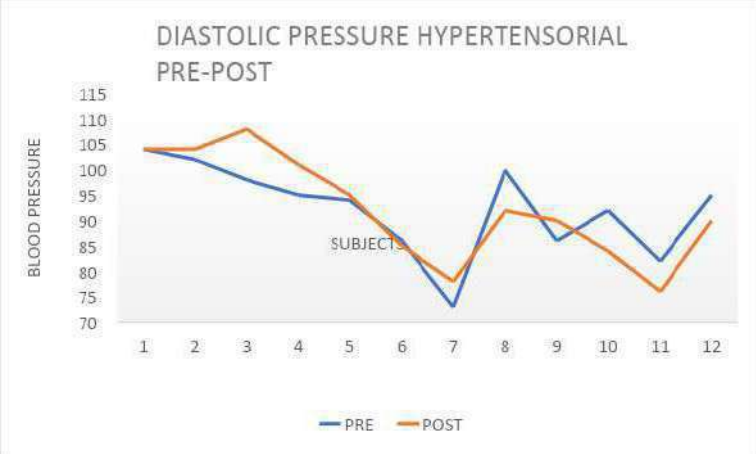


- With reference to hypertensor training, diastolic pressure does not identify a precise pattern, the situation varied from subject to subject.
- However, the trend in diastolic pressure before and after tennis showed a slight increase after activity for 4 out of 5 subjects.



Systolic Pressure

Systolic blood pressure rises slightly post tensor activity. In contrast, there is a slight lowering post tennis session. It is important to note that the small test sample creates a special situation in which systolic blood pressure differs substantially in the two pre-activity groups.

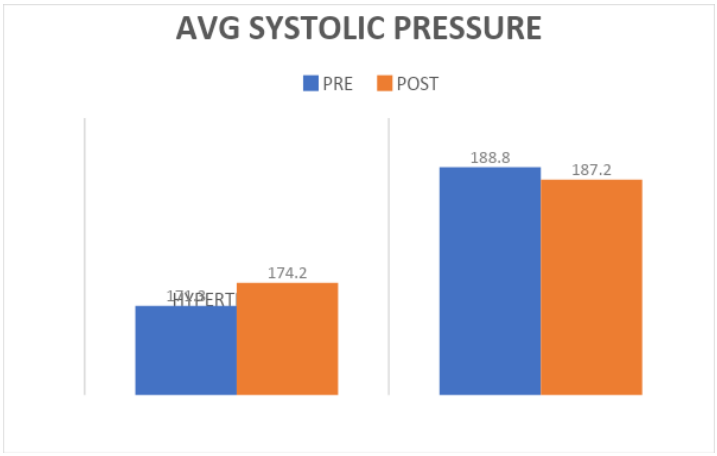


*Table SEQ Table * ARABIC 14 Avg. systolic pressure*

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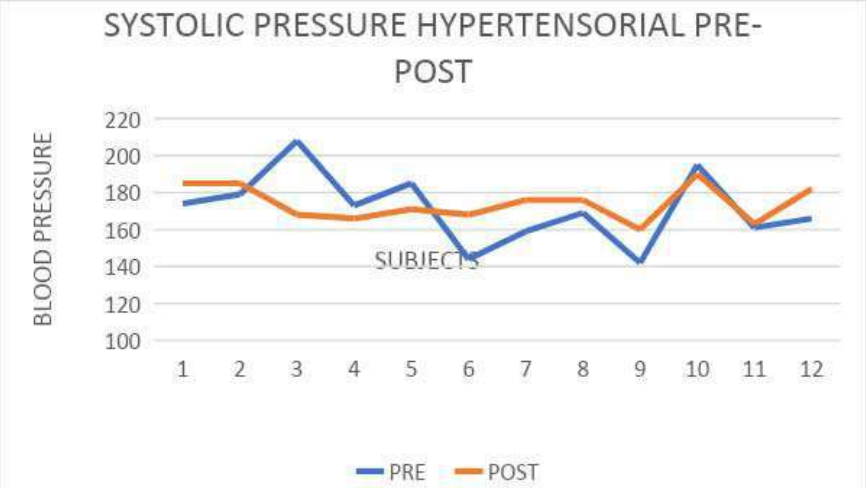


Table SEQ Table * ARABIC 15 Systolic pressure hypertensor

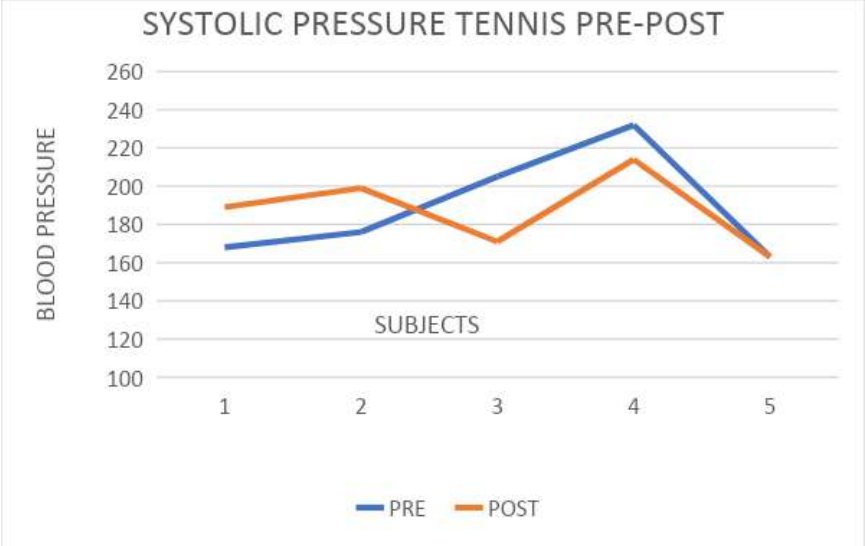
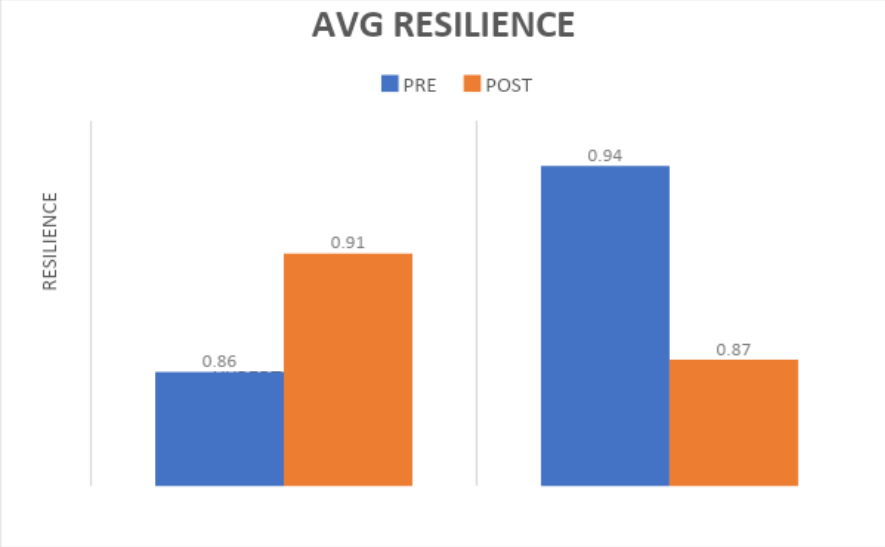


Table SEQ Table * ARABIC 16 Systolic pressure tennis

Resilience

Resilience increases post tensor activity and decreases post tennis activity.



