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Patch Pumps: What are the advantages for people with diabetes?

Bernhard Kulzer [a,b,c,*], Guido Freckmann [d], Lutz Heinemann [e], Oliver Schnell [f], Rolf Hinzmann [g], Ralph Ziegler [h]

[a] Research Institute of the Diabetes-Academy Mergentheim, Bad Mergentheim, Germany
[b] Diabetes Center Mergentheim, Bad Mergentheim, Germany
[c] University Bamberg, Bamberg, Germany
[d] Institut für Diabetes-Technologie, Forschungs- und Entwicklungsgesellschaft mbH an der Universität Ulm, Ulm, Germany
[e] Science Consulting in Diabetes GmbH, Kaarst, Germany
[f] Forschergruppe Diabetes e.V., Helmholtz Zentrum, Munich, Germany
[g] Roche Diabetes Care GmbH, Mannheim, Germany
[h] Diabetes Clinic for Children and Adolescents, Muenster, Germany

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ABSTRACT

Aim: Patch pumps, i.e. insulin pumps without tubing, are an attractive alternative to conventional insulin pumps for people with type 1 diabetes and type 2 diabetes on insulin therapy. In this review, potential patient-relevant advantages and disadvantages of patch pumps are summarized and respective studies on patient-reported outcomes (PROs) are assessed.
Methods: Relevant studies were identified through a systematic PubMed search. Reference lists in respective articles and Google Scholar were also checked for additional references. Articles in English published before June 30, 2021, were included; no other criteria on publication dates were set.
Results: A total of 12 studies were included. The results of this analysis provide evidence that patch pumps improve quality of life, reduce diabetes-related distress, increase patient satisfaction, and are preferred by patients compared to conventional insulin pumps and multiple daily injection therapy (MDI). However, several methodological limitations of the studies identified constrain the significance of this analysis.
Conclusions: Despite the limited number of studies evaluating the benefits of patch pumps on PROs, there is increasing evidence that people with diabetes prefer patch pumps. Although there are numerous PROs for patch pumps, it is surprising that this aspect has been relatively understudied. More systematic evaluation studies of the benefits of patch pumps on PROs are needed.

1. Introduction

While conventional insulin pumps have been available to patients since the 1970 s, patch pumps (PPs) have only been a therapeutic option for the last 15 years. [1,2]. Initiated by the father of a boy with type 1 diabetes (T1D), the development of a tubeless, easy-to-use insulin pump led to the creation of the Omnipod system (Insulet Corporation Acton, MA, USA), which was launched in 2005 as the first commercially available patch pump in the USA [3]. The initial focus in PP development was primarily on reducing an important source of error and barrier to insulin pump therapy (CSII) for people with T1D: Instead of connecting the pump to the body via an insulin infusion set and tubing, tubeless PPs contain the insulin reservoir and the infusion cannula within the device and adhere directly to the skin. Usually, insulin delivery in a PP is controlled and programmed with a remote hand-held device; however, some devices allow at least some functionality via the PP itself as well. Current developments try to expand the use of PPs to people with type 2 diabetes (T2D) [2–7]. Although only a few PPs are available on the market today, numerous companies have announced the development of new PPs or published positive results from the

Abbreviations: AID, Automated insulin delivery; BIT, Barriers to Insulin Treatment Questionnaire; CSII, Continuous subcutaneous insulin infusion (insulin pump therapy); DTSQ, Diabetes Treatment Satisfaction Questionnaire; DSQOLS, Diabetes-Specific Quality-of-Life Scale; IIS, Insulin infusion set; ITAS, Insulin Treatment Appraisal Scale; MDI, Multiple daily injection therapy; ns, not significant; PP, Patch pump; PRO, Patient-reported outcome; PwD, People with diabetes; T1D, Type 1 diabetes; T2D, Type 2 diabetes.

* Corresponding author at: Research Institute of the Diabetes-Academy Mergentheim (FIDAM), Johann-Hammer-Str. 24, 97980 Bad Mergentheim, Germany.
E-mail address: kulzer@fidam.de (B. Kulzer).

