Systematic review: free flaps for lower limb reconstruction in children

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Promotor : Prof. dr. K. Van Landuyt

Masterproef voorgedragen in de master in de Plastische, Esthetische en Reconstructieve heelkunde
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Preface

Being a father of two beautiful daughters and having a wife being a pediatrician made me even more aware of the importance of children. The least you can say is that they should not be treated as miniature adults.

I want to thank my family for all their support. In first place my wife Sophie for her daily support in everything I do. Next my two daughters, Alixe and Olivia, to be my everyday sunshine’s. I also want to thank my father and mother who already support me for over 3 decades.

Last but not least I want to thank my staff members of the service of Plastic Surgery and my colleagues.
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Abstract

Background
Since the first reports on microsurgery in children, there has been an evolution in the reconstruction of soft tissue defects of the extremities. This caused a shift to the use of free flaps as a primary choice for complex soft tissue defects.

Objectives
Identify 1) different free flap options for lower limb reconstruction in children; 2) complication rates of the different free flap reconstructions and 3) amount of secondary procedures needed for each of the free flap reconstructions.

Data sources
A Pubmed database search was performed according to the PRISMA guidelines [1].

Study eligibility criteria, participants and interventions
Inclusion criteria were articles with an adequate study design reporting on children (0–18y) who underwent lower limb reconstructions with a free flap. The articles should include the complication rate and the need for secondary procedures.

Results
The latissimus dorsi (LD) flap was the most frequently used flap in this systematic review. Its characteristics made this reconstructive option a first choice for lower limb reconstruction. Nowadays, with the evolution to perforator based flaps, the anterolateral thigh (ALT) flap is the first choice. Other reconstructive options have to be chosen on a case-by-case basis and depending on the experience of the surgeon.

Limitations
The most important limitation is the fact that most articles include a heterogeneous patient population: 1) in most articles the study population consisted of both adults and children; 2) some authors included patients with a variety of different defect etiologies (e.g. trauma, tumor, congenital defects); and 3) other articles failed to focus on specific anatomic regions.

Conclusions and implications of key findings
The paucity of well designed, homogenous studies addressing lower limb reconstruction with free flaps in children makes it very challenging to draw conclusions from this systematic review. Therefore more adequate studies specifically concerning free flap reconstructions for lower limb defects in children are necessary in the future.
Introduction

Rationale

Road traffic accidents and crush injuries are the most frequently reported causes of extensive lower limb trauma in children. Regarding the timing of surgery, Godina’s work recommended early (within the first 72 hours) microvascular reconstruction of the complex extremity injuries after aggressive debridement and fracture stabilization. This immediate, functional wound closure results in a decreased wound morbidity and prevents the adverse effects of prolonged open wound treatment like higher rates of infection, flap loss, and delayed bone union [2]. Since then, there has been a large paradigm shift in timing of extremity free-flaps. Recent outcome studies have shown that the timing of flap coverage is not as critical as previously believed, with good results even with coverage extending to day 28 after injury [3-7]. A review by Kolker et al. concluded that the timing of reconstruction had no influence on the ultimate outcome [8].

Traditionally, the reconstructive ladder for soft tissue defects of the extremities was a useful guide, but the evolution of microsurgery and increased knowledge of anatomy have made free flaps easier to approach and an efficient and reliable choice. It is often regarded as the primary choice for complex soft tissue defects [9, 10].

The first reports concerning microsurgery in children were in the mid-1970s by Harii et al. [11] and Ohmori et al. [12]. There is no substantial difference in the basic principles of microvascular transfers between adult and pediatric patients, but children should not be treated as miniature adults. The absence of associated diseases and other comorbidities in children (e.g. atherosclerosis, diabetes mellitus, hypertension, smoking, alcohol or drug abuse, …) also increases the functional reserve of these young patients. They tolerate longer operative periods and have a better wound healing and functional recovery compared to adults. The anatomy of children is clearly defined, often unscarred and previously unaltered. Their donor sites for free flaps are particularly scarce because of the need for a long and reliable vascular pedicle of sufficient size. Another difficulty is the length of the pedicle in regards to the recipient vessels. For extensive defects in the leg, it is difficult to expose major vessels and, frequently, a major vessel is sacrificed to anastomose to the flap. However, using small branches from the major vessel or using a perforator as a recipient vessel may prevent the sacrifice of major vessels [13]. It was reported that a supermicrosurgery approach for lower extremity reconstruction in a perforator-to-perforator anastomosis may have the same success without sacrificing major vessels and may further reduce the time of operation by
minimally dissecting the vessels for the flap and recipient site. It has been demonstrated that free tissue transfers can be performed with acceptable morbidity in children [14, 15]. The introduction of new instruments and techniques, and the accumulation of microsurgical experience, has led to high success rates and good results in pediatric free flap reconstruction [16-18], [19], [20], [21], [22]. Atraumatic dissection should avoid excess adventitia excision, which is one of the etiologic factors of vasospasm. Venous insufficiency, which is a major cause of flap loss in lower-extremity reconstruction in elderly patients, is usually not present in children. Vessels are normal [23], [24] although it was once considered a challenge because of their small size and the tendency for vasospasm [25], [26], [23]. Van Landuyt et al. showed that the size of the pedicle vessel in children is larger than in adults in relation to their body size [22]. Parry et al. [23] speculated that the under-developed muscularis layer in the vessels of children might be responsible for a less clinically relevant vasospasm. Serletti et al. [27] reported that vessel characteristics of older children, aged between 13 to 17 years, were closer to those of adults. Yucel et al. [16] demonstrated the same findings in their patients, as the vessel walls were thicker and more elastic in the older children, while they were translucent and had a gelatinous consistency in younger ones.

Another potential problem related to pediatric reconstructive surgery is the growth and functional recovery at the donor and recipient sites. In most pediatric patients, the musculoskeletal system continues to grow after surgery and the possibility of contracture always remains. But earlier reports observed that the growth pattern in these patients is within the normal range [27-30]. Chiang et al. found no obvious difference in growth rate between skin flaps, muscle flaps with split thickness skin graft, and myocutaneous flaps [31].

It has been observed that children demonstrate fewer tendencies for recurrent ulceration on weight-bearing surfaces, and this may be attributable to their capacity to learn new weight bearing habits during rehabilitation [32].
Objectives
Framing questions for the systematic review on children (age 0-18y):

1. Which are the different free flap options for lower limb reconstruction in these children?
2. What is the complication rate in lower limb reconstruction in children for each of those free flaps?
3. What amount of children underwent secondary procedures after lower limb reconstruction with free flaps?

Methods
To capture as many relevant citations as possible, a Pubmed database search was performed. Patients included were pediatric patients aged between 0 and 18 years old who underwent a lower limb reconstruction with a free flap for a soft tissue defect after trauma, tumor, infections or other reasons. The studies included were case-reports, meta-analyses, randomized controlled trials, reviews and systematic reviews. These relevant articles should include information concerning the age and gender of the patient, the used method of reconstruction, the period of follow-up (which should be at least one month), post-operative complications and secondary procedures. The first articles included were the first reports on microsurgical procedures for lower limb reconstruction in children. The last literature search was performed on March 1st 2017. This creates an extensive period of 40 years where pediatric patients were included and results in a higher risk for bias. The relevant citations chosen were written in English, French, German and Dutch.

A literature search with the keywords “lower limb reconstruction”, “children” and “free flaps” resulted in 311 citations from which relevant studies were selected for the systematic review. These records were screened if they were actually reporting on the subject chosen. This screening resulted in the exclusion of 148 articles as irrelevant.

In the next phase, the full-text articles of the remaining 163 citations were assessed for eligibility. Inclusion criteria were articles with an adequate study design reporting on children (0–18y) who underwent lower limb reconstructions with a free flap. The articles should include specific information about the patient and the procedure: age, gender, flap dimensions, complications and secondary procedures.
Exclusion criteria were 1) articles not reporting in English, French, German and Dutch; 2) articles reporting on other methods of lower limb reconstruction like local flaps, pedicled flaps,…. and 3) articles not including specific information about the procedure like complications and secondary procedures. These eligibility criteria excluded another 96 studies.

Figure 1: flow chart according to the PRISMA guidelines [1, 33].
Results
This systematic review provides an overview of the different reconstructive options for lower limb reconstruction with free flaps in the pediatric population.

Latissimus Dorsi (LD) flap (Table 1 p. 25)
Iwaya et al. [34] described the use of the latissimus Dorsi (LD) flap in 2 children with an avulsion injury of the foot. One flap survived completely and in 1 flap there was a superficial necrosis which needed a split thickness skin graft (STG).

Banic and Wulff described the use of a LD flap for the reconstruction of the lower leg, the ankle or dorsum of the foot in 15 patients [26]. All reconstructions were performed within 7 days. The post-operative period was uneventful in 13 patients. 2 flaps needed revision due to an arterial problem with partial loss of 1 flap.

Parry et al. [23] used the LD flap for the reconstruction of 3 lower limb defects. No post-operative complications developed during follow-up.

Shapiro et al. [35] used the LD flap for the reconstruction after trauma of the lower limb in 8 children. 2 patients developed a deep wound infection in the operated region which needed antibiotic treatment and caused a longer stay in the hospital. One patient even experienced a partial (50%) failure of the STG.

