Results of Kidney Transplantation From Donors After Cardiac Death
H. Ledinh, C. Bonvoisin, L. Weekers, A. de Roover, P. Honoré, J.P. Squifflet, M. Meurisse, and O. Detry

ABSTRACT
Confronting the organ donor shortage, many transplant centers around the world increasingly use donors after cardiac death (DCD). Over the past 20 years, follow-up studies in kidney recipients comparing DCD and donors after brain death (DBD) have shown comparable long-term graft function and survival. As a consequence, DCD programs should be continued and expanded, for these donors constitute a potential solution to the imbalance between the numbers of end-stage kidney disease patients on waiting lists versus available kidney grafts. DCD kidneys do not necessarily signify suboptimal grafts; they may merit to be allocated the same as DBD grafts.

IN THE EARLY DAYS of transplantation, all cadaveric organs were retrieved from donors after cardiac death (DCD). After establishment of the concept of brain death in 1968,1 DCD were largely abandoned in the mid 1970s to be replaced by donors after brain death (DBD). The interest in DCD has been renewed in the early 1990s as a potential solution for the critical universal shortage of kidney grafts.

The practices of DCD differ greatly around the world as a consequence of various cultures, religions, and legislations. To date, DCD donation have been concentrated in Europe, the United Kingdom, the United States, and Japan (Table 1). Most countries use mainly Maastricht type 3 DCD, except France and Spain, where type 2 DCD are more widely used, a practice becoming more widespread. Although type 1 DCD are not used in many countries because of concerns about logistic difficulties, ethics, and organ quality, they are the main DCD type in Spain.2 In Japan, DCD has relied almost exclusively on type 4 DCD.3

The contribution of DCD sources to the deceased donor pool varies considerably among countries (Table 1). In 2007, DCD kidney transplants constituted 10.7% of the total cadaveric kidney pool in the United States4,5 and 22.1% in the United Kingdom.5,6 In the Netherlands, almost 50% of deceased donor kidneys were provided by DCD.7 Estimates suggested that DCD programs could contribute 20%–40% of cadaveric kidneys for transplantation,8,9 and indeed there may be 2 times more potential DCD than DBD.10 Therefore, the use of DCD could have considerable impact on the kidney graft pool, markedly shortening waiting times and improving the survival and quality of life of patients on waiting lists.

It is therefore likely that DCD kidneys will be a larger part of the kidney graft pool in the future. The aim of this review was to examine the clinical experiences in kidney transplantation using various types of DCD during the 1990s and 2000s, seeking to help kidney transplantation programs to develop DCD criteria and to better allocate these grafts.

DIFFERENCES BETWEEN DCD AND DBD PERTINENT TO TRANSPLANT OUTCOMES
DCD differs from DBD in many ways. The essential differences involve the circumstances of death, warm ischemia and brain-death processes, as well as graft allocation.

Circumstances of Death
Death results from irreversible cessation of cardiopulmonary or cerebral functions, resulting in cardiac or brain death, respectively. Cardiac arrest can occur spontaneously and suddenly outside the hospital (type 1) or in the accident/emergency department (type 2), or can be planned after removal of life-sustaining treatment in a patient who has a nonrecoverable illness/injury with dependence on life-supporting therapy (type 3). Cardiac arrest in the presence of brain death is type 4.11

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Donation in types 3 and 4 DCD yield the best posttransplant results; death is anticipated and medically controlled. There is adequate time to approach the donor’s relatives, to organize the medical staffs, and to fulfill legal formalities before death. Organ procurement is therefore undertaken with a relatively short warm ischemia time (WIT). Moreover, DCD hemodynamic stability and respiratory function may be maintained until withdrawal of treatment, so one may assure the quality of the grafts.

Inversely, transplantation from type 1 or 2 DCD show worse results because death occurs unexpectedly. There is time pressure to arrange logistic support and organ harvesting takes place in an uncontrolled manner with a longer WIT.