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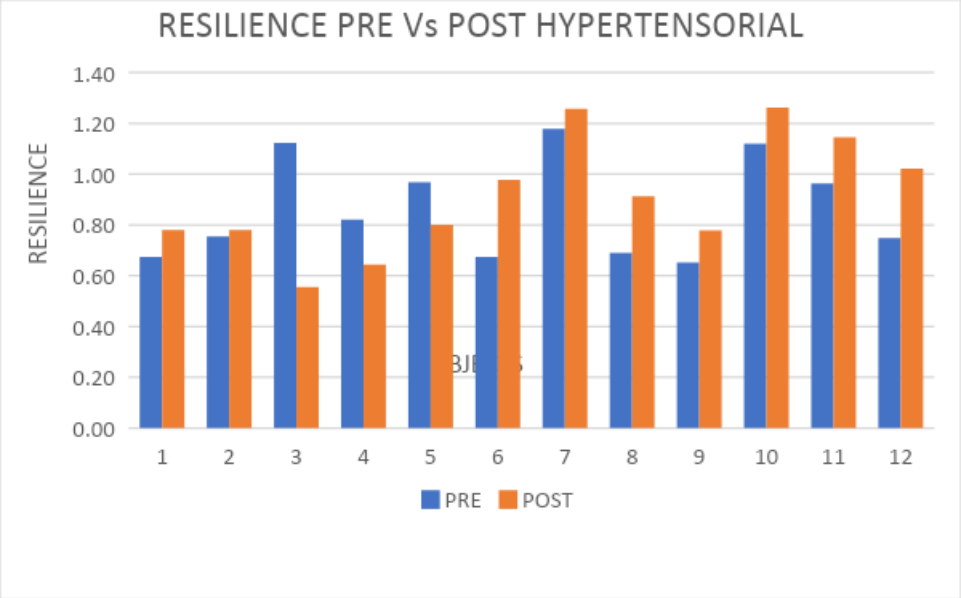
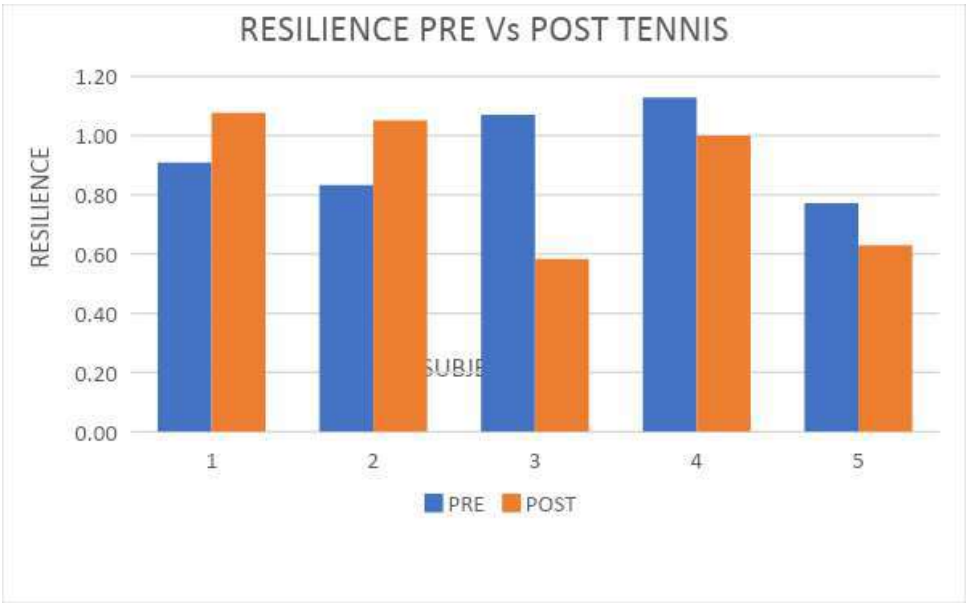
- Looking at the subjects who performed elastic tensor work, it can be seen that only in subjects 3, 4 and 5, resilience decreased post-activity, while for the other 9 subjects, the trend was the opposite, showing an increase in resilience.



- Analysing the tennis session, it can be seen that subject 3 had a sharp resilience decrease post activity, while the other subjects show a less remarkable trend. For subjects 1 and 2, resilience increased, while for subjects 4 and 5, it decreases.



V. CONCLUSIONS

In our research we have shown that diastolic pressure is influenced by the variations in inertia to which our biomechanical system is subjected due to the force of gravity. With an inertial variation simulator, a session with an inclined plane, and a sphygmomanometer applied to the calf, we measured the blood pressure data during the normal session. We subsequently evaluated the pressure when the subject slides downwards, due to the effect of gravity, by varying his inertial state. In our experimentation we used an algorithm which, thanks to the variation in blood pressure data, measured the change. For this reason, we determined the Resilience in the physiological and functional motor fields

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(vascularization and variation in inertia), dividing the Pulse value by the Diastolic pressure value. In the experiment we collected data before and after physical activities both on subjects suffering from neurofunctional diseases (Cerebrial Stroke, Parkinson's Disease, Multiple Sclerosis) and on athletes engaged in various sports. The numerical value of Resilience varied, depending on the more or less rigid state of the system, from a value of -1 to +2. In subjects with neurological pathologies, the system moves with difficulty due to muscle rigidity and uncertainty in movement, for which the recorded values ranged from 0.4 to 0.8. In athletes, however, the system assessed fatigue with less muscle stiffness and greater relaxation, for which the values fluctuated between 1.2 and 1.8. Finally, the Resilience values between 0.8 and 1.2 testified to a more or less entropic coordinated system, in which the tensor state (more or less rigid) made it more balanced. For example, in athletes who performed overload work, the system increased stiffness. For this reason, values around 1 correspond to a particular vasopressive state in which the value of the Diastolic pressure is equal to the Pulse. Furthermore, we had subjects suffering from Parkinsonism or Multiple Sclerosis carry out activities, such as walking, at a higher pace frequency. Due to the need for greater awareness of the gesture, more controlled by the brain areas, the subjects reduced, or even canceled, both the dragging of the limbs and the state of ataxia and uncertainty present. For this reason, we noticed that the Resilience value rose from 0.4/0.5 to 0.7/0.8, as evidence of a less rigid system. Therefore, from our study it emerges that a different approach to fatigue, considered as a signal, and not a value, has allowed us to modulate the work proposal, both at a sporting and rehabilitation level, in order to choose what to suggest, depending on a measurable and objective data obtained on resilience. This data allows you to choose whether to increase the load or reduce the tension, in order to reduce the entropy of the system, and therefore reduce energy expenditure in both the athlete and the neurological patient.

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A Review on the Application of Quality by Design Methodology in the Formulation, Development, and Evaluation of Fixed-Dose Combination Tablet

Simon Nyarko, Abdul-Wadudu Faridu & Julius Caesar Mahama

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ABSTRACT

Quality by Design (QbD) is a systematic approach used to develop, produce, and control high-quality products. The review article aims to provide a concise overview of the QbD approach employed in the formulation, development, and evaluation of Fixed-Dose Combination (FDC) tablets. This will buttress on the essence of the usage of this approach by pharmaceutical companies and healthcare providers to plan and achieve desired products for effective treatment and meet patients' needs. In view of this, the review paper highlights the general concepts of QbD and discusses some approaches that are employed to formulate fixed-dose combination/ilayer tablets. The current review also highlights some challenges that might impede the patronage of QbD approach.

Keywords: fixed-dose; quality by design; tablets; design space; critical quality attributes.

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A Review on the Application of Quality by Design Methodology in the Formulation, Development, and Evaluation of Fixed-Dose Combination Tablet

Simon Nyarko[α], Abdul-Wadudu Faridu[σ] & Julius Caesar Mahama[ω]

ABSTRACT

Quality by Design (QbD) is a systematic approach used to develop, produce, and control high-quality products. The review article aims to provide a concise overview of the QbD approach employed in the formulation, development, and evaluation of Fixed-Dose Combination (FDC) tablets. This will buttress on the essence of the usage of this approach by pharmaceutical companies and healthcare providers to plan and achieve desired products for effective treatment and meet patients' needs. In view of this, the review paper highlights the general concepts of QbD and discusses some approaches that are employed to formulate fixed-dose combination/ ilayer tablets. The current review also highlights some challenges that might impede the patronage of QbD approach. It is established that the utilization of QbD methodology has proven to have impacted positively and helped in the optimization of the quality of fixed-dose combination/bilayer tablets. QbD is a regulatory requirement for product development in all regulated markets, and its implementation leads to an improvement in product safety, quality, and patient compliance. Despite the challenges associated with its implementation, the benefits are numerous, and it is an essential tool for producing high-quality pharmaceutical products.