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clinical development phase. It is, therefore, to be expected that additional PPs for insulin therapy for people with diabetes (PwD) will emerge in the upcoming years.

1.1. Categories of patch pumps

Apart from the common feature of tubeless insulin delivery, the various PPs that are available or in development have major differences [1,3,8]: They can either deliver just basal insulin, bolus insulin, or both basal and bolus insulin. The target group is people with T1D and/or T2D or both. Accordingly, the focus of the development of PPs is either on the simplicity of the devices with a very easy operation or of PPs without tubing with the multiple options of modern insulin pumps for individual insulin dosing (e.g., variable basal rates, bolus options, bolus calculator). Generally, the different PPs can be divided into three categories according to restricted functionality and ease of use, additional features of the PP, and the interoperability with other devices, especially regarding the possibility of being part of systems for automated insulin delivery (AID). These differences are also particularly important for the interpretation of clinical studies of PPs with respect to patient preferences, satisfaction with the PP, and other patient-reported outcomes (PROs).

- *PPs with reduced features:* The simple forms of PPs are intended for insulin therapy for people with T2D and mainly aim to be easy to handle, easy to carry, small, and disposable. Recent developments aim to replace insulin pen therapy with PPs that use relatively simple insulin dosing regimens. There are also options to deliver only the basal or bolus insulin via a PP to simplify the insulin therapy. An example of a simple PP is the V-GO (Zealand Pharma; Zealand, Denmark) which delivers a fixed amount of basal insulin over 24 h and has a bolus button that permits up to 36 units of prandial insulin to be delivered in 2-unit increments per day. The V-GO is replaced daily. The Simplicity (CeQur; Luzern, Switzerland) PP holds up to 200 units of bolus insulin that are administered in 2-unit increments while the CeQur's PaQ (later PaQ Total) has a reservoir of 330 units for 3 days use and also allows different basal rates.

- *Fully equipped PPs:* These pumps can deliver as standard at least variable basal rate(s) and individually controllable amounts of bolus insulin. In most cases, advanced pump features are also available, such as different bolus options, information about insulin on board, a bolus calculator, or the integration of data from a system for continuous glucose monitoring (CGM). Fully equipped PPs are mainly intended to be used by people with T1D or T2D with MDI. A widely used PP is the Omnipod (Insulet Corporation Acton, MA, USA), with the Omnipod insulin management system which consists of the pod and the personal diabetes manager (PDM), a controller that is wirelessly connected to the PP by Bluetooth. The Accu-Chek Solo micropump (Roche Diabetes Care; Mannheim, Germany) is composed of a 90-day reusable pump, a disposable 200-unit insulin reservoir, a disposable pump holder including the cannula, and a remote control. Also, the A6 TouchCare System PP (A6) (Medtrum Technologies, Shanghai, China) has a reusable pump base and a disposable insulin reservoir including the cannula, in addition to a remote control. The development of the PP Panda (SFC Fluidics Fayetteville, USA.) was supported by the 2017 "Open-Protocol Automated Insulin Delivery Systems Initiative" of the Juvenile Diabetes Research Foundation (JDRF) which aimed to establish an "open-protocol" AID ecosystem. The Sigi PP (AMF Medical; Ecublens, Switzerland) works with readily available prefilled insulin cartridges and is controlled directly from a personal smartphone. Every user receives two long-lasting rechargeable PPs to be used interchangeably, avoiding batteries, and reducing waste. The Equil PP (MicroTech Medical; Hangzhou Zhejiang China) has a wireless portable diabetes assistant (PDA). With the GlucoRx Equil (GlucoRx, Guildford, UK) the user can bolus directly from the PP or via a PDA-Bluetooth controller. Medisafe WIT is a removable PP (Terumo; Shibuya, Japan) that, like most other PPs, allows the basal rate and bolus to be adjusted via remote control. The JewelPUMP (debiotech; Lausanne, Switzerland) also has a separate controller to deliver bolus insulin doses and a reservoir with 450 units of insulin.

