

and chlorambucil have been proposed¹¹. However, the efficacy of these regimens has not been evaluated in controlled clinical trials and remains anecdotal.

The impact of prolonged steroid treatment on growth and development and the increased risks of infection, infertility, and the long-term risk of malignancy limits the use of CyP or other immunosuppressive agents in the management of pediatric SLE¹². In addition, a substantial portion of children have an inadequate response or relapse taking traditional therapy, underscoring the need for therapeutic alternatives¹³⁻¹⁴.

Mycophenolate mofetil (MMF) is a new xenobiotic immunosuppressive agent. Its active metabolite, mycophenolic acid, is a reversible inhibitor of inosine monophosphate dehydrogenase, which functions as a critical rate limiting enzyme in the *de novo* pathway of purine biosynthesis. MMF also inhibits the formation of antibodies and the generation of cytotoxic cells *in vitro*¹⁵⁻¹⁷. In addition, MMF inhibits T and B lymphocyte proliferation and down-regulates the expression of adhesion molecules on lymphocytes, impairing their ability to bind to endothelial cells. In a murine model of lupus nephritis, MMF delayed deterioration of renal function and prolonged survival¹⁸. MMF has been shown to be safe and efficacious in extensive clinical trials in transplant patients¹⁹⁻²¹. Recent evidence in adult patients with treatment resistant lupus nephritis suggests that MMF in lower doses may be a safe and well tolerated alternative to traditional chemotherapy²²⁻²³. Moreover, MMF has been investigated and found beneficial in the treatment of rheumatoid arthritis, psoriasis, autoimmune hemolytic anemia, antineutrophil cytoplasmic antibody-associated vasculitis, and IgA nephropathy²⁴⁻²⁶.

Our study describes the first clinical experience with mycophenolate mofetil in 11 children with various forms of severe lupus nephritis.

MATERIALS AND METHODS

Patient selection. Eleven children from 4 pediatric rheumatology centers, who fulfilled the classification criteria for SLE²⁷, were included in the study and followed for a mean of 9.8 months (range, 3 to 17). The patient population included 9 females and 2 males with an average age at disease onset of 12.3 years (range 9 to 15.3). There were 4 Hispanic, 4 Afro-American, and 3 Caucasian patients. The mean disease duration was 2.9 years (range 0.8 to 7.8).

All patients had undergone renal biopsies at disease onset in order to establish a histologic diagnosis (Table 1). Criteria for starting MMF included (I) inadequately controlled nephritis despite aggressive treatment with long-term steroids and/or cytotoxic drugs (iv or oral cyclophosphamide, azathioprine) and/or (II) inability to taper steroids below 0.5 mg/kg/day including ongoing need of IV methylprednisolone pulses.

Therapy. Prior to treatment with MMF, 5 children (patients 1-3,7,11) had received IV cyclophosphamide (mean cumulative dose 9.32 g; range, 2 to 17.1) and one child (patient 1) had received oral cyclophosphamide. Three children (patients 2,3,7) had been treated with azathioprine, and another (patient 8) with oral methotrexate (Table 1). Five children had been treated with steroids alone but not with cytotoxic agents. Four children (patients 8-11) had received numerous pulses of IV methylprednisolone.

MMF (CellCept[®], Roche Laboratories, Nutley, NJ, USA) was administered twice daily at a dose range from 17 to 42 mg/kg/day (median 22) or

1.25 to 2.25 g qd (median 1g bid) total dose. The mean duration of therapy was 9.8 months (range 3-17). During the study all children received concomitant prednisone in various doses and 7/11 were on concomitant hydroxychloroquine (Table 2).

All parents and patients were informed that MMF, a US Food and Drug Administration approved drug, was used off label for a non-approved indication.

Clinical and laboratory assessment. In order to assess treatment outcome all patients had regular complete clinical evaluations using the SLE Disease Activity Index (SLEDAI)²⁸ and serial measurements of complete blood cell counts to monitor drug toxicity, chemistry panel, serum antinuclear antibodies by immunofluorescence, anti-dsDNA antibodies and complement fractions C3-C4 (mg/dl). Anti-dsDNA antibodies were measured by a modified Farr assay, while complement levels were determined by radial immunoelectrophoresis. Renal function was monitored through 24 h urine protein excretion (g/24 h), timed 24 h creatinine clearance (ml/min), and serum creatinine (mg/dl).

A positive response to treatment was defined as improvement of at least 2 points in the SLEDAI score, reduction of more than 0.5 g/24 h in proteinuria, reduction in serum creatinine of more than 0.2 mg/dl, increase of at least 10 ml/min in creatinine clearance, reduction of at least 50 IU/ml in the serum anti-dsDNA titer, and improvement of more than 10 mg/dl in one or both complement fractions.

