

**REVIEW**

Arterial Duct Stenting *Versus* Modified Blalock-Taussig Shunt in Patient with Ductal-Dependent Pulmonary Circulation: Systematic Review & Meta-Analysis

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ABSTRACT

Objective: Patients with ductal-dependent pulmonary circulation require alternative blood flow to provide and maintain adequate oxygenation. Modified Blalock-Taussig Shunt (MBTS) has been the standard for providing such a result. Currently, less invasive methods such as Arterial Duct (AD) stenting have been performed as alternatives. This study aims to compare the outcome of AD stenting and MBTS. **Method:** Systematic research was performed in online databases using the PRISMA protocol. The outcomes measured were 30-day mortality, complication, unplanned intervention, oxygen saturation, duration of hospital, and ICU length of stay. Any comparative study provided with full text is included. The outcome of each study was analyzed using a random effects model with relative risk and mean difference as the effect size. Bias risk assessment was conducted using the Newcastle-Ottawa Scale. All analyses were performed using Review Manager 5.4.1. **Result:** A total of 11 studies with 3154 samples included in this study. There is no significant difference in 30-day mortality between the two groups (p -value = 0.10). However, there is significantly less complication (RR 0.53 [0.35, 0.82]; p -value = 0.004) and unplanned intervention (RR 0.59 [0.38, 0.92]; p -value = 0.02) in the AD stent group. Comparison of the Nakata index showed no significant difference (p -value = 0.88). Post-operative oxygen saturation was measured significantly higher in the AD stenting (MD 1.80 [0.85, 2.74]; p -value = 0.0002). However, AD stent group shows significantly lower long-term oxygen saturation (MD -8.43 [-14.38, -2.48]; p -value = 0.005). Both hospital and ICU length of stay was significantly shorter in the AD stent group (MD -8.30 [-11.13, -5.48]; p -value < 0.00001; MD -5.09 [-7.79, -2.38]; p -value = 0.0002). **Conclusion:** AD stenting provides comparable outcomes relative to MBTS as it provides less complication and unplanned intervention and higher post-procedural O₂ saturation. However, MBTS proved its superiority in maintaining higher long-term oxygen saturation and still became the preferred option to manage complex cases where stenting is either challenging or unsuccessful.

KEYWORDS

Duct-dependent pulmonary circulation; arterial duct stenting; modified Blalock-Taussig shunt

Nomenclature

DDPC	Duct-dependent Pulmonary Circulation
AD stent	Arterial Duct Stent
MBTS	Modified Blalock-Taussig Shunt



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PRISMA	Preferred Reporting Items for Systematic Reviews and Meta-Analyses
PA	Pulmonary Artery
ICU	Intensive Care Unit
IQR	Inter Quartile Range
RR	Relative Risk/Risk Ratio
MD	Mean Difference
CI	Confidence Interval

1 Introduction

Neonates and infants with duct-dependent cardiac lesions to the pulmonary circulation may require initial palliative treatment to survive critical conditions. The goal is simply to provide adequate flow to the pulmonary circulation so that adequate oxygenation can be achieved and maintained until the next palliative stage commences. The creation of surgical shunt has long been the standard to treat such cases. Since the discovery of systemic to pulmonary shunt by Alfred Blalock and Hellen Taussig in 1944 many methods have been tried with various outcomes. Among all variations of shunts, the BT Shunt and Modified Blalock-Taussig Shunt (MBTS) have been widely accepted as the initial palliative stage to provide and maintain adequate flow to the pulmonary circulation. The fundamental difference between these two is the use of prosthetic graft which provides more benefits such as less tendency to deform hypoplastic PAs, less need for mediastinal dissection, preservation of upper extremity blood flow, consistent shunt flow (regulated by the internal diameter of the ostia of the innominate or subclavian arteries), and adequate and flexible length. With these benefits, MBTS remains the preferred choice for surgical systemic-to-pulmonary shunt [1,2].

However, MBTS still requires invasive open surgery to perform and comes with its risks and complications. Rather than creating new shunts, alternatives were then developed to make use of available physiological shunts simply by preventing them from closing. The arterial duct which is part of fetal circulation provides a shunt from pulmonary to systemic circulation. When this duct is preserved either with drugs or stenting, in neonates and infants the shunt will be reversed by the pressure gradient and may provide alternative blood flow to pulmonary circulation. Hence, Arterial Duct (AD) stenting starts to become the alternative to provide adequate flow to the pulmonary circulation therefore providing and maintaining adequate oxygenation and increasing the survival of patients in such cases. AD stenting also has its risks and possible complications, such as stent stenosis, thrombosis, dislodgement, cardiac perforation, and other risks that can result in mortality and morbidity that need unplanned reintervention or even conversion to surgical shunt. However, the pre-operative protocol may be placed in the patient selection stage, such as assessing procedural risk, considering comorbid and cardiac anomaly, and assessing Patent Ductus Arteriosus (PDA) size and tortuosity to ensure successful stenting, thus improving clinical outcomes and preventing dire complications.

Individual comparative studies between both interventions showed that AD stenting may become a comparable alternative, some study claims AD stenting provides better outcomes. However, some of these studies are limited to small sample sizes, and their single-center study design. This study aims to fill this gap by performing a systematic review and meta-analysis to evaluate any significant difference in outcomes between AD stenting and MBTS.

2 Methods

2.1 Searching Protocol

Systematic searching was conducted in online databases (PubMed, ScienceDirect, and Google Scholar) in December 2023 following PRISMA guidelines [3]. Keyword used in this study was aimed at capturing

population (infants or neonates with DDPC: ductal [All Fields] AND dependent [All Fields] AND (“pulmonary circulation” [MeSH Terms] OR (“pulmonary” [All Fields] AND “circulation” [All Fields]) OR “pulmonary circulation” [All Fields])), intervention (AD stenting: (PDA [All Fields] OR “Ductus Arteriosus, Patent” [Mesh]) AND (“stents” [MeSH Terms] OR “stents” [All Fields] OR “stenting” [All Fields])), and comparator (MBTS: (“Blalock-Taussig Procedure” [Mesh] OR (“surgical procedures, operative” [MeSH Terms] OR surgical [Text Word]) AND shunt [All Fields])). The study included was full text of a comparative study. Any non-comparative study, case series/report, or letter to the editor was excluded.

