The Effect and Outcomes of Metabolic Surgery in Pediatric Patients with Type 2 Diabetes Mellitus: A Systematic Review

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Abstract. Type Two Diabetes Mellitus (T2DM), formerly known as adult-onset diabetes, is a disease caused by impaired pancreatic insulin production and the ineffective use of insulin (insulin resistance) in the liver and periphery. It is believed that today, up to 5000 children are being diagnosed with Type Two Diabetes Mellitus per year, with the incidence of T2DM tripling between the ages of 10-14 and 15-18, especially among racial minorities. A high-yield symptom for those suffering from T2DM is weight gain, however, T2DM can also be linked to other co-morbidities including hypertension, dyslipidaemia, diabetic retinopathy, nephropathy, and neuropathy. This is why the American Diabetes Association introduced bariatric surgery as a form of diabetic treatment in 2009. Since its approval, bariatric surgical procedures such as Gastric Banding (GB), Roux-en-Y Gastric Bypass (RYGB), Biliopancreatic Diversion (BPD), and Sleeve Gastrectomy (SG) have elicited several positive results in adult patients. However, its use on children has been put into question due to safety concerns. For that reason, we searched databases such as PubMed, ScienceDirect, Cochrane Library, Embase, and Google Scholar to conduct a systematic review containing 34528 patients from 20 different studies to determine the effectiveness of bariatric surgery as a treatment option for obese pediatric patients with Type Two Diabetes Mellitus. For this systematic review, we only included patients <18 years of age with a BMI >35 along with papers that measured their patients' change in Body Mass Index (BMI), estimated weight loss (EWL), or total weight loss (TWL). Upon completion of the investigation, it was concluded that bariatric surgery is an effective treatment for obese adolescents with Type Two Diabetes Mellitus.

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Keywords: Bariatric Surgery OR weight loss surgery, Treatment, cure, remedy, management, surgery, operation, therapy, Adolescents, youths, kids, children, juveniles, minors, young people, Type 2 Diabetes Mellitus, T2D, T2DM

1. Introduction & Background:

Type Two Diabetes Mellitus (T2DM), formerly known as adult-onset diabetes, is a disease originating from impaired pancreatic insulin production and the ineffective use of insulin (insulin resistance) in the liver and periphery (WHO, 2021; Gastaldi et al., 2007). It was previously thought that T2DM could only occur in adults, hence the previous name adult-onset diabetes. T2DM is still common among adults, in 2014, 8.5% of adults aged 18 years and older had diabetes, and in 2016, diabetes was the direct cause of 1.6 million deaths amongst this age population. Additionally, research has now determined that individuals under the age of 18 are susceptible to T2DM as well (WHO, 2021). In youth (<18 years old), the incidence of type two diabetes has increased, and there are thoughts that up to 5000 children are being diagnosed with T2DM per year (Nadeau et al., 2016). Additionally, the incidence of youth-onset T2DM increases with age, tripling from age 10-14 years to 15-18 years while mostly affecting racial minorities (Nadeau et al., 2016; Tong, & D'Alessio, 2014; Dabelea et al., 2014).

One of the main symptoms of patients with T2DM is weight gain; therefore, in 2009, the American Diabetes Association introduced bariatric surgery as a treatment option for patients who suffer from obesity due to T2DM to manage patient conditions (American Diabetes Association, 2009). Patients with T2DM can often also suffer from various associated comorbidities, including hypertension and dyslipidaemia, which contribute to chronic cardiovascular complications, and diabetic retinopathy, nephropathy, and neuropathy if they suffer from microvascular changes (Levitsky et al., 2007). Several specific procedures qualify as bariatric surgery, including Gastric Banding (GB), Roux-en-Y Gastric Bypass (RYGB), Biliopancreatic Diversion (BPD), and Sleeve Gastrectomy (SG) and several studies have compared the various forms of bariatric surgery on patients with T2DM and the effects between surgical treatment and

other common forms of management such as insulin therapy and lifestyle modifications (Wazir et al., 2019; Lee et al., 2015). Unfortunately, though bariatric surgery is considered an effective treatment of type two diabetes mellitus in obese patients; and has been linked to decreasing the number T2DM related deaths by 92%, the optimal surgical procedure for the treatment of T2DM patients is still to be established. For this reason, many healthcare professionals believe that individuals under the age of 18 with T2DM should not undergo a surgical procedure (Hofmann, 2013). Therefore, even though the effects of bariatric surgery on T2DM have become a topic of interest, it is much more commonly investigated among older populations, especially patients above the age of 18, because healthcare professionals believe it should be saved for adulthood (Hofmann, 2013). However, studies have shown that even with a five-year follow-up period, bariatric surgery's positive effects are much stronger in those under the age of 18 than it is among the adult population (Hofmann, 2013; Inge et al., 2019a).