Keywords: fixed-dose; quality by design; tablets; design space; critical quality attributes.

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I. INTRODUCTION

The concept of quality by design was succinctly summarized by the quality expert, Joseph Moses Juran in his trilogy published in 1992 [1]. He believes that a product's quality can be carefully planned in advance, and any issues with the product's quality can be traced back to the planning process. In other words, if a product is planned out effectively, it is more likely to turn out as originally intended, with high quality standards [2][3]. The Quality by Design (QbD) methodology is a systematic approach to development that is based on scientific evidence and quality risk management. It involves setting predefined objectives and takes into consideration the understanding and control of both the product and manufacturing process. The QbD approach emphasizes the importance of designing a design space that allows for adjustments to be made during the production process [4]. During the 21st century, the FDA introduced Quality by Design (QbD) and Process Analytical Technology (PAT) principles in 2003 with the goal of improving the quality of drug products from the very beginning of the development process. These principles are outlined in the International Council for Harmonisation of Technical Requirements for Pharmaceuticals for Human Use (ICH) Q8, Q9, and Q10 guidance documents[5]. A decade ago, the traditional Quality by testing (QbT) approach was used to ensure the quality of drug products by checking them against regulatory specifications. It has been realized that quality must be built into the drug from the beginning rather than tested after it is manufactured [6]. In the pharmaceutical industry, two approaches for ensuring product quality are Quality by Testing (QbT) and Quality by Design (QbD). QbT involves testing finished products to ensure they meet preestablished

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standards. On the other hand, QbD involves focusing on the critical quality attributes of the product and manufacturing process from the outset of development and production to ensure the product meets its intended quality and performance standards. The key principle of QbD is that quality should be integrated into the product from the beginning, rather than being tested at the end[7].

QbD can be applied in developing fixed-dose combination drugs to achieve the desired quality and therapeutic effect on patients [8]. Studies have shown that fixed-dose combination drugs can have drug interactions as well as issues with how the drug moves through the body and how the drug affects the body [9]. Despite these challenges, fixed-dose combination drugs offer several benefits, such as reducing the number of pills patients need to take, lowering the risk of adverse reactions when compared to higher doses of monotherapy, and also being more effective [10]. When developing a drug, various factors such as drug substance, excipients, container closure system, production processes, and quality control tests all play important roles in determining the quality of the final product. To ensure that the quality is up to standards, critical formulation attributes and process parameters are typically defined and regulated. This is an important responsibility in the drug development process [3]. The aim of this review is to provide a comprehensive and in-depth overview of the Quality by Design (QbD) approach for the formulation, development, and evaluation of Fixed-Dose Combination (FDC) tablets. This review is unique in that it specifically focuses on fixed-dose combination/bilayer tablets. It is intended to assist pharmaceutical companies and health service providers in planning FDCs to achieve their desired products, ensure efficient treatment, and meet patients' demands.

II. OVERVIEW OF THE QUALITY BY DESIGN METHODOLOGY

The Quality by Design (QbD) methodology is a structured approach used in pharmaceutical research and development to improve the quality of new drugs. It achieves this by integrating analytical and risk management methods throughout the design, development, and manufacturing stages [11]. QbD enables pharmaceutical manufacturers to accumulate knowledge throughout the drug substance or product's lifecycle, which allows them to proactively mitigate potential errors and manufacturing issues. This method enables them to take proactive measures in identifying and fixing potential errors and manufacturing issues. [12][13]. Quality by Design (QbD) is a versatile approach that can be applied to optimize most of the pharmaceutical unit operations [14]. QbD and QbT are two important concepts in pharmaceutical development and manufacturing. While they share the common goal of ensuring the quality of pharmaceutical products, they differ in their approach to achieving this goal. Understanding the differences between these two concepts can help pharmaceutical companies choose the most appropriate approach for ensuring the quality of their products. *Table 1* highlights some of the key distinctions between quality by testing and quality by design.

Table 1: Differences between Quality by Testing and Quality by Design [15]

Quality by Testing (QbT)	Quality by Design (QbD)
Based on trial, error and understanding approach	Based on a systematic approach
Performance is guaranteed by product testing and validation	Quality is constructed in the robustness and reproducibility of the method built-in method development stage
The method is based on batch trial and validation report	Based on method performance to ATP criteria
The method is frozen and discourages changes.	The method is flexible and allows continuous improvement.
A rigid process that avoids changes; causing a burden to the FDA.	A flexible process that accepts changes within the design space; not required to add supplements to FDA.

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Although a promising approach for producing desired products, QbD has also got shortcoming which are summarized in *Table 2*.

Table 2: Advantages and Disadvantages of QbD

Advantages of QbD	Disadvantages of QbD
It offers a higher level of assurance regarding the quality of the medication product	Implementing it can be costly, as it requires additional resources, such as trained personnel, specialized software, and equipment
It gives the pharmaceutical business cost savings and efficiency	QBD is a detailed and time-consuming process that involves identifying key factors that affect quality, verifying that the design meets the standards, and monitoring and controlling the quality of the final product or process
It creates transparency, reason, and predictability in the scale-up, validation, and commercialization processes	It is a structured and systematic approach, which can limit flexibility and creativity in product development. This can be a disadvantage when dealing with new or innovative products.
It makes the pharmaceutical manufacturing process more efficient and lowers production costs and product rejects	It is not suitable for every product or process. It is mainly applied to products or processes that are relatively stable, consistent, and well-understood
It also gets rid of batch failures	It requires a lot of data collection and analysis to assess the impact of changes. This can be difficult when dealing with complex processes or systems.
It lowers the CMC supplement and encourages continual improvement	It relies heavily on data to make decisions and identify areas for improvement. If the data is inaccurate or incomplete, it can lead to incorrect conclusions and ineffective solutions
It improves chances for approval during the first cycle	It requires a lot of documentation, which can be time-consuming and difficult to maintain. This can lead to delays and errors

III. ELEMENTS OF QUALITY BY DESIGN

The fundamental components of QbD encompass several crucial elements, namely, the Quality target product profile (QTPP), Critical quality attributes (CQAs), Risk assessment, Design of experiments (DOE), Process analytical technology (PAT), and Control strategy as summarized in *Figure 1* [14].

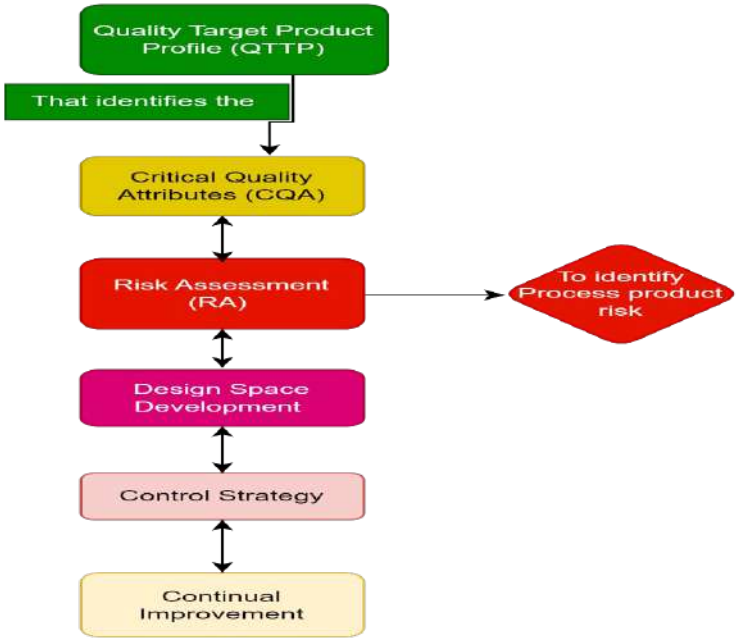

Figure 1: Flowchart Showing the key Elements of QbD and How they Relate

The quality target product profile (QTPP) is a prospective summary of the quality attributes of a drug product that should be taken into consideration to assure the intended quality, safety and efficacy[16]. To ensure high-quality drugs, the qualities are established based on feedback from pharmacists, physicians, and patients. This approach takes into consideration

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both the pharmaceutical equivalent and bio-equivalent factors[17]. Additionally, the drug's quality target product profile aligns with the QTPP template outlined in the USFDA guidance document for fixed-dose combination tablets[18].

