OBJECTIVE: The prevalence of diabetes mellitus is higher in patients with cystic fibrosis than in the general population. Solid organ transplantation is a significant risk factor for diabetes mellitus, which has been linked to type of immunosuppression. The aim of this study was to analyze whether lung transplantation represents a significant risk factor for the onset of abnormal carbohydrate metabolism in cystic fibrosis, whether it affects severity of alterations, and whether there is a relation to type of immunosuppression.

PATIENTS AND METHODS: The following data were extracted retrospectively for 54 patients with cystic fibrosis: type of carbohydrate metabolism alteration and treatment received, whether or not transplantation took place, and type of immunosuppression used.

RESULTS: Twenty of the 54 patients (37%) underwent lung transplantation; 18 of them (89%) developed diabetes mellitus. Eight of the patients (24%) who did not receive a transplantation; 18 of them (89%) developed diabetes mellitus, which has been linked to type of immunosuppression used.

Conclusions: For cystic fibrosis patients, lung transplantation is a significant risk factor for developing abnormal carbohydrate metabolism and it influences severity and treatment. No significant differences in the frequency of development of diabetes mellitus were found in relation to type of immunosuppression.

Key words: Cystic-fibrosis-related diabetes. Diabetes and cystic fibrosis. Post-transplantation diabetes mellitus.
Abnormal carbohydrate metabolism develops in patients with exocrine pancreatic insufficiency, particularly carriers of the AF508 mutation, and the prevalence of diabetes is 100-fold higher in cystic fibrosis patients than in the general population. A factor that can influence the incidence of abnormal carbohydrate metabolism in these patients, lung transplantation, is an end-stage treatment and the only alternative in many cases. A serious, common complication of solid organ transplantation is diabetes mellitus. Numerous studies have analyzed the factors that affect the onset of diabetes, and type of immune suppression employed has been identified as relevant. Studies have mostly often been done in the setting of kidney transplantation but similar factors must be involved in patients who undergo other procedures such as lung transplantation.

Considering that patients with cystic fibrosis are a population at risk, with greater predisposition to abnormal carbohydrate metabolism, it would seem that the incidence of diabetes in these patients would rise considerably because of added risk from transplantation and associated therapy. One recent study suggested this hypothesis.

The aim of the present study was to analyze whether lung transplantation constitutes an important risk factor for developing abnormal carbohydrate metabolism in cystic fibrosis patients, whether it influences the severity and treatment of such abnormalities, and whether there exists a relation with type of immunosuppression initially employed.

**Patients and Methods**

This retrospective, cross-sectional study included 54 patients with cystic fibrosis treated at the endocrinology clinic of Hospital Universitario La Fe in Valencia, Spain. The following data were gathered: sex, age at the time of the study, weight, height, body mass index (kg/m²), insulin, and glucose levels at baseline and 120 minutes after oral intake of 75 g of glucose. Glycemia was determined by the enzymatic method (glucose oxidase) with the AU5400 analyzer (Olympus Europe, Hamburg, Germany). Insulin levels were determined with a chemical luminescence immunoassay (IMMULITE 2000, Diagnostic Products Corporation, Los Angeles, California, USA). The homeostasis model assessment of insulin resistance (HOMA-IR) index was calculated according to the following formula: insulin level in µU/mL × glucose level in mmol/L/22.5.

Type of mutation was analyzed in 31 patients; no information was available for the remaining patients. In certain cases in Hospital Universitario La Fe, exon sequences and adjacent intron sequences were amplified by way of polymerase chain reaction, followed by a search for the mutations that are most common in the Spanish population. We used single-strand conformation polymorphisms and heteroduplex analysis or restriction-enzyme digestion.

Information on exocrine pancreatic insufficiency was obtained for 45 patients by the van de Kamer method. Fat in stool collected over 3 consecutive days under a diet rich in fat starting 3 days earlier was analyzed with infrared spectrophotometry (PENIR 8820, Aerobic, Madrid, Spain). A finding of more than 6 g/day of fat in stool was considered abnormal.

Whether or not transplantation was carried out was recorded. If the procedure was performed, the following data was also noted: age at the time of transplantation, time since transplantation, whether or not there was a prior history of abnormal carbohydrate metabolism and what type, the development or not of nontransient post-transplantation diabetes mellitus, when it developed and the treatment required, and the type of immunosuppression initially used.