Henceforth, this systematic review aims to assess the efficacy of various forms of bariatric surgery on pediatric patients with T2DM to determine if metabolic surgery is an acceptable treatment modality for adolescent patients. Success will be based on their estimated weight loss (EWL), total weight loss (TWL), reduction in BMI, and rate of remission of T2DM and its associated comorbidities over various time periods.

2. Methods:

This systematic review was formatted by adhering to the 2009 Preferred Reporting Items for Systematic Reviews and Meta-Analyses (PRISMA) guidelines (Moher et al., 2009). Initially, an independent literature search in PubMed, PMC and Medline, EMBASE, Cochrane Library, ScienceDirect, and Google Scholar was conducted for data collection; and to find the most relevant papers, keywords such as "Bariatric Surgery," "Youth," "Treatment," and "Type 2 Diabetes Mellitus" were used to refine the search within these databases. On PubMed specifically, these keywords were applied both separately and in conjunction with one another to yield the most relevant results, a summary of which is viewable in Table 1. After conducting a thorough literature search of all databases and applying filters that only included papers published in the last six years with patients under the age of 18, a total of 2000 articles were selected after the removal of duplicates. Authors then subsequently screened articles in pairs by title, age of participants, and then by abstract, which left a total of 81 papers. These remaining papers were screened by different pairs by reading through the full text and applying the inclusion and exclusion criteria. After the full screening process was complete, a total of 20 articles to be included in our systematic review, the table below summarizes the keywords and the search strategy used (Table 1).

There were no preferred languages or study design types, however the articles used were all published in English, however, study designs included: randomized control trials (RCTs), non-randomized control trials (NRCTs), systematic reviews, observational studies, and case studies so long as they met the rest of the inclusion criteria. That said, we chose to only pursue papers published from January 2015 onwards that focused on the effect of bariatric surgery on obese pediatric patients as a result of T2DM. For specificity, all patients had to be <18 years of age at the time of the operation and had to have a BMI >35; which is the minimum requirement to receive bariatric surgery according to the American Academy of Pediatrics (AAP) and equates to the 95th percentile which is the lower boundary of obesity according to the CDC (Defining Childhood Obesity, 2018).

Table One: Summary of Search Strategy on PubMed

Keyword	Regular/MeSH	Number of Search Results
"Bariatric Surgery"	Regular	13 643
Adolescents	Regular	9
Treatment	Regular	406 669
"Type 2 Diabetes Mellitus"	Regular	3296
"Bariatric Surgery" AND Adolescents AND Treatment AND "Type 2 Diabetes Mellitus"	MeSH	441
Adolescent: 13-18 years, Child: birth-18 years, Newborn birth-1 month, Infant: birth-23 months, Infant: 1-23 months, Preschool Child: 2-5 years, Child: 6-12 years, from 2015 - 2021		

Additionally, only papers that calculated the change in BMI, estimated weight loss (EWL), or total weight loss (TWL) were included. The exclusion criteria included patients with Type One Diabetes Mellitus, the adult population (>18 years old), patients with obesity secondary to something other than T2DM, pregnant patients, and patients who had undergone previous metabolic surgery before the study. Grey literature and animal studies were also not included, a summary of the articles used in this systematic review is depicted below

3. Results:

As displayed in Figure 1, a total of 2000 non-duplicate studies were obtained for possible data collection by scouring through various databases. Once obtained, each article was analysed and, in some cases, eliminated from inclusion based on the relevancy of their titles and abstracts. After the initial review process was completed, the remaining articles were again filtered and eliminated