The identification of Critical Quality Attributes (CQAs) is done through risk assessment as per the ICH guidance Q9. CQAs are generally associated with the drug substance, excipients, intermediates (in-process materials), and finished drug products. They are summarized on the basis of quality attributes identified as a target along with the justification for being so. The identification and understanding of Critical Quality Attributes (CQAs) is crucial in drug development. For drug products, CQAs include physical attributes, assay, content uniformity, drug release/dissolution, degradation products, and impurities, while critical material attributes of drug substances are based on physical, chemical, and biological characterization[19]. Excipient functionality and material qualities such as salt, solid forms, particle size, and morphology can also influence CQAs. Raw materials, starting materials, reagents, solvents, processing aids, intermediates, packaging, and labeling materials are used. Material qualities can be quantified and fixed, but they may also change throughout processing, including impurity profile, porosity, specific volume, and sterility[20].

In quality by design, refers to a range of operating conditions where a process or product can perform as intended and meet quality standards [21]. It is defined by input variables such as temperature, pressure, and composition, which produce consistent product quality.

Understanding the underlying processes, experimentation, and risk assessment help identify key process parameters (KPPs) and critical quality attributes (CQAs) to define the design space. Systematic exploration of the design space optimizes the process of product design, reducing variability and increasing quality. Knowledge of the design space enables the implementation of appropriate process controls to ensure product performance within the defined limits [22].

IV. TOOLS USED IN THE QBD APPROACH

There are several tools and techniques used to ensure that the final product or process meets the desired quality standards. Some of the most commonly used tools include. This is summarized in Table 3.

Table 3: Tools used in the QbD Approach

Tool	Purpose	Key Features
Design of Experiments (DOE)	Determine critical elements that influence a process/product's quality	Systematic varying of inputs to assess their influence on output, exploration of design space to find elements with the biggest influence on product quality
Prior Knowledge (PK)	Incorporate existing knowledge about process/product into design process	Includes information about materials, equipment, and manufacturing processes, as well as data from previous studies or experiments, used for risk management
Risk Assessment (RA)	Systematic identification and assessment of potential risks related to a product/procedure	Hazard identification and risk characterization to assess the likelihood and seriousness of hazards, implementation of risk mitigation strategies such as process/product design changes or testing
Mechanistic Models (MM)	Mathematical representation of a process/system that details underlying physical and chemical processes	Used to enhance understanding of underlying processes and to optimize the design of the process or product, can simulate behavior and identify important process parameters and relationships
Process Analytical Technology (PAT)	Collection of tools and techniques for understanding, controlling, and optimizing manufacturing processes in real time	Enables continuous monitoring and control of manufacturing process, real-time monitoring of critical quality attributes, identification of key process parameters and relationships, definition of design space

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V. FIXED DOSE COMBINATION (FDC) DRUGS

The Food and Drug Administration, USA defines a combination product as a product composed of any combination of a drug and a device or a biological product and a device or a drug and a biological product or a drug, device, and a biological product [23]. They are also known as single-pill combinations [24]. FDCs can be grouped into three (3) types based on the number of drugs present in the product. However, there are both therapeutic and non-therapeutic benefits *(table 5)* and drawbacks to the FDC drugs [25]

Table 4: Types of FDC Drugs Based on the Number of Constituent Drugs Present

Type of FDC drugs	Examples
Two dose combination	Augmentin = Amoxicillin (250 mg) + Clavulanic acid (125 mg)
	Co-trimoxazole = Sulphamethoxazole (800 mg) + Trimethoprim (160 mg)
Three dose combination	Rinizide = Isoniazed (100 mg) + Pyrazinamide (375 mg) + Rifampicin (150 mg)
Four dose Combination	Sinarest = Paracetamol (500 mg) + Phenylephrine hydrochloride (10 mg) + Chlorpheniramine maleate (2 mg) + Caffeine (30 mg)

Table 5: Therapeutic and Non-Therapeutic Benefits of FDCs

Therapeutic advantages of FDC products

Advantage	Description
Synergistic effect	Combining two or more drugs in a single FDC product can provide a synergistic therapeutic effect that is more effective than the individual drugs administered separately.
Enhanced effectiveness	Certain drugs can be more effective when combined with other agents, leading to enhanced therapeutic outcomes.
Mitigating drug abuse and resistance	FDC products can help mitigate drug abuse and prevent the development of drug-resistant bacteria.
Improved patient compliance	FDC products can improve patient compliance by reducing the number of dosing units and simplifying medication regimens.
Enhanced safety and tolerance	Certain FDC products can improve safety and tolerance by reducing side effects and adverse reactions.

Non-therapeutic advantages of FDC products:

Advantage	Description
Improved patient compliance	FDC products can improve patient compliance, especially in third-world countries, due to decreased dosing burden and lower costs.
Lower manufacturing costs	FDC products have lower manufacturing costs compared to producing separate items.
Maintaining product pipeline	FDC products provide pharmaceutical companies with an opportunity to maintain their product pipeline when the market for blockbuster medications slows.

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VI. QBD DESIGN APPROACH IN THE DEVELOPMENT OF SELECTED FDC/BILAYER TABLETS

Since its inception, Quality by Design (QbD) has been used to develop fixed-dose combination tablets, including bilayer tablets [26].

A bilayer tablet with a high-dose sustained release layer of metformin HCl and a low-dose immediate release layer of evogliptin tartrate was developed using a QbD approach [27]. The Design of Experiment (DOE) methodology was employed to optimize the high-risk bilayer tableting process parameters, which were identified through risk analysis, in order to implement the QbD approach. The DOE allowed for optimization of the tableting conditions for pharmaceutical products to meet the predetermined Quality Target Product Profiles (QTPP). To confirm the uniformity of the low-dose evogliptin tartrate content in the optimized bilayer tablet produced on a large scale, at-line transmittance Raman spectroscopy was used as a process analytical tool. In vitro drug release and in vivo pharmacokinetic studies established the bioequivalence of metformin HCl and evogliptin tartrate in the bilayer tablet to that of the corresponding reference drugs. The tablet's physicochemical stability was also confirmed during storage under extended and accelerated conditions. The study concluded that implementing the QbD approach is an effective strategy for developing a new FDC bilayer tablet that is easy to scale up for successful commercialization.

Additionally, to improve patient compliance, Kanwal and his colleagues[28] created a differential release fixed dose matrix tablet of amlodipine besylate (AML-B) and simvastatin (SIM) using the wet granulation method. To ensure quality, a risk assessment approach using failure mode and effect analysis (FMEA) was adopted instead of traditional quality control methods. The tablet's quality target product profiles (QTPPs) and critical quality attributes (CQAs) were selected based on the desired characteristics. Potential risk factors that could affect tablet quality were identified using the FMEA method and ranked according to their Risk Point Number (RPN) score. Those with an RPN score above 15 underwent further evaluation. The formulation factors of the FDC were chosen based on the preliminary study. However, the study revealed that while AML-B exhibited continuous release, SIM did not achieve the desired eight-hour release profile after FDC administration. This implies the approach help improved the release time.

Moreover, in a study conducted by Lee et al. [29], a bilayer tablet called Telmiduo® was developed through a Quality by Design (QbD) approach using a high shear wet granulation method. The researchers used primary knowledge and target values of a control tablet called Twynsta® to determine control and response factors. The bilayer tablet was optimized using a numeric optimization technique and then evaluated against the control tablet through various physical evaluations and in vivo pharmacokinetic parameters. The results demonstrated that the bilayer tablet containing telmisartan and amlodipine besylate can be produced in a more cost-effective and simpler manner than Twynsta®. Based on their findings, the researchers concluded that QbD is a suitable approach for effective pharmaceutical product development.