2.2 Outcomes & Quality and Bias Risk Assessment

The outcome measured was 30-day mortality, complication (any complication post-procedure), unplanned intervention (any intervention to treat cyanosis), oxygen saturation (post-procedure measured within 24-h and long term measured near the next stage commence), duration of hospital and ICU length of stay. Two authors independently screened, extract the data, and assess each study’s quality and bias using Newcastle-Ottawa Scale (NOS) and categorized them as follows: (1) Good; (2) Fair; (3) Poor [4]. We only include good and fair studies and exclude poor-quality studies. Independent screening and data extraction were conducted to prevent misinterpretation and error in data collection. Any disagreements were resolved by discussion and consensus.

2.3 Meta-Analysis

Meta-analysis was performed for similar outcomes reported by a minimum of two studies. Data were classified as dichotomous and continuous outcomes. Some continuous outcomes (Nakata index, post-procedure oxygen saturation, length of stay) were reported using mean and standard deviation, as well as median and interquartile range. Values that were provided as median and IQR were converted to mean and standard deviation using the method described by Hozo et al. [5] Dichotomous data were analyzed using relative risk (RR) as effect size with 95% CI. Meanwhile, continuous data were analyzed using mean difference (MD) as effect size with 95% CI. Both sets of data were analyzed using a random-effects model. All analyses were performed using Review Manager 5.4.1. Statistical heterogeneity was calculated using I^2 which is classified as follows: (1) $I^2 < 25\%$: low heterogeneity; (2) $I^2 = 25\%–75\%$: moderate heterogeneity; (3) $I^2 > 75\%$: high heterogeneity. p -value < 0.05 was defined as a statistically significant result. All data were tabulated in the Appendix Files, and all analyses were presented using a forest plot.

3 Results

3.1 Study Selection & Characteristics

Keyword search initially identified 903 individual studies, which were then screened using title and abstract alone. Of these, 892 and 21 studies were excluded for not being related to the topics or fulfilling the aim of the meta-analysis and for lacking accessible abstracts. Out of all included studies, 22 were retrieved, but 11 studies were subsequently excluded due to the wrong type of study design and the same sample population. A total of 11 studies comprising 3154 samples were included in this paper. The PRISMA flow diagram of the study selection process is depicted in [Appendix A](#). Three papers were multicenter studies, one study included two centers as a population, and seven studies were single-center studies. One paper by Ghaderian in 2023 was cross-sectional, two studies by Bentham in 2017 and Nasser in 2020 were cohort prospective, and the rest were cohort retrospective. The general characteristics of the studies are described in [Table 1](#). Details of clinical characteristics are depicted in [Appendix B](#).

Table 1: General information of studies included

No.	Author	Year	Period	Country	Study design	Sample	
						AD stent	MBTS
1.	Santoro et al. [6]	2009	April 2003–Jan 2009	Italy (single center)	Cohort retrospective	13	14
2.	Amoozgar et al. [7]	2012	April 2009–April 2011	Iran (2 center)	Cohort retrospective	15	15
3.	McMullan et al. [8]	2014	Des 2022–April 2011	USA (single center)	Cohort retrospective	13	42
4.	Bentham et al. [9]	2018	Jan 2012–Des 2015	UK (multi-center)	Cohort prospective	83	171
5.	Glatz et al. [10]	2018	Jan 2008 (PDA), Jan 2012 (MBTS)–Nov 2015	USA (multi-center)	Cohort retrospective	106	251
6.	Nasser et al. [11]	2020	Nov 2012–Jan 2019	Saudi (single center)	Cohort prospective	33	10
7.	Ratnayaka et al. [12]	2021	Jan 2013–June 2020	USA (single center)	Cohort retrospective	47	41
8.	Mini et al. [13]	2022	2010–2019	German (single)	Cohort retrospective	71	56
9.	Ghaderian et al. [14]	2023	2012–2020	Iran (single)	Cross-sectional	18	18
10.	Lemley et al. [15]	2023	Jan 2017–Des 2020	USA (multi-center)	Cohort retrospective	534	1340
11.	Sirisani et al. [16]	2023	Jan 2015–Oct 2019	Malaysia (single)	Cohort retrospective	183	80

3.2 Quality and Bias Risk Assessment

The assessment was performed by two independent reviewers using the Newcastle-Ottawa Scale (NOS) for all 11 included studies. Ten studies were classified as good quality, while one study was classified as fair (Appendix C). Any disagreements were resolved through discussion and consensus.

3.3 Outcomes

The detailed data for each study are depicted in Appendix D, Table S1. The analysis of 30-day mortality was conducted using data from seven studies. The pooled mortality rate in the AD stent group was 7.88%, whereas in the MBTS group was 9.98%. Although the forest plot appears to favor the AD stent group, there is no significant difference between AD stenting and MBTS (RR 0.63 [0.36, 1.10]; *p*-value = 0.10; *I*² = 53%, Fig. 1) [7–11,13,15,16].

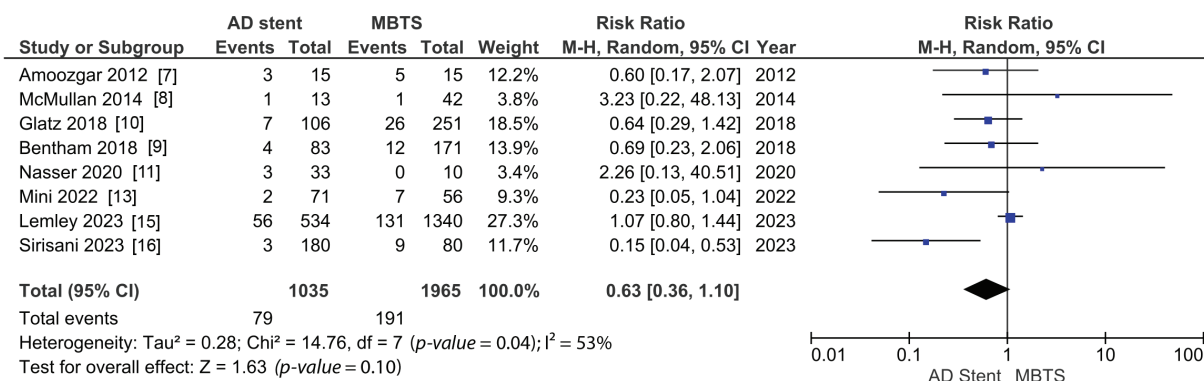


Figure 1: Pooled estimate of 30-day mortality for AD stent vs. MBTS

However, there are significantly fewer complications (RR 0.53 [0.35, 0.82]; p -value = 0.004; I^2 = 13%, Fig. 2) and unplanned intervention to treat cyanosis (RR 0.59 [0.38, 0.92]; p -value = 0.02; I^2 = 0%, Fig. 3) observed in the AD stent group [8,10–13].