Warm Ischemia

DCD kidneys are submitted to an inevitable albeit variable period of warm ischemia. DCD WIT is the longest among types 1 and 2 DCD (90–120 minutes); it is shorter among types 3 and 4 DCD, namely, 15–20 minutes and rarely exceeding 30 minutes. Figures 1 and 2 present the primary WIT intervals in each donor type with desirable time frames for successful kidney transplantation. For uncontrolled donors, various methods of kidney protection and harvesting have been advocated to decrease primary WIT: in situ intravascular cooling using a double balloon and triple lumen catheter (Maas-tricht protocol), intraperitoneal lavage and cooling (Washington protocol), or hypothermic and normothermic cardiopulmonary bypass with extracorporeal membrane oxygenation (ECMO; Madrid and Barcelona proto-

![Table 1. DCD Programs in Some Countries Around the World in 2007](image)

<table>
<thead>
<tr>
<th>Country</th>
<th>DCD Type Used for Transplant</th>
<th>Kidney Allocation</th>
<th>Number of DCD Kidney Transplants</th>
<th>% DCD Kidney Transplants/DD Kidney Transplants (%)</th>
<th>% DCD/DD Pool (Any Organ) (%)</th>
<th>DCD/pmp</th>
</tr>
</thead>
<tbody>
<tr>
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<td>2,3,4</td>
<td>ETKAS</td>
<td>65</td>
<td>14.7</td>
<td>13.1</td>
<td>3.7</td>
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<td>2,3,4</td>
<td>ETKAS</td>
<td>166</td>
<td>36.1</td>
<td>41.1</td>
<td>7</td>
</tr>
<tr>
<td>Spain</td>
<td>1,2,4</td>
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<td>104</td>
<td>5.1</td>
<td>5.7</td>
<td>2</td>
</tr>
<tr>
<td>France</td>
<td>1,2,4</td>
<td>Locally</td>
<td>42</td>
<td>1.6</td>
<td>2.4</td>
<td>0.6</td>
</tr>
<tr>
<td>United Kingdom</td>
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<td>Locally</td>
<td>313</td>
<td>22.1</td>
<td>23.3</td>
<td>3.1</td>
</tr>
<tr>
<td>United States</td>
<td>2,3,4</td>
<td>Locally</td>
<td>1130</td>
<td>10.7</td>
<td>9.8</td>
<td>2.6</td>
</tr>
<tr>
<td>Japan</td>
<td>2,4</td>
<td>JOTN</td>
<td>163</td>
<td>87.1</td>
<td>87.6</td>
<td>0.7</td>
</tr>
</tbody>
</table>

Abbreviations: ETKAS, Euro Transplant Kidney Allocation System; JOTN, Japanese Organ Transplant Network; DD, deceased donor; pmp, per million population.

Fig 1. Procedure of kidney donation in type 1 and 2 uncontrolled DCD. AB: asystole time (time without cardiac massage) <15–30 minutes. BC: assistance time with advanced cardiopulmonary resuscitation (minimum 30 minutes). CD: waiting time (no-touch period) between 2 and 10 minutes. DE: catheter insertion period (<20 minutes). AD: time between cardiac arrest and arrival to the hospital (<90 minutes). AE: time between cardiac arrest and start of in situ perfusion or hypothermic ECMO (<150 minutes). EF: in situ perfusion period (<150 minutes) or hypothermic ECMO period (maximum 240 minutes). EG: cold ischemia time (<18 hours).
Additionally, machine preservation methods may help to “resuscitate” already compromised, warm ischemic organs, thereby improving their quality and early outcomes. Machine perfusion may also help to select transplantable kidneys versus nonviable ones for discard (kidney viability testing). The development of a DCD program is no longer acceptable if machine perfusion and viability testing are not available. With regard to the logistic organization, 2 initiatives have been applied effectively to reduce primary WIT: the “Maastricht box,” namely, a kit containing all the necessary equipment and instructions for in situ perfusion at the accident and emergency department, and the Madrid “rapid identification and response system,” an highly qualified prehospital emergency services with response time within 7 minutes in urban areas and with the ability to perform advanced life support measures in mobile intensive care units.

For controlled donors, the method of choice proposed by the American Society of Transplant Surgeons is a super-rapid recovery technique, including rapid laparotomy and direct cannulation of the aorta. However, if withdrawal of life-sustaining support is realized outside the operating room, a premortem cannulation technique may be used to decrease the rush inherent with the super rapid recovery technique and WIT.