RESULTS

Treatment response. After a mean of 10 months of treatment we observed a marked reduction of disease activity in 80% of the children as determined by SLEDAI score, which decreased from a mean of 9.6 at baseline to 3.4 (mean change of -6.3) (Table 3). Serum C3 and C4 levels increased in 3/6 children (patients 4-6) with low values at baseline (patients 3-6,8,11) and decreased below normal in one patient whose levels were normal at study entry (patient 10). Anti-dsDNA levels decreased in 3/4 children (patients 2,5,8) with elevated titers at baseline (patients 2,3,5,8) and increased in one child (patient 10). Patient 6 who was negative for anti-dsDNA showed a significant drop in previously elevated Sm antibodies (Table 3).

Out of 8 children with baseline proteinuria ≥ 0.5 g/24 h, we observed decreased proteinuria in 5/8 children (patients 4-7, 11), unchanged values in 1/8 (patient 2), and increased proteinuria in 2/8 children (patients 1,3). Three children had less than 0.5 g protein/24 h at baseline (patients 8-10). Creatinine clearance increased in 6/11 children (patients 2,4-6,8,9), decreased in 2/11 (patients 1,3), and remained stable in 3/11 (patients 7,10,11). Among the 6 children with a serum creatinine ≥ 1.2 mg/dl at baseline, levels increased in 3/6 (patients 1-3), remained stable in 1/6 (patient 11) and decreased in 2/6 (patients 4,9) (Table 4).

Four children (patients 4-7) had an overall excellent response to MMF, with normalization of serum creatinine, proteinuria, SLEDAI score (≤ 2), anti dsDNA antibodies and increased C3 and C4 serum levels. Three of these children had membranous glomerulonephritis and the fourth had mixed features of membranous and proliferative nephritis by renal biopsy. Concomitant prednisone was discontinued in 1/11 children, tapered in 9/11 (mean drop 0.5 mg/kg/day, range 0.2 to 1) and remained unchanged in

Table 1. Demographic and baseline clinical variables of study cohort.

Study No./ Patient-Center	Gender	Race	Age, yrs	Age at Onset, yrs	Disease Duration, yrs	Renal Biopsy, (WHO Class)	Previous Cytotoxic Therapy
1/CHLA	F	AA	16.0	12.3	3.7	IV	Oral and IV CyP
2/CHLA	F	AA	16.4	12.2	4.2	IV	AZA-IV CyP
3/CHLA	F	AA	17.0	10.8	6.2	IV	AZA-IV CyP
4/CHSD	M	H	16.1	15.3	0.8	V	—
5/CHSD	F	H	13.3	11	2.3	V	—
6/CHSD	F	H	14.2	13.4	0.8	V	—
7/LRCH	M	AA	16.8	9	7.8	V+III	AZA-IV CyP
8/LRCH	F	W	14.3	12.8	1.5	III	Oral MTX
9/LRCH	F	W	13.8	12.9	0.9	Interstitial nephritis	—
10/LRCH	F	H	14.4	13	1.4	III	—
11/CHUWM	F	W	15	12.8	2.2	Diffuse sclerosis	IV CyP

W: white; AA: Afro-American; H: Hispanic; CyP: cyclophosphamide; AZA: azathioprine; MTX: methotrexate. CHLA: Children's Hospital Los Angeles; CHSD: Children's Hospital San Diego; LRCH: La Rabida Children's Hospital; CHUWM: Children's Hospital University of Wisconsin-Madison. WHO: World Health Organization.

Table 2. Treatment during the study.

Study No./ Patient-Center	MMF Dose (mg/kg/day and total dose)	Treatment Duration, months	Cumulative Dose, Total g	Concomitant Medications	Prednisone Starting Dose, mg/day	Prednisone Ending Dose, mg/day
1/CHLA	19.4 (1 g bid)	15	900	Pred-HCQ	10	0
2/CHLA	17.6 (1 g bid)	(2) ^a 3	180	Pred-HCQ	15	5
3/CHLA	20.6 (1 g bid)	13	780	Pred-HCQ	10	10
4/CHSD	35 (1.25 g+1 g)	11	743	Pred-HCQ	100 qod	7.5 qod
5/CHSD	35 (1 g bid)	10	600	Pred-HCQ	120 qod	30 qod
6/CHSD	42 (1 g bid)	9	540	Pred-HCQ	70 qod	15 qod
7/LRCH	22 (0.75 g bid)	8	360	Pred	30	15
8/LRCH	21.7 (0.25 qd to 0.75 bid)	17	600	Pred-HCQ	20+ weekly MP pulses	5+ monthly MP pulses
9/LRCH	20.0 (0.75 bid)	6	270	Pred	30	15
10/LRCH	17.5 (0.75 bid)	7	315	Pred	20+ weekly MP pulses	5+ monthly MP pulses
11/CHUWM	17.1 (0.75 g+0.5 g)	7	262.5	Pred	15	2.5