- *PPs suitable for AID systems:* The development of algorithms to optimize glucose control for PwD using AID systems means that several functions can be "outsourced" to a controlling algorithm and do not need to be present in an insulin pump [9,10]. Since in most open AID systems the user can choose from several insulin pumps, PPs score point due to their small size, inconspicuousness when worn, and ease of use. The prerequisite for this is the PP's interoperability, which is its fulfillment of the FDA requirements for the interaction with the CGM system and the algorithm. An example is the Omnipod 5 system [11]. Via the controlling algorithm, the PP can communicate directly with a Dexcom CGM system and also with a handheld device with the Omnipod 5 App implemented. With this device, the user can start and stop the automated mode, deliver boluses, change settings, and view glucose data and glucose profiles. SFC Fluidics designed its PP Panda to be interoperable with an open protocol that allows a wireless, secure connection to other devices such as the CGM systems or AID algorithms. They announced a partnership with the French company Diabeloop (Diabeloop; Grenoble, France) to develop an AID system together.

1.2. Advantages and disadvantages of PP from the patient's point of view

Despite the significant differences between the various PPs, all have important common benefits for PwD compared to conventional insulin pumps. One main advantage is that PPs are tubeless and do not need an insulin infusion set (IIS). This eliminates potential risks and disadvantages that can exist with the use of conventional pumps where improper priming, occlusions, and cannula and tubing kinks or dislocation by pulling can interrupt insulin delivery [12–15]. Problems with IISs are common. Pickup et al. reported that in a survey of insulin pump users, 64.1% had experienced a kinked tube, with 12% experiencing it very frequently. Blockage of the IIS was noted by 54.3% of the insulin pump users at some time, with 9.8% of the total number of users recording frequent blockage of the cannula. Occasional leakage at the connection between the IIS and the pump was observed by 16.3% of users sometimes. Infusion site problems such as skin changes (e.g., lipohypertrophy) were reported by 26.1% of users and site infection by 17.4% of users at some time [16]. Due to the length of the IIS, there is a risk of tangling, catching, or pulling the tube when moving. Moreover, the IIS can be uncomfortable in some situations, such as during sports, romping with children, animals, or while having sex. Overall, the comfort of PPs and the elimination of potential sources of failure of the IIS (which carries the risk of life-threatening ketoacidosis if the tube becomes occluded or kinked), may lead to a decrease in diabetes-related worries.

One of the main reasons for barriers to CSII is the visibility of insulin pumps, which is of importance to most if not all PwD. In a survey of 1,503 adults from the T1D Exchange registry (70% CSII), 47% of the pump users reported barriers related to the hassle of wearing devices, 35% did not like having diabetes devices on their bodies, and 26% were disturbed by how diabetes devices look on the body. These barriers were more pronounced among women and younger people using CSII. Among the reasons for discontinuing CSII, disliking wearing diabetes devices (46%) and finding them uncomfortable/painful (44%) were the most common, followed by the cost of the accessories (21%) and not trusting the device (21%) [17]. Concerns about body image due to the size of the pump, the visibility of the pump through clothing, and the conspicuous wearing of the pump were particularly prevalent among female teenagers and women [17–19]. Body image concerns also emerged as a major barrier in a review of biopsychosocial factors associated with sustained pump use [20]. PPs are also a useful alternative for PwD who have practical problems keeping a pump on their body, which can be an advantage for already older children, while for infants the pod could be too large. This may also apply to people who exercise very frequently or engage in very physically demanding activities that involve heavy sweating. Because of the lighter weight, PPs may be more comfortable to

Table 1
Advantages and disadvantages of PPs from the PwD's point of view.