Serletti et al. [27] described 20 free tissue transfers for lower limb reconstruction in 19 pediatric patients. In 7 patients, a free LD flap was used to reconstruct the defect. All free tissue transfers were successful without partial flap losses. Over a mean follow-up period of 31 months, almost all patients demonstrated normal skeletal growth.

Chiang et al [31] reported on 25 free tissue transfers performed in 23 children for reconstruction after lower limb trauma or release of scar contractures. 15 patients underwent a reconstruction with a 17 free LD flaps for the reconstruction of soft tissue losses at the distal tibia, ankle or foot. No post-operative complications occurred. In twelve patients, the soft tissue defect was associated with other major injuries before reconstruction with a LD flap. 2 patients experienced a partial loss of the flap, in one case due to venous obstruction which needed salvage. One flap had to be replaced by a new free flap. One patient lost the STG due to infection. One donor site hematoma occurred.

Kaplan et al. used 3 free LD flaps for the reconstruction of 3 lower limb defects after a traffic accident with 2 boys [36]. No post-operative complications were described.

Erdmann and colleagues reported on 16 children with lawnmower injuries [37]. 4 of the lower limb injuries needed reconstruction with a free LD flap. One flap needed revision of the
venous anastomosis and another patient had a seroma of the donor site. All patients could ambulate 3 months after admission.

Kuran et al. used a free LD flap combined with an STG for the reconstruction of a crush avulsion injury of left foot. 14 years after surgery, a significant growth retardation was described.

Yucel et al. [16] reported on 7 free-tissue transfers for lower limb reconstruction. One patient received a LD flap for the reconstruction of an electrical burn injury. No post-operative complications nor adjunctive procedures were reported.

Gonzalez et al. described the use of the LD flap in the reconstruction of an ankle defect due to a motor vehicle accident in a 7-year-old boy [38]. There were no post-operative complications nor partial or complete flap loss described.

Duteille et al. [17] used the LD flap in combination with a free serratus flap for the reconstruction of a leg defect. No complete or partial failure of the flap was reported.

Lickstein and Bentz [18] described the use of two free LD flaps for the reconstruction of a lower leg injury. Due to the dusky appearance of one flap, the STG was delayed. The other flap needed an anastomotic revision with partial failure of the flap with conservative treatment.

Ozkân et al. described a case report of an 8-year-old female with a crush and avulsion injury of both the proximal and distal parts of the lower extremities caused by a vehicular accident. A flow-through functioning musculocutaneous free flap was used to reconstruct the defect. The flow-through flap concept was first utilized by Soutar and colleagues [39]. With using a functioning muscle transfer, the ankle-joint active dorsiflexion was restored.

Germann et al [40] described the use of a musculocutaneous LD flap for the reconstruction of the dorsum of the foot after resection of a congenital malignant fibrosarcoma. No complications were described.

Yıldırım et al [21] described 12 free flap reconstructions due to various etiologies (congenital defects, trauma and tumor resection). 3 reconstructions were executed with a free LD muscle flap and all three flaps survived. No further information was available regarding other post-operative complications.

Hallock described the use of a free LD flap in combination with a parascapular flap in a 12-year-old boy who sustained a hunting accident [41]. No post-operative complications occurred.

Bouffaut et al. [42] used 12 muscle flaps for the reconstruction of lower limb defects. 4 of them were LD flaps. No complications nor secondary procedures were described.
Namdar et al. [43] reported on the use of 14 LD flaps used for the reconstruction of lower limb defects in 11 children. 93% of the flaps needed revision (4 major revisions and 9 minor revisions) which resulted in the complete loss of 3 and the partial loss of 1 flap.

Wechselberger et al. [44] reported on a 7-month-old boy who sustained an extensive soft-tissue defect of the left knee. A free LD flap reconstruction was performed. Post-operative, there was a dehiscence between the skin edges and the muscle over the patella. This was managed by mobilizing the skin of the lower thigh.

Vankatramani et al. [45] reported a series of 32 free flaps for cover of complex injuries of the knee involving the distal femur, the knee joint and the upper tibia. All defects were reconstructed using the descending genicular branch of the femoral artery in the adductor canal and its muscular branches to the vastus medialis as the recipient vessels. 3 patients were children between 6 and 15-year-old who had a reconstruction with a free LD flap. One flap suffered from an arterial thrombosis and could not be salvaged. The defect was later reconstructed with a cross leg flap.

Rednam and Rinker reported on an 8-year-old child who sustained a severe crushing injury when he fell off a tractor [46]. The posterior muscle compartments and overlying skin were reconstructed with a free LD musculocutaneous flap. To provide a functional muscle transfer, a branch of the tibial nerve to the absent soleus muscle was identified and coapted to the thoracodorsal nerve. The muscle was inset proximally to the remaining stump of the medial and lateral gastrocnemius muscle and distally to the Achilles tendon at functional resting tension.

Thoracodorsal Artery perforator (TDAP) flap (Table 2 p. 27)
The Thoracodorsal Artery Perforator (TDAP) flap was originally described by Angrigiani et al. in 1995 [47] as a method for diminishing the volume of the conventional latissimus dorsi myocutaneous flap.

Van Landuyt et al. [22] described the use of the TDAP flap for the reconstruction of major soft-tissue defects of the lower limb. 11 patients had a reconstruction with 12 TDAP flaps: two of them were sensate, 6 had a chimeric flap (1 bilateral) and 1 was combined with the latissimus dorsi and serratus muscle. Complications were the following: one wound dehiscence which needed closure, one flap needed an arterial revision, the bilateral case had a bilateral wound dehiscence and the patient received a shortening of the metatarsal heads, one patient had an ongoing necrosis which was treated with cross-leg, gastrocnemius and fasciocutaneous flap. Five years later, a bipedicled Deep Inferior Epigastric Artery Perforator flap was used.
(DIEAP) flap was performed in the same child for aesthetic reasons, to improve the contour defect of the lower leg. There was one total failure which resulted in a lower leg amputation. Lee et al. described the use of 10 TDAP flaps for the reconstruction of various wounds of the lower extremity. These was 1 total flap loss due to arterial insufficiency. Besides that complication, there was 1 venous revision and 1 donor wound dehiscence.

**Free radial forearm (FRFA) flap (Table 3 p. 28)**
The radial forearm flap, first described by Yang et al. in 1981 [48], is a fasciocutaneous flap supplied by the radial artery.

Serletti et al [27] described 20 free tissue transfers for lower limb reconstruction in 19 pediatric patients. 6 patients had a reconstruction with a free neurosensorial radial forearm flap. All free tissue transfers were successful with no partial or complete flap losses. Over a mean follow-up period of 31 months, almost all patients demonstrated normal skeletal growth. In two of the patients, a tissue expander was immediately placed under the intact dorsal skin for subsequent removal of the skin-grafted donor site.

Kaplan et al used a free radial forearm flap for the reconstruction of a foot injury in a 14-year-old boy after a traffic accident [36]. No post-operative complications occurred.

Weinzweig and colleagues used the free radial forearm flap for the reconstruction of a foot and ankle injury in 3 children [49]. No post-operative complications were described.

Yucel et al. used a neurosensorial free radial forearm flaps for the reconstruction of a sole or heel defect in 3 children [50]. 2 foot ulcers developed post-operatively.

For the reconstruction of an avulsion injury of right heel and an unstable postburn wound of left heel Kuran et al. used a sensate free radial forearm flap [51].

Yucel et al. [16] described 4 children who underwent a lower limb reconstruction with a free radial forearm flap, 3 of them were neurosensorial. One flap needed revision, but survived completely.

**Lateral arm flap (Table 4 p. 28)**
In 1982, Song et al. [52] introduced the lateral upper arm free flap (LAFF). Shapiro et al [35] were the only authors describing the use of a lateral arm flap for the reconstruction of an unstable scar in a 7-year-old boy. There were no complications, partial or total flap failures described.
**Scapular flap (Table 5 p. 28)**
This free flap, which is based on the cutaneous branch of the circumflex scapular artery, was first described by dos Santos in 1980 following and was later clinically performed by Gilbert and Teot [53].
Parry et al. [23] used a scapular flap for the reconstruction of a defect on the heel in a 14-year-old girl. No post-operative complications developed during follow-up.
The scapular flap was used by Shapiro et al [35] for the reconstruction of the foot of an 4-year-old boy after failure of a posterior medial release. Besides a dehiscence no other complication was described.
Serletti et al [27] described 20 free tissue transfers in 19 pediatric patients. 1 patient had a reconstruction with a scapular fasciocutanous flap. This free tissue transfer was successful without partial or complete flap loss. The patient needed 2 separate debulking procedures to obtain a normal contour following excess weight gain. Over a mean follow-up period of 31 months, the patient demonstrated a normal skeletal growth.
Erdmann and colleagues [37] reported on 16 children with lawnmower injuries. One of the children had a free scapular flap reconstruction for a calcaneal defect. Besides a hematoma of the flap, there was no flap loss reported.
Saito and colleagues described the use of a combined osteocutaneous scapular-parascapular flap for the reconstruction of an ankle defect after resection of a soft-tissue or osteosarcoma at this region [54]. The patient had a very good results on post-operative skin contour, ankle stability and mobility and toe function. Unfortunately the patient needed an amputation due to recurrence.