A second WIT exists during vascular anastomoses of the graft, which also has impact on DGF. The time constraint on this part of the procedure is 40–45 minutes.

Absence of Brain Death

Brain death owing to a rapid increase in intracranial pressure provokes a cascade of changes in the hemodynamics, hormones, and immune response, which show negative impacts on donor organ viability and transplant outcomes. In brain death, renal vasoconstriction owing to excessive secretion of catecholamines and volume depletion leads to hypoperfusion and ischemic damage. Renal inflammatory and degenerative lesions appear on histologic examination, including glomerulitis, periglomerulitis, vacuolization/atrophy, and necrosis of proximal and distal tubules, as well as proliferation of arterial intima and glomerular endothelium. Upregulation of circulating cytokines and chemokines, increased endothelial cell expression of adhesion molecules and major histocompatibility classes I and II, as well as greater infiltration of T cells, macrophages, and polymorphonuclear leukocytes into renal parenchyma, result in increased renal immunogenicity and host alloreactivity. Consequently, brain-dead donor kidneys are at higher risk of rejection. The more rapid the increase in intracranial pressure the more intense, the degree of peripheral organ damage. In clinical transplantation, mechanisms involving donor brain death are quite varied. Relationships have been confirmed in different types of solid organ allografts between donor cause of death and transplant outcomes of graft rejection, function and survival.

Uncontrolled DCD whose cause of death is usually other than neurologic do not undergo the process of brain death; most controlled DCD have sustained irreversible cerebral injuries. As a result, organs from controlled DCD are likely to suffer more from the harmful immunologic, inflammatory, and coagulation effects than those from uncontrolled DCD. Events around the time of brain death may play more important roles in the genesis of renal damage than warm ischemia. In addition, the impact of donor cause of death on DCD kidney transplant outcomes has also been described.

Allocation of DCD Kidney Grafts

Allocation of DCD kidney grafts varies according to country and regulations. In Japan and in the 5 countries belonging to the EuroTransplant International Foundation (Austria, Belgium, Luxemburg, The Netherlands, and Slovenia), DCD kidneys are allocated in the same manner as DBD kidneys, through the Japan Organ Transplant Network (JOTN) or the EuroTransplant Kidney Allocation System (ETKAS), respectively. Legislation in Croatia and Germany (2 other EuroTransplant countries) does not permit the procurement and transplantation of DCD kidneys. In Spain and France, allocation of DCD kidneys is center oriented, that is, to patients on the waiting list of the center that procured the DCD kidney. In a hospital in Madrid, 70% of transplanted kidneys were types 1 and 2 DCD
shorten the CIT. 

In the United Kingdom, to minimize cold ischemia time (CIT) and encourage new DCD programs, the policy stipulates transplantation of both DCD kidneys locally. 

The United States reserves the allocation to Organ Procurement Organizations (OPOs), some of which distribute the kidneys using an extended criterion donor (ECD) list, whereas others offer them to every recipient on the deceased donor waiting list, discussing the DCD origin with the transplant center and the candidate at the time of allocation. Recipients may refuse the allocated kidney without jeopardizing their chance of being offered another one. However, this allocation policy should hasten the process of organ placement. 

Because DCD organs have already been subjected to WIT injury, it is conceivable that additional CIT would have a greater adverse impact on their survival than those from DBD. Kidneys considered to be marginal are often turned down by multiple transplant centers before placement, resulting in prolonged CIT and increased DGF. The proper, rapid allocation of marginal kidneys can result in decreased CIT and DGF rates. Among DCD kidneys, the incidence of DGF is reduced to 15% if the CIT was less than compared with over 12 hours (25.2% vs 40.2%). One-year graft survival of DCD kidneys was similar to DBD kidneys when shared locally (89.3% vs 89%; P = .682) but slightly inferior when shared regionally (81% vs 87%; P = .437) or nationally (82.7% vs 89.5%; P = .0089). Hence, Doshi et al have supported the policy to favor local use of DCD kidneys. Locke et al have argued that DCD kidneys from donors <50 years old may function like standard criterion donor (SCD) kidneys and should be allocated using the standard deceased donor waiting list, whereas the ECD list should be used for DCD kidneys from donors >50 years old. Moreover, these kidneys tend to be offered to nonsensitized recipients; hence, the necessity for a pretransplant cross-match is obviated, which may shorten the CIT.