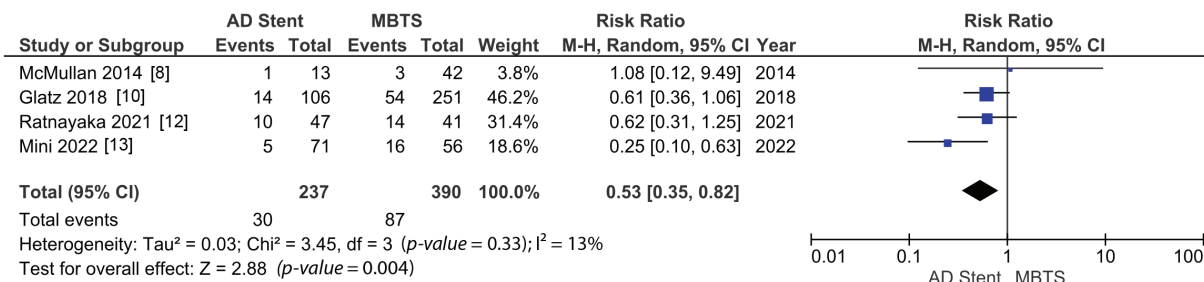


Figure 2: Pooled estimate of post-procedural complication for AD stent vs. MBTS

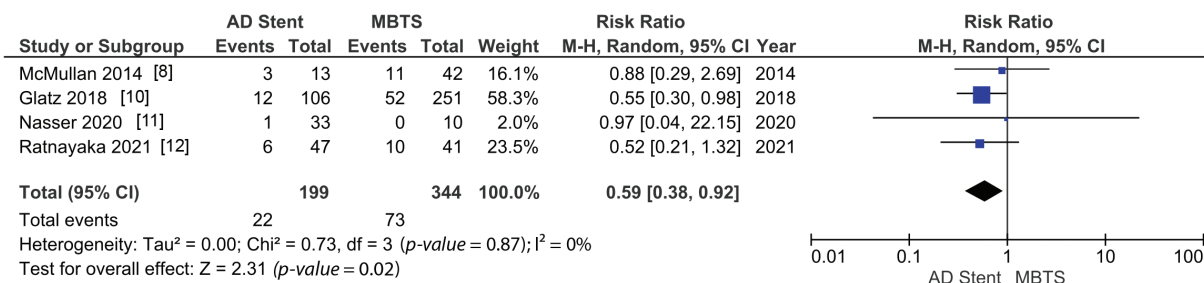


Figure 3: A pooled estimate of unplanned intervention for AD stent vs. MBTS

The comparison of the Nakata index revealed no significant difference between the two groups (MD 1.87 [-23.20, 26.93]; p -value = 0.88; I^2 = 93%, Fig. 4) [6,9–13,14].

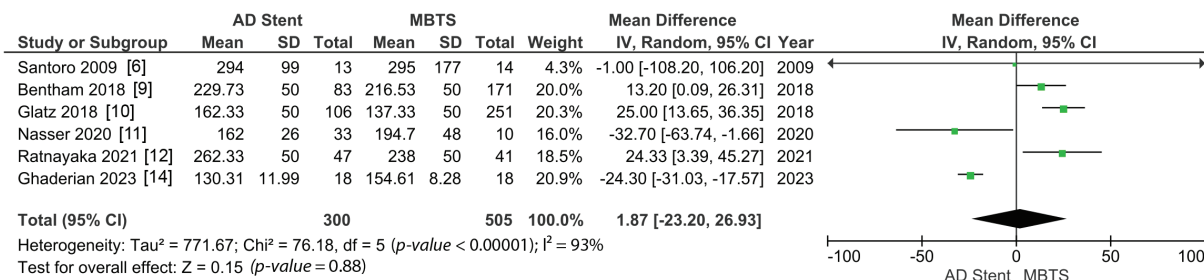


Figure 4: Pooled estimate of Nakata index for AD stent vs. MBTS

Postoperative oxygen saturation was measured significantly higher in the AD stenting (MD 1.80 [0.85, 2.74]; p -value = 0.0002; I^2 = 0%, Fig. 5). However, in the long term, the AD stent group shows significantly lower oxygen saturation (MD -8.43 [-14.38, -2.48]; p -value = 0.005; I^2 = 93%, Fig. 6) [6–9,11,14].

Both hospital and ICU length of stay were significantly shorter in the AD stent group (MD -8.30 [-11.13, -5.48]; p -value < 0.00001; I^2 = 82%, Fig. 7; MD -5.09 [-7.79, -2.38]; p -value = 0.0002; I^2 = 94%, Fig. 8) [10–12,14–16].

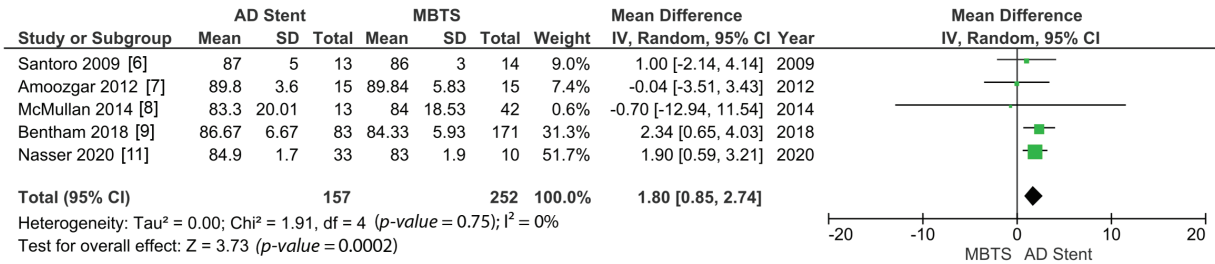


Figure 5: A pooled estimate of post-procedural oxygen saturation for AD stent vs. MBTS