**Parascapular flap (Table 6 p. 29)**
Nassif et al. first described the vascular anatomy of the parascapular flap and the possibility of combining it with a scapular flap, which were nourished by the transverse and vertical branches of circumflex scapular artery [55]. Koshima and Soeda used the combined scapular/parascapular flap to reconstruct the wide defect of the lower leg [56].
Morghari et al. [28] reconstructed 4 extensive cutaneous defects of the lower limb with expanded parascapular free flaps. Measurements indicated an approximate doubling in skin area. A normal growth of the affected limbs and no donor site morbidity were reported.
Hallock described the use of a free latissimus dorsi flap in combination with a parascapular flap in a 12-year-old boy who sustained a hunting accident. No post-operative complications occurred.
Saito and colleagues described the use of a combined osteocutaneous scapular-parascapular flap for the reconstruction of an ankle defect after resection of a soft-tissue or osteosarcoma at this region [54]. The patient had a very good results on post-operative skin contour, ankle stability and mobility and toe function. Unfortunately the patient needed an amputation due to recurrence.

Rectus abdominis muscle/myocutaneous flap (Table 7 p. 29)
Latissimus dorsi and gracilis free flaps have been used extensively for lower limb reconstruction. The rectus abdominis muscle/myocutaneous flap provides a suitable alternative for the reconstruction of sternal or other chest-wall defects, but it has a very limited use in lower limb reconstruction as shown in literature.

Serletti et al. [27] described 20 free tissue transfers for lower limb reconstruction in 19 pediatric patients. In 3 patients, a free rectus flap was used to reconstruct the defect. All free tissue transfers were successful without partial flap losses. Over a mean follow-up period of 31 months, almost all patients demonstrated normal skeletal growth.

Gonzalez et al. described the use of one free rectus flap for the reconstruction of a chronic wound of the lower leg in a 18-year-old patient [38]. The patient developed a local osteomyelitis. There was no partial or complete flap loss described.

Bouffaut et al. [42] used 12 muscle flaps for the reconstruction of lower limb defects. 1 was a free rectus abdominis flap. No complication nor secondary procedure was described.

Deep Inferior Epigastric Artery Perforator (DIEAP) flap (Table 8 p. 29)
The DIEAP flap was first described by Koshima and Soeda [57] as “inferior epigastric artery skin flap” in 1989.

Van Landuyt et al. [22] described the use of the DIEAP flap for the reconstruction of major soft-tissue defects of the lower limb. 6 patients had a reconstruction with the DIEAP flap and experienced the following complications: Arterial revision (1), partial failure which needed debridement and advancement of the flap, a small wound dehiscence/necrosis (2) and a superficial partial failure (1).

Grinsell et al [58] described a pre-expanded, bipedicled free ‘stacked’ DIEAP flap. This was done with osmotic self-inflating tissue expanders to reconstruct a 26 x 19cm defect. The post-operative period was uneventful.
Superficial Inferior Epigastric Artery Perforator (SIEAP) flap (Table 9 p. 30)
In 1991, Grotting refined his technique to describe the superficial inferior epigastric artery (SIEA) flap for breast reconstruction.

Van Landuyt et al. [22] described the use of the Superficial Inferior Epigastric Artery Perforator (SIEAP) flap for the reconstruction of major soft-tissue defects of the lower limb. 2 patients had a reconstruction with 3 SIEAP flaps. One patient had a small wound dehiscence which was treated conservatively.

Groin flap (Table 10 p. 30)
McGregor and Jackson were the first to describe the vascular basis of the groin flap [59]. The microvascular transfer of the groin flap was first reported in 1973 by Daniel and Taylor [60]. Over time, its use has gradually declined, partly because of technical difficulties such as a variable vascular origin, narrow-caliber vessels, and the development of other donor sites.

Harii and Ohmori [11] were the first to describe the use of the free groin flap for the reconstruction of the lower limb in two four-year-old children. In one case the flap was used for the reconstruction of a laceration due to a traffic accident. The second child had a free groin flap reconstruction as a replacement for a thick scar due to a laceration a year earlier. No post-operative complications were described.

Baudet and colleagues used the free groin flap for the reconstruction of 2 lower limb injuries. Both children sustained a traffic accident and the resulting lower limb defects were reconstructed with a free groin flap. No complications were described.

Iwaya et al [34] described the use of the groin flap in 5 children with an avulsion injury of the foot. 2 patients had an uneventful post-operative period, a thrombectomy was needed in one patient and a partial necrosis of the distal part developed in 2 patients.

Chiang et al [31] reported on 25 free tissue transfers performed in 23 children for reconstruction after lower limb trauma or release of scar contractures. 5 groin flaps were used for the reconstruction and all flaps survived. In three flaps, the superficial epigastric vessels were included and were also anastomosed to decrease the risk of vascular insufficiency.

Duteille and colleagues [17] described the use of the free groin flap for the reconstruction of a lower limb soft-tissue defect. A partial necrosis of the flap developed post-operatively.
Antero Lateral Thigh (ALT) flap (Table 11 p. 31)
The Antero Lateral Thigh (ALT) flap was first described by Song et al. [61]. The flap has gained popularity as a versatile and reliable option for soft tissue reconstruction. In the article of Segev et al. [62], 7 children underwent a reconstruction of lower extremity defects, using a combination of a free vascularized flap and an external fixator. Two patients underwent 3 ALT fasciocutaneous flap reconstructions (one for soft tissue and bone avulsion due to a lawnmower injury, and another for severe burn contractures of both feet). Well-established free flaps can withstand bone transfer and limb lengthening if they are located below the active lengthening zone [19, 63, 64]. There were no flap failures.

Of the 12 free flap cases described by Yildirim et al. [21], there was only one free ALT flap. There was a complete survival of the flap.

Demirtas and colleagues [65] described 5 car tire injuries on the dorsal foot which were reconstructed with a free ALT-flap: 4 immediate after initial debridement and 1 delayed reconstruction. Only one artery and one vein were anastomosed to vascularize each flap. All of the flaps survived completely. One of the flaps required re-exploration due to hematoma formation and patient encountered a wound infection which was managed with administration of parenteral antibiotics. There was a hematoma in one patient and an infection in another. In contrary to free perforator flaps, muscle flaps are criticized for the bulkiness that disturbs the contouring of the foot and constraining the patient to wear custom-made shoes [27, 31, 66-68]. In this study, contour adaptation was good in all of the flaps and none of the patients required custom shoe wear or any type of debulking procedures.

Gharb and colleagues [69] presented 8 ALT flap reconstructions in children for lower limb reconstruction. All flaps were commonly raised on 2 perforators. There were no complete flap losses and no significant donor-site morbidity.

Acartürk reported the case of an 11-year-old girl who underwent a reconstruction with a femur-vastus intermedius-anterolateral thigh osteomyocutaneous chimeric free flap based on the descending branch of the lateral femoral circumflex artery (LCFA) for the reconstruction of a complex composite defect of the lower extremity. The post-operative period was uneventful and the patient was ambulating almost normally one year after surgery.

El-Gammal et al. [70] reported on their experience using the free ALT flap for reconstruction of soft tissue defects over the dorsum of the foot and ankle in 42 children. The authors reported that all of the flaps were vascularized by at least two perforators. 88.23% were musculocutaneous and 11.77% were septocutaneous perforators. Initial thinning was performed in five flaps and 35% required subsequent debulking. About 41% of donor sites
were closed primarily while 59% required skin grafting. Primary flap survival rate was 92.8% (39/42 cases). Three flaps showed venous congestion. After venous reanastomosis, two flaps showed partial loss and one flap was lost completely.

Vankatramani et al. [45] reported a series of 32 free flaps for cover of complex injuries of the knee involving the distal femur, the knee joint and the upper tibia. 2 of them were children who underwent a reconstruction with a free ALT flap combined with the vastus lateralis muscle. There was no complete or partial flap failure.

Acar et al. [71] described the use of the ALT flap in 11 patients for the reconstruction of foot and ankle defects. The flap was used as a “sensate” flap in the heel area of three patients and as a “perforator” flap in seven patients. Full flap survival was observed in all patients. Due to venous thrombus after 24 hours in one patient, reexploration was performed, and blood flow was regained with a vein graft. In the same patient, because partial necrosis developed on the lateral edge of the flap after debridement of the necrotic areas, closure was performed with a split thickness skin graft.

**Gracilis flap (Table 12 p. 32)**
The gracilis flap was first described by Bartholdson and Hulten in 1975.

Parry et al. [23] described the use of 9 free gracilis flaps for the reconstruction of lower limb defects. No post-operative complications developed during follow-up.

Chiang et al [31] reported on 25 free tissue transfers performed in 23 children for reconstruction after lower limb trauma or release of scar contractures. 3 patients underwent a reconstruction with a free gracilis flap for the reconstruction of soft tissue losses at the distal tibia, ankle or foot with other major injuries. No post-operative complications were reported.

Yucel et al. [16] reported on 7 free-tissue transfers for lower limb reconstruction. One patient had a reconstruction with a free gracilis flap for the reconstruction of a heel defect. Post-operatively, the patient developed a wound infection.

Lorea et al. used 2 gracilis flaps for the reconstruction of a lower limb defect in two children of 9 and 11-year-old [71, 72]. No post-operative complications were reported.