Advantages	Disadvantages
Tubeless, no need for an IIS (1,12,13,52)	Accuracy of insulin delivery of some PPs is often lower than that of conventional pumps, in particular at low basal rates (27,28,29)
Reduction of problems with the IIS (e.g., occlusions, tubing kinks, risk of getting tangled with the tube) (1,12,14,50,52)	Infusion site is not visible and cannot be regularly inspected; thus an infection might not be recognized immediately (29,30)
Needle is not visible (1,3,4,17)	Waste of insulin if PPs are replaced and remaining insulin is disposed of (1,32,33)
More freedom of movement (17,46,50,52)	Sometimes poor ecological balance due to waste from plastic material, batteries (32,33,34,35)
PP can be attached to many parts of the body (17,18,19,21)	Higher cost compared to MDI (3,4,9,21)
Discreete carrying options (1,3,17)	
Automatic insertion of the needle (offered only by certain PPs) can make application less painful (1,53)	
Smaller and lighter than conventional pumps (17,21)	
Ease of use, simple handling (17,21,22, 46)	
Simple education and training (1,3, 21)	
Technical features are often specifically tailored to the needs of special patient groups (e.g. type 2 diabetes) (5,7,21,22)	
Lower costs for certain PPs compared to conventional pumps (1,3,5,21)	
More convenient than conventional pumps when showering, swimming, and sweating or during exercise or sex (1,3,17,18)	

wear under these conditions and stick better to the skin. In user surveys regarding insulin pumps [21] or AID systems [22], it was repeatedly requested that the devices should be as small as possible and discreet to wear. Small size, lightweight, and ease with which PPs can be worn on different parts of the body are therefore considered a highly important aspect in PROs for PPs (see below). Finding a suitable bag and place to carry the conventional insulin pump is also reported as an obstacle.

Most PPs are waterproof and are thus particularly comfortable for everyday use with diabetes. They are more convenient than conventional pumps when showering, swimming, or during exercise or sex. These obstacles and hassles in everyday life are important reasons for diabetes distress, which is a major challenge for many PwD [23,24].

Ease of use in the handling of a PP can lower the hurdles for initiating CSII and can also minimize treatment errors. Particularly with simple PPs for people with type 2 diabetes, the possibility of errors during handling is reduced and the effort needed for training and education is lower. This can lead to a positive attitude towards diabetes-specific technologies, a higher level of self-efficacy in managing CSII, and a positive impact on treatment outcomes [25,26].

However, there are also potential disadvantages of PPs that of course also shape the experiences and attitudes of PwD. The accuracy of insulin pumps with which insulin is delivered into the subcutaneous tissue depends on the technology used in the different pump models. Given the small size of PPs, dosing accuracy is a technical challenge. This is particularly true for the dosing accuracy of small amounts of insulin or low basal rates. Especially with low insulin quantities, some PPs appear to have a poorer accuracy than conventional pumps [27–30], although this may only be relevant for people with very low insulin requirements. However, in the largest comparative study to date of the insulin delivery accuracy among different insulin pumps [31], no meaningful differences were found in mean bolus doses and basal rate among the 10 different models tested.

The easy replacement of PPs is another advantage of these devices, however, because the insertion site is covered by the PP, it cannot be regularly inspected. As a consequence, changes such as inflammation at the insertion site might not be immediately recognized.

Ecological considerations and the generation of considerable amounts of waste play an increasingly important role in PwD's choice of devices [32–34]. As a result, disposable PPs are increasingly being viewed as critical, leading most manufacturers to differentiate between recyclable and disposable components. In addition to the packaging, waste is generated from the individual components, which is particularly high for sterile products. The recyclability of the individual components is also important. Pfützner et al. demonstrated that the environmental burden of infusion sets with conventional insulin pumps is much lower than the load induced by PPs like the Omnipod [35]. From an ecological, as well as from an economic point of view, it is also critical if insulin remaining in the cartridge must be disposed of with the PP because of the shorter time of use of the complete pods.

Here Table 1: Advantages and disadvantages of PPs from the PwD's point of view

1.3. Patient-reported outcomes

Since PPs have several patient-relevant advantages, this analysis aims to determine whether these advantages are also supported by PROs from studies involving PPs. Benefits have been successfully demonstrated for conventional pumps for various PROs such as overall and diabetes-specific quality of life, reduced diabetes distress, increased patient satisfaction, and increased self-efficacy [36–41]. The objective of this analysis is to provide an overview of the existing literature regarding PROs related to the use of PPs.