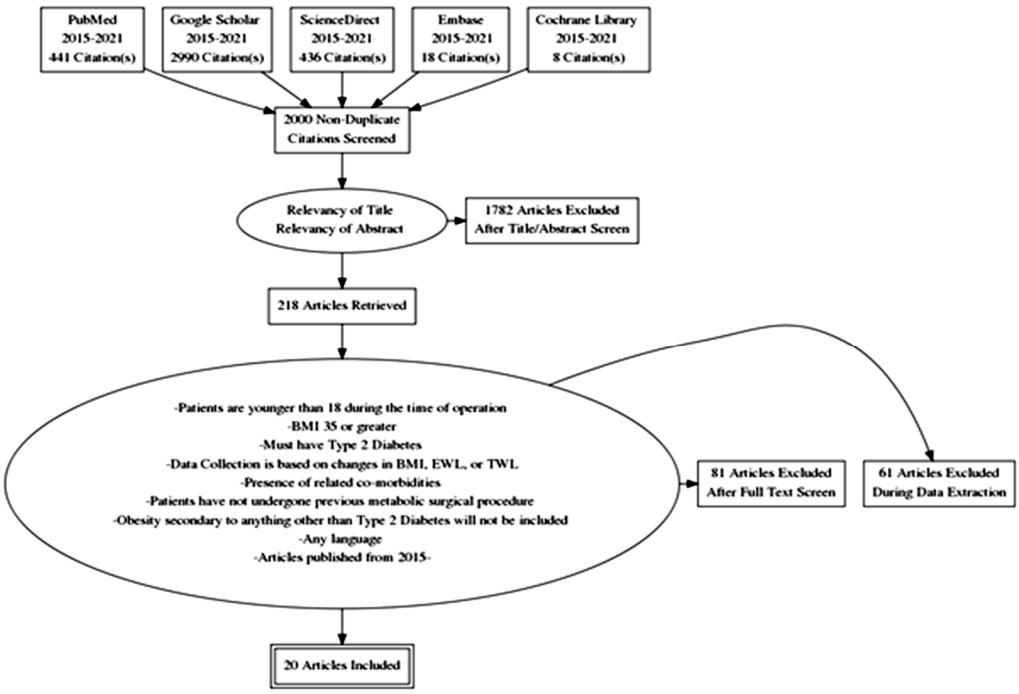

Figure One. Prisma Flow Diagram

based on their adherence to the inclusion/exclusion criteria. Once completed, the final step in the data screening process was to assess full-text articles using a quality assessment tool. During this process, it was decided that only articles that achieved a 70% benchmark score would be acceptable for use in the systematic review, regardless of the used assessment tool. In total, 81 studies were assessed for quality; however, only 20 of the aforementioned articles qualified for inclusion in the systematic review. It is important to note that different quality assessment tools were used for different types of research articles/ studies, including:

Clinical trials: Cochrane Risk Bias Assessment tool,
Observational studies: Newcastle Ottawa, AXIS,
Systematic reviews/Meta-analysis: AMSTAR,
Animal trials: SYRCLE,
Literature review articles: SANRA,
Case Reports: CARE guidelines,

Our review includes 34528 obese pediatric patients from 20 different studies with T2DM and/or T2DM associated co-morbidities. Of those 20 studies, there were two observational studies, eight review articles, one original article, one comparative study, and eight clinical trials used to evaluate the effect of bariatric surgery on T2DM. Overall, we found that based on their reduction in BMI along with their remission of T2DM and other comorbidities that pediatric patients benefit from receiving bariatric surgery as a form of lifestyle intervention treatment in T2DM. Table 2, Table 3, and Table 4 below summarize where each article will be analysed in the discussion section.

4. Discussion

Diabetes Remission and Co-morbidity Resolution

In a study by Sarah B Ogle, she found that 21 out of a total of 29 patients to be in remission from T2DM after undergoing bariatric surgery, and after their five-year follow-up period, they found that only one out of a possible 29 adolescent patients still suffered from T2DM after receiving a form of bariatric surgery. They also found that most patients with T2DM comorbidities, including dyslipidaemia and hypertension, are in remission after receiving bariatric surgery (Ogle et al., 2021). Furthermore, a study done by Margaret Stefater & Thomas H. Inge discovered that Roux-en-Y Gastric Bypass might be the most effective form of bariatric treatment for adolescent T2DM treatment. In their study they noted that within the first cohort, RYGB caused T2DM remission in 40% of patients. Meanwhile, in their second cohort RYGB caused 38% remission, and VSG caused 24% remission. However, interestingly enough, remittance was not caused in any patients that underwent an Adjustable Gastric Banding (AGB) procedure. This discovery could perhaps lead to the conclusion that AGB is the only non-appropriate form of metabolic surgery to use in adolescents with T2DM (Stefater & Inge, 2017). These findings were further substantiated in a systematic review conducted by Anna Zenno and Evan Nadler, which showed that most of the T2DM and their prediabetes patients achieved remission following a bariatric surgery procedure. This systematic review also showed psychosocial improvements among obese adolescent T2DM patients following a bariatric surgical procedure (Zenno & Nadler, 2020).

As well, a systematic review on the effect of bariatric surgery on morbidly obese adolescents conducted by Givan F. Paulus showed a positive correlation between bariatric surgery and T2DM remission, stating that all patients in five out of the six studies analysed showed complete remission from T2DM. Furthermore, Paulus' review showed that bariatric surgery also helped relieve most patients with diabetes-associated co-morbidities such as hypertension and dyslipidaemia (Paulus et al., 2015). Moreover, a recent review was conducted by Ahmed Khattab, and Mark Sperling, which suggested that the information gathered from Paulus' review involving the remission of T2DM and its co-morbidities in obese adolescents was accurate, seeing as the majority of the patients included in this studied showed positive results after the conclusion of the procedure (Khattab, & Sperling, 2019). More positive results were seen in a review published by Dror Dicker, which revealed that after one year of follow-up, 53.2% of his T2DM patients experienced remission, and after the full five-year follow-up period, 54.4% of patients had experienced T2DM remission while maintaining a significant reduction in BMI (Dicker et al., 2016).