CLINICAL RESULTS

Although DCD were the main donor source of cadaveric kidney grafts in the pioneer years, markedly inferior transplant outcomes led to the abandon of this practice during the mid 1970s in favor of DBD. However, since the resurgence of interest in DCD in the early 1990s due to the growing discrepancy between graft demand and supply, there has been significant medical progress in organ preservation, operative techniques, immunosuppressive drugs, treatment of posttransplant complications, histocompatibility testing, and organ allocation. Thus, long-term kidney transplant outcomes from DCD have significantly improved over time, to be comparable to those from DBD.

The finding that DCD and DBD kidney transplant outcomes are comparable in the long term has several important implications for clinical practice. First, it supports the use of DCD kidney transplants despite the worse short-term outcomes, emphasizing the interest in development of DCD programs. Second, to a certain extent, DCD kidneys should not be considered suboptimal. Third, DBD and DCD kidneys should be allocated through the standard kidney allocation system. Fourth, the use of such donor organs could considerably increase the donor organ pool and, therefore, have an important impact on the organ shortage.

In general, early graft function and survival (within the first 3 months posttransplant) was worse among DCD than DBD kidney recipients, manifested by significantly higher rates of PNF, DGF, and lower renal function. Afterward, comparable long-term results continue up to 10 and 15 years posttransplant. Among DCD better transplant outcomes are obtained among controlled rather than uncontrolled donors.

PNF

PNF is defined as inadequate renal function after transplantation that necessitates continuation of dialysis. It is the consequence of ischemic cortical necrosis secondary to ischemia and reperfusion injury. Studies using type 3 and 4 DCD kidneys have shown no significant difference in the rate of PNF compared with DBD kidneys (between 0% and 13%). This observation may relate to the fact that kidney grafts from controlled DCD experience relatively short WIT (rarely >30 minutes). Their similar posttransplant results to DBD kidneys mitigate requirements for machine preservation and viability testing.

By comparison, the PNF rate of kidneys from uncontrolled DCD is significantly higher than that from controlled DCD, varying between 13% and 25%. Lower PNF rates (<6%) have been explained by the adoption of restrictive DCD acceptance criteria (donor age <45–55 years, exclusion of donors with comorbidities), improved donor management (rapid in situ cooling), better preservation, and establishing viability by machine perfusion. Up to one third and to one half of kidneys from uncontrolled DCD are discarded owing to poor perfusion parameters during machine perfusion or for other reasons, a policy that may keep the PNF rate of uncontrolled DCD kidney at acceptable levels of <10%. Therefore, the development of a successful uncontrolled DCD program may not be feasible in the absence of machine perfusion and viability testing. Transplantation of nonviable kidneys results in unnecessary risks of surgery and immunosuppression, as well as of recipient sensitization toward future transplants. Moreover in most cases, renal transplantation is not directly life saving, but a procedure to improve the quality and expectancy of life. Thus, a cautious approach to uncontrolled DCD kidney transplantation is necessary.
Mixed studies including both controlled and uncontrolled DCD have demonstrated PNF rates between 6% and 15%. Snoeij et al presented a PNF rate of up to 21%, because of the use of more older DCD (up to 74 years) and a relatively high percentage of uncontrolled experiences. A recent meta-analysis comparing controlled versus uncontrolled DCD with DBD showed that the PNF incidence may be 2.4 times higher among DCD kidney transplantations.

When analyzing deceased donor kidney transplant outcomes from the UNOS database during different time periods, Cho et al, Rudich et al, and Locke et al confirmed that DCD kidneys showed higher PNF incidences compared with DBD organs. However no significant difference was observed between DCD kidneys from donors younger versus >50 years old, as well as under versus >65 years old.