2. Methods

This review is based on a literature search of the PubMed database using. This review is based on a systematic literature search of the PubMed database using. Articles in English were included if published before June 30, 2021; no other criteria for publication dates were set. Additionally, references of relevant articles and Google Scholar were checked for further references. The literature search did not include studies on patch pumps that were not applied to diabetes and articles that did not collect quantitative data on PROs. The systematic literature search and selection of relevant articles was performed by two independent researchers, using the following search strategy and a joint clearing process regarding exclusion criteria:

1. Patch pump OR insulin patch pump OR insulin micro-pump OR tubeless insulin pump OR tubeless patch pump; n = 1112
2. AND diabetes OR diabetes mellitus OR Type 1 diabetes OR Type 2 diabetes; n = 88
3. OR quality of life OR patient satisfaction OR treatment satisfaction OR patient preferences OR treatment preferences OR diabetes distress OR human factors; n = 32
4. Not relevant (Exclusion Criteria: no full text; technical review, where PRO is mentioned; no operationalization of PRO; no instrument to measure PRO was applied; duplicates); n = 12

Of the original 32 relevant articles, a total of 12 were relevant for this review; however, two articles refer to the same investigation [42,43]. For more information on the studies, see the Appendix Table 2.

Table 2
Study characteristics, design and results of studies on PPs and PROs.