Additionally, Petter Bjornstad conducted a study that investigated the effect bariatric surgery had on patients with diabetic kidney disease, which presented extremely interesting results. Petter Bjornstad's investigation used two different patient cohorts: the TODAY study and another set from Teen-LABS. At baseline, diabetic kidney disease (DKD) was present in 21% of patients from the TODAY study; however, after surgery, DKD incidence increased to 43% after a five-year follow-up period. Conversely, however, DKD and albuminuria incidence decreased from 27% of patients to 5% of patients after the same five-year follow-up period had elapsed in the Teen-LABS study (Bjornstad et al., 2020). Because the results from each study directly oppose each other, bariatric surgery's effect on the remission of DKD and albuminuria in pediatric patients is yet to be determined. In 2017, a randomized control trial done by Torsten Olbers assessed the effects of bariatric surgery in children against adults after a five-year follow-up period. In this study, the "Obesity-Related Problems Scale" (OP-14) was used to assess the patients' weight-related psychosocial problems, such as depression or anxiety. At baseline, it was discovered that one-third of the patients receiving bariatric surgery had been diagnosed with some type of neuropsychiatric disorder, and almost 40% of the pediatric surgery patients had received psychiatric treatment. However, at follow-up, after receiving bariatric surgery, it was discovered that a significant portion of pediatric patients no longer received neuropsychiatric treatment (Olbers et al., 2017). Finally, an original article published by Francesco Rubino suggests that even though a more streamlined approach to bariatric surgery needs to be established, it can lead to increased remission of T2DM and associated co-morbidities (Rubino et al., 2016).

Ordinarily, the systematic reviews completed by Paulus, Rubino, and Yahalom would not be considered the other papers because they were published in 2015 or 2016, respectively. In contrast, all of the other studies were published from 2017 onward. However, seeing as the results of Paulus' study were substantiated by a more recent study conducted by Khattab and Sperling, the results collected by Paulus are given more bearing. However, in this case, all the studies that have been analysed draw the same conclusion; bariatric surgery on obese adolescent patients helps in both T2DM remission and the remission of associated co-morbidities. However, with that said, more specific research on the relationship between bariatric surgery and psychosocial outcomes should be conducted. Additionally, seeing that the only undrawn conclusion is the effects of bariatric surgery on adolescents with DKD, this topic should also be explored further. Another topic to investigate further is which form of bariatric surgery most positively impacts T2DM patients, adolescents, or otherwise and if different procedures should be used for different populations and co-morbidities. The table above (Table 2) summarizes the articles used while discussing diabetes remission and co-morbidity resolution.

Presently, there is strong evidence that bariatric surgery positively impacts obese adults, especially those with T2DM. The bariatric procedures currently being used also have strong evidence of safety, which allows all adult patients with T2DM, and other causes of severe obesity, to engage in a decision-making process that outlines the risks and benefits of surgery compared to traditional lifestyle intervention therapies (Arterburn et al., 2020). However, despite this supportive evidence, there is still a belief that bariatric surgical procedures should not be conducted on children and adolescents (Adams et al., 2007). Therefore, studies were conducted comparing the efficacy of bariatric surgery in T2DM patients of different age groups to determine if the ideal age for bariatric surgery should be moved down to adolescents or remain an adult procedure.

In a study published by Sarah Ogle, bariatric surgery's efficacy on two sets of obese T2DM adolescent patients was compared. The first set age was between 13-15, while the second set of patients was between 16-18. After the study was completed, it was determined that younger patients, in this case, the 13-to 15-year-olds showed greater reductions in BMI and remission from T2DM associated co-morbidities such as hypertension and dyslipidaemia. However, it was also discovered that the older group of adolescents showed greater remission from T2DM itself; therefore, for this systematic review, this study suggests that bariatric surgery should be conducted on older aged adolescents with T2DM to achieve the best results (Ogle et al., 2021).

Table Two: Summary of Articles Discussed on Diabetes Remission and Co-morbidity Resolution

Author/ Year of Publication	Type of Study	Number of Patients	Intervention	Result/ Conclusion	Number of Follow-up Years
Ogle et al., (2021)	Observational Study	228	RYGB VSG Non-Surgical Treatment	The presence of type 2 diabetes mellitus remission was high in both groups; however, results were higher in the cohort of older adolescents. Both age groups saw positive impacts in weight loss and quality of life as well. Therefore, the data suggests that obese adolescents should be considered for surgical therapy.	5
Zenno & Nadler, (2020)	Review	242	RYGB VSG AGB	At present, bariatric surgery is the most effective treatment to elicit weight loss in severely obese children. Additionally, bariatric surgery is associated with the co-morbidity resolution, and therefore should be increasingly used to treat children and adolescents with Type 2 Diabetes (T2D).	N/A
Bjornstad et al., (2020)	Observational Study	1153	RYGB VSG Non-Surgical Treatment	Currently, bariatric surgery is becoming a viable treatment option for severely obese youth with and without T2D, because bariatric surgery mitigates DKD risk better than standard medical therapy. Additionally, because there are less invasive surgical procedures, such as VSG, now available which could improve the safety of surgical procedures, however, more research needs to be done on the nephroprotective effects of VSG.	3.9
Khattab, & Sperling, (2019)	Review	367	RYGB VSG	Bariatric surgical procedures are an effective and cost-effective intervention for obesity and T2DM. There is clear evidence that surgical procedures cause significant BMI reduction while improving or resolving associated comorbid conditions, especially T2DM.	N/A
Stefater & Inge, (2017)	Review	2050	RYGB VSG	Bariatric surgery, specifically RYGB and VSG, elicited powerful therapeutic results in obese adolescents with T2D and should be considered as a regular form of treatment. Additionally, earlier surgical intervention could result in more complete remission in obese patients with T2D.	3
Olbers et al., (2017)	Clinical Trial	262	RYGB	After undergoing RYGB, adolescents with severe obesity experienced positive results in long-term weight loss, co-morbidity improvements, and quality of life although there was a linkage between surgical and nutritional deficiencies. However, the non-surgical treatment cohort experienced weight gain over the long term.	5
Rubino, et al., (2016)	Original Article	N/A	N/A	Based on the result of this trial, there is sufficient clinical and mechanistic evidence to support using metabolic as an intervention for people with T2D and obesity.	N/A