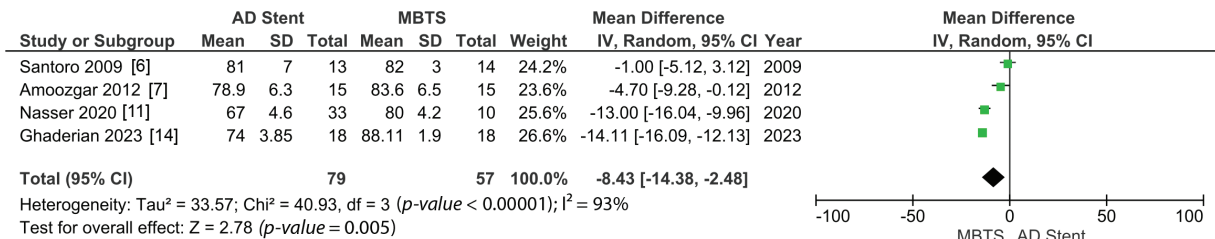


Figure 6: A pooled estimate of long-term oxygen saturation for AD stent vs. MBTS

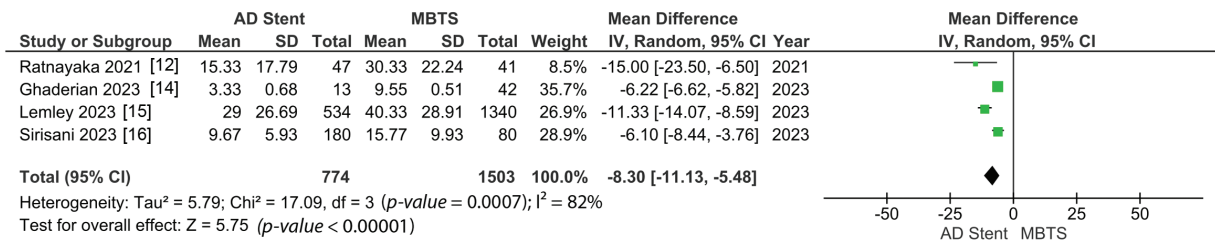


Figure 7: Pooled estimate of hospital length of stay for AD stent vs. MBTS

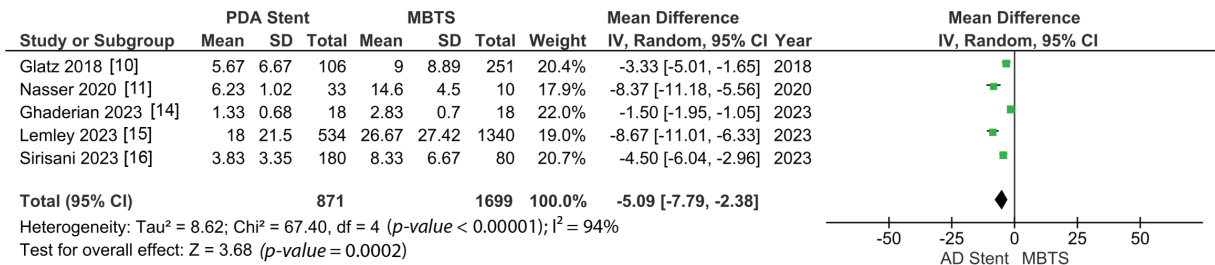


Figure 8: Pooled estimate of ICU length of stay for AD stent vs. MBTS

4 Discussion

The goal of palliative treatment in critical congenital heart disease is generally to provide adequate circulation and prepare the patient for the next stage. In cases of ductal-dependent pulmonary circulation (DDPC), the palliative procedure involves redirecting blood flow to the pulmonary artery from another source, thereby ensuring sufficient blood flow to the pulmonary circulation and, consequently, adequate oxygenation to ensure overall survival. For a long time, MBTS has been the accepted method to address this problem. However, in this era, less invasive methods have been developed to achieve comparable or

even superior outcomes to invasive surgical procedures. Several individual studies have been conducted, mostly retrospectively, aiming to compare outcomes between the two groups. The limitation of small sample size and single-center study designs need to be addressed before applying the findings of those studies to other centers. This study aims to systematically review these studies and conduct a meta-analysis of the same outcome measured thereby generating a more precise estimation that can be applied considerably in the future.

4.1 The Decision of AD Stenting & MBTS

Different centers follow distinct protocols regarding the selection of palliative treatment in DDPC cases. Two predominant patterns have been observed: universal and selective AD stenting. Notably, only one study, conducted by Nasser et al. implemented universal AD stenting from the outset, resulting in 21.4% (9/42) cases requiring immediate conversion to surgical shunt. Another study by Ratnayaka et al. initially employed selective AD stenting for the first five years of their study, before transitioning to universal AD stenting in 2018–2020 [12]. Although this change led to an imbalance increase in AD stenting procedures in their center, their study compared outcomes between the selective stenting and the universal stenting eras, revealing no significant difference in interstage and overall mortality, complications, and unplanned interventions. The remaining study adopted selective AD stenting as a protocol. In the study by Santoro et al., AD stenting was attempted in patients with high surgical risk or when short-term support to pulmonary circulation was anticipated [6]. McMullan et al. made case-by-case decisions between AD stenting and MBTS based on procedural risk, appropriateness of PA size, AD anatomy, and patient comorbidities [8]. Ghaderian et al. strategy relied on age; all infants aged under two months old were offered AD stent placement, while MBTS was performed in patients over 2 months old [14]. These considerations were aimed at anticipating the outcomes in order to enhance survival and mitigate complications.