Lickstein and Benz [18] described the use of seven free gracilis flaps for the reconstruction of a lower leg injury. Complications were: an anastomotic revision with partial loss of the flap (conservative management), a fever hematoma, hypertrophic scarring and an ureteral obstruction.
**Profundal Artery Perforator (PAP) flap (Table 13 p. 32)**
The main indication for the posteromedially based profunda artery perforator flap is a breast reconstruction [73-75]. Profunda artery perforator flaps, described as adductor flaps, have also been reported for lower extremity and burn reconstruction, with praise given for their sizable vessel caliber and large perfusion territory [76, 77]. In these kind of reconstructions, a vertical or longitudinal design is favored, which provides versatility, minimizes the pull of gravity on the incision, and offers the ability to choose from a number of perforators [78]. Mayo et al. [78] reported on six soft-tissue defects that were covered with a vertically oriented profunda artery perforator flap. 2 of them were lower limb reconstructions in children. No flap complications were encountered, including operating room take-back and partial and full flap losses. One child needed minor flap debulking.

**Peroneal artery perforator flap (Table 14 p. 32)**
The peroneal flap was first reported by Yoshimura et al. in 1984 [79].
The report of Ozkan and colleagues describes the results of free peroneal artery perforator flaps used to cover soft tissue defects in the distal leg and foot area in nine patients. 2 of them were children. No complications were reported.
Discussion

Summary of evidence
There are 14 types of free flaps that are reported in literature for reconstruction of lower limb defects in children:

1. Latissimus dorsi flap (Table 1 p. 25)

There were 88 children, aged between 15 weeks and 17 years, who underwent a reconstruction with 91 free latissimus dorsi muscle or musculocutaneous flaps. This was the largest group of children in this systematic review and is a reflection of the literature where the latissimus dorsi muscle and rectus abdominis muscle flaps are reported to be the most commonly used vehicles in pediatric microsurgical reconstruction [15, 19, 80, 81]. The latter could not be confirmed for lower limb reconstruction with only 5 patients. The microvascular transfer of the latissimus dorsi muscle or musculocutaneous flap is perhaps the most reliable of all free-tissue transfers for the lower extremity [82, 83]. In comparison with perforator flaps, the latissimus dorsi flap offers a large amount of tissue (it is the largest flap that can be transferred which was confirmed in this systematic review with surface area’s up to 750cm²), a constant vascular anatomy enabling straight forward dissection and long (average 9cm) and high-caliber vessels (2.5-4.0mm) combined with a low morbidity at the donor site. The latter because it can be sacrificed without significant loss of strength of the upper extremity. If the motor nerve is sutured, these flaps can have a functional muscle. Less attention was paid to the eventual cumbersome bulkiness if the flap was used as a myocutaneous flap. In this systematic review, the reconstructions resulted in a 32% complication rate. A total loss of 3 flaps (3% of total amount of flaps) and a partial loss of 4 flaps (4% of total amount of flaps) were reported. These results confirmed that the use of the latissimus dorsi flap is a safe option. One third of the flaps needed secondary procedures. The need for repositioning the patient during surgery to harvest the flap is a drawback for this reconstructive option.

2. Thoracodorsal artery perforator flap (Table 2 p. 27)

The group of children, aged between 6 months and 17 years, who underwent a reconstruction with a free TDAP flap was less extensive with 21 pediatric patients included. The same area of skin and subcutaneous tissue island can be harvested without the muscle, using the perforator-flap technique. This flap dissection is reported to be much more time consuming and demands a tedious and risky transmuscular perforator dissection, prolonging operating
time and leading to a higher complication rate [22]. This was reflected in the results of this systematic review with a complication rate of 38% and a total loss of 2 flaps (9.5% of total amount of flaps). 24% of the flaps needed secondary procedures. In some cases where lack of sufficient skin is critical (e.g., in meningococcal sepsis), it has the advantage being the second largest skin flap amenable to primary closure. TDAP flaps show superior results by leaving scars accompanied by less contour deformity, in relatively hidden areas. An additional advantage is its possible use as a compound flap, to augment even further the size of the flap or, if indicated, to harvest specialized tissue based on the same pedicle. The flap can be reinnervated through the intercostal branches to provide for sensate flaps if necessary. Conventionally the free TDAP flap has been orientated vertically along the long axis of the latissimus dorsi muscle, i.e. along the course of the descending branch of the thoracodorsal artery. The traditional donor scar of the TDAP flap runs perpendicular to the relaxed skin tension line (RSTL) of the back, and thus frequent scar widening and hypertrophy have been problems, especially in Orientals. Lee et al. described the use of a transverse design in a free TDAP flap [84]. Like the LD flap, the need for repositioning the patient during surgery to harvest the flap is a drawback for this reconstructive option.

3. Free radial forearm flap (Table 3 p. 28)

There were 13 male and 3 female pediatric patients, aged between 3 and 16 years, who underwent a reconstruction with a free radial forearm flap. The complication rate was 16% (3 out of 19 flap reconstructions). Although there were revisions described, there were no total or partial flap failures. 16 percent of flaps needed secondary procedures. Although these results seem to make this flap an excellent option for lower limb reconstruction because it can be combined with bone [39, 85, 86], tendons [86] or cutaneous nerves [85-87], we must keep in mind that use of the forearm flap results in a cosmetically unacceptable appearance of the donor site and the sacrifice of a main artery to the hand, which could lead to functional impairment. Therefore, this flap should not be used as a first choice option in children.

4. Free lateral arm flap (Table 4 p. 28)

There was only one author describing the use of a lateral arm flap for the reconstruction of an unstable scar in a 7-year-old boy. There were no complications, partial or total flap failures described. The flap can be used in a variety of anatomical reconstruction procedures for areas because it is a thin, soft, and sensory tissue flap that offers a suitable amount of tissue and
color for reconstruction as well as low morbidity at the donor site. The drawback of this flap is the fact that it is only advantageous for smaller defects (< 6cm) but inadequate for larger defects where it results in a conspicuous skin grafted donor site. Like the free radial forearm flap, this flap should only be used for specific indications.

5. Free scapular flap (Table 5 p. 28)

There were 4 male and 1 female pediatric patients, aged between 4 and 16 years, who underwent a reconstruction with a free scapular flap. The complication rate was high (40%), but the 2 complications involved were minor. No partial or total flap failure was described. Only 1 patient underwent secondary debulking procedures. This reconstructive method is a very good option in case of the need of a chimeric flap (osteocutaneous scapular or combination with the parascapular flap). Like the LD and TDAP flap, the need for repositioning of the patient during surgery to harvest the flap is a drawback for this reconstructive option.

6. Free parascapular flap (Table 6 p. 29)

Only 6 male pediatric patients, aged between 4 and 12 years, underwent a reconstruction with a free parascapular flap. Half of the patients had complications, but also in this population they were minor: 3 patients had a tip necrosis which eventually treated with debridement and primary closure. No partial or total flap failure was described. Like the scapular flap is this reconstructive method a very good option in case of the need of a chimeric flap (combination with the scapular flap). Also for this reconstruction is the need for repositioning the patient during surgery for harvesting the flap a drawback.

7. Free rectus abdominis muscle/musculocutaneous flap (Table 7 p. 29)

The free rectus abdominis muscle/musculocutaneous flap is used in the older children aged between 14 and 18 year. Besides 1 patient that developed an osteomyelitis, no partial or total flap failures were described. No secondary procedures were described. These result also seem to make this reconstructive option a first choice for lower limbs. Like mentioned earlier is the rectus abdominis muscle flap reported to be the most commonly used vehicles in pediatric microsurgical reconstruction [15, 19, 80, 81], although it could not be confirmed in this systematic review specifically addressing lower limbs. A major drawback of harvesting a rectus abdominis flap is abdominal wall weakness or even herniation of intra-abdominal
contents. This should prevent the use of this flap as a first choice for lower limb reconstruction in children.

8. Free deep inferior epigastric artery perforator flap (Table 8 p. 29)

The versatility and reliability of this flap in lower extremity aesthetic and functional reconstruction was already presented in both adults and children [88], [22], [89]. In this systematic review there were 4 male and 3 female pediatric patients, aged between 4 and 16 years, who underwent a reconstruction with a free DIEAP flap. The complication rate was very high (71%), the reason for this was the high reportage of complications in one of the articles. There was one partial failure and almost half (43%) of the flaps needed secondary procedures. This makes this reconstructive option less valuable. The reason for the high amount of complication parallels that of the latissimus dorsi and the TDAP-flap: the flap corresponds to that included in the myocutaneous rectus abdominis flap, but flap dissection much more time consuming due to tedious and risky transmuscular perforator dissection, prolonging operating time and leading to a higher complication rate. The flap offers the largest possible skin flap, but even in children it can be rather bulky. This can easily be corrected by tumescent liposculpture in a subsequent procedure. Because the muscle is left innervated and functionally intact, there is no contraindication to augmenting the size of the skin paddle by harvesting a bilateral pedicle, thereby recruiting “zone IV.” Alternately, the contralateral superficial epigastric vein can be used to enhance venous outflow where necessary. An extra advantage of the DIEAP flap is its relatively inconspicuous donor-site scar.

9. Free superficial inferior epigastric artery perforator flap (Table 9 p. 30)

Only one author described the use of the SIEAP flap for the reconstruction of major soft-tissue defects of the lower limb. 2 patients had a reconstruction with 3 SIEAP flaps. One patient had a small wound dehiscence which was treated conservatively. Due to anatomic variation of caliber in patients, this flap is not available in every pediatric patient.

10. Free groin flap (Table 10 p. 30)

The groin flap was used in earlier publications. 14 children between 2 and 18 year old underwent 15 free flap reconstructions with a groin flap. There was a 27 percent complication
rate with a partial necrosis in 3 children (20% of the total amount of flaps). 3 flap reconstructions needed additional debulking procedures.