VII. RISK ASSESSMENT AND ANALYSIS IN THE QBD METHODOLOGY

In Quality by Design (QbD), risk assessment is essential to identify and evaluate potential risks associated with a product or procedure. The goal is to ensure that the product meets quality requirements and is safe for its intended use. Risk assessment also helps in implementing appropriate risk mitigation strategies, such as process or product design changes, testing, or monitoring, and establishing the design space for optimal performance. According to a research conducted by Prajapati and colleagues [30], risk assessment and analysis begins with the identification of method risk parameters. They identified about 20 method risk parameters, listed and grouped them into method, materials, instrumental, environment, analyst, and measurement using the cause-effect diagram. The

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risk assessment was then done using the Risk Priority Number (RPN) ranking and filtering as indicated in ICH Q9 guidelines for QRM [31]. Risk assessment is vital and widely used for formulation development of tablets. It was used for the development of a chromatographic method for the analysis of FDC products of anti-diabetic drugs[32]. The study demonstrated a quadratic correlation between CMPs and CMAs, and the developed method was highly accurate, precise, and specific. The assay results were found to be in good agreement with the labeled claim.

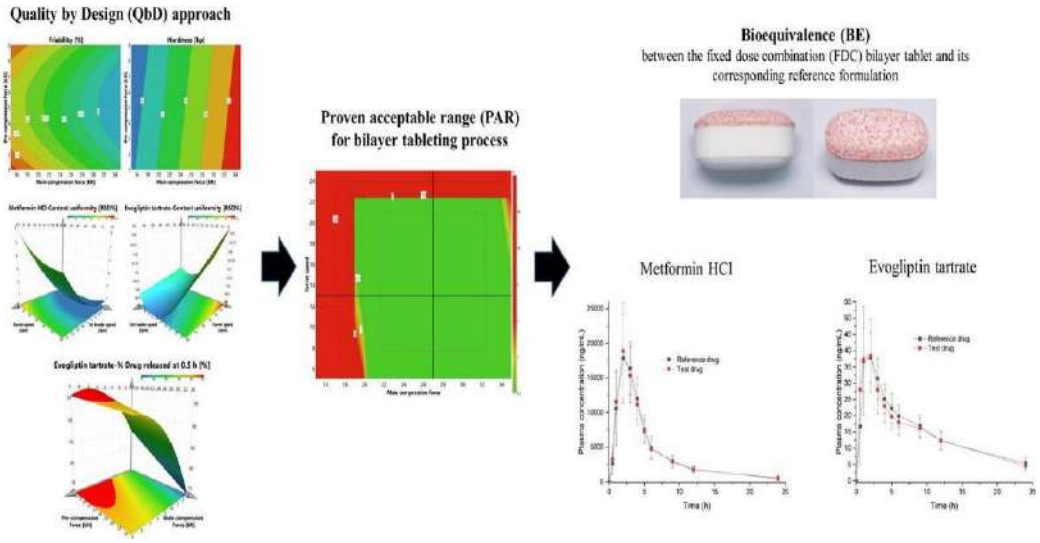

Figure 2: A new FDC bilayer tablet consisting of 1000 mg metformin HCl in a SR layer and 6.87 mg evogliptin tartrate in an IR layer was developed based on the QbD approach. Won, D. H., Park, H., Ha, E. S., Kim, H. H., Jang, S. W., & Kim, M. S. (2021). Optimization of bilayer tablet manufacturing process for fixed dose combination of sustained release high-dose drug and immediate release low-dose drug based on quality by design (QbD). International Journal of Pharmaceutics, 605, 120838. https://doi.org/10.1016/J.IJPHARM.2021.120838.

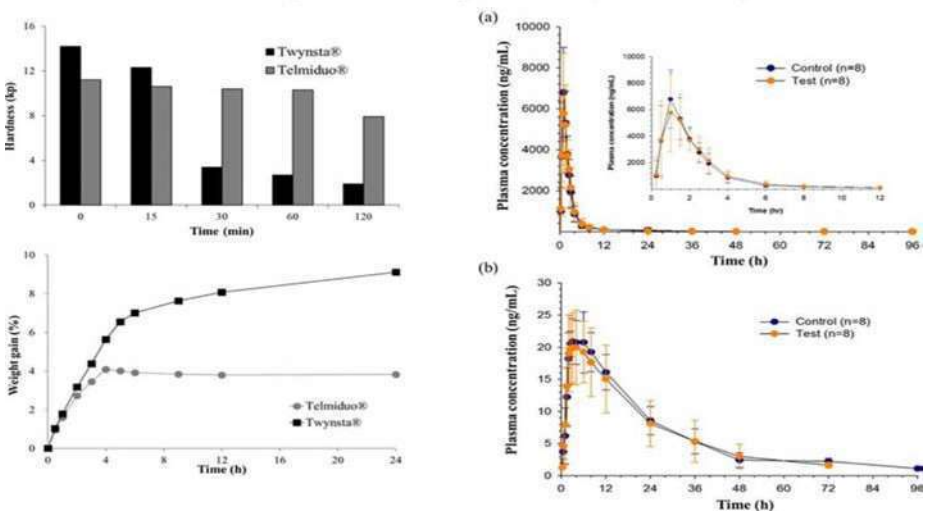

Figure 3: A bilayer tablet that consisted of telmisartan and amlodipine besylate was formulated based on the QbD approach. Lee, A. R., Kwon, S. Y., Choi, D. H., & Park, E. S. (2017). Quality by Design (QbD) approach to optimize the formulation of a bilayer combination tablet (Telmiduo®) manufactured via high shear wet granulation. International Journal of Pharmaceutics, 534(1–2), 144–158. https://doi.org/10.1016/J.IJPHARM.2017.10.004.

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VI. CHALLENGES OF THE QBD APPROACH

Quality by Design (QbD) is a methodology that has been gaining momentum in the pharmaceutical industry in recent years. However, despite its numerous advantages, the implementation of QbD is not without challenges.

One of the primary barriers to QbD implementation is a lack of knowledge about the pharmaceutical process. Mostly, the end result has been more important to pharmaceutical companies than the scientific understanding of the process involved [33]. Another challenge with QbD is reaching agreement on how to address it through collaboration and cooperation between field inspectors and the FDA review and compliance sectors[34]. While QbD has been embraced by the FDA, it can be difficult to apply in practice, especially when there are differing opinions on what constitutes quality. Again, many pharmaceutical companies believe that more concrete instructions on how to adopt QbD are necessary. For example, companies have requested clarification from the FDA on QbD terminology, approved procedures, criteria for selecting and deselecting important quality attributes, standards by which to appraise the sufficiency of controls, and criteria for analytical method substitution. Again, for the effective application of QbD, there is a need for more collaboration across numerous disciplines inside the organization, including process development, production, and quality control. This can be challenging when each department has its own priorities and goals. Finally, some pharmaceutical companies believe that QbD may prolong the time it takes to submit an application for approval or may give the regulatory body unneeded information that could pose a barrier to the approval process [35].

IX. CONCLUSION

The implementation of Quality by Design (QbD) in pharmaceutical development is crucial for ensuring high-quality products that perform consistently as expected. Although there are challenges associated with QbD, its use is required in all regulated markets such as the United States and Europe. The implementation of QbD can improve product safety and quality, as well as patient compliance. For QbD to be successful, the necessary infrastructure, training, and resources must be provided, and it should be viewed as a continuous process of monitoring, analyzing, and improving the product and manufacturing process. A cross-functional approach involving R&D, manufacturing, regulatory, and quality teams is essential for effective QbD implementation. Ultimately, the use of QbD tools and principles will help ensure that the pharmaceutical industry continues to produce safe and effective products that benefit patients.

Author contribution statement

All authors listed have significantly contributed to the development and the writing of this article.

Data availability statement

No primary data was used for the research described in the article.