There are no clinical manifestations that indicate a diagnosis of abnormal glucose tolerance and the condition remains undiagnosed if it is not studied systematically. Therefore, it is currently accepted that carbohydrate metabolism should be assessed when these patients have associated exocrine pancreatic insufficiency and are over 10 years old. The established protocol calls for an annual glucose tolerance test, according to which patients are classified in 5 categories (criteria of the American Diabetes Association for 2004): 1. Normal glucose tolerance: fasting glucose level less than 100 mg/dl, (≤4.4 mg/dl at 2 hours).

2. Impaired fasting glucose tolerance: fasting glucose level of 100 to 125 mg/dl, (≤140 mg/dl at 2 hours).

3. Impaired carbohydrate tolerance: fasting glucose level less than 126 mg/dl, (≤100 mg/dl at 2 hours).

4. CFRD, without fasting hyperglycemia: fasting glucose level less than 126 mg/dl, (≤200 mg/dl at 2 hours).

5. CFRD, with fasting hyperglycemia: fasting glucose level 126 mg/dl, or more (≥200 mg/dl at 2 hours).

Patients not diagnosed with diabetes who developed exocrine pancreatic insufficiency and who were followed at our clinic underwent oral glucose tolerance testing annually. Follow-up after transplantation also included fasting glucose levels. This information was not available for patients referred from other hospitals for transplantation who were not previously examined at our hospital. Carbohydrate metabolism classification of such patients was based on medical history and fasting blood tests. Post-transplant diabetes mellitus was defined as the presence of hyperglycemia, according to the criteria of the American Diabetes Association of 2004, beyond 30 days after transplantation, whether medical treatment was necessary or not.

Data were analyzed with the SPSS software package, version 12.0. Quantitative variables were expressed as mean (SD) and range. Qualitative variables were expressed as percentages and compared with a χ² test.

Transplanted patients who were already diabetic (n=4) were included in the nontransplanted group of patients with CFRD, with fasting hyperglycemia. Transplantation could not be considered a factor that influenced treatment type in these patients, who were already receiving insulin. Therefore, treatment type was only considered for the 14 patients with post-transplantation diabetes. The 10 patients with impaired carbohydrate tolerance, the 8 nontransplanted patients with CFRD, and the 4 transplanted patients with CFRD were included in the nontransplanted group. Patients without impaired carbohydrate metabolism, who required no treatment, were excluded from both groups.

The influence of initial immunodepression was only analyzable in the 15 patients who did not have diabetes before transplantation. As information was unavailable for 1 of them the number finally analyzed was 15. All patients were on triple immunosuppression, receiving a calcineurin inhibitor (cyclosporin in 10 and tacrolimus in 5), a calcineurin-inhibitor–free immunosuppressant (azathioprine in 13 and mycophenolate mofetil in 2), and prednisone. Doses were similar for all patients.

**Results**

Thirty-four of the 54 patients (63%) were male and 20 (37%) were female. Mean age at the time of the study was...
25.4 (4.7) years (range, 15-39 years). Body mass index was 20.4 (3.3) kg/m² (range, 14.3-28.2 kg/m²).

The distribution of types of abnormal carbohydrate metabolism in all patients at the time of the study are shown in Figure 1. The prevalence of diabetes mellitus was 45%. The HOMA-IR index was 1.14 (0.65).

Twenty of the 54 patients included (37%) underwent transplantation. Their mean age at the time of the operation was 19.6 (4.9) years (range, 10-31 years) and mean time elapsed (between transplantation and the time of the study) was 5.3 (3.2) years (range, 2 month to 11 years).

Eighteen (58.1%) carriers of the ΔF508 mutation were heterozygous and 5 (16.1%) were homozygous; 8 (25.8%) patients carried other mutations. All ΔF508 homozygotes experienced some form of abnormal carbohydrate metabolism: 60% (n=3) developed impaired carbohydrate tolerance and 40% (n=2) developed diabetes. Half of the ΔF508 heterozygotes or carriers of another type of mutation had normal glucose tolerance and half developed impaired carbohydrate tolerance or diabetes.

Thirty-nine patients (86.7%) developed exocrine pancreatic insufficiency. Among those patients who did not (13.3%, n=6), none had abnormal carbohydrate metabolism, none underwent transplantation, none carried the ΔF508 homozygous mutation, and all were at least 23 years of age at the time of the study.

Two of the transplanted patients (Figure 2) had CFRD and another 2 had type 1 diabetes mellitus before transplantation. Fourteen of the 16 remaining patients (87.5%) developed nontransient post-transplantation diabetes mellitus and 2 maintained normal glucose levels. The 2 patients with type 1 diabetes mellitus were excluded from this analysis, as their carbohydrate metabolism abnormalities were unrelated to cystic fibrosis or transplantation.