Table Two: Summary of Articles Discussed on Diabetes Remission and Co-morbidity Resolution

Author/ Year of Publication	Type of Study	Number of Patients	Intervention	Result/ Conclusion	Number of Follow-up Years
Dicker et al., (2016)	Review	2190	AGB LSG RYGB	All three surgical procedures caused a positive impact compared to the baseline data. However, the greatest initial results were seen in patients who underwent RYGB, however, the advantages of the operation did not have long-term effects.	5
Paulus et al., (2015)	Systematic Review	2625	AGB RYGB LSG	Each bariatric procedure resulted in co-morbidity improvement and substantial weight loss with a limited amount of complications. This indicates that for properly selected patients, surgical intervention is appropriate.	1

Table Three: Summary of Articles Discussed on Efficacy of Surgery on Different Age Groups

Author/ Year of Publication	Type of Study	Number of Patients	Intervention	Result/ Conclusion	Number of Follow-up Years
Ogle, et al., (2021)	Observation-al Study	228	RYGB VSG Non-Surgical Treatment	The presence of type 2 diabetes mellitus remission was strong high in both groups; however, its results were higher in the cohort of older adolescents. Both age groups saw positive impacts in weight loss and quality of life. Therefore, the data suggests that obese adolescents should be considered for surgical therapy.	5
Zenno & Nadler, (2020)	Review	242	RYGB VSG AGB	At present, bariatric surgery is the most effective treatment to elicit weight loss in severely obese children. Additionally, bariatric surgery is associated with co-morbidity resolution, and therefore should be increasingly used to treat children and adolescents with Type 2 Diabetes (T2D).	N/A
Bonouvrie et al., (2020)	RCT	950	RYGB VSG	There were similar results between adults and adolescents in terms of weight-loss outcomes between adolescents, however, the resolution of co-morbidities such as hypertension was stronger in adolescents, supporting the case for early surgical intervention.	3
Bjornstad et al., (2020)	Observation-al Study	1153	RYGB VSG Non-Surgical Treatment	Currently, bariatric surgery is becoming a viable treatment option for severely obese youth with and without T2D, because bariatric surgery mitigates DKD risk better than standard medical therapy. Additionally, because there are less invasive surgical procedures, such as VSG, now available which could improve the safety of surgical procedures, however, more research needs to be done on the nephroprotective effects of VSG.	3.9

Table Three: Summary of Articles Discussed on Efficacy of Surgery on Different Age Groups

Author/ Year of Publication	Type of Study	Number of Patients	Intervention	Result/ Conclusion	Number of Follow-up Years
Khattab, & Sperling, (2019)	Review	367	RYGB VSG	Bariatric surgical procedures are an effective and cost-effective intervention for obesity and T2DM. There is clear evidence that surgical procedures cause significant BMI reduction while improving or resolving associated comorbid conditions, especially T2DM.	N/A
Rubino et al., (2016)	Review	380	RYGB AGB VSG	There is a need for open access to bariatric surgical procedures for paediatric patients because there is evidence suggesting its positive impact on obesity and comorbidity resolutions.	5+
Inge et al., (2018a)	RCT	911	RYGB VSG Non-Surgical Treatment	Compared with medical therapy, surgical treatment of severely obese adolescents with type 2 diabetes elicited greater weight loss, glycaemic control, and co-morbidity improvement.	2
Inge et al., (2018b)	Comparative Study	544	RYGB SG AGB	Adolescents who underwent RYGB and SG experienced long-term decline and were able to maintain this weight loss, the long-term effects were not as strong in patients who underwent AGB.	1,3,5
Mingrone, (2017)	Review	277	RYGB	BMI reduction was similar in all population groups; however, the adolescent population saw greater remission of co-morbidities associated with T2DM.	5
Olbers et al., (2017)	Clinical Trial	262	RYGB	After undergoing RYGB, adolescents with severe obesity experienced positive results in long-term weight loss, co-morbidity improvements, and quality of life although there was a linkage between surgical and nutritional deficiencies. However, the non-surgical treatment cohort experienced weight gain over the long term.	5
Stefater & Inge, (2017)	Review	2050	RYGB VSG	Bariatric surgery, specifically RYGB and VSG, elicited powerful therapeutic results in obese adolescents with T2D and should be considered as a regular form of treatment. Additionally, earlier surgical intervention could result in more complete remission in obese patients with T2D.	3