Competing Interests

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ABSTRACT

Kluyveromyces marxianus, a non-conventional yeast, carries traits deemed suitable for industrial applications, such as ethanol production, exhibiting advantages over Saccharomyces cerevisiae in terms of growth rate and thermotolerance. Non-invasive parallel monitoring of biomass in shake flask cultures allows for efficient microorganism characterization, providing much-needed and accurate data on these strains through continuous sampling. Therefore, this study aimed to assess the behaviour of two K. marxianus strains during continuous shake flask cultivation. Strain IZ 1339 exhibited a constant, however, slower growth pattern when compared to strain FT 146L, which grew constantly up until the 12 h, after that the strain presented flocculation, affecting the quality of the readings. Strain IZ 1339 also had a higher ODmax value when compared to FT 146L, nevertheless, their growth rate was similar, showing that both strains had a satisfactory performance in both concentrations of molasses.

Keywords: cell growth, shake flask, cell growth quantifier, kluyveromyces marxianus.

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Nadia Cristina Viana[α], Sandra Helena da Cruz[σ], Ana Paula Maria da Silva[ρ] & Antonio Sampaio Baptista[ω]

ABSTRACT

Kluyveromyces marxianus, a non-conventional yeast, carries traits deemed suitable for industrial applications, such as ethanol production, exhibiting advantages over Saccharomyces cerevisiae in terms of growth rate and thermotolerance. Non-invasive parallel monitoring of biomass in shake flask cultures allows for efficient microorganism characterization, providing much-needed and accurate data on these strains through continuous sampling. Therefore, this study aimed to assess the behaviour of two K. marxianus strains during continuous shake flask cultivation. Strain IZ 1339 exhibited a constant, however, slower growth pattern when compared to strain FT 146L, which grew constantly up until the 12 h, after that the strain presented flocculation, affecting the quality of the readings. Strain IZ 1339 also had a higher ODmax value when compared to FT 146L, nevertheless, their growth rate was similar, showing that both strains had a satisfactory performance in both concentrations of molasses. Non-invasive monitoring makes it possible to accompany the growth pattern of the strains, indicating that both K. marxianus strains perform well when grown in a sugarcane molasses medium. This feature makes these K. marxianus strains an interesting non-conventional alternative to S. cerevisiae when it comes to industrial application.

Keywords: cell growth, shake flask, cell growth quantifier, kluyveromyces marxianus.

I. INTRODUCTION

Kluyveromyces marxianus is a homothallic, hemiascomycetous yeast observed to have potential and many beneficial traits for industrial applications (KARIM; GERLIANI; AÏDER, 2020), such as bioethanol production from both sugarcane and cheese whey, protein derived from biomass, enzyme production such as inulinase and β-galactosidase, pharmaceutical compounds (LANE; MORRISSEY, 2010), aromatic compounds and food-grade proteins, due to its Qualified Presumption of Safely (QPS) and GRAS status in European Union and United States, respectively (KARIM; GERLIANI; AÏDER, 2020).

Some of the traits that make this yeast a promising candidate for biotechnological application is thermotolerance, high growth rates, and a broad range of substrates (FONSECA et al., 2008). *K. marxianus*, like *S. cerevisiae*, is a respiro-fermentative yeast. Although *K. marxianus* is generally classified as Crabtree negative, it does carry the genes necessary for ethanol productions and will veer towards the fermentative lifestyle under certain conditions, questioning the Crabtree status of this species (LANE; MORRISSEY, 2010).

This diversity in measurements is not primarily based on manual error but on the physiological differences of strains used in different studies. Strain preservation, origin, and manipulation from stock to growth medium, all play a major role in the physiological diversity of this yeast known to present high levels of intraspecific polymorphism (BELLOCH et al., 1998; FONSECA et al., 2007).

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This divergence is also explained by the intraspecific variations and the fact that most studies utilize one single strain as the representative of the species. It can be concluded that *K. marxianus* is capable of carrying out simultaneous fermentation and respiration, and the shift between these pathways is strain-specific (LANE; MORRISSEY, 2010).

This metabolic shift responsible for the Crabtree effect results from multiple related factors, and these may not express themselves equally for all strains, creating a spectrum between Crabtree negative and Crabtree positive, which explains why some, but not all *K. marxianus* strains are effective ethanol producers (HONG et al., 2007; LANE; MORRISSEY, 2010; NONKLANG et al., 2008).

As for *K. marxianus*, there are conflicting data regarding the maximum specific growth rate, particularly due to differences in experimental conditions and the intraspecific variation displayed by this species (KARIM; GERLIANI; AÏDER, 2020). The untapped biotechnological potential of *K. marxianus* serves as a guide for future developments, such as genetics, evolutionary engineering and other physiological and molecular tools for *K. marxianus* (KARIM; GERLIANI; AÏDER, 2020).

However, in order to better explore the biotechnological potential of a yeast strain, it is essential to understand its metabolism and response to growth medium and other factors, such as temperature, pH, sugar consumption and biomass concentration, even more so in the case of production of compounds whose titer are linked to biomass production (FONSECA et al., 2007).

Monitoring the growth of cultures in shake flasks has been traditionally carried out by manual sampling and offline biomass analysis, however, this process is insufficient for modern bioprocess monitoring, due to low data density, invasive sampling and lack of parallelization. Non-invasive parallelized biomass monitoring of cultures in a shake flask under agitation allows the characterization of microorganisms in a precise and efficient way, providing high data density and accuracy (BRUDER et al., 2016).

In order to characterize the growth profile of two *K. marxianus* strains, this study evaluated growth in shake flasks under continuous agitation through an online, automated biomass monitoring system, aiming to better understand the differences in metabolism of two strains cultivated under the same conditions.

II. MATERIAL AND METHODS

2.1 Microorganisms and Substrate

Two *Kluyveromyces marxianus* strains were utilized: strain IZ 1339 (native strain isolated from Drosophila) (GOMES et al., 2003; LEAL et al., 2008), kindly provided by Prof. Dr. Luiz Humberto Gomes (ESALQ/USP), and strain FT 146L (isolated from ethanol production), kindly provided by Fermentec Ltda (Piracicaba, SP, Brazil).

Strains were inoculated on Petri dishes containing YPDA medium (10 $g.L^{-1}$ yeast extract; 10 $g.L^{-1}$ peptone; 20 $g.L^{-1}$ glucose; 18 $g.L^{-1}$ agar), and, subsequently transferred to cryotubes containing skim milk as a cryoprotectant for maintenance at -80°C.

Sugarcane molasses, a by-product of the sugar industry, utilized in this study was provided by Sugar and Ethanol Industries from the region of Piracicaba, São Paulo, Brazil. The molasses was diluted to the desired concentrations and sterilized at 121° C, 1 atm, for 15 min. Aliquots were stored at -20°C.

2.2 Study of Growth Profile of K. marxianus

Cultivations was carried out utilizing sterile sugarcane molasses (SCM), diluted to 8 and 15 °Brix (M8 and M15, respectively). Both strains were previously cultivated in YPD medium, and the cell suspension was adjusted to O.D.600 1,6. Subsequently, 1 mL of the cell suspension was inoculated in 50 mL of M8 and M15 in an Erlenmeyer flask (250 mL).

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Biomass growth was monitored online and non-invasively by the CGQ dispositive ("Cell Growth Quantifier", Aquila Biolabs), readings were performed at approximately every 4 sec. The experiments were carried out in duplicates, at 30°C for 24 h. Both yeast strains were also cultivated in YPD medium, which was utilized as a reference.

The CGQ (Cell Growth Quantifier) method has the advantage of high data density and non-invasive sampling, thus, eliminating possible manual errors, sampling biases, sedimentation and equipment calibration. For both strains, graphs were obtained, detailing backscatter and maximum growth rate (h^{-1}).

The measurement of cell density by backscattering takes place through light radiated by an LED located at the base of the equipment, which interacts with the cells and is then reflected back by a photodiode, which converts the light into an electrical signal. This method allows the reading of higher cell densities, in the range of 0.1 to 150 O.D.600, without the need for any dilution (BRUDER et al., 2016).