Despite its rather variable and small vasculature [34] can this flap be a safe method of reconstruction, providing ample, extremely pliable tissue that serves as an ideal skin substitute in a variety of anatomic locations, with the advantage of very little donor-site morbidity. The groin flap is thin, especially if harvested in the flexural crease, and the donor scar is well disposed. The major disadvantage of this flap is the relatively short pedicle, in which suitably matched vein grafts may not be available. This makes it difficult to stay out of the zone of injury in cases of traumatic lower limb defects.

11. Free antero lateral thigh flap (Table 11 p. 31)

In this systematic review, the free ALT-flap was the second most common used flap. 71 pediatric patients aged between 2.5 and 18 years underwent a reconstruction with 72 free ALT flaps. The complication rate was low (12.5%), although it resulted in 3 partial (4%) and 1 total (1%) flap failure. One in four flaps needed additional surgical procedures. This high amount of children who underwent this reconstruction and the possibilities of transferring large skin paddles and different tissue types on a large and long pedicle, potential for thinning, reinnervation, flow through revascularization and coverage of the extremities, with minimal donor-site morbidity make this flap a first choice method of reconstruction. This is reflected in literature with a high grade of success of this flap [90].

12. Free gracilis flap (Table 12 p. 32)

The gracilis flap is also a quite frequently used flap in a population of pediatric patients aged between 2 and 18 years old. The complications rate was 23% with only one (4.5%) partial flap loss. No secondary procedures were described.

The flap is, owing to a smaller vascular pedicle and a smaller size, less commonly used. The gracilis muscle seems a rather slim muscle suitable only to cover small defects, although after removal of the epimysium its width can be extended considerably, on average by over 100%, allowing coverage of defects measuring up to 300 cm² [91]. Due to the minimal donor site dysfunction and morbidity, it is for some authors the choice for foot and ankle reconstruction which was already shown in this systematic review and confirmed in the literature [72].
13. Free profunda artery flap (Table 13 p. 32)

Only one author reported 2 lower limb soft-tissue defects that were covered with a vertically oriented profunda artery perforator flap. No flap complications were encountered, including operating room take-back and partial and full flap losses. One child needed minor flap debulking. Although these results seem promising, more lower limb reconstructions have to be performed with this flap to draw conclusions about its use.

14. Free peroneal artery perforator flap (Table 14 p. 32)

The report of Ozkan and colleagues describes the results of free peroneal artery perforator flaps used to cover soft tissue defects in the distal leg and foot area in nine patients. 2 of them were children. No complications were reported. During harvesting the peroneal flap, the peroneal artery, a main artery of the lower leg, is usually used for the vascular pedicle. Although this may not be critical to perfusion of the foot in the young healthy patient, it may prove crucial in the elderly patient in whom the peroneal artery may provide retrograde perfusion through the posterior and anterior tibial artery systems. The peroneal artery perforator flap has been described in order to avoid sacrifice of the peroneal artery. This does not necessitate sacrifice of the peroneal artery, in elevating from the distal and middle thirds of the lateral lower leg [92]. Venous drainage of the flap can be provided in terms of both concomitant and superficial cutaneous systems. There is minimal donor site morbidity with possible direct closure of the leg. Therefore the skin defect should be less than 6 cm in width and the recommended vascular pedicle length can’t be more than 6cm. When this is possible, the reconstruction provides a thin and flexible flap. Several disadvantages that limit the use of this flap are described [93]: 1) irregularities and variations in the location and course of the perforators make standardized flap rising more difficult. The surgeon has to be familiar with the anatomy of the donor site and its possible variations. 2) Anastomosing vessels with a diameter of only 1 mm requires considerable surgical skill. This “supermicrosurgery” should only be performed by an experienced microsurgeon.
**Limitations**
The most important limitation is the fact that most articles include a heterogeneous patient population: 1) in most articles the study population consisted of both adults and children; 2) some authors included patients with a variety of different defect etiologies (e.g. trauma, tumor, congenital defects); and 3) other articles failed to focus on specific anatomic regions [24, 35].

The latter two parameters, however, are known to have an impact on reconstructive success of a surgery. So drawing conclusions without including these parameters as inclusion or exclusion criteria will be challenging. The microsurgical reconstruction of traumatic defects is most often reported but tends to be associated with a somewhat lower success rate when compared to other defect etiologies such as after tumor resection. This may be secondary to trauma-induced vascular changes (e.g. perivascular inflammation and fibrosis) that result in a higher risk for developing thrombosis subsequent to iatrogenic manipulation [2]. In this review, some articles could not provide us with the information needed e.g. age or size of the flap. This prohibited the association between complications and age or flap size.

**Conclusions**
A highly discussed subject in lower extremity reconstruction is the choice of flap in the pediatric population. The ultimate goal of reconstructive surgery is to replace like with like to optimally restore not only the function of the lower limb, but also its form and contour. Unfortunately, this is a principle that cannot be achieved in many clinical situations.

Therefore, the reconstruction of the tissue defects has to be planned carefully with regards to the specific pediatric anatomy and the evolution of children’s tissue and skeletal structures. Apart from these surgical considerations, psychosocial ramifications, and discomfort of prolonged disability at a young age have to be kept in mind.
Overall, the (pediatric) reconstructive surgeon has to choose between a muscle flap or a skin flap:

### Muscle flap:
- Leads to functional loss
- Needs an split thickness skin graft (STG) for coverage, which leads to a higher donor site morbidity.
- Is difficult to shape and reshape. This makes subsequent procedures (e.g. orthopedic) more difficult.

### Skin flap:
- Can be sensate with inclusion of a sensory nerve.
- Is pliable and thin
- Can be reshaped in secondary (e.g. orthopedic) procedures when there is a need to make an incision over the previous scars.

In this systematic review, the most commonly used flap was the latissimus dorsi muscle flap (91 flaps). This is a reflection of the literature where the latissimus dorsi muscle and rectus abdominis muscle flaps are reported to be the most commonly used in pediatric microsurgical reconstruction. This popularity is based on a consistent anatomy and familiarity with flap harvest. Free flap reconstructions in children should not be done by surgeons who can only master the latissimus dorsi flap. The result is also historically biased: where earlier articles used a multitude of muscle or musculocutaneous flaps, has the focus of lower limb reconstruction switched from flap survival to concerns related to donor-site morbidity. This change in flap choice in pediatric reconstruction thus parallels this trend with fasciocutaneous and perforator-based flaps being increasingly advocated. Skin flaps are preferred in those cases where there is no necessity to include bulk or provide a functional reconstruction. In the Ghent University hospital, perforator flaps make up the majority of free flap procedures. These flaps provide larger flaps with longer pedicles and less donor-site morbidity based on well-known and sizable source vessels. The microsurgical reconstruction of lower extremity defects in the pediatric population is proven to be safe as evidenced by a high flap survival rate of more than 90 percent. Although its dissection requires a certain amount of experience, once the surgeon becomes acquainted with the technique of perforator flaps, it should not be more difficult to perform than any other free flap technique. On the contrary, free-flap failure in children is a relevant complication and even immediate surgical revision cannot avoid complete free-flap loss. Therefore, we strongly advise that free tissue transfer, especially in
children, should be performed in specialized departments by specialized surgeons. Survival rates will also improve when the possibility of growth retardation with development and the cooperation after surgery are considered in the planning of free flap procedures in pediatric patients. Reason for this is the fact that in the growing child, limb salvage procedures present unique concerns and challenges. These concerns include the small size of the pediatric skeleton, the growth potential of the patient, the proposed final length of the unaffected limb, and the need for correction of the ensuing limb-length discrepancy. There are many variables that contribute to the overall limb-length discrepancy: systemic chemotherapy, overgrowth of the contralateral limb, slowing of the preserved growth plate in the affected joint, muscle atrophy, and muscle loss. Each of these variables can alter the expected growth of an extremity and must be considered when estimating the final growth of a patient and the final limb-length discrepancy and hence the best functional reconstructive option. Therefore we consider the free ALT and the free groin flap good candidates for lower limb reconstruction in children. Donor site morbidity is also very important, because the subsequent scars after reconstructive surgery tend to enlarge during the growth of the children. Other reconstructive methods are second choice and dependent on the case and the experience of the surgeon.

The paucity of well designed, homogenous studies addressing lower limb reconstruction with free flaps in children make it very challenging to draw more extensive conclusions from this systematic review. Therefore more adequate studies specifically concerning free flap reconstructions for lower limb defects in children are necessary in the future.