^a Patient 2 temporarily discontinued treatment due to herpes zoster virus cerebritis (see side effects). CHLA: Children's Hospital Los Angeles; CHSD: Children's Hospital San Diego; LRCH: La Rabida Children's Hospital; CHUWM: Children's Hospital University of Wisconsin-Madison. Pred: prednisone; HCQ: hydroxychloroquine. MP: IV methylprednisolone.

1/11 (0.10). Patients 8 and 10 were able to decrease weekly methylprednisolone treatment to monthly pulses (Table 2).

Adverse events. MMF was overall well tolerated and only one patient discontinued MMF due to an adverse event. The most frequent adverse events included infections: one (patient 2) became leukopenic after 2 months of treatment (white blood cell count, WBC, 1100/mm³) and developed a herpes zoster virus infection with cerebritis. MMF was discontinued. The patient recovered and MMF was restarted 5 months after the infection with no further complications. A second patient (patient 8) presented with oral thrush in the context of leukopenia (WBC 2400/mm³) and required a gradual taper of MMF from 0.75 bid to 0.25 g qd. Infections possibly related to MMF were reported in 2 other children.

One had necrotizing lymphadenitis and another a re-infection of a jaw cyst.

In addition, 4 children complained of nausea, one child complained of itching and fatigue, one complained of headaches, and another of transient generalized body aches.

In general the adverse events did not seem to be dose related.

DISCUSSION

Traditional treatment of children with severe lupus glomerulonephritis combines corticosteroids with immunosuppressive drugs such as azathioprine and cyclophosphamide. Despite clinical effectiveness in most children, potential serious toxicity and longterm adverse events limit the use of

Table 3. Disease activity variables at start of MMF therapy and at last followup.

Study No./ Patient-Center	Anti dsDNA**		C3/C4 (mg/dl) ^b		SLEDAI Score ^c	
	Start	End	Start	End	Start	End
1/CHLA	Neg	Neg	122/28	165/26	6	4
2/CHLA	156	66	128/30	189/37	2	2
3/CHLA	> 590	> 590	112/17	75/10	30	12
4/CHSD	Neg	Neg	49/9	117/28	10	0
5/CHSD	160	Neg	60/< 10	79/12	8	2
6/CHSD	Neg	Neg	23/< 10	88/15	10	2
	Sm > 100	Sm Neg				
7/LRCH	Neg	Neg	120/41	163/52	5	0
8/LRCH	551	Neg	93/13	101/18	12	2
9/LRCH	Neg	Neg	138/25	97/24	6	0
10/LRCH	Neg	160	121/23	83/11	11	11
11/CHUWM	Neg	Neg	114/16	98/19	6	2

^a Modified Farr assay (< 50 = negative); Sm: anti-Smith antibodies

^b Serum complement (normal values: C₃ 86–184 mg/dl, C₄ 22–59 mg/dl)

^c SLEDAI: 24 descriptors grouped into 9 organ systems, each descriptor ranging from 1 to 8, with a total maximum possible score of 105.

CHLA: Childrens Hospital Los Angeles; CHSD: Children's Hospital San Diego; LRCH: La Rabida Children's Hospital; CHUWM: Children's Hospital University of Wisconsin-Madison.

Table 4. Renal function at the start of MMF therapy and at last followup.

Study No./ Patient-Center	24 h Urine Protein g/24 h		Creatinine Clearance, ml/min		Serum Creatinine, mg/dl	
	Start	End	Start	End	Start	End
1/CHLA	3.4	6.1	72.9	58.2	1.4	1.7
2/CHLA	0.5	0.5	12	30.2	1.8	2.3
3/CHLA	2.6	3.7	84	72	1.2	1.4
4/CHSD	2.6	0.1	90	120	1.4	0.7
5/CHSD	1.4	0.3	70	88	0.8	0.6
6/CHSD	3	0.2	80	120	1.0	0.6
7/LRCH	6.4	0.3	71	73	0.8	0.8
8/LRCH	0.2	0.2	92	142	0.3	0.5
9/LRCH	0.16	0.16	40	107	1.3	0.9
10/LRCH	ND	0.17	78	80	0.6	0.6
11/CHUWM	0.84	0.16	48	40	1.4	1.4

ND: not done.