A study completed by Petter Bjornstad investigated the effect bariatric surgery had on pediatric patients with diabetic kidney disease; because there was already evidence that suggested albuminuria and GFR following bariatric surgery was improved in adult populations.

To substantiate bariatric surgery results on DKD in children, an initial three-year observational study was conducted, which yielded similar results to the previously published literature concerning adults. However, a subsequent five-year study investigating two different patient cohorts was used, one from the TODAY study and another set from Teen-LABS, and presented interesting results.

Initially, 21% of patients from the TODAY study presenting with DKD; however, after surgery, DKD incidence increased to 43% after a five-year follow-up period within this patient population. Conversely, in the Teen-LABS study, DKD and albuminuria incidence decreased from 27% of patients to 5% of patients after the same five-year follow-up period had elapsed (Bjornstad et

al., 2020). Due to this study's contradictory results, the effects of bariatric surgery on pediatric DKD are yet to be substantiated and need to be investigated further; however, there is some evidence that suggests there might be a positive impact on children.

Furthermore, a study by Margaret Stefater & Thomas H. Inge discovered that while bariatric surgery does significantly reduce the incidence of T2DM in adult populations, their study suggests that using surgical intervention in adolescents could yield greater results due to the increased weight loss seen in younger populations (Stefater & Inge, 2017). These findings are supported by papers written by Christopher Bolling and Danielle Bonouvrie. In the study completed by Bolling, he reported that while both adults and adolescents saw improvement in weight reduction, the adolescent population saw a greater remission in cardiovascular co-morbidities and risk factors (Rubino et al., 2016). The study published by Bonouvrie echoed Bolling's findings by supporting using bariatric surgery as an earlier form of treatment to be used in adolescents because her results reported higher rates of T2DM and hypertension remission amongst her adolescent cohort than their adult counterparts. In her paper, Bonouvrie substantiated her opinion on early usage of bariatric surgery by suggesting that based on the fact that co-morbidity remission rate was higher amongst adolescents, younger populations of patients have a better probability of reversing the cardio-metabolic effects of obesity and T2DM; however, this suggestion needs to be further researched (Bonouvrie et al., 2020).

Additionally, a randomized control trial was conducted by Torsten Olbers that compared the effects of bariatric surgery in obese adolescents and obese adults. The results of this study suggest that even though a greater percentage of adults achieved a 20% reduction in weight post-surgery, the follow-up period showed that the adolescents were better at maintaining their weight loss than the adult population was; suggesting that bariatric surgery should be more utilized on adolescents to achieve long-term effects (Olbers et al., 2017). However, an original paper by Geltrude Mingrone suggests that there is no significant difference in BMI loss between adolescents and adults after receiving bariatric surgery. Mingrone did suggest that utilizing bariatric surgery in younger age groups could indeed be beneficial so long as adolescents undergo consistent medical monitoring to prevent complications (Mingrone, 2017). Moreover, a study conducted by Ahmed Khattab suggests that it is more cost-effective to conduct bariatric surgery on adolescents than adults (Khattab, & Sperling, 2019).

Finally, two studies published by Thomas H. Inge compared the effects of bariatric surgery in children compared to adults. In his first study, Thomas H. Inge suggests that the results of weight loss in T2DM patients who have received both adjustable gastric band and sleeve gastrectomy procedures are similar between the adult and adolescent patient populations (Inge et al., 2018a). However, in his second study, Thomas H. Inge contradicts the findings made in Torsten Olbers' article by suggesting that glycaemic control, therefore, subsequent weight control, is stronger among the adult population than adolescents (Inge et al., 2018b). The findings discovered in Thomas H. Inge's second article are strengthened by a recent systematic review that was conducted by Anna Zenno and Evan Nadler, whose results showed that after a five-year follow-up period, glycaemic control and T2DM remission was much better amongst the adolescent population in comparison to their adult counterparts (Zenno & Nadler, 2020).

Based on the contradictory results garnered from the various articles that have been analysed, it cannot be definitively said whether or not bariatric surgical procedures have a greater positive impact on adults or adolescent populations. There needs to be more research done on this topic before coming to a decisive decision on the matter; however, before that can be done, there needs to be a streamlined selection process to determine which adults and adolescents should be selected for surgical procedures. Furthermore, more investigation into the type of bariatric surgery that most greatly impacts these two patient populations should be done to ensure only the best and most accurate trials are being compared to each other.