**Funding**

No sources of funding.
### Table 1: Latissimus dorsi musculocutaneous flap reconstruction

<table>
<thead>
<tr>
<th>Study</th>
<th>Age (Year)</th>
<th>Gender (Male or female)</th>
<th>Flap (cm x cm or cm²)</th>
<th>Complications (# children, % of total amount of flaps)</th>
<th>Secondary procedures (# children, % of total amount of flaps)</th>
</tr>
</thead>
<tbody>
<tr>
<td>Iwaya et al., 1982</td>
<td>6 – 14y</td>
<td>2 male</td>
<td>15 x 24 cm 20 x 10 cm</td>
<td>Superficial necrosis (1 child, 50%)</td>
<td>STG (1 child, 50%)</td>
</tr>
<tr>
<td>Banic and Wulff, 1987</td>
<td>3 – 9y</td>
<td>10 male 5 female</td>
<td>15 x 8 to 24 x 11</td>
<td>Arterial revision (1 child, 7%) Arterial revision with partial loss (1 child, 7%)</td>
<td>STG zone of necrosis (1 child, 7%) Regraft back (4 children, 27%)</td>
</tr>
<tr>
<td>Parry et al., 1988</td>
<td>6 – 13y</td>
<td>3 male</td>
<td>No information</td>
<td>No complications</td>
<td>None described</td>
</tr>
<tr>
<td>Shapiro et al., 1989</td>
<td>6 – 16y</td>
<td>3 male 5 female</td>
<td>5 x 8 cm to 25 x 30 cm</td>
<td>Wound infection (2 children, 25%) Partial failure STG (1 child, 12.5%)</td>
<td>Reapplication STG (1 child, 25%)</td>
</tr>
<tr>
<td>Serletti et al., 1996</td>
<td>3 – 17y</td>
<td>4 male 3 female</td>
<td>No information</td>
<td>No complications</td>
<td>Posterior ankle release (1 child, 14%)</td>
</tr>
<tr>
<td>Chiang et al., 1997</td>
<td>2 – 13y</td>
<td>10 male 5 female</td>
<td>No information</td>
<td>Venous obstruction (3 children, 18%) Partial loss (2 children, 12%) Loss STG due to infection (1 child, 6%) Hematoma donor site (1 child, 6%)</td>
<td>New free flap (1 child, 6%)</td>
</tr>
<tr>
<td>Kaplan et al., 1998</td>
<td>8y and 10y</td>
<td>2 male</td>
<td>10 x 16 cm – 12 x 24 cm</td>
<td>No complications</td>
<td>None described</td>
</tr>
<tr>
<td>Erdmann et al., 2000</td>
<td>2 – 4y</td>
<td>4 male</td>
<td>No information</td>
<td>Venous revision (1 child, 25%) Seroma donor site (1 child, 25%)</td>
<td>Multiple procedures performed without specific information.</td>
</tr>
<tr>
<td>Kuran et al., 2000</td>
<td>6y</td>
<td>1 male</td>
<td>15x10cm</td>
<td>No complications</td>
<td>Contour revision and volume reduction (1 child, 100%)</td>
</tr>
<tr>
<td>Yucel et al., 2001</td>
<td>15y</td>
<td>1 male</td>
<td>No information</td>
<td>No complications</td>
<td>None described</td>
</tr>
<tr>
<td>Gonzalez et al., 2002</td>
<td>7y</td>
<td>1 male</td>
<td>7x22cm</td>
<td>No complications</td>
<td>None described</td>
</tr>
<tr>
<td>Duteille et al., 2003</td>
<td>No information</td>
<td>No information about patient</td>
<td>500cm²</td>
<td>No complications</td>
<td>None described</td>
</tr>
<tr>
<td>Lickstein and Benz, 2003</td>
<td>4 and 7y</td>
<td>No information about 2 patients</td>
<td>No information</td>
<td>Dusky appearance (1 child, 50%) Anastomotic revision (1 child, 50%)</td>
<td>Delay STG due to dusky appearance (1 child, 50%)</td>
</tr>
<tr>
<td>Ozkän et al., 2005</td>
<td>8y</td>
<td>1 female</td>
<td>7 x 18cm</td>
<td>No complications</td>
<td>Exploration distal part flap and debridement nonviable remnants of metatarsal bones (1 child, 100%)</td>
</tr>
<tr>
<td>Study</td>
<td>Age Range</td>
<td>Gender</td>
<td>Flap Size</td>
<td>Complications</td>
<td>Flap Type</td>
</tr>
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<td>---------------------------------------------------------------------------</td>
</tr>
<tr>
<td>Germann et al., 2006</td>
<td>15 weeks</td>
<td>1 male</td>
<td>6.5 cm x 5 cm</td>
<td>No complications</td>
<td>Debulking flap (1 child, 100%)</td>
</tr>
<tr>
<td>Yildirim et al., 2008</td>
<td>6 – 15 y</td>
<td>No info</td>
<td>No info</td>
<td>No complications</td>
<td>Release contracture toe with eventual amputation in 1 patient (33%), no info about the other 2 patients</td>
</tr>
<tr>
<td>Hallock, 2008</td>
<td>12 y</td>
<td>1 male</td>
<td>8 x 25 cm</td>
<td>No complications</td>
<td>None described</td>
</tr>
<tr>
<td>Bouffaut et al., 2008</td>
<td>3-14 y</td>
<td>No info</td>
<td>72 - 300 cm²</td>
<td>No complications</td>
<td>None described</td>
</tr>
<tr>
<td>Namdar et al., 2010</td>
<td>4 – 17 y</td>
<td>8 male</td>
<td>No info</td>
<td>4 major revisions: reanastomosis and 9 minor revisions with complete loss of 3 and partial loss in 1 flap (10 patients, 93%)</td>
<td>None described</td>
</tr>
<tr>
<td>Wechselberger et al., 2011</td>
<td>15 months</td>
<td>1 male</td>
<td>5 x 4 cm</td>
<td>Wound dehiscence (1 child, 100%)</td>
<td>Skin mobilization (1 child, 100%)</td>
</tr>
<tr>
<td>Venkatramani et al., 2014</td>
<td>6 – 15 y</td>
<td>2 male</td>
<td>7 x 5 cm</td>
<td>Arterial thrombosis (1 child, 33%)</td>
<td>Cross leg flap as replacement reconstruction (1 child, 33%)</td>
</tr>
<tr>
<td>Rednam et al., 2016</td>
<td>8 y</td>
<td>1 male</td>
<td>100 cm²</td>
<td>No complications</td>
<td>Debridement of residual defect and STG coverage (1 child, 100%)</td>
</tr>
<tr>
<td><strong>Total</strong></td>
<td>15 weeks – 17 y</td>
<td>55 male</td>
<td>20 – 750 cm²</td>
<td>29/91 flaps = 32%</td>
<td>26/91 flaps = 29%</td>
</tr>
</tbody>
</table>
Table 2: Thoracodorsal Artery Perforator (TDAP) flap reconstruction

<table>
<thead>
<tr>
<th>Study</th>
<th>Age (Year)</th>
<th>Gender (Male or female)</th>
<th>Flap (cm x cm or cm²)</th>
<th>Complications (# children, % of total amount of flaps)</th>
<th>Secondary procedures (# children, % of total amount of flaps)</th>
</tr>
</thead>
<tbody>
<tr>
<td>Van Landuyt et al., 2005</td>
<td>6mo – 16y</td>
<td>5 male 6 female</td>
<td>No information</td>
<td>Wound dehiscence (3 children, 27%) Arterial revision (1 child, 9%) Ongoing necrosis (1 child, 9%) Total failure (1 child, 9%)</td>
<td>Closure wound dehiscence (1 child, 9%)</td>
</tr>
<tr>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
<td>Shortening wound metatarsal heads (2 children, 18%)</td>
</tr>
<tr>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
<td>Treatment ongoing necrosis with cross-leg, gastrocnemius and</td>
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<tr>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
<td>fasciocutaneous flap</td>
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<tr>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
<td>After 5 years reconstruction with bipedicled DIEAP flap</td>
</tr>
<tr>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
<td>for aesthetic reasons (1 child, 9%)</td>
</tr>
<tr>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
<td>Lower leg amputation due to total failure (1 child, 9%)</td>
</tr>
<tr>
<td>Lee et al., 2008</td>
<td>7 - 16y</td>
<td>5 male 5 female</td>
<td>7x5 – 16x9.5cm</td>
<td>Total flap loss due to arterial failure (1 child, 10%) Vein revision (1 child, 10%) Donor dehiscence (1 child, 10%)</td>
<td>None described.</td>
</tr>
<tr>
<td>Total</td>
<td>6mo – 16y</td>
<td>10 male 11 female</td>
<td>35 – 152 cm²</td>
<td>8/21 flaps = 38%</td>
<td>5/21 flaps = 24%</td>
</tr>
</tbody>
</table>
### Table 3: free radial forearm flap reconstruction

<table>
<thead>
<tr>
<th>Study</th>
<th>Age (Year)</th>
<th>Gender (Male or female)</th>
<th>Flap (cm x cm or cm²)</th>
<th>Complications (# children, % of total amount of flaps)</th>
<th>Secondary procedures (# children, % of total amount of flaps)</th>
</tr>
</thead>
<tbody>
<tr>
<td>Serletti et al., 1996</td>
<td>4 – 16y</td>
<td>4 male 2 female</td>
<td>No information</td>
<td>Venous thrombosis (1 child, 17%)</td>
<td>Tissue expander for subsequent removal of the skin-grafted donor site (2 children, 33%)</td>
</tr>
<tr>
<td>Kaplan et al., 1998</td>
<td>14y</td>
<td>1 male</td>
<td>11x22cm</td>
<td>No complications</td>
<td>None described</td>
</tr>
<tr>
<td>Weinzeig et al., 1998</td>
<td>3 -16y</td>
<td>3 male</td>
<td>40 -120cm²</td>
<td>No complications</td>
<td>None described</td>
</tr>
<tr>
<td>Yucel et al., 2000</td>
<td>5 – 8y</td>
<td>1 male 2 female</td>
<td>No information</td>
<td>Superficial ulcer (2 children, 67%)</td>
<td>Excision excessive flap tissue and flap insetting (1 child, 33%)</td>
</tr>
<tr>
<td>Kuran et al., 2000</td>
<td>16 and 18y</td>
<td>2 male</td>
<td>6x7cm – 8x7cm</td>
<td>No complications</td>
<td>None described</td>
</tr>
<tr>
<td>Yucel et al., 2001</td>
<td>5 – 8y</td>
<td>2 male 2 female</td>
<td>No information</td>
<td>Flap revision (1 child, 25%)</td>
<td>None described</td>
</tr>
<tr>
<td>Total</td>
<td>3 – 16y</td>
<td>13 male 6 female</td>
<td>40 - 242 cm²</td>
<td>3/19 flaps = 16%</td>
<td>3/19 flaps = 16%</td>
</tr>
</tbody>
</table>