DGf

DGF is commonly defined as the need for dialysis in the first posttransplant week with subsequent recovery of renal function with the exception of dialysis treatments to correct hyperkalemia or volume overload. The etiology of DGF is multifactorial. In the clinical setting, DGF may mask the presentation of an acute rejection episode. Serial transplant biopsies until resolution of DGF are recommended to exclude subclinical acute rejection processes as a cause of graft dysfunction. Early effects of DGF include prolonged hospital stays, additional diagnostic radiology examinations, repeated renal biopsies, need for supportive hemodialysis, as well as treatment of complications related to a biopsy or to inappropriate immunosuppression. The inevitable consequences are increased costs and patient dissatisfaction.

All studies agree that DGF is more frequent after DCD kidney transplantation. The DGF rate of types 3 and 4 DCD kidneys vary from 40% to >70% in uncontrolled DCD kidneys and even higher DGF rates of 60% to 80% in mixed studies. In mixed studies, the incidence of DGF was prone to be higher when they included a greater proportion of uncontrolled compared with controlled donors.

The UNOS database from 1998 to 2004 suggested a 2.5-fold adjusted relative risk of DGF among DCD compared with DBD kidney transplantations. Similar results were also presented by Cho et al, Rudich et al, Locke et al, Doshi et al, and Gagandeep et al, who analyzed the UNOS database at different times. A recent meta-analysis of renal transplant outcomes for all DCD types and for DBD showed the incidence of DGF to be 3.6-fold higher after DCD kidney transplantation.

Another interesting aspect is that the negative effects of DGF on graft survival observed among recipients of DCD kidneys may not present in DCD. In several studies, the survival of kidney grafts after DGF was better among DCD compared with DBD groups. DCD kidneys may tolerate DGF better than DBD kidneys; there is a 23%–52% decrease in risk of graft loss. Several factors seem to make DCD kidneys less vulnerable to lasting injury, such as the absence of donor brain death, in association with more favorable donor characteristics and less comorbidity.

Acute Rejection Episodes

Many studies have demonstrated that DCD kidneys, despite the greater DGF rates, do not display a greater incidence of acute allograft rejection episodes compared with DBD kidneys. In single center reports and in large studies using national databases as well as in recent meta-analysis of all DCD types. The acute rejection rate during the first year was not significantly different in DCD versus DBD kidneys, both except in Cho’s et al study, which showed DCD kidneys displayed an higher rate of acute rejection than DBD kidneys (19% vs 14%; P = .04).

Most acute rejection episodes occur in kidneys displaying DGF. The incidences of episodes among transplants with DGF and their severity were comparable for DCD and DBD groups. Sanchez-Fructuoso et al found DDB transplants with DGF to show a higher incidence of acute vascular rejection than those from DCD with DGF (57.9% vs 27.9%). Brain death emerged as a clear risk factor for vascular rejection. Rudich et al’s study suggested that transplants from DCD sources showed less graft loss from acute episodes and chronic rejection compared with conventional DBD sources; 22.2% graft losses at 6 months in the DBD group versus only 16.9% of graft losses in the DCD group were attributable to acute rejection.

Renal Function

In clinical transplant practice, renal function is determined by serum creatinine levels or estimated glomerular filtration rate (eGFR) via the Cockcroft-Gault formula or the Modification of Diet in Renal Disease (MDRD) equation. DCD kidneys recover slower than DBD kidneys, failing to optimize their function in the early postoperative period. Given higher incidence of DGF, DCD kidney function is often poorer at the time of hospital discharge and at 1 month posttransplantation. The difference diminishes over time becoming insignificant from 3 months to 1 year posttransplantation. DCD kidneys recover slower than DBD kidneys, failing to optimize their function in the early postoperative period. Given higher incidence of DGF, DCD kidney function is often poorer at the time of hospital discharge and at 1 month posttransplantation. The difference diminishes over time becoming insignificant from 3 months to 1 year posttransplantation. 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and DBD graft losses were approximately 3% at 5 years; both groups showed similar declines in GFR after 1 year (−1.3 mL/min for the DCD group versus −1.4 mL/min for the DBD group. This means that DCD kidneys have a reduced functioning glomerular mass because of the initial ischemic damage, but once transplanted there was no evidence of accelerated deterioration.24 In a single-center report, comparable renal function between the 2 groups was reported up to 15 years posttransplantation.61 However, interpretation of this study must be cautious due to the small number of patients in each group: 112 DCD versus 164 DBD kidneys. Also a general analysis showed that the serum creatinine levels were significantly higher among 164 DBD kidneys. Also a general analysis showed that the serum creatinine levels were significantly higher among DBD kidneys during the first 30 days and 3 months posttransplantation.