Table Four: Summary of Articles on Surgical vs Non-Surgical Treatments of Type Two Diabetes Mellitus

Author/ Year of Publication	Type of Study	Number of Patients	Intervention	Result/ Conclusion	Number of Follow-up Years
Bjornstad et al., 2020	Observational Study	1153	RYGB VSG Non-Surgical Treatment	Currently, bariatric surgery is becoming a viable treatment option for severely obese youth with and without T2D, because bariatric surgery mitigates DKD risk better than standard medical therapy. Additionally, because there are less invasive surgical procedures, such as VSG, now available which could improve the safety of surgical procedures, however, more research needs to be done on the nephroprotective effects of VSG.	3.9

Table Four: Summary of Articles on Surgical vs Non-Surgical Treatments of Type Two Diabetes Mellitus

Author/ Year of Publication	Type of Study	Number of Patients	Intervention	Result/ Conclusion	Number of Follow-up Years
Shah et al., (2020)	Review	790	Non-Surgical Treatment	Metabolic bariatric surgery is a recommended treatment modality of T2D in adults because of its associated improvements with weight, glycaemic control, and diabetes remission. If performed on adolescents with severe obesity and T2D, results will show high rates of T2D remission.	5
Hagman et al., (2020)	NRCT	21449	Bariatric Surgery	Due to lack of resources, once patients receive treatment for obesity the long-term results do not improve, despite early intervention. Therefore, the treatment strategies for paediatric obesity and T2DM need to be enhanced.	N/A
Janson, et al., (2020)	RCT	50	RYGB Non-Surgical Treatment	There were no significant differences between the groups.	2
Roebroek et al., (2019)	RCT	60	AGB Non- Surgical Treatment	In summary, this randomized controlled trial provided information on the efficacy of LAGB surgery in severely obese adolescents.	0.5,1,2,3
Olbers et al., (2017)	Clinical Trial	262	RYGB	After undergoing RYGB, adolescents with severe obesity experienced positive results in long-term weight loss, co-morbidity improvements, and quality of life although there was a linkage between surgical and nutritional deficiencies. However, the non-surgical treatment cohort experienced weight gain over the long term.	5
Stefater & Inge, (2017)	Review	2050	RYGB VSG	Bariatric surgery, specifically RYGB and VSG, elicited powerful therapeutic results in obese adolescents with T2D and should be considered as a regular form of treatment. Additionally, earlier surgical intervention could result in more complete remission in obese patients with T2D.	3

Displayed above is a table (Table 3) that condenses information on the efficacy of bariatric surgery on different age groups.

Because there is still a stigma around the safety and efficacy of conducting metabolic surgery on adolescent patients, non-surgical treatment options remain a possible intervention for patients with T2DM, regardless of age group, especially with those deemed unfit for surgical procedures. However, while non-surgical intervention has proven to be an effective form of treatment for adults with T2DM, it is yet to be determined whether or not the same argument can be made for its effectiveness on the younger

adolescent population. At present, there are only two FDA-approved medications that can be used to treat pediatric patients with T2DM, which are insulin and metformin. However, other medications such as thiazolidinediones and incretins are being used in conjunction with metformin to enhance the medications' effectiveness. In a study published by Margaret Stefater & Thomas H. Inge, they discovered that using metformin in conjunction with rosiglitazone, a thiazolidinediones class medication, does indeed increase the efficacy of metformin in glycaemic control; however, they found that the combined therapy was still not enough to maintain long-term glycaemic control in adolescent T2DM patients. Stefater and Inge also tested the effectiveness of lifestyle management, including exercise and a changed diet, which was not enough to elicit glycaemic control in adolescents with T2DM, even in conjunction with metformin (Stefater & Inge, 2017; PubChem, 2021; Bauman et al., 2017). An investigation conducted by Amy Shah substantiates the findings from Stefater & Inge's study. In this study, Shah echoed the idea that using metformin in conjunction with rosiglitazone provided better results than using metformin alone; the study also conceded that neither form of treatment causes long-term glycaemic control or T2DM remission in adolescent populations (Shah et al., 2020).

Furthermore, a study published by Torsten Olbers tested the efficacy of bariatric surgery on adolescents with T2DM by comparing them to a non-surgical control group of patients the same age. Olbers' study shows that metabolic surgical procedures were more effective than the control group at causing diabetes remission, helping patients lose weight, maintaining weight loss after the five-year follow-up period, and maintaining long-term glycaemic control (Olbers et al., 2017). This again suggests that metabolic/bariatric surgery is a suitable and more effective treatment for adolescents with T2DM. A study conducted by Roebroek in 2019 agrees with Olber's findings. In his study, Roebroek suggests that regardless of the specific surgical procedure, bariatric surgery enables pediatric patients to lose more weight and maintain weight loss over extended periods compared to non-surgical treatments. Roebroek agrees that even though more research on safety and complication management needs to be done, bariatric surgery could be an appropriate form of treatment for obese children with T2DM (Roebroek et al., 2019).