Reference	Study Characteristics and Study Design	Outcomes (PRO)	Limitations
Bergenstal et al. [44]	Randomized controlled trial, 48 weeks, with crossover at week 44; Adults T2D; N = 139 PP, N = 139 pen; **Device:** PAQ MEAL; CeQur, Marlborough, MA, formerly Calibra Medical, Wayne, PA)	- Treatment satisfaction: Insulin Delivery System Rating Questionnaire - Quality of life: Diabetes Specific Quality of Life Scale (from baseline to week 24). - Subject-experience surveys (from baseline to at week 24 (11 items) and week 44 (4 items)) - Patient preference: (self-developed questionnaire: 7 items)	- PRO not primary outcome - Inconsistent, more non-significant than significant results
Bohannon et al.,2011[45]	Randomized controlled study (RCT); multicenter, 6-week cross-over study; N = 26 T1D, N = 12 T2D Use of Insulin bolus-patch vs. use of current device (55% pen and 45% syringe) **Device:** Finesse (Calibra Medical Inc., USA)	- Device Satisfaction: Insulin Delivery System Rating Questionnaire (IDSRQ) - Quality of Life: Diabetes Specific QOL Scale (DSQOLS) - Patient-Preference: (Self-developed Questionnaire: 1 Item)	- PROs not primary outcome - Small sample size
Carlson et al.,2021 [52]	Retrospective observational study (N = 3,592) of adults with T2D before and 90 days after initiating PP **Device:** Omnipod, Omnipod DASH-Insulin Management Systems (Insulet Corporation, USA)	- Patient preference: Reason for initiating Omnipod (retrospective, self-developed items)	- No control group - Selective sample - Only PRO-Data of n = 2,028 patients were collected - Unclear time of measurement: The reasons for switching to PP where measured both at baseline or follow-up (3 month)
Mader et al.,2014, Hermanns et al.,2015[42,43]	Single-center, single-arm study, lasting three 2-week periods: baseline (MDI), transition from MDI to PaQ, and PaQ therapy N = 19 MDI-treated individuals with T2D with HbA1c ≤ 9% (75 mmol/mol) **Device:** PaQ (CeQur, Switzerland)	- Patient satisfaction with PaQ: Device use Questionnaire (Self-developed Questionnaire: 2 Items) - Barriers to Insulin Treatment (BIT) - Insulin Treatment Appraisal (ITAS) - Problem Areas in Diabetes (PAID)	- No control group - Small sample size - Inconsistent results
Mader et al.,2018 [48]	Prospective, non-controlled study, comprising three periods: a baseline (MDI), a transition from MDI to PaQ, and a PaQ treatment period (12 weeks) N = 28 MDI-treated individuals with T2D with HbA1c ≥ 7% and ≤ 11 % **Device:** PaQ (CeQur, Switzerland)	- Diabetes Treatment Satisfaction Questionnaire (DTSQ) - Barriers to Insulin Treatment (BIT)	- No control group - Small sample size - Inconsistent results (compared to (42,43)
Layne et al., 2016 [50]	Multicenter, retrospective study (N = 461 medical practices), T1D previously receiving treatment with either MDI (78.1%) or CSII (21.9%) with a tubed insulin pump switched to the Omnipod system N = 873 T1D; 23.4% pediatric; 12.6% adolescent; 64.0% adult; age 29 years; 58% female; diabetes duration 11.1 years; Hba1c 8,4% **Device:** Omnipod (Insulet Corporation, USA)	- Patient preference: Reason for initiating Omnipod (retrospective, self-developed items)	- No control group - Selective sample - No specification of the measuring instrument, the quality of the measurement - No information about the response rate of PROs
Layne et al., 2019 [51]	Online survey of the T1D Exchange Glu online community. N = 147; T1D ≥ 1 year; Omnipod use > 0,5 - <2,0 years; prior therapy: MDI 72%; CSII 28% Duration: Omnipod 1–2 years **Device:** Omnipod (Insulet Corporation, USA)	- Treatment preferences (self-developed questionnaires) - Factors impacting treatment choice (self-developed questionnaires)	- No control group - Selective sample - No specification of the measuring instrument, quality of the measurement - No information about the response rate of PRO
Lebenthal et al., 2012[46]	Randomized, two-arm, 12-week cross-over study: Omnipod vs. conventional (infusion set) insulin pumps N = 29 T1D (CSII therapy) **Device:** Omnipod (Insulet Corporation, USA)	- Diabetes Treatment Satisfaction Questionnaire (DTSQ) - General user satisfaction (with current insulin pump system) - Patient preference (self-developed questionnaire) - Omnipod System User Evaluation Questionnaire (self-developed 25-item questionnaire, satisfaction with the Omnipod System)	- No control group - Small sample size - Selective reporting bias (DTSQ, General user satisfaction are not reported) - No specification of the measuring instrument, the quality of the measurement
Peyrot et al., 2018 [49]	Prospective, non-controlled study, comprising two periods: Current mealtime insulin-delivery system (syringe, pen, or pump), and then assessed simulated (no active medication) patch use over a 3-day period N = 101; T1D 71% - T2D 29%; Treatment: N = 49 syringe; N = 22 pen; N = 28 CSII **Device:** Finesse (Calibra, Medical Inc., USA)	- Insulin Delivery System Rating Questionnaire (IDSRQ): Domains - convenience, interference of treatment with daily activities, diabetes-related worries, psychological well-being (positive and negative) - Treatment system satisfaction - Patient preference (compare, switch)	- No control group - No real experience with PP, use of the patch was simulated - Very short observation period (3 days)
Polonsky et al., 2016 [47]	Retrospective online survey from the Insulet registry N = 1269; age ≥ 18 years, T1D > 1 year, using Omnipod for 6–24 months Perceived changes in patient relevant quality of life since Omnipod initiation. **Device:** Omnipod (Insulet Corporation, USA)	- WHO Well-being Index (WHO-5/change version) - Diabetes Distress Scale for Type 1 Diabetes (T1-DDS/change version) - Diabetes Technology Impact Measure (DTIM/ change version)	–No control group - Selective sample - Cross-sectional data - Most of the critical QOL scales were modified for this study - Without a formal pre-post testing design and further instrument validation, the true impact of Omnipod use on QOL cannot be determined

(*continued on next page*)

Table 2 (*continued*)

Reference	Study Characteristics and Study Design	Outcomes (PRO)	Limitations
Zisser, Jovanovich, 2006 [53]	Non-controlled observation study N = 20 user of a conventional insulin pump, switching to Omnipod for 30 days T1D, age 43 years, 15 females, diabetes duration 43 years **Device:** Omnipod (Insulet Corporation, USA)	- Omnipod compared with one's current pump) Self-developed questionnaire, 1 most favorable – 5 least favorable Patient preference (comparing the Omnipod with the current pump) (self-developed questionnaire, 1 most favorable – 5 least favorable)	- No control group - Observational report (short communication) - Selective sample - No specification of the measuring instrument, the quality of the measurement