Four of the 20 transplanted patients were already diabetics and 16 were not. Fourteen of 16 nondiabetic patients developed post-transplantation diabetes mellitus. Before transplantation, 2 had impaired carbohydrate tolerance, and 9 had no carbohydrate metabolism disorder as demonstrated by a glucose tolerance test; the 3 remaining patients reported no prior metabolic impairment but tolerance test information was unavailable as they had been treated in another hospital.

Impaired carbohydrate tolerance was more common than diabetes among the patients who did not undergo transplantation (Figure 3). The prevalence of abnormal carbohydrate metabolism was significantly related to lung transplantation (Pc.01, χ² test). The prevalence of diabetes was 89% in transplanted patients (78% of those with post-transplantation diabetes mellitus and 11% of those with who already had CFRD). In patients not undergoing transplantation, 24% developed CFRD and 29% developed impaired carbohydrate tolerance; the remaining patients had normal glucose tolerance (Figure 4).

The time elapsing before the appearance of post-transplantation diabetes mellitus was 1.8 (2.5) years (range, immediately to 7 years later). Time of follow-up of post-transplantation diabetes mellitus was 4.5 (3.4) years (range, 6 months to 11 years).
Figure 5 shows the distribution of carbohydrate metabolism abnormalities by age brackets. In patients up to 18 years old, 66.7% had diabetes, whereas the prevalence was 45% in patients aged 19 to 22 years and 33.4% in those aged 23 years or older. Thus, the prevalence of normal glucose tolerance increased with age ($P<.05$, $\chi^2$ test). We analyzed whether age was related to lung transplantation (Figure 6). The age bracket up to 18 years had most of the diabetic patients and most of the transplanted patients (66.7%), whereas most of the patients not undergoing transplantation (71.4%) were in the other 2 age brackets, which also had most of the nondiabetic patients ($P=.05$, $\chi^2$ test).

Analysis by treatment showed that 11 of the nontransplanted patients (50%) required only dietary treatment, 3 (13.6%) required oral antidiabetic drugs, and 8 (36.3%) required insulin. Among transplanted patients, 2 (14.3%) only followed a special diet, 1 (7.1%) received oral antidiabetic treatment, and 11 (78.6%) required insulin. Analysis by type of immunosuppression showed that post-transplantation diabetes mellitus developed in 9 of the 10 patients treated with cyclosporin (90%) and 4 of the 5 treated with tacrolimus (80%). The differences were not significant.

Discussion
In this patient series with a mean age of 25 years at the time of study, the prevalence of diabetes mellitus was 45%, slightly higher than the rates of 15% to 35% described in the literature for cystic fibrosis patients in that decade of life.2,10,11 None of the cited studies related the prevalence of abnormal carbohydrate metabolism to lung transplantation, which could be one of the factors that...
would explain a higher or lower frequency of impaired carbohydrate tolerance.

In our study the higher prevalence of abnormal carbohydrate metabolism, and especially of diabetes mellitus with fasting hyperglycemia, again was observed in patients aged 18 years or younger (15-18 years). This observation is consistent with what might be expected, that abnormal carbohydrate metabolism would become more prevalent with age. The pattern observed in our study is probably attributable to the fact that most lung transplant patients were performed in patients in the youngest age bracket (66.7% vs 28.6% in each of the other 2 brackets), therefore, the youngest patients had a higher prevalence of abnormal carbohydrate metabolism ($P=0.05$, $\chi^2$ test). Lung transplantation seems to have considerable impact on the development of CFRD. One recent study compared the prevalence of diabetes before and after transplantation in the same population of cystic fibrosis patients. The prevalence before transplantation of 28.6% rose to 49.4% afterwards ($P=0.008$), thus attesting to a noteworthy influence of lung transplantation on the onset of diabetes in these patients. Another recent study described a prevalence of post-transplantation diabetes mellitus in cystic fibrosis patients of 56.3%. The prevalence in our study was even higher at 89%. The differences might be attributable to differences in criteria used to define post-transplantation diabetes mellitus. We defined the condition as the persistence of high glucose levels for more than 30 days after transplantation, regardless of the need for medical treatment of the condition or not. Other authors have used the persistence of high glucose levels beyond 60 days after transplantation to define the condition. Such differences mean that studies of the prevalence of post-transplantation diabetes mellitus are difficult to compare and they explain the large discrepancies reported.