Additionally, clinical trials conducted by Annika Janson and Emilia Hagman compared the effectiveness of metabolic surgery on T2DM patients aged 13-16 to strict lifestyle management in the form of caloric restrictions or pharmacological treatments, respectively, in T2DM patients of the same age. Annika Janson's study suggested that at follow-up, patients who had received metabolic surgery displayed a greater reduction in BMI compared to the patients who had undergone a strict diet change. However, she also acknowledged that the difference between the results was not significant (Janson et al., 2020). Hagman's study results showed similar results between the surgical and non-surgical cohorts as well (Hagman et al., 2020).

However, a study conducted by Petter Bjornstad suggests that non-surgical interventions such as the use of SLGT2 inhibitors or vasopressin receptor blockers can become a more effective form of treatment than bariatric surgery for adolescent patients with DKD because almost a quarter of the patients who exhibited positive results from bariatric surgery during the study later developed complications that required a subsequent operation (Bjornstad et al., 2020). For reference, SGLT2 inhibitors are a class of novel medications currently being used to treat T2DM, and their function is to promote the excretion of excess glucose by inhibiting kidney reabsorption (Madaan et al., 2016). Meanwhile, vasopressin receptor antagonists are another novel class drug that promotes urine formation by binding to receptors and inhibiting anti-diuretic hormone release, thereby increasing urine formation (Enhörning & Melander, 2018).

Ordinarily, the most recent article should be the most accurate in comparing the efficacy of surgical vs. non-surgical procedures in obese pediatric patients with T2DM. However, because more literature needs to be done on the causes of DKD and the potential forms of treatment, the conclusion drawn in Bjornstad's study cannot be substantiated. Additionally, even though the article is older, the study by Stefater and Inge should be taken in high regard because the results of this study are substantiated by more recently published papers analysed above. Therefore, based on the previously mentioned literature, it is clear that non-surgical interventions are not as effective as metabolic surgical procedures on adolescent patients suffering from T2DM. A summary of articles comparing surgical vs. non-surgical treatments of type two diabetes mellitus

5. Limitations

There are several limitations to this study. Firstly, because this paper is a systematic review I could not receive any funding to conduct my own study, therefore, none of the results extracted from the effects of bariatric surgery on adolescents can be compared to a baseline data set. Systematic reviews limit our own bias because it simply requires processing and analysing data that has already been collected, however, if we had collected our own data and used it as a baseline against the data collected in other studies, we would have known more about the other papers' accuracy. Another limitation of the published papers used is that not all the studies gave an exact age range. While the term 'adolescents' implies that only young people participate in a given study, adolescents' cut-off age varies. This is because the WHO considers an adolescent to be someone between the ages of 10-19, one of the exclusion criteria for this systematic was patients over the

age of 18 (WHO, 2020). Therefore, by using a study that does not explicitly say what age range is being tested, inaccurate results may be compared. An additional limitation for this paper is the substantial amount of missing data, especially the data on the resolution of co-morbidities after the follow-up period had elapsed. The absence of this data could introduce bias to the paper's discussion portion, damaging the validity of its conclusions. This paper's final limitation was that not all of the outcomes were substantiated by a follow-up period. In the majority of cases, bariatric surgery had a remarkable short-term and long-term effect on adolescent patients with T2DM; however, failure to follow-up on those initial results introduces bias to the assessment because even though we know that bariatric surgery may have an initial positive impact on adolescent T2DM patients, we are unaware of how the surgery affected them long term, including any potential complications, relapse, or co-morbidity effects.

6. Conclusions

After exploring numerous databases and screening through hundreds of published research papers, we conducted a systematic review that detailed the effects and outcomes of bariatric surgery in adolescents with T2DM by accounting for the resolution of patients' diabetes as well as their associated co-morbidities, by comparing the efficacy of bariatric surgery across various age groups, and by comparing bariatric surgical procedures to other non-surgical forms of treatment; while observing the long term effects those treatments had on glycaemic control. Based on the evidence gathered above, there are two major takeaways from this paper. The first is that bariatric surgery is effective at treating adolescent patients with T2DM and therefore should be utilized more regularly within this patient population. The other takeaway from this paper is that the current non-surgical treatments for T2DM do not seemingly elicit positive long-term results, seeing as so many patients were unable to maintain glycaemic control. Therefore, we recommend that further research be done on how to improve long-term results in individuals not fit for surgical procedures. Additionally, more research needs to be conducted on which type of bariatric surgery is most effective at achieving weight loss and diabetes remission while limiting complications and side effects. Finally, further study on the indications necessary to receive bariatric surgery is needed to create a more streamlined patient selection process. Based on the evidence gathered above, bariatric surgery is an appropriate form of T2DM treatment in adolescent patients.

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