### Table 4: free lateral arm flap reconstruction

<table>
<thead>
<tr>
<th>Study</th>
<th>Age (Year)</th>
<th>Gender (Male or female)</th>
<th>Flap (cm x cm or cm²)</th>
<th>Complications (# children, % of total amount of flaps)</th>
<th>Secondary procedures (# children, % of total amount of flaps)</th>
</tr>
</thead>
<tbody>
<tr>
<td>Shapiro et al., 1989</td>
<td>7y</td>
<td>1 male</td>
<td>3 x 3cm</td>
<td>No complications</td>
<td>None described</td>
</tr>
</tbody>
</table>

### Table 5: free scapular flap reconstruction

<table>
<thead>
<tr>
<th>Study</th>
<th>Age (Year)</th>
<th>Gender (Male or female)</th>
<th>Flap (cm x cm or cm²)</th>
<th>Complications (# children, % of total amount of flaps)</th>
<th>Secondary procedures (# children, % of total amount of flaps)</th>
</tr>
</thead>
<tbody>
<tr>
<td>Parry et al., 1988</td>
<td>14y</td>
<td>1 female</td>
<td>No information</td>
<td>No complications</td>
<td>None described</td>
</tr>
<tr>
<td>Shapiro et al., 1989</td>
<td>4y</td>
<td>1 male</td>
<td>10 x 20cm</td>
<td>Dehiscence (1 child, 100%)</td>
<td>None described</td>
</tr>
<tr>
<td>Serletti et al., 1996</td>
<td>16y</td>
<td>1 male</td>
<td>No information</td>
<td>No complications</td>
<td>2 debulking procedures (1 child, 100%)</td>
</tr>
<tr>
<td>Erdmann et al., 2001</td>
<td>5y</td>
<td>1 male</td>
<td>No information</td>
<td>Hematoma flap (1 child, 100%)</td>
<td>None described</td>
</tr>
<tr>
<td>Saito et al., 2010</td>
<td>12y</td>
<td>1 male</td>
<td>No information</td>
<td>No complication</td>
<td>Amputation due to recurrence 2 y after surgery</td>
</tr>
<tr>
<td>Total</td>
<td>4y – 16y</td>
<td>4 male 1 female</td>
<td>130 – 200 cm²</td>
<td>2/5 flaps = 40%</td>
<td>1/5 flaps = 20%</td>
</tr>
</tbody>
</table>
### Table 6: free parascapular flap reconstruction

<table>
<thead>
<tr>
<th>Study</th>
<th>Age (Year)</th>
<th>Gender (Male or female)</th>
<th>Flap (cm x cm or cm(^2))</th>
<th>Complications (# children, % of total amount of flaps)</th>
<th>Secondary procedures (# children, % of total amount of flaps)</th>
</tr>
</thead>
<tbody>
<tr>
<td>Morghari et al., 1989</td>
<td>4 – 6y</td>
<td>4 male</td>
<td>No information</td>
<td>Tip necrosis (3 children, 75%)</td>
<td>Debridement tip necrosis and primary closure (3 children, 75%)</td>
</tr>
<tr>
<td>Hallock, 2008</td>
<td>12y</td>
<td>1 male</td>
<td>8x25 cm</td>
<td>No complications</td>
<td>None described</td>
</tr>
<tr>
<td>Saito et al., 2010</td>
<td>12y</td>
<td>1 male</td>
<td>No information</td>
<td>No complication</td>
<td>Amputation due to recurrence</td>
</tr>
<tr>
<td><strong>Total</strong></td>
<td>4 – 12y</td>
<td>6 male</td>
<td>8 x 25 cm</td>
<td>3/6 flaps = 50%</td>
<td>3/6 flaps = 50%</td>
</tr>
</tbody>
</table>

### Table 7: free rectus abdominis flap reconstruction

<table>
<thead>
<tr>
<th>Study</th>
<th>Age (Year)</th>
<th>Gender (Male or female)</th>
<th>Flap (cm x cm or cm(^2))</th>
<th>Complications (# children, % of total amount of flaps)</th>
<th>Secondary procedures (# children, % of total amount of flaps)</th>
</tr>
</thead>
<tbody>
<tr>
<td>Serletti et al., 1996</td>
<td>14 – 17y</td>
<td>3 male</td>
<td>No information</td>
<td>No complications</td>
<td>None described</td>
</tr>
<tr>
<td>Gonzalez et al., 2002</td>
<td>18y</td>
<td>1 male</td>
<td>7x12 cm</td>
<td>Local osteomyelitis (1 child, 100%)</td>
<td>None described</td>
</tr>
<tr>
<td>Bouffaut et al., 2008</td>
<td>15y</td>
<td>No information</td>
<td>50cm(^2)</td>
<td>No complications</td>
<td>None described</td>
</tr>
<tr>
<td><strong>Total</strong></td>
<td>14-18y</td>
<td>4 male</td>
<td>50 – 84 cm(^2)</td>
<td>1/5 flaps = 20%</td>
<td>0/5 flaps = 0%</td>
</tr>
</tbody>
</table>

### Table 8: Deep Inferior Epigastric Artery Perforator flap reconstruction

<table>
<thead>
<tr>
<th>Study</th>
<th>Age (Year)</th>
<th>Gender (Male or female)</th>
<th>Flap (cm x cm or cm(^2))</th>
<th>Complications (# children, % of total amount of flaps)</th>
<th>Secondary procedures (# children, % of total amount of flaps)</th>
</tr>
</thead>
<tbody>
<tr>
<td>Van Landuyt et al., 2005</td>
<td>4 – 15y</td>
<td>4 male 2 female</td>
<td>No information</td>
<td>Arterial revision (1 child, 17%)</td>
<td>Debridement + advancement flap due to partial failure (1 child, 17%)</td>
</tr>
<tr>
<td></td>
<td></td>
<td></td>
<td></td>
<td>Partial failure (1 child, 17%)</td>
<td>Liposuction (1 child, 17%)</td>
</tr>
<tr>
<td></td>
<td></td>
<td></td>
<td></td>
<td>Wound dehiscence (2 children, 33%)</td>
<td>Debridement and STG due to wound edge necrosis (1 child, 17%)</td>
</tr>
<tr>
<td></td>
<td></td>
<td></td>
<td></td>
<td>Wound edge necrosis (1 child, 17%)</td>
<td></td>
</tr>
<tr>
<td>Grinsell et al., 2012</td>
<td>16y</td>
<td>1 female</td>
<td>26 x 19 cm</td>
<td>No complications</td>
<td>None described</td>
</tr>
<tr>
<td><strong>Total</strong></td>
<td>4 – 16y</td>
<td>4 male 3 female</td>
<td>494 cm(^2)</td>
<td>5/7 flaps = 71%</td>
<td>3/7 flaps = 43%</td>
</tr>
</tbody>
</table>
### Table 9: Superficial Inferior Epigastric Artery Perforator (SIEAP) flap

<table>
<thead>
<tr>
<th>Study</th>
<th>Age (Year)</th>
<th>Gender (Male or female)</th>
<th>Flap (cm x cm or cm²)</th>
<th>Complications (# children, % of total amount of flaps)</th>
<th>Secondary procedures (# children, % of total amount of flaps)</th>
</tr>
</thead>
<tbody>
<tr>
<td>Van Landuyt et al., 2005</td>
<td>9 and 12y</td>
<td>2 male</td>
<td>No information</td>
<td>Wound dehiscence (1 child, 33%)</td>
<td>None described</td>
</tr>
</tbody>
</table>