The pathogenesis of CFRD is multifactorial. The main cause is insulin deficiency because of loss of pancreatic $\beta$ cells due to fibrosis and fatty infiltration of islets. Insulin resistance may intervene in some situations such as when a patient is taking glucocorticoids during puberty, but outside of such contexts its role is less clear and studies have yielded inconsistent results. The HOMA-IR values in our patients were normal, indicating absence of insulin resistance. These considerations would be important for management, given that it would be inappropriate to administer drugs to overcome insulin resistance. Instead, treatment should be based on drugs capable of stimulating insulin secretion.

We observed that the prevalence of diabetes in transplanted patients was 89% (78% with post-transplantation diabetes mellitus and 11% with CFRD before transplantation), whereas nontransplanted patients developed impaired carbohydrate tolerance (29%) more often than diabetes (24%) and 47% maintained normal glucose metabolism. The differences were statistically significant ($P<0.01$, $\chi^2$ test). These observations provide additional support for the hypothesis that transplantation plays an important role in the development of diabetes in these patients. Furthermore, of the 16 patients who underwent transplantation and were not already diabetic, developed post-transplantation diabetes mellitus and only 2 maintained normal glucose levels.

Numerous studies have looked at the relationship between solid organ transplantation and the development of impaired carbohydrate metabolism. Post-transplantation diabetes mellitus is currently recognized as one of the most severe complications of this procedure, as it is associated with lower graft and patient survival rates and it increases the risk of other complications. The real incidence of this serious complication is unknown because of a lack of unified criteria for diagnosis, as can be observed in the variety of published studies that can not be compared. Diagnosis in patient ten years after transplantation seems to have considerable impact on the development of CFRD. One recent study compared the prevalence of diabetes before and after transplantation in the same population of cystic fibrosis patients. The prevalence before transplantation of 28.6% rose to 49.4% afterwards ($P=0.008$), thus attesting to a noteworthy influence of lung transplantation on the onset of diabetes in these patients. Another recent study described a prevalence of post-transplantation diabetes mellitus in cystic fibrosis patients of 56.3%. The prevalence in our study was even higher at 89%. The differences might be attributable to differences in criteria used to define post-transplantation diabetes mellitus. We defined the condition as the persistence of high glucose levels for more than 30 days after transplantation, regardless of the need for medical treatment of the condition or not.

The HOMA-IR values in our patients were normal, indicating absence of insulin resistance. These considerations would be important for management, given that it would be inappropriate to administer drugs to overcome insulin resistance. Instead, treatment should be based on drugs capable of stimulating insulin secretion. The first intervention is a lifestyle change. The next steps are to add oral antidiabetic drugs and then insulin, depending on the level of metabolic control achieved. Patients with cystic fibrosis who undergo transplantation are a special group because of the reduced pancreatic insulin release that is natural to their disease; consequently, management of post-transplantation diabetes mellitus may be different in these patients than in other organ recipients. Over 60% of our nontransplanted patients achieved adequate control of glucose levels with dietary changes with or without oral antidiabetic agents, over 70% of transplanted patients, however, required insulin. This may be attributed to the higher prevalence

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among nontransplanted patients of impaired carbohydrate
tolerance and diabetes mellitus (38% diagnosed by oral glucose tolerance testing) in comparison
with the prevalence of diabetes with fasting hyperglycemia (15%); the difference in the prevalence of fasting hyperglycemia among
transplanted patients, in contrast, was 89%. These differences in the severity of abnormal carbohydrate
metabolism would mark the difference in treatment applied. When oral antidiabetic agents were prescribed, the drugs
of choice were glinides at varying dosages.

Upon reviewing the literature, we found 2 studies evaluating the incidence of post-transplantation diabetes mellitus in patients with cystic fibrosis who undergo lung transplantation. Patients with this hereditary disease
have a high prevalence of abnormal carbohydrate metabolism per se, whether in the form of diabetes mellitus or impaired carbohydrate tolerance. Therefore, they form a group of patients for whom it is logical to assume that post-transplantation diabetes mellitus would be more
common if they become solid organ recipients because of the additional toxic effect of immuno suppressants on pancreatic β cells plus the effect of corticosteroids on insulin resistance, both superimposed on an already impaired pancreatic function.

We observed that lung transplantation is the most
important risk factor for the development of diabetes in cystic fibrosis patients. However, we studied a small number of patients and our observations should be confirmed in a larger population. Our results should serve to underline the importance of careful monitoring of glucose levels in cystic fibrosis patients who undergo lung transplantation, even when their glucose tolerance is normal. Such monitoring should be carried out over the long term, given that the mean time lag between transplantation and the onset of diabetes in our study was 1.8 years and some cases did not appear until 7 years later. Detecting and treating abnormalities in carbohydrate metabolism early could contribute to lower morbidity and mortality rates in these patients.

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