2.3 Parameters Analysis

After the 24-hour period of growth, the samples cultivated in M8 and M15 were centrifuged at 2046 g for 3 min (NT-815, Novatecnica), and the supernatant was collected for analysis. Parameters were determined at 0 and 24 h of cultivation.

The pH was determined through a digital pH meter (LUCA-210, Lucadema). Total Acidity (acetic acid g/L) was determined by the titratable total acidity method (BRASIL, 1986).

Residual sugars were determined through DNS method (MILLER, 1959) in order to determine sugar consumption.

IV. RESULTS AND DISCUSSION

In order to evaluate the biomass data and strain-specific characteristics, strain IZ 1339 and FT 146L were grown on diluted sugarcane molasses (M8 and M15).

The growth profile of the strains (Figure 1) shows that strain IZ 1339 exhibited a distinct growth pattern in the Reference (cultivated in YPD medium). Adaptation took around 6.5 h, followed by the initial rapid growth phase, which then shifted to a much slower growth. This behavior is similar to that observed by Bruder et al. (2016) in *Saccharomyces cerevisiae*, where the authors attribute this growth pattern to the positive Crabtree-effect, the rapid growth phase is associated with ethanol formation, followed by the typical metabolic shift to respiratory ethanol metabolization. Similar behaviour can be observed for the Reference in Figure 1, for both repetitions, in strains cultivated in glucose (superior left and right).

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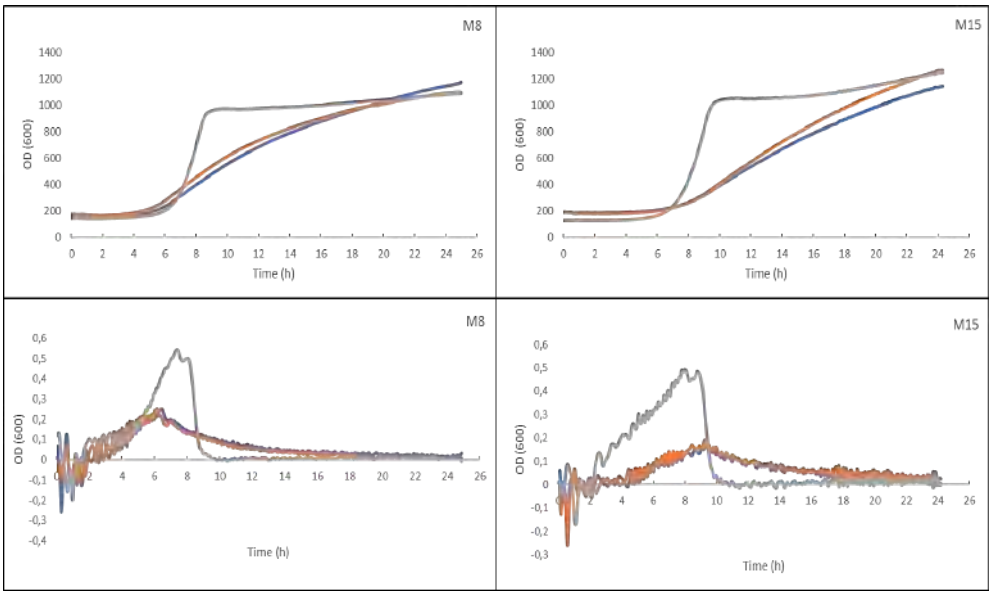

Figure 1: Growth of strain IZ 1339 in sterile molasses 8° Brix (M8) (left), 15° Brix (M15) (right) and PD 2% (Reference), at 30°C during 24 h. Experiments performed in duplicates. Sup. Growth rate by backscattering, Inf. Maximum specific growth rate

As for the growth in molasses, there was not an evident rapid growth phase. The adaptation period was similar to the Reference, around 6 to 7 h, followed by a slower growth curve. In terms of cell density, as determined by backscattering, both molasses concentrations (M8 and M15) and the Reference were fairly similar.

The maximum specific growth rate for strain IZ 1339 in M8 (Figure 1, bottom row) presented a peak, related to the maximum growth rate recorded, around 6 h of cultivation (0.24 h^{-1}). The Reference displayed a higher growth rate, probably due to the exponential growth phase (0.54 h^{-1}). Fonseca et al. (2013) observed growth rates of 0.39 and 0.49 h^{-1} utilizing 10g/L of supplemented carbon source.

When grown in M15, strain IZ 1339 also presented smaller growth rates when compared to growth in M8, reaching higher values around 9 h of cultivation at 0.17 h^{-1}, as opposed to 0.49 h^{-1} observed in the Reference (Figure 1, left).

As for strain FT 146L, growth in the Reference medium (2% glucose) presented a similar pattern to strain IZ 1339, with a rapid growth phase followed by a slower growth, much as described by Bruder et al. (2016). The one notable difference for strain FT 146L was that M15 yielded a higher biomass concentration, over 1200 (Figure 2, top row).

Growth in M8 presented a constant growth curve up until 15 h, starting to decline shortly after, unlike the Reference, which remained stable. The maximum growth rate graph (Figure 2, bottom row) showed abnormal peaks at the beginning of cultivation, after 18 h. This probably occurred because the strain presented flocculation, which makes it difficult to accurately read the cell density.

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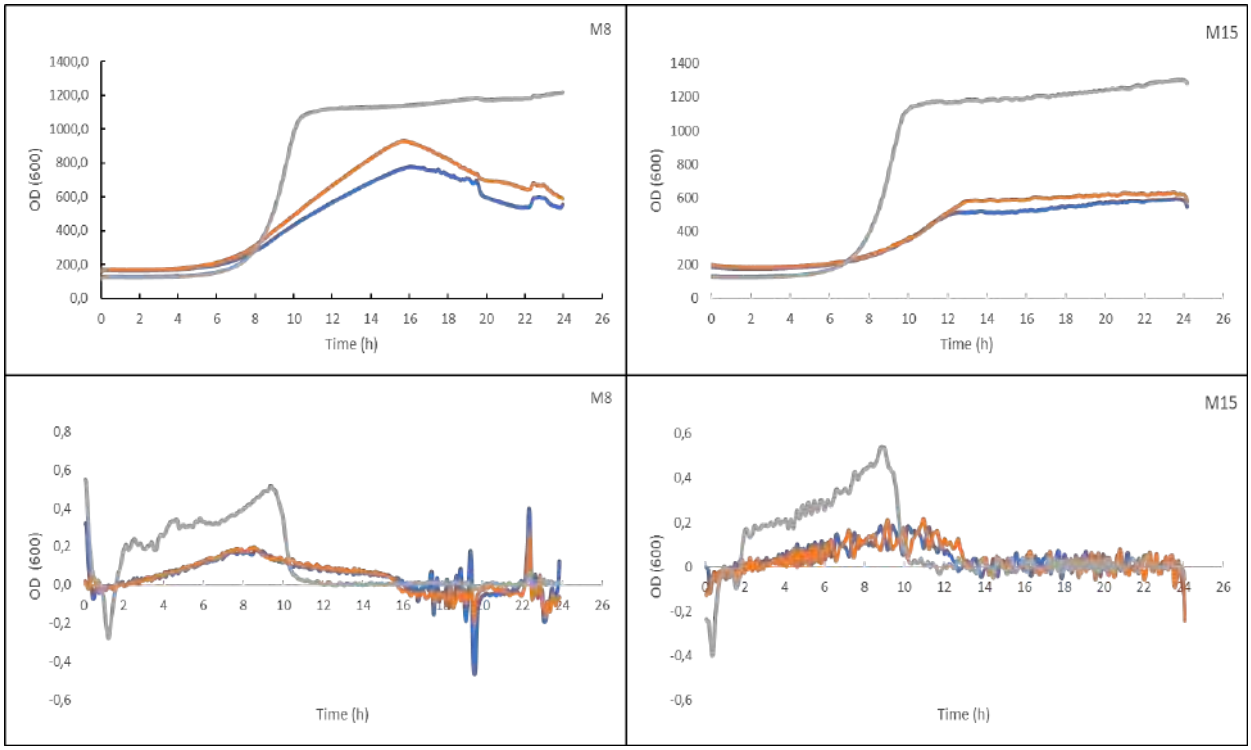

Figure 2: Growth of strain FT 146L in sterile molasses 8° Brix (M8) (left), 15° Brix (M15) (right) and YPD 2% (Reference), at 30°C during 24 h. Experiments performed in duplicates. Sup. Growth rate by backscattering, Inf. Maximum specific growth rate.