3. Results

3.1. Quality of life

A total of three papers examined aspects of quality of life. In a randomized controlled trial with a six-week cross-over design, Bohannon et al. used the "Diabetes Specific Quality of Life Scale" (DSQOLS) for the measurement of quality of life [44]. In their study, an insulin bolus patch pump was compared with conventional therapy using an insulin pen or syringe. A significant difference in favor of the PP was found in six of seven dimensions, no significant difference was observed for treatment goals ($p = 0.972$). Using the same questionnaire, Bergenstal et al. found a significant result in 2 of 7 dimensions of the DSQOLS in a randomized controlled trial with PPs and pen users [45]. In a retrospective study of 1269 PP-users, Polonsky et al. examined perceived changes in quality of life with the "WHO-Five Well-Being Index" (WHO-5) since initiation of PP. A total of 58% of respondents said that their wellbeing improved after switching to the PP [46].

3.2. Diabetes distress

In the same study [46], 69.9% of respondents reported a reduction in their diabetes-related burden as measured by the "Diabetes Distress Scale" (DDS). The "Diabetes Technology Impact Measure" (DTIM) measure, which was also used, provides evidence of a reduction of diabetes-related stress, as 72.5% of respondents indicated that their perceived control over diabetes improved, and 50.6% reported feeling safer regarding hypoglycemia. However, in a study with a simple PP (PaQ), Hermanns et al. [43] found no effect with the "Problem Area of Diabetes" (PAID) questionnaire, which also measures diabetes-related stress.

3.3. Barriers to insulin treatment

Regarding barriers to insulin therapy, Hermanns et al. [43] and Mader et al. [47] reported mixed results, which might be due to the small samples used. While the fears of insulin therapy due to the PP were reduced in the "Barriers to Insulin Treatment" (BIT) questionnaire ($p < 0.01$) , this was not the case in the "Insulin Treatment Appraisal Scale" (ITAS) ($p = 0.14$) [43]. However, in the subsequent study by Mader et al., the results of the BIT did not show a statistically significant difference [47].

3.4. Treatment satisfaction

Using the "Diabetes Treatment Satisfaction Questionnaire" (DTSQ), Mader et al. demonstrated a significant effect ($p < 0.005$) in the study already mentioned [42]. In contrast, Lebenthal et al. could not detect any effect in a randomized study of a PP versus a conventional insulin pump also measured with the DTSQ [48]. There was also no difference in overall satisfaction with the device between the PP and the conventional pump. Bohannon et al. used the "Insulin Delivery System Rating Questionnaire" (IDSRQ) and found a significant effect in five of six subscales [44]. A similar conclusion was reached by Peyroth et al., who compared a bolus PP with previous therapy (syringe, pen, or conventional pump) [49]. Overall, there were superior results when comparing the PP to syringe or pen therapy but no major differences when compared to previous conventional pump therapy. Using a self-developed questionnaire, Mader et al. concluded that users of the PaQ pump are very satisfied and like it [42]. Bergenstal et al. reported a significant effect of PPs in terms of overall satisfaction ($p < 0.01$), but only one significant advantage for PP in the ITAS, namely satisfaction with ease-of-use ($p < 0.001$), while the other dimensions did not differ significantly [45].