In other related studies by Qureshi et al., a classification scheme has been proposed to assess ductal morphology in patients undergoing AD stenting. This classification is based on the tortuosity index (TI) using Ductal Curvature Index (DCI), with three types identified: (1) Type I (straight–DCI 0–0.16); (2) Type II (one turn–DCI 0.12–0.38); (3) Type III (multiple turns–DCI 0.17–0.45), where a greater TI is associated with greater risk of unplanned intervention. This study demonstrates that AD stenting can be performed in high tortuosity Patent Ductus Arteriosus (PDA), with the classification scheme aiding in vascular approach decisions. Subsequent studies by Mini et al. further examine ductal stenting outcomes in patients with high tortuosity PDA ($DCI \geq 0.45$). In their initial study, 80% of patients with $DCI \geq 0.45$ failed to achieve the primary outcome. Further analysis revealed that this particular group is at elevated risk for early surgery or unplanned reintervention. In a later study by the same author, 15 patients with $DCI \geq 0.45$ underwent PDA stenting, of whom 8 required later conversion to surgical shunt due to desaturation or acute stent occlusion. This scenario poses a challenge in the perioperative stage due to pre-operative desaturation and its negative changes to pulmonary arteries and the lungs. Consequently, Mini et al. suggest that: (1) the DCI classification can serve as a useful guide in clinical decision-making for patients with challenging anatomy; (2) although PDA stenting is feasible in cases of high tortuosity, and while surgical shunts carry their own risk, MBTS could be preferred as alternative or prepared as emergency measure. This underscores the importance of considering procedural risk (based on age, clinical condition, cardiac anomaly), pulmonary artery size, and ductal anatomy in choosing appropriate treatment to achieve optimal outcomes [13,17,18].

Each study demonstrates the growing interest in utilizing AD stenting as the initial choice for palliative treatments, as it offers similar or superior overall outcomes. In a study by Glatz et al., 43.3% of the AD stenting group had pulmonary atresia with the intact interventricular septum (PA/IVS), a condition conducive to stent placement due to favorable anatomical characteristic (normal origin from proximal

descending aorta, short straight course, and insert right to main PA) [10]. While certain conditions such as PA/IVS may facilitate stent placement, several morphological features may pose challenges for stent placement, making MBTS a safer option for palliative treatment in these cases. Hence, it is evident that selection bias exists in the studies we examined.

4.2 Mortality, Complication, and Unplanned Intervention

The primary cause of death in both AD stenting and MBTS is primarily related to complications associated with the interventions. The overall mortality rates for modified BT shunt vary across different centers and are attributed to factors such as shunt thrombosis, over-shunting, atrioventricular valve regurgitation, myocardial ischemia, necrotizing enterocolitis, and the need for extracorporeal membrane oxygenation support. For instance, in one study by Dave, the overall mortality rate of MBTS ranged from 7% to 9%. In another cohort study by Oofuvong et al., the mortality rate prior to Glenn/total repair could be as high as 31.3% [2,19]. Thrombotic occlusion of an MBTS can result in life-threatening hypoxemia, necessitating surgical or catheter-based reintervention as a rescue procedure. Conversely, in the case of AD stenting, there is a progressive decline in oxygen levels due to intimal ingrowth within the stent, fibro intimal peel formation, and thrombus formation within the shunt, leading to sudden death in 5% to 20% of patients during follow-up [10]. However, the overall mortality rate between patients undergoing AD stenting and MBTS did not show a significant difference [20].

In this systematic review, each included study indicates no significant difference in 30-day mortality, consistent with two recent meta-analyses [21,22]. Additionally, McMullan et al. demonstrated no significant difference in survival to the next stage (second-stage palliation or definitive repair) [8]. Conversely, Sirisani et al. reported a significantly lower overall mortality rate in the AD stent group compared to the MBTS group. (11.25% vs. 1.64%; $p = 0.001$) [16]. Bentham et al. conducted a survival analysis of longer-term outcomes revealing a significant reduction in mortality associated with AD stenting before repair (HR of 0.25 [0.07–0.85], $p = 0.026$) [9]. However, Glatz et al. analyzed the adjusted effect of treatment strategy on time-dependent outcomes with survival models, showing no significant difference in terms of death between the two groups [10].

Significant differences were observed in complications and unplanned interventions. Our study found that there is a 51% reduced risk of complication in the AD stenting group compared to the MBTS group, consistent with findings from three recent meta-analyses [21,23]. This result pooled various complications including acute kidney injury, necrotizing enterocolitis, diaphragm paralysis, vocal cord palsy, thrombosis, stroke, bleeding, post-operative infection, cardiac arrest, and arrhythmia [8,10,12,13].

Threatening hypoxemia can result from occlusion in the stent/shunt, significant leakage, and stent migration, necessitating unplanned interventions to restore blood flow and alleviate cyanosis. Our study revealed a 59% less risk of unplanned intervention in the AD stent compared to MBTS. Unplanned intervention was defined as any surgical or transcatheter intervention intended to treat cyanosis of any cause after the procedure. Stenting remains a challenging procedure to perform due to various conditions and anatomical variation, often requiring immediate intervention even emergency surgical shunt creation. Santoro et al. report four failed stenting attempts which were excluded from their study without clear information on the reason for subsequent treatment done in these patients [6]. Amoozgar et al. reported three failed stent attempts, with one of them due to difficulty achieving vascular access, and in the two remaining patients the wire cannot cross even with axillary access, all of which require immediate referral for surgery [7]. McMullan et al. included 13 successfully stented patients with no procedure-related death. This study also demonstrated that all MBTS patients needing unplanned intervention required multiple reintervention (surgical and transcatheter), while no case in the AD stent group required more than one reintervention [8]. Bentham et al. reported 13 failed attempts, with various reasons including four cases

due to failure to cross tortuous duct; two cases failed due to inability to cover proximal duct; one failure due to RV perforation; one case not achieving adequate flow, one failure due to duct dissection; and four early stent failure (inadequate flow, thrombosis, in-stent stenosis), all of which required surgical referral [9]. Glatz et al. reported 12 cases of AD stent requiring reintervention, with five cases converted to surgical shunts. Their multicenter study in 2018 presented the most detailed data and analysis, recording unplanned interventions including stenting of the pulmonary or systemic artery, angioplasty of stent/shunt or pulmonary artery (with or without stent), RVOT stent, balloon atrial septostomy, surgical revision of both groups, drainage of hemopericardium, and early superior cavopulmonary connection [10]. Nasser et al. encountered similar cases where nine out of 42 patients initially offered AD stenting later failed to be performed and were immediately referred to surgical shunt, which later classified and followed up as MBTS group. In one case, a second stent placement was needed to cover the entire ductus after the first stent proved inadequate [11]. Ratnayaka et al. specifically reported conversion to surgical shunt in eight of 15 patients who have tortuous PDA anatomy. Ratnayaka et al. showed two general intervention post-procedures: surgical revision and transcatheter approach. Their study showed there is significantly more surgical revision in the MBTS group compared to the AD stent. Although more transcatheter approach re-intervention (angioplasty with or without stent) were seen in the AD stent group, group analysis showed no statistical significance [12]. All this information further highlights the importance of pre-operative consideration in terms of patient selection and consideration to improve clinical outcomes in each group.