### Table 10: Free groin flap reconstruction

<table>
<thead>
<tr>
<th>Study</th>
<th>Age (Year)</th>
<th>Gender (Male or female)</th>
<th>Flap (cm x cm or cm²)</th>
<th>Complications (# children, % of total amount of flaps)</th>
<th>Secondary procedures (# children, % of total amount of flaps)</th>
</tr>
</thead>
<tbody>
<tr>
<td>Harii et al., 1975</td>
<td>4 and 4.5y</td>
<td>2 Male</td>
<td>9 x 7 and 12 x 6</td>
<td>No complications</td>
<td>None described</td>
</tr>
<tr>
<td>Baudet et al., 1975</td>
<td>14y and 18y</td>
<td>1 male 1 female</td>
<td>12 x 8cm – 19 x 10cm</td>
<td>No complications</td>
<td>None described</td>
</tr>
<tr>
<td>Iwaya et al., 1982</td>
<td>2 – 8y</td>
<td>4 male 1 female</td>
<td>13 x 5.5 cm – 10 x 19 cm</td>
<td>Thrombosis (1 child, 20%) Partial necrosis (2 children, 40%)</td>
<td>None described</td>
</tr>
<tr>
<td>Chiang et al., 1997</td>
<td>3 – 6y</td>
<td>3 male 2 female</td>
<td>No information</td>
<td>No complications</td>
<td>Debulking (3 children, 60%)</td>
</tr>
<tr>
<td>Duteille et al., 2003</td>
<td>No specific information</td>
<td>No specific information</td>
<td>76 cm²</td>
<td>Partial (1/3 necrosis) (1 child, 100%)</td>
<td>None described</td>
</tr>
<tr>
<td><strong>Total</strong></td>
<td>2 – 18y</td>
<td>10 male 4 female</td>
<td>63 – 190 cm²</td>
<td>4/15 flaps = 27%</td>
<td>3/15 flaps = 20%</td>
</tr>
<tr>
<td>Study</td>
<td>Age (Year)</td>
<td>Gender (Male or female)</td>
<td>Flap (cm x cm or cm²)</td>
<td>Complications (# children, % of total amount of flaps)</td>
<td>Secondary procedures (# children, % of total amount of flaps)</td>
</tr>
<tr>
<td>-----------------------------</td>
<td>------------</td>
<td>-------------------------</td>
<td>-----------------------</td>
<td>-------------------------------------------------------</td>
<td>-----------------------------------------------------------</td>
</tr>
<tr>
<td>Segev et al., 2007</td>
<td>8 and 12y</td>
<td>1 male 1 female</td>
<td>No information</td>
<td>No complications</td>
<td>None described</td>
</tr>
<tr>
<td>Yildirim et al., 2008</td>
<td>7y</td>
<td>No information</td>
<td>No information</td>
<td>No complications</td>
<td>None described</td>
</tr>
<tr>
<td>Demirtas et al., 2010</td>
<td>4 – 6y</td>
<td>4 male 1 female</td>
<td>8 x 5cm – 12 x 7cm</td>
<td>Hematoma (1 child, 20%) Infection (1 child, 20%)</td>
<td>None described</td>
</tr>
<tr>
<td>Gharb et al., 2011</td>
<td>5 – 18y</td>
<td>7 male 1 female</td>
<td>4 x 6cm – 25 x 8cm</td>
<td>Proximal and distal tip necrosis (1 child, 12.5%)</td>
<td>None described</td>
</tr>
<tr>
<td>Gharb et al., 2011</td>
<td>11y</td>
<td>1 female</td>
<td>16X8cm skin, 6x18 vastus lateralis and 2x14cm femur</td>
<td>No complications</td>
<td>None described</td>
</tr>
<tr>
<td>El-Gammal et al., 2013</td>
<td>2.5 – 13y</td>
<td>32 males 10 females</td>
<td>Mean 15.5 ± 2.72 cm x 7.44 ± 1.28 cm</td>
<td>Venous congestion with partial (2 children, 5%) and complete (1 child, 3%) failure after reanastomosis</td>
<td>Debulking (15 children, 36%)</td>
</tr>
<tr>
<td>Vankatramani et al., 2014</td>
<td>12 – 16y</td>
<td>1 male 1 female</td>
<td>25x10cm – 30x15cm</td>
<td>No complications</td>
<td>Bone grafting for femur (1child, 50%)</td>
</tr>
<tr>
<td>Acar et al., 2015</td>
<td>3 – 15y</td>
<td>8 male 3 female</td>
<td>8x6cm – 13x9cm</td>
<td>Venous thrombosis with partial necrosis after salvage (1 child, 9%)</td>
<td>STG for partial necrosis (1 child, 9%)</td>
</tr>
<tr>
<td>Total</td>
<td>2.5 – 18y</td>
<td>53 male 18 female</td>
<td>24 – 450 cm²</td>
<td>9/72 flaps = 12.5%</td>
<td>17/72 flaps = 24%</td>
</tr>
</tbody>
</table>
### Table 12: Free gracilis flap

<table>
<thead>
<tr>
<th>Study</th>
<th>Age (Year)</th>
<th>Gender (Male or Female)</th>
<th>Flap (cm x cm or cm²)</th>
<th>Complications (# children, % of total amount of flaps)</th>
<th>Secondary procedures (# children, % of total amount of flaps)</th>
</tr>
</thead>
<tbody>
<tr>
<td>Parry et al., 1988</td>
<td>2 – 11y</td>
<td>4 male 5 female</td>
<td>No information</td>
<td>No complications</td>
<td>None described</td>
</tr>
<tr>
<td>Chiang et al., 1997</td>
<td>6 – 14y</td>
<td>3 male</td>
<td>No information</td>
<td>No complications</td>
<td>None described</td>
</tr>
<tr>
<td>Yucel et al., 2001</td>
<td>17y</td>
<td>1 male</td>
<td>No information</td>
<td>Wound infection (1 child, 100%)</td>
<td>None described</td>
</tr>
<tr>
<td>Lorea et al., 2001</td>
<td>9 and 11y</td>
<td>1 male 1 female</td>
<td>20 and 32 cm²</td>
<td>No complications</td>
<td>None described</td>
</tr>
<tr>
<td>Lickstein and Benz, 2003</td>
<td>3 – 18y</td>
<td>No information</td>
<td>No information</td>
<td>Anastomotic revision with partial loss of flap (1 child, 14%) Fever hematoma (1 child, 14%) Hypertrophic scarring (1 child, 14%) Ureteral obstruction (1 child, 14%)</td>
<td>None described</td>
</tr>
<tr>
<td>Total</td>
<td>2 – 18y</td>
<td>9 male 6 female</td>
<td>10 – 32 cm²</td>
<td>5/22 flaps = 23%</td>
<td>0/22 flaps = 0%</td>
</tr>
</tbody>
</table>

### Table 13: Free profunda artery perforator flap

<table>
<thead>
<tr>
<th>Study</th>
<th>Age (Year)</th>
<th>Gender (Male or Female)</th>
<th>Flap (cm x cm or cm²)</th>
<th>Complications (# children, % of total amount of flaps)</th>
<th>Secondary procedures (# children, % of total amount of flaps)</th>
</tr>
</thead>
<tbody>
<tr>
<td>Mayo et al., 2016</td>
<td>4y and 12y</td>
<td>1 male</td>
<td>Both 13x5cm</td>
<td>No complications</td>
<td>Minor flap debulking (1 child, 50%) No information about other child</td>
</tr>
</tbody>
</table>

### Table 14: Free peroneal artery perforator flap

<table>
<thead>
<tr>
<th>Study</th>
<th>Age (Year)</th>
<th>Gender (Male or Female)</th>
<th>Flap (cm x cm or cm²)</th>
<th>Complications (# children, % of total amount of flaps)</th>
<th>Secondary procedures (# children, % of total amount of flaps)</th>
</tr>
</thead>
<tbody>
<tr>
<td>Ozkan et al</td>
<td>6 and 8y</td>
<td>2 male</td>
<td>Both 4x2cm</td>
<td>No complications</td>
<td>None described</td>
</tr>
</tbody>
</table>
References
tremity reconstruction.


Microsurgical free flap.


Nederlandse samenvatting

Inleiding


Doelen van de systematische review

Identificatie van 1) de verschillende vrije flap reconstructies voor onderste lidmaat traumata die beschreven zijn voor kinderen; 2) de complicatieratio van de verschillende vrije flap reconstructies; 3) het aantal secundaire ingrepen die vereist zijn bij een bepaalde vrije flap reconstructie.

Zoekopdracht en selectiecriteria voor de systematische review

Een zoekopdracht werd uitgevoerd in Pubmed zoals beschreven door de PRISMA guidelines [1]. Inclusiecriteria voor deze systematische review zijn artikels met een adequaat studieopzet die rapporteren over kinderen tussen 0 en 18 jaar die een onderste lidmaatreconstructie hebben ondergaan door middel van een vrije flap. Informatie met betrekking tot de complicatieratio en de nood aan bijkomende procedures dienen tevens te worden beschreven in het artikel.

Resultaten

De brede rugspier (M. latissimus dorsi), al dan niet gecombineerd met een huidflap dan wel met een huidgreffe, werd het meest beschreven als reconstructieve optie voor onderste lidmaat reconstructies bij kinderen. De eigenschappen van de flap maakten van deze reconstructieve optie vroeger een eerste keuze. Met de evolutie van de vrije flapreconstructies naar het gebruik van vrije perforatorflappen is de eerste keuze vrije perforatorflap op dit ogenblik de antero-laterale dij flap, ook wel ALT flap genoemd. Andere reconstructieve mogelijkheden door middel van een vrije flap moeten beslist worden op basis van de casus die zich op dat moment aandient en op basis van de expertise van de chirurg.
**Beperkingen van de studie**

De beperkingen van de studie zijn de volgende:

- De meeste artikels bevatten een heterogene studiepopulatie bestaande uit zowel volwassenen als kinderen.
- De oorzaken van de onderste lidmaat wonden waren in vele studies zeer uiteenlopend: traumatata, tumoren, infecties,…
- Andere artikels hadden hun focus op te verschillende anatomische gebieden.

**Conclusie**

Door het gebrek aan voldoende goed opgezette studies met betrekking tot onderste lidmaat reconstructies door middel van vrije flappen bij kinderen is het onmogelijk om goede conclusies te trekken uit deze systematische review. Nieuwe studies met een beter design zijn noodzakelijk in de toekomst.