3.5. Patient preference

In the study by Layer et al., users of PPs primarily stated not wanting to be tethered to a tube (86.4% of the previous CSII treatment group) and wanting to get better glycemic control (24.1% of the previous CSII treatment group) [50]. The authors were able to replicate this in an evaluation of the T1D Exchange Glu Online community. The most important reported benefits of choosing a PP were lifestyle improvements (85%), better glucose control (73%), lower HbA1c (60%), and the ability to exercise more (50%) [51]. In a similar retrospective study of people with T2D, the main reasons for switching the therapy to PP were better glycemic control (25%), not wanting to be tethered to tubing (24%), no inconvenient injections (16%), and greater flexibility in eating and exercise compared to MDI (12%) [52]. In the study of Bohannon et al., 76% would prefer the bolus PP after the trial [44], and Peyroth et al. reached similar conclusions in comparison with syringe and pen therapy [49]. PP vs. syringe was significantly in favor of PP (78% vs. 22%) ($p < 0.001$); PP vs. pen was significantly in favor of PP (76% vs. 24%) ($p < 0.001$). However, in comparison with the conventional pump therapy (PP vs. pump (52% vs. 48%) no significant difference was observed. After the end of the study of Bergenstal et al., more participants wanted to switch from pen to PP, but there was no preference for PP in any of the other 6 items of the questionnaire [45]. In a randomized cross-over trial between a PP and a conventional pump, 43% of young adults who participated in the study would have chosen the PP [48] and also in the study by Zisser and Jovanovic, after 30 days of experience with a PP, 90% of the users of a conventional pump would have chosen to switch to the PP long-term [53].

4. Discussion

PPs are becoming increasingly popular with PwD and a variety of new models can be expected to come to the market in the near future, addressing a wide range of patient needs. The selection of PPs is highly dependent on the goal of therapy, ranging from a simple replacement of MDI therapy to use in AID systems. In particular, for children with T1D, the small size, low weight, reduced risk of interrupted insulin delivery due to no tubing, ease of use, and, above all, the minimization of the risk of problems due to the IIS, which is a source of concern especially in children, are significant. Young people particularly appreciate the small size of the PP and the ability to wear it discreetly on different parts of the body. For individuals with T2D, simple PPs, e.g., with a fixed basal rate or standard fixed boluses, can reduce the effort of therapy and potentially minimize the diabetes-related burden. Other specific indications for PP can be people with high insulin needs or insulin resistance.

However, insulin delivery by family members or caregivers with a PP may also be conceivable in the elderly. The comfort of wearing PPs, the absence of IIS, and the interoperability with other devices are further arguments in favor of their use in AID systems.

In view of these many potential benefits of PP for patients, who ultimately decide on the form of therapy and the device, it is surprising that there have been relatively few studies investigating PROs with the different PPs to date.

In the systematic literature search, only 12 respective publications could be identified, referring to 11 studies with mostly weak methodological quality: Overall, the analysis refers to only three randomized controlled trials, which are more robust against bias. However, PROs were not the primary end point in two of the three RCT-studies [44,45], and in one study it remains unclear from the publication because three end points are mentioned but no power analysis was performed to estimate the required sample size for a significant effect [48]. An estimate of the significance level of PROs is important because they are known to often have lower effect sizes than glycemic outcomes [54]. It is also important for the methodological quality of the studies to indicate, in accordance with the Cochrane recommendations [55], how the respective studies deal with the risk of bias (e.g. selection, performance, detection, attrition bias) in the results, which could over- or underestimate the intervention effect. The present studies do not address potential biases or report strategies for dealing with confounding factors. All other studies [42,43,46,47,49–51,53] have a very limited validity because they do not test the effect of PP against a control group. Therefore, no statement at all can be made about other confounding factors. Moreover, in most studies the sample size is far too small to detect differences in PROs. Self-constructed, non-validated questionnaires were also commonly used. Especially for the investigation of the most frequently studied question of patient preferences, well-established and methodologically better methods such as the Analytic Hierarchy Process, the discrete choice experiment, or conjoint analysis are available [56].

However, taking into account these serious methodological shortcomings, the analysis of the 12 studies provides some evidence that the use of PPs improves quality of life and treatment satisfaction, and that PwD typically prefer PPs compared to MDI and conventional pumps. For the future, it is important to conduct methodologically better designed studies to obtain scientifically more sound data with respect to PROs when using PPs. This includes randomized studies with a control group design and PROs as primary endpoint, as well as the use of representative samples from different patient groups and studies with multiple measurement time points to investigate the stability of PROs [57].

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Declaration of Competing Interest

In this article the respective conflicts of interest are given.

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