Several individual cases have demonstrated that successful stenting or the use of drug-eluting stent in occluded MBTS may prolong survival, improve saturation, improve exercise tolerance, and lower hematocrit levels [24–27]. In studies by Bonnet et al., percutaneous interventions have been shown to effectively restore MBTS patency albeit with potential major complications [27]. These findings suggest that, despite the higher prevalence of complications and unplanned interventions in MBTS groups, reliable rescue measures are available to prolong survival and improve outcomes. However, further research is needed to investigate this issue more specifically.

4.3 Nakata Index and Oxygen Saturation

Pulmonary artery size is measured near the next stage of palliation, with the distance to the next stages varying between studies based on each center's protocol and the patient's general condition. Individual studies in our analysis showed no significant difference in the Nakata index in both groups, and so does the meta-analysis of the pooled result. This finding is consistent with one recent meta-analysis by Tseng et al. in 2022, but not consistent with one study by Abdelmassih et al. in 2020. The difference between our study and the study by Abdelmassih is that they use a fixed effect model for analysis [21,23]. However, even Abdelmassih's random effect analysis showed no significant difference in this outcome. Two individual studies indicated that AD stents showed more symmetrical growth of the pulmonary artery [6,10].

As a general rule, an average Nakata index of $330 \text{ mm}^2/\text{m}^2$ is considered normal. However, the lowest Nakata index to preclude a patient from surgery has not yet been established. One study suggested that a preoperative Nakata index $<250 \text{ mm}^2/\text{m}^2$ does not restrict the functional efficacy of the later Fontal circulation [28]. Another study by Itatani et al. showed that only those with a Nakata index below $110 \text{ mm}^2/\text{m}^2$ would experience exercise intolerance and increased pressure in later Fontan circulation [29]. Overall, the accepted Nakata index for the next palliation procedure may depend on various factors and should be determined on a case-by-case basis. Another method can be used to measure the PA index such as the McGoon ratio and Lower Lobe Index (LLI). Further analysis is required to determine which method is better for estimating the prognosis of the later stage.

In terms of oxygen saturation, both AD stenting and MBTS showed significant improvement. Our study indicated significantly higher post-procedural saturation in the AD stent groups, consistent with two recent meta-analyses [22,23]. However, in the longer term, saturation was significantly higher in the MBTS groups. This difference may be attributed to intimal ingrowth within the stent, fibro intimal peel formation and thrombus within the shunt, affecting the patency and durability of the stent, causing a progressive decline of saturation in AD stent in the long run [10,20]. Nonetheless, reintervention such as stent re-dilatation after AD stenting is a feasible and safe treatment option that can improve pulmonary blood flow. Strut dilation of branch pulmonary artery stenosis after arterial duct stenting has been shown to augment pulmonary blood flow and improve oxygen saturation levels [30].

4.4 Hospital LOS, and ICU LOS

In this study, the hospital and ICU length of stay (LOS) were significantly shorter in the AD stent group, a result consistent with three recent meta-analyses [21–23]. Post-procedural hospital LOS and ICU LOS depended on postoperative complications and reintervention. In one multi-center study by Valencia et al., longer hospital and ICU LOS in MBTS were associated with higher hospital charges and costs. However, this analysis also needs to consider the use of other services such as imaging, lab, drugs, and all the costs contributed to the overall cost which will be different in each case in each center [31]. In this meta-analysis, we were unable to calculate the cost across studies due to a lack of data measuring that particular outcome.

4.5 Limitation

The nature of the observational study remains a limitation in this study. All studies are prone to confounders and covariates that may not have been considered in each analysis. The variability in the selection protocol of treatment in DDPC cases across different centers introduces selection bias in the included studies. Furthermore, the imbalance in sample size, difference in follow-up time, and variation in baseline characteristics across studies contribute to high heterogeneity in this study. To determine the superiority of both treatments, a randomized trial with a detailed protocol is necessary to provide results with greater confidence.

5 Conclusion

This meta-analysis demonstrates that AD stenting provides comparable outcomes relative to MBTS, with fewer complications and unplanned interventions, higher short-term oxygen saturation, and shorter lengths of stay. However, MBTS has shown superiority in maintaining higher long-term oxygen saturation. Additionally, MBTS remains the preferred option for managing complex cases where stenting is either challenging or unsuccessful. Therefore, to achieve the most optimal outcomes, the pre-operative protocol should be placed regarding patient selection and careful consideration when choosing the appropriate intervention.

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Author Contributions: The authors confirm contribution to the paper as follows: study conception and design: KPY, NSSB; data collection: NSSB, PFKP; analysis and interpretation of results: KPY, NSSB; draft manuscript preparation: KPY, NSSB, PFKP. All authors reviewed the results and approved the final version of the manuscript.

Availability of Data and Materials: The data set used for this meta-analysis will be shared upon request from the study authors.

Ethics Approval: Not applicable.

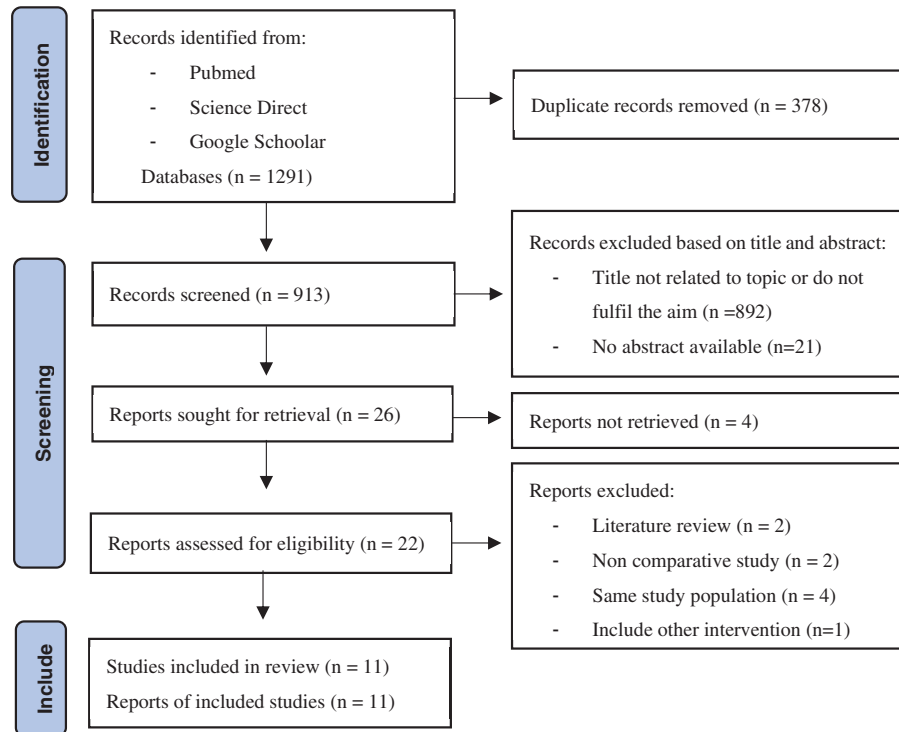
Conflicts of Interest: The authors declare that they have no conflicts of interest to report regarding the present study.