Graft Survival

Short-term graft survival at 1 year posttransplantation was similar between DBD and types 3 and 4 DCD kidneys varying between 80% and >90%,12,13,21,49–51,54,74,75 despite the greater graft loss experienced among DCD than DBD kidneys during the first 30 days and 3 months posttransplantation.49–51 Kidneys from uncontrolled donors showed 1-year graft survivals between 70% and >80%,12,21,40,56,66 which was significantly lower than that from controlled sources.12,21

Most studies have considered outcomes beyond the first year posttransplantation as long term, namely, graft survival according to Kaplan-Meier method or graft half-life with or without death censoring. Many factors, including immunologic and nonimmunologic injuries, have been shown to impact long-term outcomes after renal transplantation. Five- and 10-year survivals of kidneys from controlled DCD were 60%–80%13,45,50,51 and 50%–60%,50,53,54 respectively, similar to those observed using kidneys from uncontrolled donors.21,40,48,56,66 Up to 5, 6, and 10 years, there was no difference in graft survival between DCD and DBD kidneys.13,34,42,45,50–51,54,56,60,61,63,68 Two recently published studies with 15-year follow-up showed no significant difference in 5-, 10-, and 15-year allograft survivals between DCD and DBD.50,61 Nevertheless, there was a tendency toward better graft survival among the DBD group.50,61 In unpublished data, Snoeijis et al60 reported the 25 year outcomes of viable DCD kidneys to be equivalent to DBD kidneys.

Studies using the UNOS database reported the 1-, 2-, and 3-year survivals of DCD kidneys to be nearly comparable to those of organs from SCD (P = NS) and superior to ECD (P < .001). ECD kidneys and extended criteria DCD kidneys showed no significant difference in graft survival.20 With regard to graft survival at 5 years, DCD kidneys from donors <50 years old performed as well as CSD kidneys, while DCD kidneys from donors >50 years old functioned as well as ECD kidneys (Table 2).42 Gagandeep et al46 reported similar long-term outcomes up to 5 years posttransplantation between uncontrolled DCD, controlled DCD, and DBDs. A recent meta-analysis of outcomes of all types of DCD and DBD renal transplantations confirmed that the survival of DCD kidneys from 3 months to 6 years posttransplant was somewhat inferior to DBD kidneys, but this difference may become nonsignificant at 10 years.62 Median graft survival was 96–126 months in the DCD group versus 159 months in the DBD group.54,61

The comparable long-term graft survival of organs from DCD and DBD is supported by histologic data that show DCD kidneys to not display greater allograft fibrosis than those from DBD.77 The rate of development of chronic allograft nephropathy among DCD transplantations does not exceed that associated with DBD kidneys.78

Operative Complications

Likewise, no statistical difference has been demonstrated between DBD and DCD kidney recipients in the rate of technical complications.50,54 However, when ureteral fistulae and stenosis rates were combined, the difference was significantly greater among the DCD group (15% vs 7%).54 Analyzing the UNOS database including 708 DCD and 97,990 DBD kidney transplants between 1993 and 2000, Rudich et al63 showed that operative and urologic complications, thromboses, and infections were not a greater cause of graft loss in DCD than in DBD transplantations, a conclusion that was recently confirmed in Khairoun et al’s study.79

In conclusion, the results of DCD kidney transplantation are comparable to DBD kidney transplantation with careful donor and recipient selection and management. As a result DCD programs should be expanded. DCD donors are a potential source to partially solve the imbalance between the growing number of end-stage kidney disease patients on waiting lists and the limited number of available kidneys. DCD kidneys are not always suboptimal organs; they merit to be shared equally as DBD kidneys in renal allocation systems.

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RESULTS OF KIDNEY TRANSPLANTS WITH DCD DONORS


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