For industrial applications, such as the production of enzymes, flocculation is a desirable trait in *K. marxianus*, as a means to obtain higher cell density, therefore increasing productivity in bioreactor operations. Flocculation is a mechanism that occurs in some yeast strains as a result of non-sexual aggregation of single cells into a multicellular mass, which then sediments at the bottom of the medium. The mechanism behind flocculation is correlated by cell wall proteins (ALMEIDA et al., 2003; VERSTREPEN et al., 2003).

Growth in M15 presented a notably small growth rate and cell concentration when compared to M8 and the Reference, even though the growth curve was more stable throughout the 24 h of cultivation. Cell density for both media was smaller than strain IZ 1339 in both concentrations assayed.

Growth rates for M15 also presented abnormal peaks in the reading, due to the flocculent behaviour, even though the peaks have a more uniform pattern, which indicates a more constant maximum growth rate throughout the 24 h period, averaging 0.18 h^{-1}. It is worth noting that the Reference was grown in YPD, a complex medium that provides all nutrients necessary for yeast growth, the sugar, vitamins, minerals and amino acids present in the medium act as carbon and nitrogen sources.

The *K. marxianus* strains were also cultivated on molasses, a raw byproduct of the production of sugar and ethanol, consisting of 75–85% total solids, 30–36% sucrose, 10– 17% fructose + glucose, 10–16% ash, and minor varying compositions of oligosaccharides, polysaccharides, organic acids, proteins, and nitrogen compounds (CARIOCA; LEAL, 2019). Therefore, there are notable differences in the composition, and mainly, available sugars to stimulate growth.

It is worth noting that while the Reference was grown in YPD medium containing glucose, the duplicates for M8 and M15 had to hydrolyze the sucrose present in the medium, which would explain the slower growth curves when compared to the Reference.

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Overall, strain IZ 1339 presented a more constant growth pattern, and higher growth rate/biomass concentration compared to strain FT 146L. Table 1 shows the average maximum specific growth rate for each strain and media concentration, as well as the Reference.

Table 1: Average values of maximum specific growth rates μmax (h^{-1}) presented by strains IZ 1339 and FT 146L in M8, M15 and reference YPD 2%

Medium	Strain	
	IZ 1339	FT 146L
YPD 2%	0.54	0.54
M8	0.25	0.18
M15	0.18	0.19

M8 – sterile molasses 80 g/L; M15 – sterile molasses150 g/L; study was conducted in duplicates

From the average growth rate (h^{-1}) values, it is possible to infer that the Reference provided better conditions for both strains to grow, as for the molasses in both concentrations; there were not significant variations in growth rate values. Strain IZ 1339 had a higher biomass concentration and average growth rate for M8, however, strain FT 146L had a higher average growth rate for M15, despite having a lower concentration of biomass.

From a biotechnological standpoint, strain IZ 1339 seems to be more adapted for biomass production in this particular condition, while strain FT 146L grows at a faster rate, adapting more easily to the growth medium.

Maximum specific growth rate (μmax h^{-1}) of 0.56 was obtained during batch cultivations by Fonseca et al. (2007), utilizing glucose as the sole carbon source at 10 g/L, in a complex mineral medium, supplemented for growth optimization. However, there are sparse and conflicting data regarding the maximum specific growth rate for *K. marxianus*, due to the intraspecific variation and the distinct conditions assayed (KARIM; GERLIANI; AÏDER, 2020). Fonseca et al. (2007) highlights the diversity of measurements is not based on measurement errors, but on the physiological differences of strains used in different studies. It is possible to speculate that strain preservation, origin, and manipulation play a major role in this physiological diversity. *K. marxianus* is known to present high levels of intraspecific polymorphism, and may be prone to high mutation rates that result in rapid and unexpected evolution during the propagation process (BELLOCH et al., 1998).

4.1 Experimental Variables

After 24 h of cultivation, the supernatant was obtained by centrifugation. The parameters of the supernatant were evaluated for pH, total titrated acidity and residual sugar concentration (Table 2).

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Table 2: Post-Cultivation Parameters Analysis Values for Strains IZ 1339 and FT 146L in both Media

Samples	T (h)	RS (g/L)	TRS (g/L)	Consumed sugar (%)	Acidity (g/L)	pH
M8	0	7.33	80.62	*	0,62	5.61
IZ1339 M8	24	24.35	46.70	42.1	3.62	3.86
FT146L M8	24	18.32	39.81	50.6	2.25	4.19
M15	0	14.95	135.77	*	1.17	5.52
IZ1339 M15	24	89.98	74.12	45.4	4.27	4.20
FT146L M15	12	13.65	82.44	39.3	2.49	4.92
FT146L M15	24	111.35	132.23	2.61	3.03	4.03

M8 – sterile molasses 80 g/L; M15 – sterile molasses150 g/L; Acidity = concentration of acetic acid (g/L); T = time of sampling; RS = reducing sugars; TRS = total reducing sugars

It is possible to observe that neither of the strain was able to consume all of the sugar content in the medium, whether to produce biomass or, likely, to produce ethanol. Strain FT 146L was able to consume half of the sugar present in M8, while strain IZ 1339 consumed 42% (33.9 g/L out of 80 g/L). As for M15, there were even more residual sugars left at the end of the growth period, with strain IZ 1339 consuming 45.4% (74.1 g/L), as opposed to strain FT 146L, which consumed 39.3 % (53.33 g/L) at the 12 h of cultivation.

On average, both *K. marxianus* strains consume around 45% of the total sugars present in the growth medium. It is worth noting that strain FT 146L presented flocculation midway through the cultivation period, around the 12h mark, which is why the readings around 24h are not as accurate. Because growth in CGQ cannot be interrupted for external sampling, an experiment was done again in order to sample total soluble sugars and other parameters described in Table 2.

The behaviour herein observed for strain FT 146L could be triggered due to fructose or the total sugars inhibiting growth and causing flocculation. This could also occur due to this strain being suffering mutations throughout the generations, causing unstable behaviour (KARIM; GERLIANI; AÏDER, 2020; LANE; MORRISSEY, 2010).

Korkoutas et al. (2002) produced wine utilizing *K. marxianus* strain IMB3 and noticed that, while the final product had good quality and reached the desired ethanol concentration, there was a relatively high content of residual sugars, presumably due to a combination of cell density and temperature, which require further exploration. Plessas et al. (2008) utilized *K. marxianus* strain IFO 288 to produce lactic acid from cheese whey, with an initial sugar concentration of 36 g/L, and observed 0.4 g/L of residual sugar concentration of 36 g/L, and observed 0.4 g/L of residual sugars after the fermentation. The outcome of sugar consumption can vary depending on the employed conditions, which is why it is essential to understand a particular strain behaviour and metabolism.

As for total acidity, no condition demonstrated a significant increase, being the highest concentration M15 for strain IZ 1339, at 4.27 g/L, a regular byproduct of fermentation. Acetic acid production under fermentative conditions is linked to glycerol formation via redox balancing (EGLINTON et al., 2002), also, aeration and sugar content are also responsible for the increase of organic acids during fermentation, such as acetic acid, produced by yeast metabolic activity (LEE et al., 1999).

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V. CONCLUSION

Characterizing a strain via growth-based methods provides essential data to understand sugar consumption and biomass production. The CGQ method for online biomass monitoring proved to be a valuable tool regarding growth rates and biomass data with high-resolution and non-invasive sampling. It was possible to infer that both *K. marxianus* strains had distinct behaviour and diverging growth patterns when cultivated under the same conditions.

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