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Appendix



Appendix A: Prisma flow diagram of study selection process

Appendix B: Clinical characteristic of each study

Author	Follow up	Characteristics
Santoro et al. [6]	10 ± 5 months	AD stent <ul style="list-style-type: none"> • Age (m): 8.1 ± 3.6 (range 3–15, median 7) • Weight (kg): 5.7 ± 1.8 (range 3.6–10.6, median 5) • Malformation: TOF (2), PA/IVS (6), complex CHD + PA or stenosis (5) MBTS: <ul style="list-style-type: none"> • Age (m): 13.7 ± range 6–22, median 9) • Weight (kg): 8.7 ± 1.5 (range 7.3–11.5, median 8) • Malformation: TOF (6), PA/IVS (2), complex CHD + PA or stenosis (6)
Amoozgar et al. [7]	6 months	AD stent: <ul style="list-style-type: none"> • Age (d): 41 ± 51.07 (range 4–180, median 20) • Weight (kg): 3.55 ± 0.95 (range 2.50–6.50, median 3.2) • Malformation: TOF + PA (2), PA + mitral atresia (1), PA + TA (1), PA + AVSD (1), PA + VSD (1), PA + VSD + RAA (3), PA/IVS (2), PA single ventricle (1), TGA + VSD + PS (1), PA + tricuspid atresia (1)

(Continued)

Appendix B (continued)		
Author	Follow up	Characteristics
		MBTS: <ul style="list-style-type: none"> • Age (d): 98.13 ± 116.1 (range 6–330, median 20) • Weight (kg): 4.9 ± 2.27 (range 2.5–9.0, median 4.0) • Malformation: TOF (4), PA + VSD (5), PA + TA (2), PA single ventricle (1), PS + DORV (1), PS + ASD (1), PS + VSD + TA (1)
McMullan et al. [8]	12 months	AD stent: <ul style="list-style-type: none"> • Age (d): 13 (range 4–43) • Weight (kg): 3.3 (2.0–4.5) • Malformation: TOF (1), PA (8), Complex TGA (2), unbalanced AV canal (2) MBTS: <ul style="list-style-type: none"> • Age (d): 12 (range 2–218) • Weight (kg): 3.3 (range 2.3–8.6) • Malformation: DORV (7), TOF (7), PA (12), ebstein anomaly (3), TA (4), complex TGA (8), unbalanced AV canal (1)
Bentham et al. [9]	N/A	AD stent: <ul style="list-style-type: none"> • Age (d): 8 (IQR 4–13) • Weight: 3.1 (IQR 2.8–3.5) • Malformation: DORV (6), TOF (6), PA + VSD (22), PA/IVS (23), TA (5), complex TGA/DORV (15), unbalanced AV canal (3), Ebstein anomaly (2), DILV (1), others (5) MBTS: <ul style="list-style-type: none"> • Age (d): 8 (IQR 5–15) • Weight (kg): 3.1 (IQR 2.8–3.4) • Malformation: DORV (17), TOF (18), PA + VSD (31), PA/IVS (32), TA (17), complex TGA/DORV (24), unbalanced AV canal (7), ebstein anomaly (2), DILV (6), others (24)
Glatz et al. [10]	6 months	AD stent: <ul style="list-style-type: none"> • Age (d): 9 (IQR 5–15) • Weight (kg): 3.2 (IQR 2.7–3.7) • Malformation: PA/IVS (47), VSD/PS (26), VSD/PA (18), TA + PA/PS (5), isolated PS (10) MBTS: <ul style="list-style-type: none"> • Age (d): 6 (IQR 4–15) • Weight (kg): 3.1 (IQR 2.7–3.5) • Malformation: PA/IVS (50), VSD/PS (62), VSD/PA (99), TA + PA/PS (39), isolated PS (1)

(Continued)

Appendix B (continued)		
Author	Follow up	Characteristics
Nasser et al. [11]	N/A	AD stent: age (d): 30 ± 10 ; weight (kg): 3.5 ± 0.15 MBTS: age (d): 42 ± 17 ; weight (kg): 3.3 ± 0.15
Ratnayaka et al. [12]	N/A	No specific characteristic available for AD stent and MBTS groups
Mini et al. [13]	6 months	AD stent: <ul style="list-style-type: none"> • Age (d): 18 ± 23.18 (range 1–120) • Weight (kg): 3.3 ± 0.68 (range 2–5) • Malformation: PA/IVS (10), PA/VSD (49), Critical PS/IVS (12) MBTS: <ul style="list-style-type: none"> • Age (d): 30.3 ± 34.8 (range 1–155) • Weight (kg): 3.6 ± 1.1 (range 2.1–7.4) • Malformation: PA/IVS (7), PA/VSD (49)
Ghaderian et al. [14]	N/A	AD stent: age (m): 1.28 ± 0.46 ; weight (kg): 3.38 ± 0.45 ; MBTS: age (m): 2.50 ± 0.51 , weight (kg): 4.98 ± 0.57 ; Malformation (total): PA/VSD (16), TA (8), PA/IVS (2), TOF/DORV (8), TGA-VSD-PS (2)
Lemley et al. [15]	N/A	AD stent: <ul style="list-style-type: none"> • Age (d) 7.0 (4.0–12.0) • Malformation: PA/IVS (34), VSD/PS (113), VSD/PA (26), tricuspid anomaly (184), isolated PS (19), other/missing (158) MBTS: <ul style="list-style-type: none"> • Age (d): 7.0 (range 4.0–10.5) • Malformation: PA/IVS (36), VSD/PS (178), VSD/PA (84), tricuspid anomaly (476), isolated PS (15), other/missing (551)
Sirisani et al. [16]	N/A	AD stent: <ul style="list-style-type: none"> • Age (w): 5.7 (IQR 3.1–10.3) • Weight (kg): 3.3 (IQR 3.0–3.8) • Malformation: P A/IVS (57), PA/VSD (13), TOF (34), single ventricle (32), others (20) MBTS: <ul style="list-style-type: none"> • Age (w): 5.9 (IQR 3.5–9.8) • Weight (kg): 3.5 (IQR 3.0–4.0) • Malformation: PA/IVS (13), PA/VSD (13), TOF (16), single ventricle (23), others (15)