CHLA: Childrens Hospital Los Angeles; CHSD: Children's Hospital San Diego; LRCH: La Rabida Children's Hospital; CHUWM: Children's Hospital University of Wisconsin-Madison.

these agents. In addition, a significant proportion of children have an inadequate renal response, underscoring the need for alternative therapeutic agents^{13–14}.

Clinical studies with mycophenolate mofetil, initially approved for the prevention of renal allograft rejection, have demonstrated that rejection rates in renal transplant patients with 2–3 g of daily MMF were lower than with azathioprine^{19–21}. Adverse events included leukopenia and/or pancytopenia, gastrointestinal complaints such as nausea, diarrhea, gastritis, esophagitis, duodenal ulcer, pancreatitis, stomatitis, and alopecia. Central nervous system toxicity such as confusion, asthenia, and infections with cytomegalovirus or herpes simplex virus have also been reported^{22,29,30}.

The short term clinical superiority of MMF over cyclosporine A in glomerular disease complicated by nephrotic syndrome and/or renal insufficiency has been suggested²². Briggs, *et al* reported a substantial reduction in proteinuria, stabilization of serum creatinine and a potential steroid-sparing effect in 8 patients treated with MMF at a dose range of 0.75 to 1 g bid alone or in combination with low dose steroids. Dooley, *et al* described the efficacy of MMF/prednisone combination therapy in controlling major renal manifestations of SLE in 12 patients with resistant or relapsing DPGN following cyclophosphamide (CyP) therapy²³. A significant reduction of serum creatinine, proteinuria, urine-creatinine ratio, and an improvement in

serum C3 and anti-dsDNA antibody levels was observed in most patients. Adverse events included leukopenia, in one case associated with a severe herpes simplex stomatitis, thinning of scalp hair, pneumonia without leukopenia, and one case of recurrent pancreatitis that led to discontinuation of MMF.

We report here the first clinical experience in 11 children treated with MMF for refractory lupus nephritis over a mean of 9.8 months (range 3 to 17). Although the children presented with different types of nephritis at onset, most were resistant to traditional immunosuppressive therapy (CyP and azathioprine) and required ongoing high dose steroids.

Our study demonstrates that MMF at a dose range of 1.25 to 2.25 g/day was fairly well tolerated and resulted in a marked reduction of disease activity, assessed through the SLEDAI score. MMF allowed a steroid taper in 6/11 children, without deterioration or, indeed, with improvement of renal function and disease activity, confirming that MMF has a considerable steroid sparing effect. Unfortunately, we also observed worsening of renal function or disease activity variables in 4 patients during steroid taper.

Of note a complete response to treatment was achieved in all 3 children with membranous glomerulonephritis with substantial reduction in proteinuria and serum creatinine, increase in creatinine clearance, marked reduction in autoantibody formation, and increased serum complement levels. MMF may therefore be a valuable alternative to steroids, azathioprine, and cyclosporine A in this subset of patients. This observation is even more important since disease course and outcome vary in children with membranous glomerulonephritis, and optimal treatment is controversial. In addition a complete response to therapy was observed in one child presenting with mixed membranous and proliferative lesions in the renal biopsy, a feature that seems to be associated with a higher risk of renal disease progression³¹⁻³².

In contrast, efficacy of MMF in children with diffuse proliferative glomerulonephritis appeared less favorable than reported by studies in adults²²⁻²³. Despite an improvement in the SLEDAI scores, we observed deterioration in renal function in all 3 children presenting with DPGN. During the prednisone taper serum creatinine increased in all patients and proteinuria worsened or remained stable.

Eight children (73%) experienced one or more adverse events, that were possibly related to MMF. Infections were observed in 4 children (36%), in one case requiring a temporary discontinuation of MMF. Leukopenia was observed in 2 children (18%) and minor side effects in 5 children (45%). Opportunistic infections were presumably caused by increased immunosuppression, possibly related to MMF. Unfortunately, our cohort is too small to draw any further meaningful conclusions.

In summary, we conclude that MMF may represent a

valuable alternative to traditional cytotoxic agents in the treatment of renal disease of pediatric SLE. In our small cohort of children, MMF had a notable effect on membranous glomerulonephritis, but not on DPGN. MMF acted as a steroid sparing agent, which is of particular importance for children. Infections were frequently observed and may limit the use of this agent in some patients. The small patient number and the non-controlled nature of the study limit the reliability of our results. Controlled, prospective, randomized pediatric trials are needed to investigate the efficacy and safety of MMF in selected subsets of children with lupus nephritis.

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