Note: CHD: Congenital Heart Disease, TOF: Tetralogy of Fallot; PA/IVS: Pulmonary Atresia with Intact Ventricular Septum, TGA: Transposition of Great Arteries; AV: atrioventricular; DORV: Double Outlet Right Ventricle; DILV: Double Inlet Left Ventricle; PA: Pulmonary Atresia; AVSD: Atrioventricular Septal Defect; VSD: Ventricular Septal Defect; RAA: Right Aortic Arch; PS: Pulmonary Stenosis; TA: Tricuspid Atresia; d: day(s); w: week(s); m: month(s).

Appendix C: Quality and Bias risk assesment using Newcastle-Ottawa Scale (NOS)

No.	Author	Year	Selection	Comparability	Outcome	Overall risk of Bias
1.	Santoro et al. [6]	2009	****	*	***	Good
2.	Amoozgar et al. [7]	2012	***	*	***	Good
3.	McMullan et al. [8]	2014	****	*	***	Good
4.	Bentham et al. [9]	2018	****	*	***	Good
5.	Glatz et al. [10]	2018	***	*	***	Good
6.	Nasser et al. [11]	2020	**	*	***	Fair
7.	Ratnayaka et al. [12]	2021	****	*	***	Good
8.	Mini et al. [13]	2022	****	*	***	Good
9.	Ghaderian et al. [14]	2023	***	*	***	Good
10.	Lemley et al. [15]	2023	****	*	***	Good
11.	Sirisani et al. [16]	2023	***	*	***	Good

Appendix D**Table S1:** (A) Data of Dichotomous Outcome; (B) Data of Continuous Outcome

(A)				
Outcome of 30-day mortality event				
Author	AD stent		MBTS	
	Event	Total	Event	Total
Amoozgar 2012 [7]	3	15	5	15
McMullan 2014 [8]	1	13	1	42
Glatz 2018 [10]	7	106	26	251
Bentham 2018 [9]	4	83	12	171
Nasser 2020 [11]	3	33	0	10
Mini 2022 [13]	2	71	7	56
Lemley 2023 [15]	56	534	131	1340
Sirisani 2023 [16]	3	180	9	80
Outcome of complication event				
Author	AD stent		MBTS	
	Event	Total	Event	Total
McMullan 2014 [8]	1	13	3	42
Glatz 2018 [10]	14	106	54	251

(Continued)

Table S1 (continued)				
Outcome of complication event				
Author	AD stent		MBTS	
	Event	Total	Event	Total
Ratnayaka 2021 [12]	10	47	14	41
Mini 2022 [13]	5	71	16	56
Outcome of unplanned intervention event				
Author	AD stent		MBTS	
	Event	Total	Event	Total
McMullan 2014 [8]	3	13	11	42
Glatz 2018 [10]	12	106	52	251
Nasser 2020 [11]	1	33	0	10
Ratnayaka 2021 [12]	6	47	10	41
(B)				
Outcome of post-procedural oxygen saturation (mean \pm SD)				
Author	AD stent		MBTS	
	Mean	SD	Mean	SD
Santoro 2009 [6]	87.0	5.0	30.33	22.24
Amoozgar 2012 [7]	89.8	3.6	9.55	0.51
McMullan 2014 [8]	83.3	20.01	40.33	28.91
Bentham 2018 [9]	86.67	6.67	15.77	9.93
Nasser 2020 [11]	84.9	1.7	30.33	22.24
Outcome of long-term oxygen saturation (mean \pm SD)				
Author	AD stent		MBTS	
	Mean	SD	Mean	SD
Santoro 2009 [6]	81.0	7.0	82.0	3.0
Amoozgar 2012 [7]	78.9	6.3	83.6	6.5
Nasser 2020 [11]	67.0	4.6	80.0	4.2
Ghaderian 2023 [14]	74.0	3.85	88.11	1.9
Outcome of nakata index near the next stage (mean \pm SD)				
Author	AD stent		MBTS	
	Mean	SD	Mean	SD
Santoro 2009 [6]	294.0	99.0	295.0	177.0
Bentham 2018 [9]	229.73	50.0	216.53	50.0

(Continued)

Table S1 (continued)				
Outcome of nakata index near the next stage (mean \pm SD)				
Author	AD stent		MBTS	
	Mean	SD	Mean	SD
Glatz 2018 [10]	162.33	50.0	137.33	50.0
Nasser 2020 [11]	162.0	26.0	194.7	48.0
Ratnayaka 2021 [12]	262.33	50.0	238.0	50.0
Outcome of hospital length of stay duration (mean \pm SD)				
Author	AD stent		MBTS	
	Mean	SD	Mean	SD
Santoro 2009 [6]	294.0	99.0	30.33	22.24
Bentham 2018 [9]	229.73	50.0	9.55	0.51
Glatz 2018 [10]	162.33	50.0	40.33	28.91
Nasser 2020 [11]	162.0	26.0	15.77	9.93
Ratnayaka 2021 [12]	262.33	50.0	30.33	22.24
Outcome of ICU length of stay duration (mean \pm SD)				
Author	AD stent		MBTS	
	Mean	SD	Mean	SD
Glatz 2018 [10]	15.33	17.79	30.33	22.24
Nasser 2020 [11]	3.33	0.68	9.55	0.51
Ghaderian 2023 [14]	29.0	26.69	40.33	28.91
Lemley 2023 [15]	9.67	5.93	15.77	9.93
Sirisani 2023 [16]	3.83	3.35	8.33	6.67